HUMAN RESPONSE TO VIBRATION FROM EARTHMOVING MACHINES

by

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A thesis submitted to the Council for National Academic Awards in partial fulfilment of the requirements for the degree of MASTER of Philosophy.

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Abstract

The study was concerned with the low frequency vibration generated by wheeled earth moving machines and the consequent discomfort or fatigue risks for the drivers. For these machines the vertical, 'Z', axis was established as the direction of vibration propogation presenting greatest potential risk.

The principal reference was ISO2631:1978(E) and acceleration levels were measured at frequencies up to 100 Hertz for analysis and comparison. A proposed 'comfort factor' investigation was omitted after the hypothesis was found to require a different methodology and more detailed measurement. Vibrations were recorded from a Landrover and three JCB 3C excavator-loaders, courtesy of JCB Research Ltd. Subsequent analysis showed that excessive acceleration levels, at low frequencies, were received at the driver's seat and that these frequencies also appeared in cab and axle vibrations. Thus the identification of the vibration source became an important aim of the study. The siting of the driver's seat above the drive wheels axle and the absence of axle springing/damping focussed attention onto the tyred wheel. A typical drive wheel was supported in a test/frame and its response to vibration measured. Free vertical movement of the axle was provided by a cantilever arrangement designed not to influence the low frequency response anticipated from the wheel. Finally, a survey of drivers was completed to obtain their subjective assessment of vibration received. Analysis and cross correlation of measured and survey data confirm that discomfort and fatigue will be experienced by the drivers of these machines. The study also provided evidence that the large pneumatic tyres are the sources of the low frequency vibration.

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Thank you All

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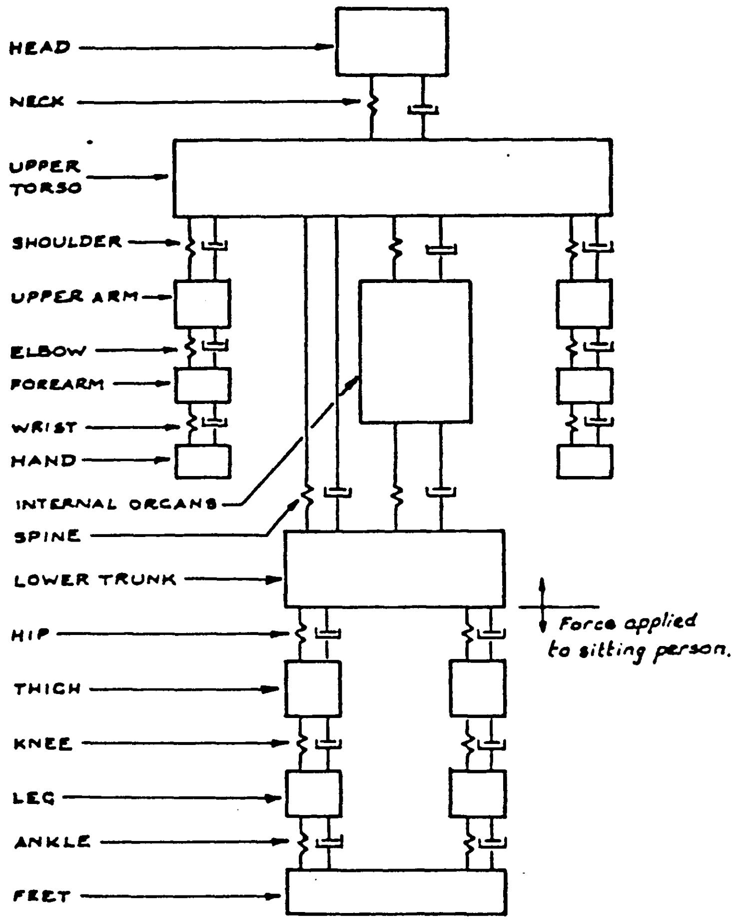


PROPOSED LUMPED-PARAMETER VERTICAL MODE HUMAN BODY VIBRATION MODEL. ref D.P.Garg (1981)

Figure 1

CHAPTER 1

Human Response to Vibration

1.1 Introduction

The Human body is a very complex organism in its construction with its skeletal frame, internal organs, muscles and ligaments often delicately connected. These elements of the body can be considered as a mechanical system but when this analogy is applied to individuals the resulting performance differs from person to person.

If the body's mechanical system was as straightforward as the lumped mass arrangement shown in Figure 1 the effects of vibration could be predicted with reasonable confidence. However, the body is also equipped with the mechanical system to register degrees of pain. Therefore, when these two parameters are combined with psychological effects, such as perception or satisfaction, the effects of vibration become very complex. However, it is necessary to take both mechanical and psychological systems into account if human response to vibration is to be considered. GARG (1981) considered that when the body is subjected to low frequency vibrations at low levels it is found to approximate to a lumped parameter system. Also Frolov (1981) found that the basic resonant frequencies of vertical oscillation of the human body, in the sitting position, lie in the 4 — 6Hz area. This, then implies that careful design of vehicles is required if such frequencies are to be prevented from reaching the driver.

The criteria which need to be considered as influencing the body's response to vibration are:-

(a) - frequency of vibration
(b) - intensity of vibration
(c) - direction of vibration, and
(d) - exposure time

1.2 International Standard ISO2631:1978(E)

Studies which have been carried out into these criteria, eg O'Hanlon and McCauley (1974) have been used to produce the International Standard ISO2631:1978(E). This International Standard recognises three kinds of human exposure to vibration:

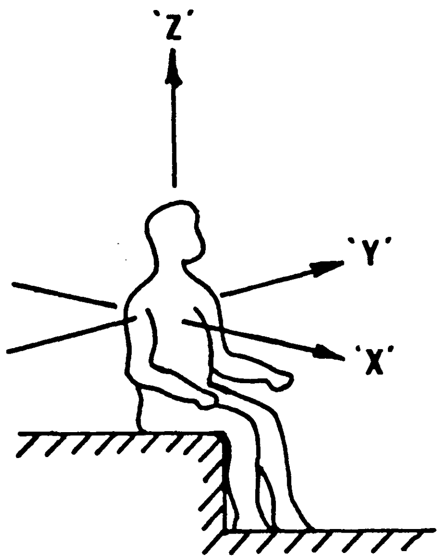
(i) vibrations transmitted simultaneously to the whole body,
(ii) vibrations applied to particular parts of the body eg hands, head or feet; and
(iii) vibrations transmitted to the body as a whole but through a supporting surface, eg the buttocks of a seated man.

The last of these three conditions is the principal feature of this study. It is also stated to be the condition which the International Standard applies chiefly - Ref ISO2631:1978(E) p.1, therefore it naturally becomes a principal reference source for levels of tolerance or discomfort.

In view of the importance of the four criteria previously mentioned, a brief explanation of each is appropriate.

(a) Frequency of Vibration : Many valuable observations have been made into the effects of frequency of vibration on human comfort; Guignard & King (1972) and Dupius (1980). In these and others the most useful data has been in the frequency range between 1Hz and 100Hz. It has also been noted that above 100Hz the analysis of the vibration requires methods much more complex than the comparatively simple model previously shown in Figure 1. In this work a narrow band analysis, ie 0.25Hz band width, was completed for each accelerometer location and the results extracted at one third octaves, from 1Hz to 80Hz, for study and comparison with ISO2631:1978(E).

(b) Vibration Intensity : Theoretically it is irrelevant to the frequency analysis of a vibration signal which of the three parameters, displacement, velocity or acceleration are selected for measurement. However, where physiological factors are concerned, acceleration is the primary quantity used to describe



DIRECTIONS OF CO-ORDINATE SYSTEM
FOR MECHANICAL VIBRATIONS
INFLUENCING HUMANS ISO 2631: 1978

Figure 2

the intensity of vibration and the magnitude is expressed as a root-mean-square (r.m.s.) value (m.s-2). The acceleration limits, as applicable to the human body, are related to three generally recognisable criteria ie

(a) for preservation of comfort - this is particularly applicable to passenger ride conditions, ie 'reduced comfort boundary'
(b) for maintenance of working efficiency - this refers more to vehicle drivers or machine operators, ie 'fatigue-decreased proficiency boundary', and

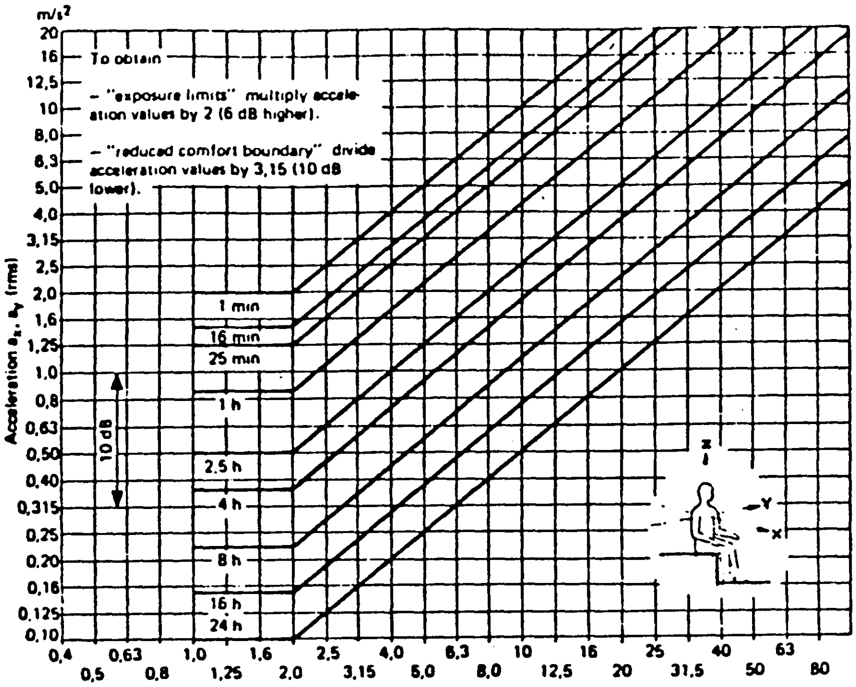
(c) for avoidance of risks to health or safety - these limits should not be exceeded without special justification and precautions being taken, ie 'exposure limit'.

The boundary most relevant to the drivers of excavator-loader vehicles will be the 'fatigue-decreased proficiency boundary' criteria (b) above.

(c) <u>Direction of Vibration</u> : As shown in Figure 2, the appropriate directions in which rectilinear vibrations should be measured are designated:

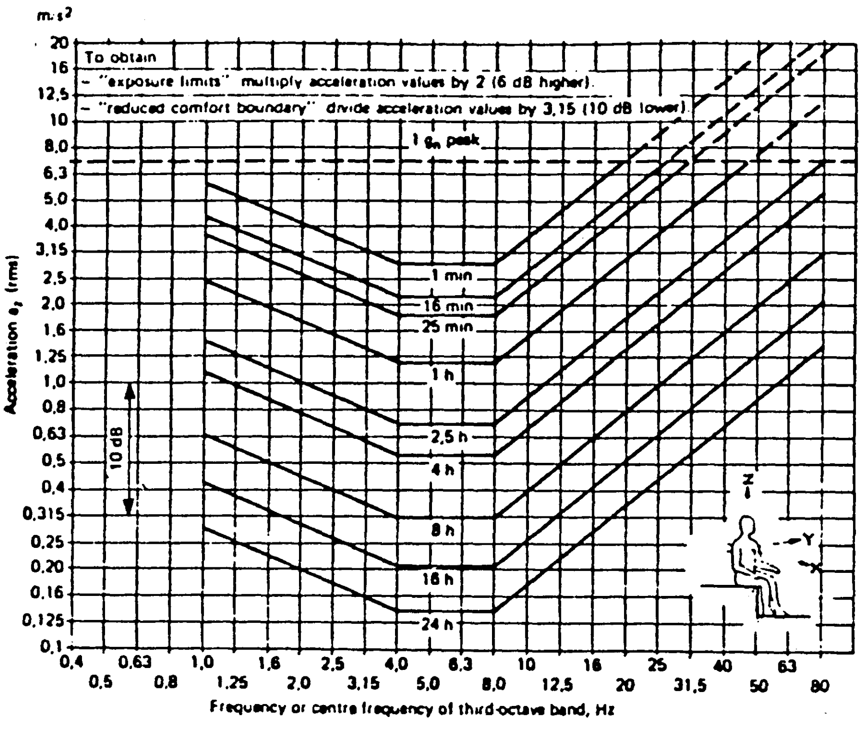
(i) 'Z', longitudinal axis, ie foot (or buttocks) to head,

ISO 2631:1978(E) EXPOSURE CRITERIA CURVES.



Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries 'X'; 'Y' AXES

Figure 3



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries 'Z' AXIS

Figure 4

(ii) 'X', fore and aft axis, ie chest to back (anteroposterior)

(iii) 'Y', lateral axis, ie right to left side

These relate the co-ordinate system to the human skeleton in a normal position and centre at the heart. It is recognised that angular (rotational) vibrations are often present in a vibration environment, as for example, in the case of an excavator-loader. However, the Standard considers that there is insufficient data available about their effects on human comfort and consequently does not include these in the recommendations.

(d) Exposure Time : The period of time which a person is subjected to vibrations, whilst carrying out tasks of varying complexity, will affect their proficiency. The International Standard ISO2631:1978(E), Figures 3 and 4, recommend guide lines for the amount of time which should not be exceeded if significant risk of impaired working efficiency is to be avoided. The degree of interference which a vibration environment has on a task will obviously depend on a variety of factors of both human and task origin. However, for people in normal health, ie considered fit to undergo the stress of a typical working day, the trend lines indicate the likely onset of this interference related to frequency and acceleration level.

The limits shown can be applied to tasks causing continuous exposure over the stated period or to a task where the exposure is a daily event over many years. These conditions are relevant to the drivers of excavator-loaders and other similar earthmoving vehicles.

1.3 Summary of objectives

The purpose of this study was an investigation into the vibration environment to which the drivers of earthmoving vehicles are exposed during travel over the irregular terrain of construction sites. Its principal aim was to discover their degree of discomfort risk by analysing the vibration they received, for frequency content and acceleration level relative to ISO2631:1978(E).

To facilitate this and to identify the source or sources of the vibration it was considered necessary to study:

(i) the influence of different road profiles on vehicle vibration.

(ii) the transmissibility of frequency and energy between road and driver, and

(iii) the static and dynamic characteristics of the earthmovers main suspension system, the tyres.

This work was carried-out on JCB 3CX Excavator-Loaders at JCB Research Ltd's test site and in the laboratories at Sheffield City Polytechnic.

CHAPTER 2

Landrover Tests

2.0 Introduction

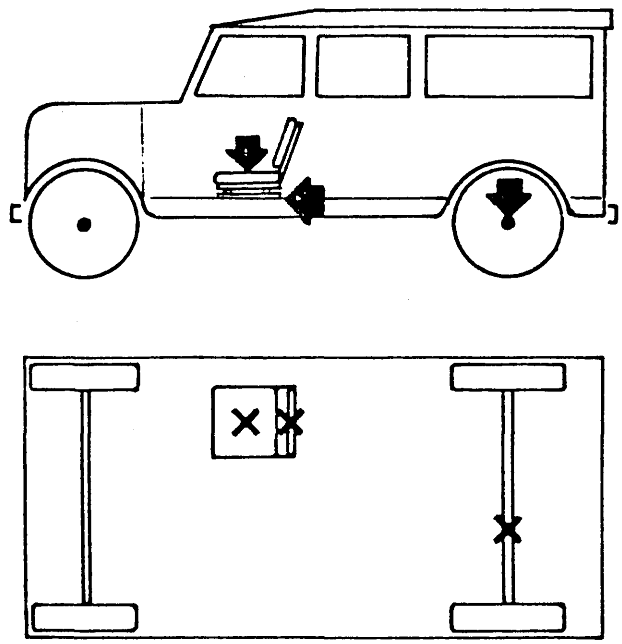
All vehicles travelling over a 'road' will be affected by the roads roughness, or profile, and consequently vibrations will be generated at the contact points. The profile of the terrain over which a wheeled excavator/loader can be expected to travel, during the period of a construction contract, can vary from the comparative smoothness of an asphalt road to a rough broken stone surface such as a quarry floor.

2.1 Road Surface

This variability of surface highlights the following points for investigation:-

(i) How will the roughness of different surfaces influence the vibration at the driver's seat through acceleration?

(ii) Must the frequency spectrum of the road be known for prediction of and correlation with the response at the seat?



ACCELEROMETER LOCATIONS
ON LANDROVER

Figure 5

(iii) What is the relative importance of the vibration in each axis with respect to the recommendations in ISO2631:1978(E)? Studies have shown that vibrations transmitted to the human body in the vertical direction, ie 'Z' axis, Figure 2, page 6 are the principal ones causing discomfort or disability: Stayner, Hilton & Moran (1975). As a consequence, a study was made to substantiate this for earthmoving vehicles. Due to the high lateral forces peculiar to rough terrain the study was extended to determine the influence of the road forces as they affect the other two cartesian axes.

2.2 Landrover Vibration Tests

These tests were carried out on a standard, long-wheel base vehicle with the accelerometer located on the axle, the anchorage point of the driver's seat to the cab and between the driver and his seat cushion, Figure 5.
The instrumentation used was that described in Appendix 'A'. and a detailed description of which was given by McNulty and Douglas (1982).
The aims of the tests were to determine:

(i) the frequency response of the vehicle at each location in the 'X', 'Y' and 'Z' axes.

(ii) whether different road profiles produced a different frequency response, and

(iii) the influence of road profile amplitude, ie road roughness on the frequency responses.

Care was taken in selecting the test roads such that they had different surface profiles and different degrees of 'roughness'; being designated 'smooth', 'cobbled' and 'rough'.

2.2.1 Smooth Road

This was a typical Class 'A' trunk road surface with a bitumen and aggregate finish. It did not have any faults in its surface and provided as 'smooth' a ride as could be obtained on any road surface.

2.2.2 Cobbled Road

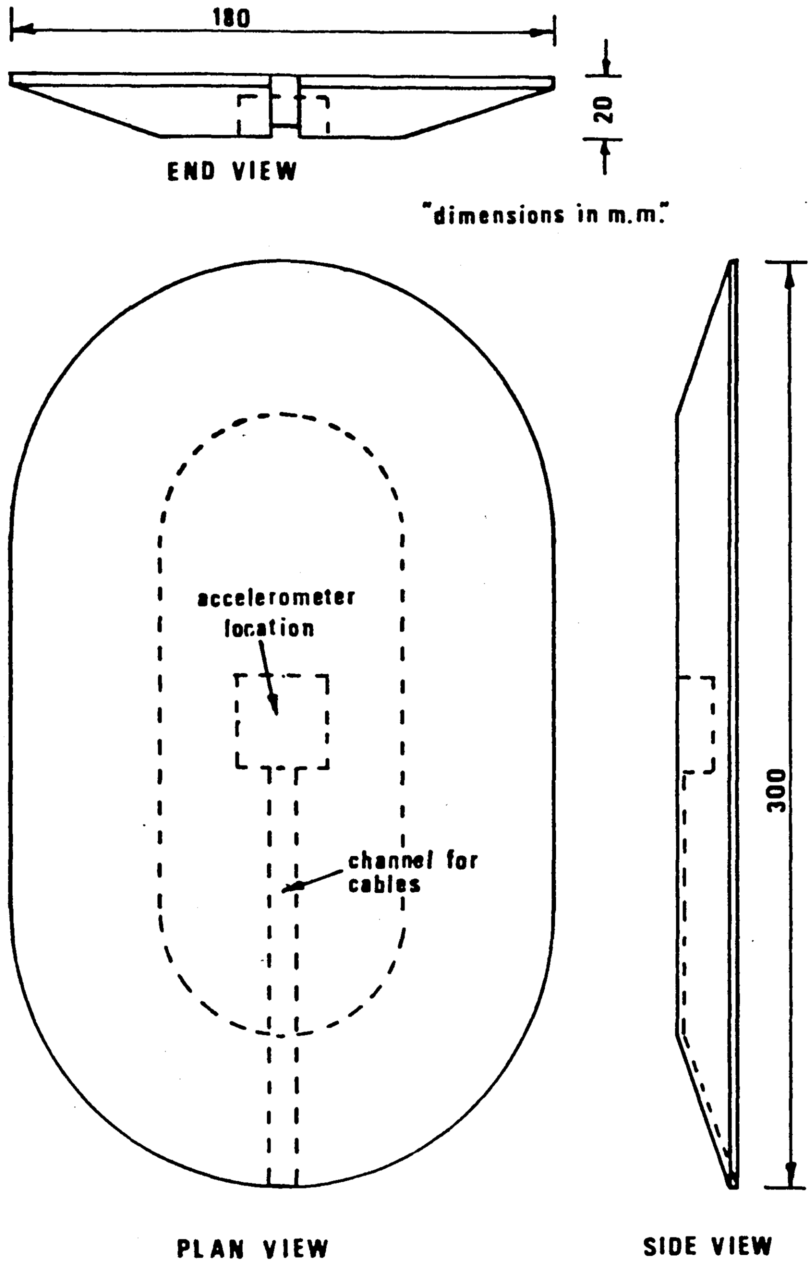
This road was the type as laid principally in the nineteenth and early twentieth centuries. It was finished with granite setts, about 100mm cube, but had not been maintained in a good condition. In numerous places the setts had been depressed varying distances down to some 50mm or canted over causing edges or corners to project above the general level of the surface. Consequently, this road presented a totally different surface profile for the vehicle to traverse yet one reasonably mid-way between the 'smooth' and the 'rough'.

2.2.3 Rough Track

This title indicates exactly the nature of this road for it was an unmade track leading on to moorlands used mainly by Forestry Commission workers for access to a plantation. The track varied in width and consisted of boulder clay with patches of moorland grass. Due to the land contours, water from rain or melting snow ran down the track from the moors and onto the minor road nearby. This resulted in furrows down the track and at various angles across it of differing widths and depths. In addition, grass mounds and rocks were caused to project as much as 150mm above their immediate surrounding area. It will be obvious that this presented a very rough surface for the vehicle and yet:

> one for which the vehicle was designed, and one which equates very well with the type of terrain which may be found on a construction site.

Over each surface it was possible to travel for about 400m in a relatively straight line and, in order that the road surface remained the only variable, a constant speed of 10 m.p.h was maintained during the recording period. This speed was chosen for its relevance to construction site speeds and the problems which would be encountered in attempting higher speeds over the rough track.



'SIT-BAR' by permission of Dr M J Griffin
(Southampton University)

Figure 6

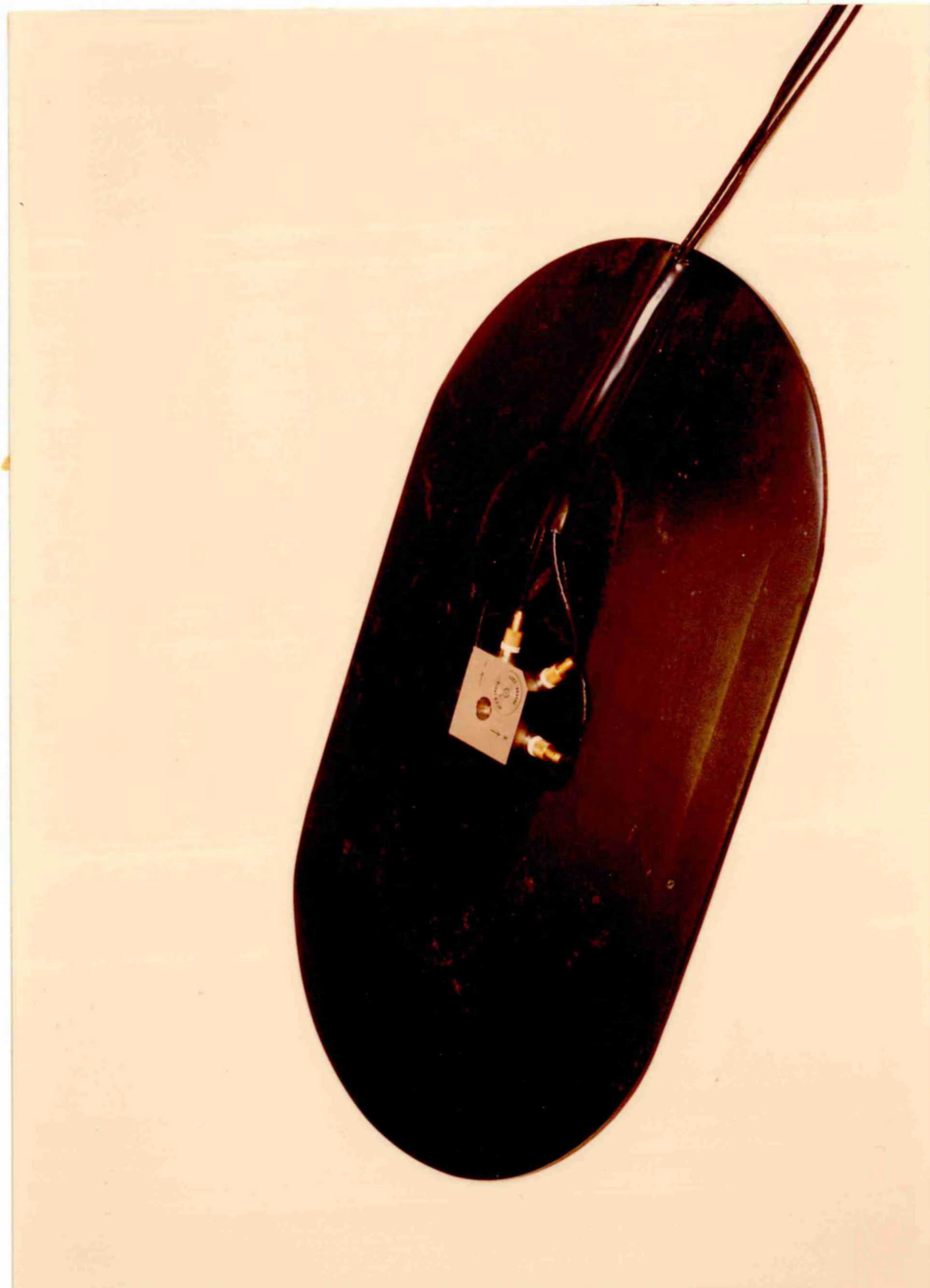


Plate 1

'SITBAR' showing the accelerometer located centrally in the lower face

2.2.4 Accelerometer Locations

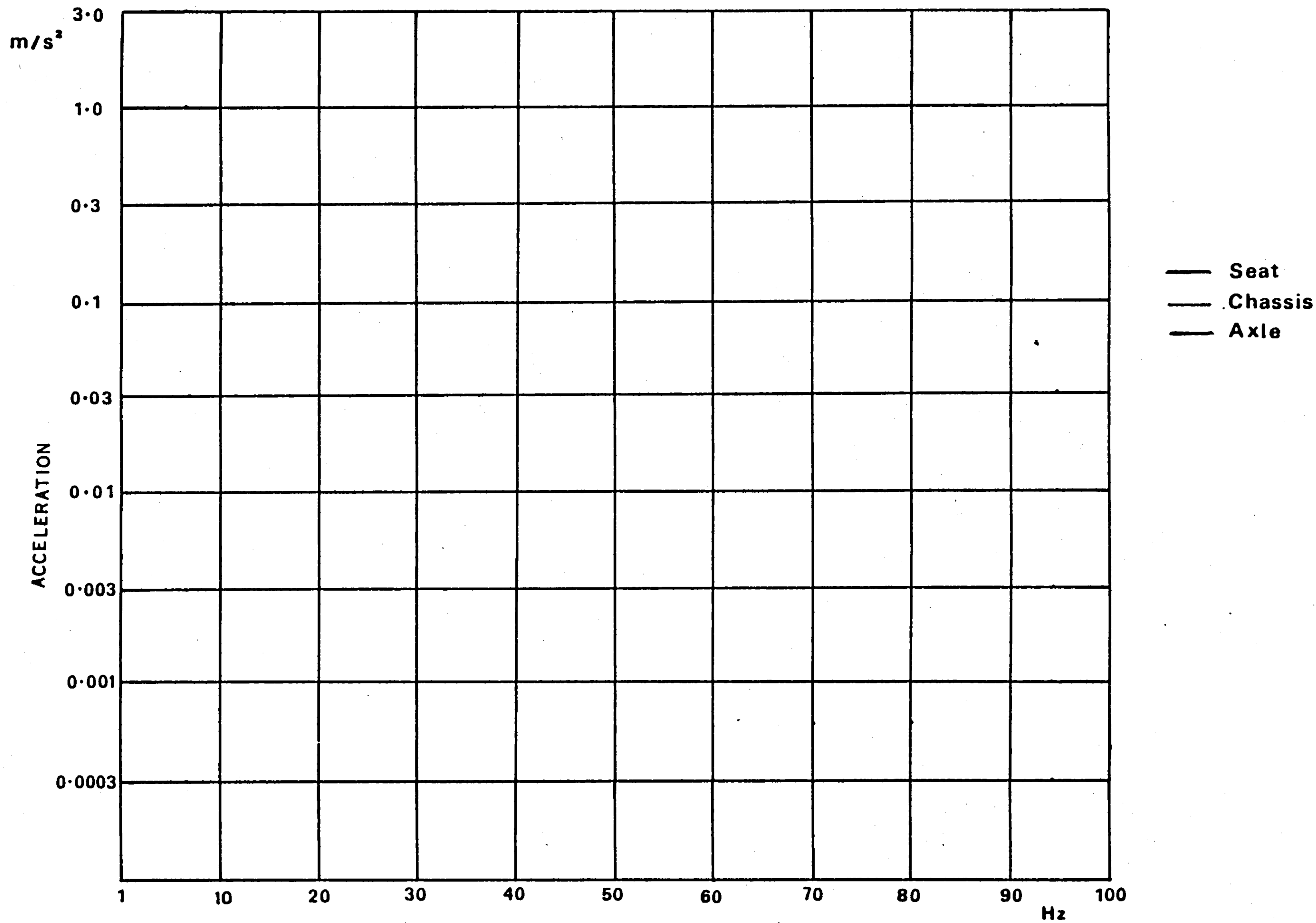
Each road surface was traversed and recordings made before the accelerometer was moved to a new location. The 'cab' location did not present any difficulties but care had to be exercised at the 'axle' to prevent damage to the accelerometer and to stop 'noise' occurring on the tape from the cables.

In order to measure and record the seat transmissibility the accelerometer was fixed into a rigid plastic 'plate' as designed by Whitham and Griffin (1977). This 'plate', or 'SIT-BAR', (Seat Interface for Transducers indicating Body Acceleration Received) is shown in Figure 6, Plate 1. It was designed to locate the accelerometer below the ischial tuberosities of the driver and present to the cushion, on the driving seat, a surface similar in shape and size to that portion of the human buttocks normally in contact with a seat.

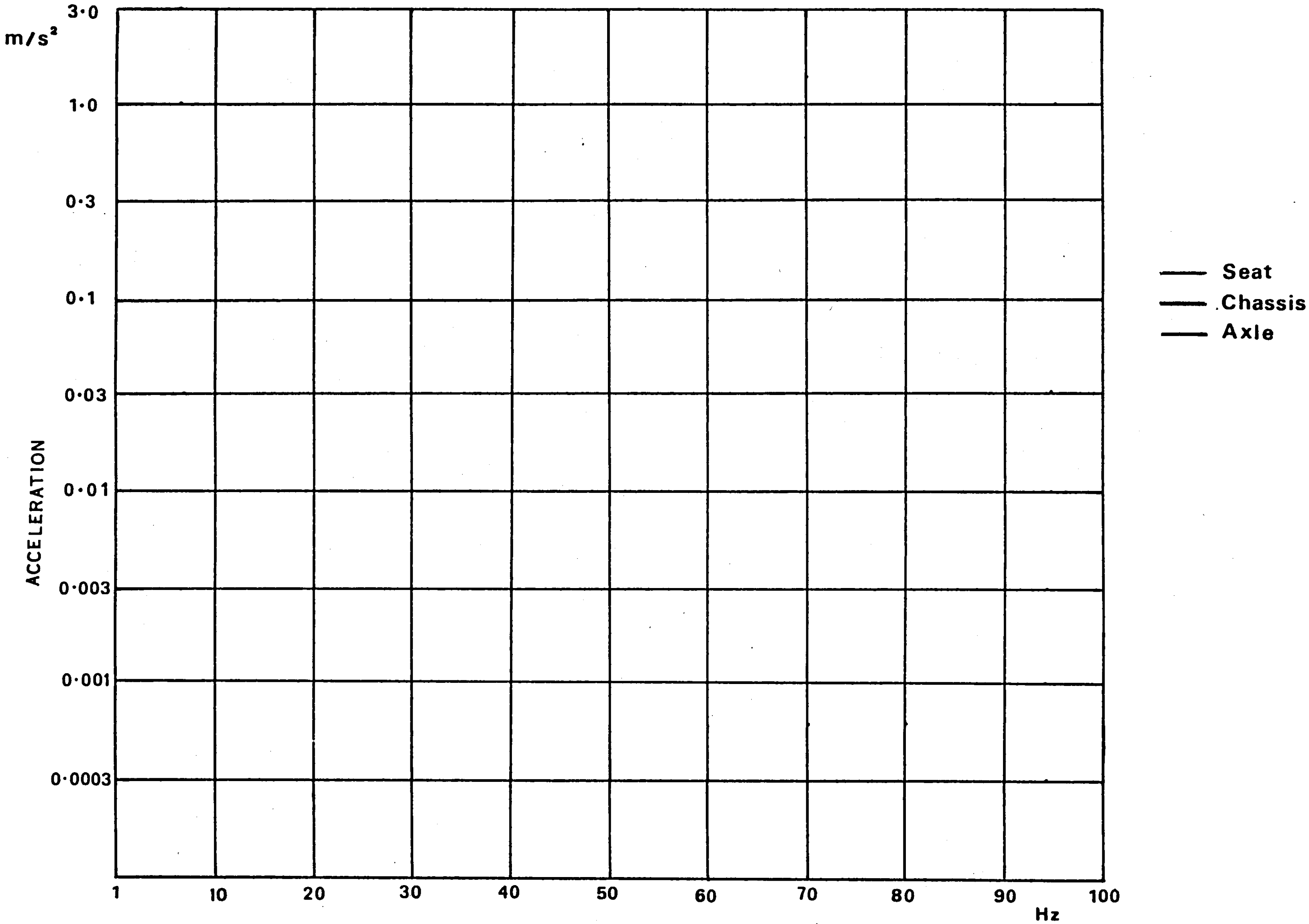
2.3 Test Results

The chart recordings of frequency response at 'axle', 'cab' and 'seat', in all three co-ordinate directions over the 'smooth', 'cobbled' and 'rough track' surfaces are shown in Appendix B.

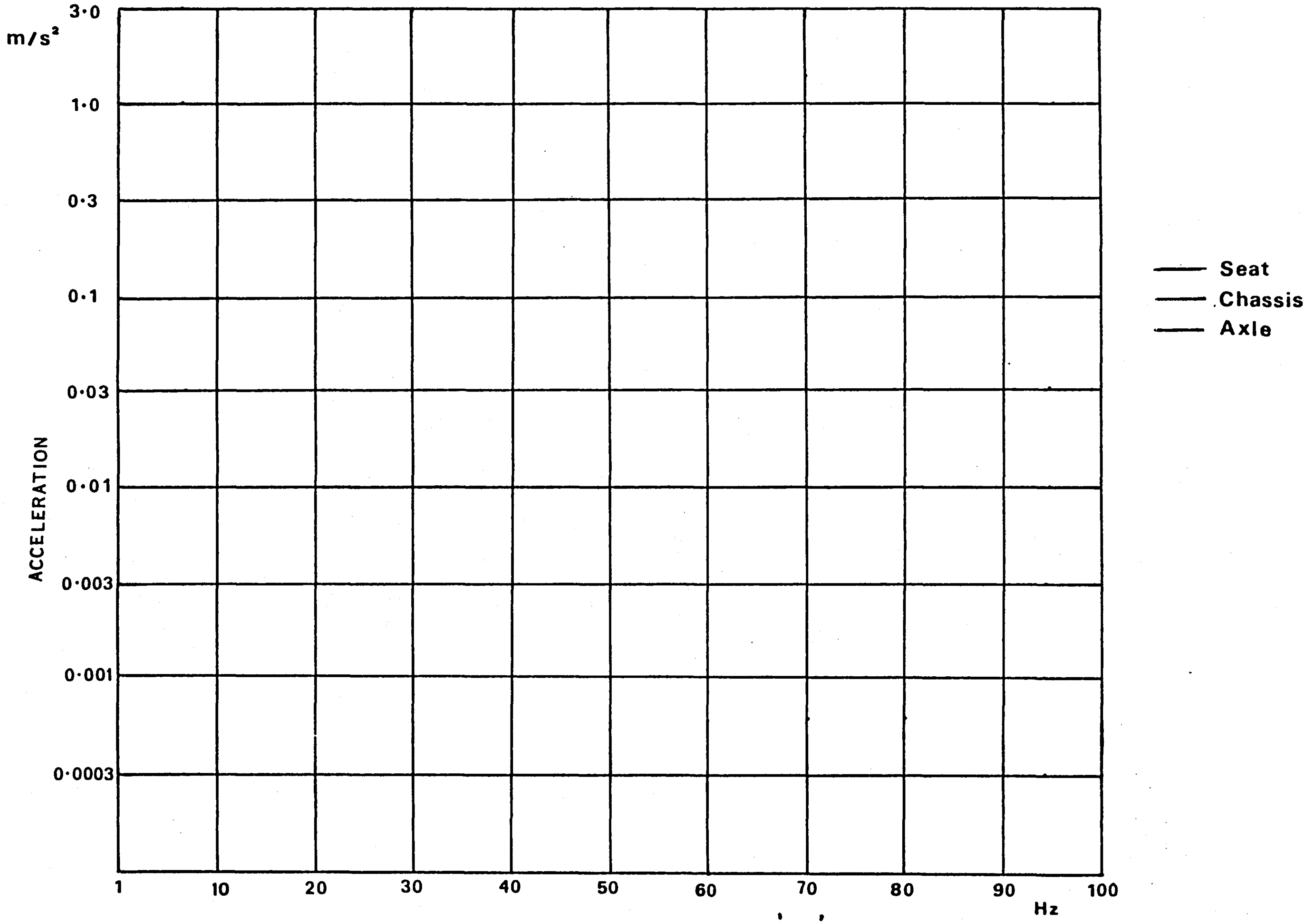
In addition, and to assist with the discussion of the results which follow, the same recordings are presented in an overlay



FREQUENCY SPECTRA OF LANDROVER VIBRATIONS 'X' axis



FREQUENCY SPECTRA OF LANDROVER VIBRATIONS 'Y' axis



FREQUENCY SPECTRA OF LANDROVER VIBRATIONS 'Z' axis form, to a reduced scale in Figures 7, 8 and 9.

2.3.1 Comparison of the graphs allows the following observations to be made:-

(i) That each axis has its own characteristic frequency response at axle, chassis and seat. This suggests that the components responsible for the resilience at each location are acting as a specific type of filter to the excitation applied.

(ii) This characteristic response is independent of the road profile traversed. A consequence of this is that the response within the frequency domain, can be predicted in general terms and the amplitude of a road profile will only influence the acceleration levels of the response.

(iii) <u>'X' axis</u> : The chassis response is 'flat' across the frequency domain for each 'road'surface and yet the responses at axle and seat show striking similarity.

<u>'Y' axis</u> : The responses here are much more random than in the other axes, however, the general trend is similar, particularly with respect to the 'axle'.

'Z' axis : The features of these responses are the similarities between:-

(a) the axle trends over 'cobbled' and 'rough track' roads, and

(b) the seat trends over all three road surfaces.

It is also particularly noticable how the greater roughness of the 'rough track' produces a more pronounced response from the chassis.

A general comparison of these graphs shows there is a more individual response in the 'Y' axis direction, and a similarity, in the frequency domain of the peaks in the 'X' and 'Z' axes. Whilst the vehicle is in motion the springs will allow greater movement in pitching than in rolling, consequently, any frequency strongly associated with a pitching action may have its horizontal and vertical components transmitted to the 'X' and 'Z' axes.

2.3.2 Comparison with International Standard ISO2631:1978 (E)

The areas where movements of the vehicle infringe on the driver's comfort and efficiency during his work can be deduced from comparison of the vibration responses with ISO2631:1978. In order to make these comparisons, it was necessary to convert the

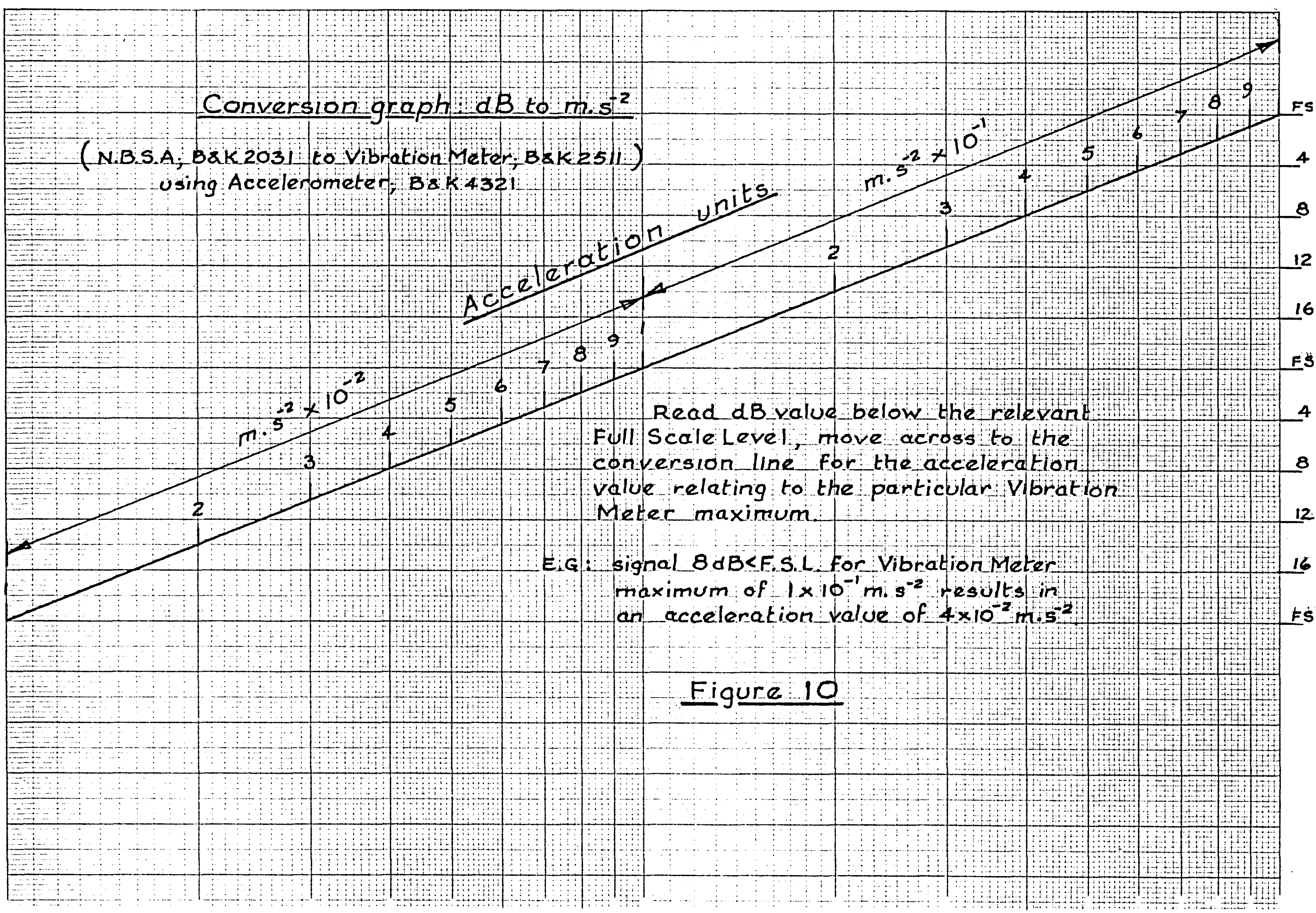
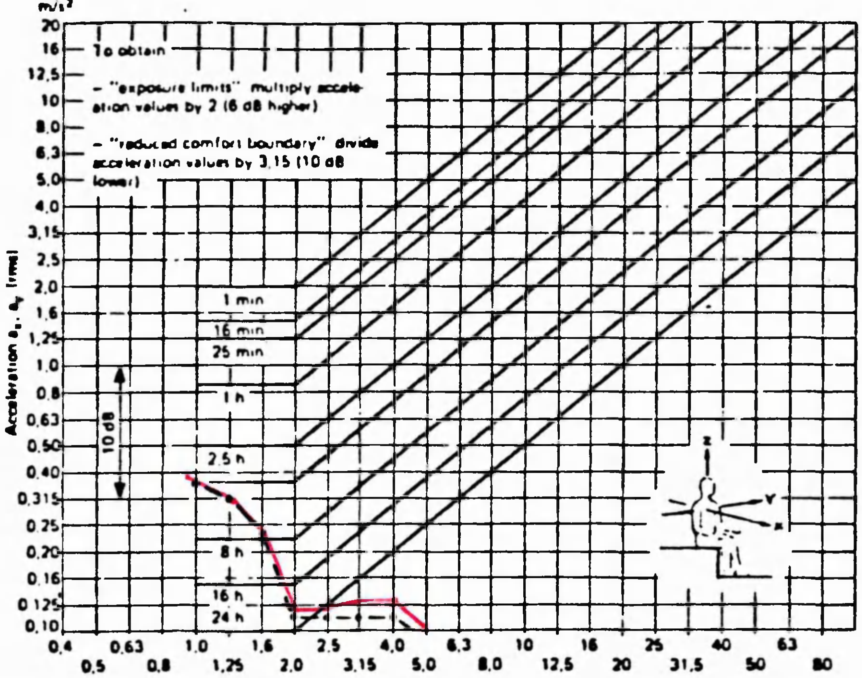

Conversion graph: dB to m.s⁻²
(N.B.S.A.; B&K 2031 to Vibration Meter; B&K 2511)
using Accelerometer; B&K 4321
Acceleration units
m.s⁻² x 10⁻¹
m.s⁻² x 10⁻²
Read dB value below the relevant Full Scale Level, move across to the conversion line for the acceleration value relating to the particular Vibration Meter maximum.
E.G: signal 8 dB<F.S.L. for Vibration Meter maximum of 1 x 10⁻¹ m.s⁻² results in an acceleration value of 4 x 10⁻² m.s⁻²
FS
4
8
12
16

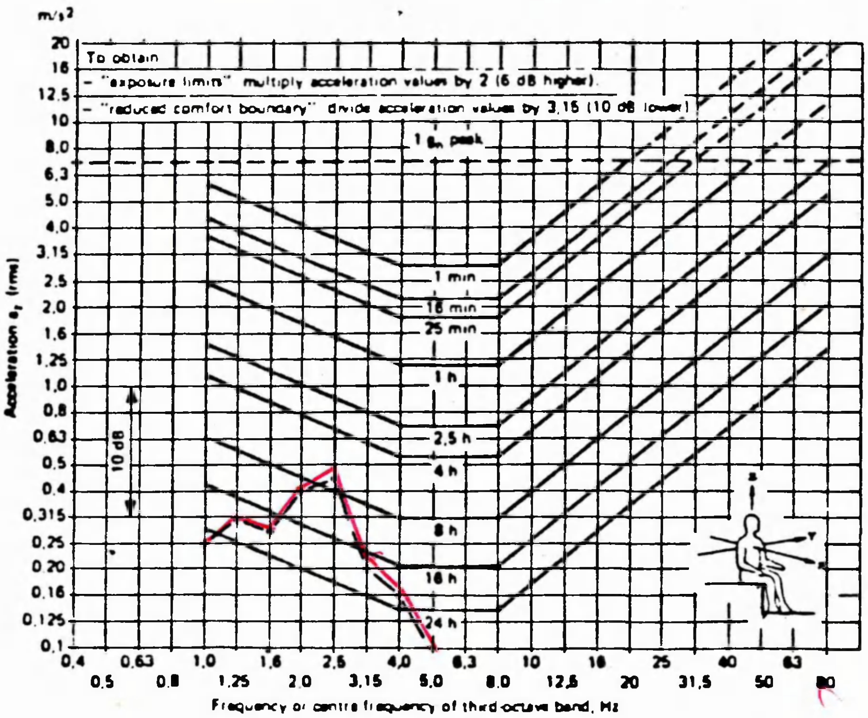
Figure 10



Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

LANDROVER (rough track) 'Y' axis Figure 11

see page 30



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

LANDROVER (rough track) 'Z' axis

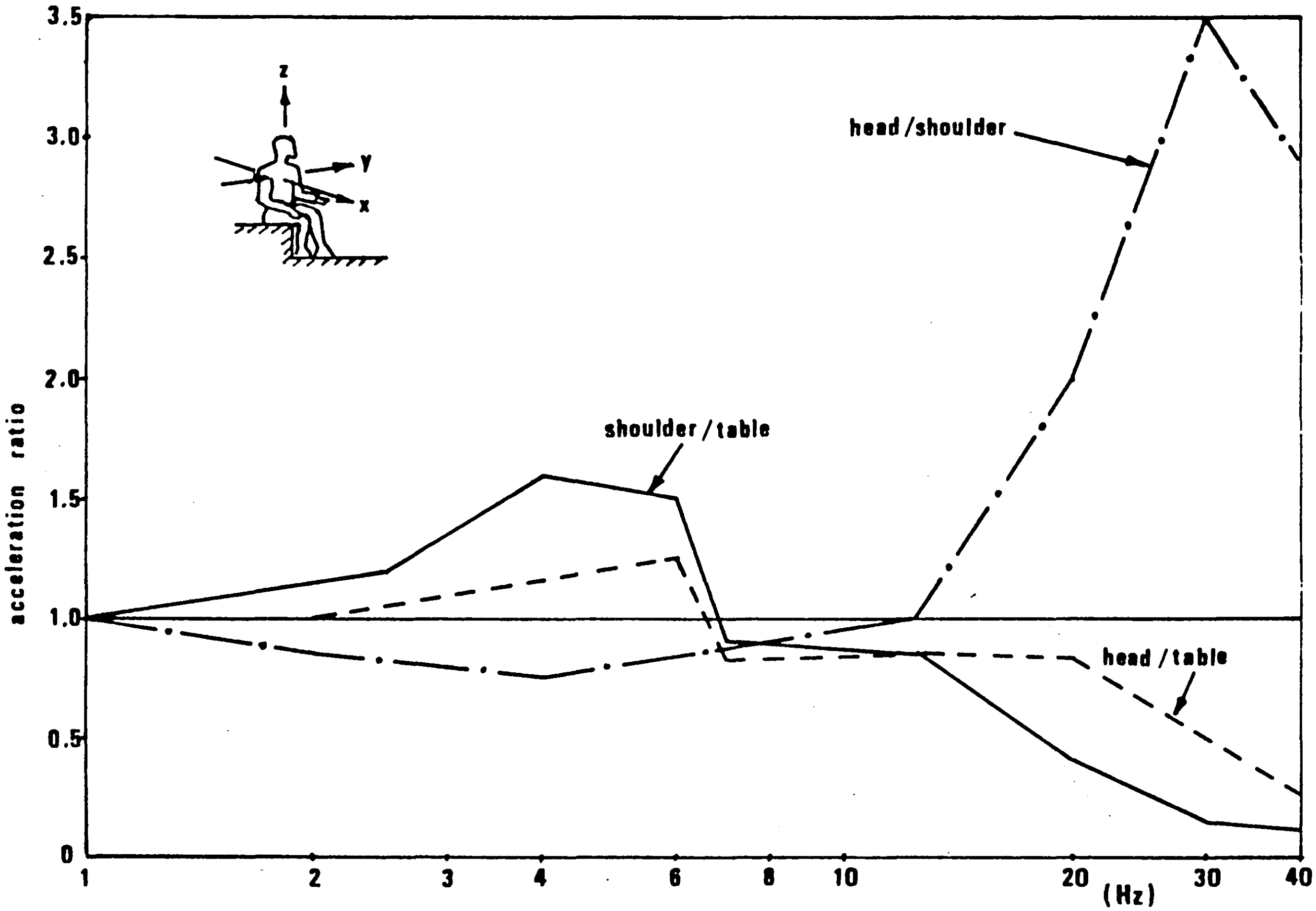
Figure 12

Comparison of spectral density of Landrover vibrations with ISO 2631 exposure criteria curves acceleration levels, at the relevant frequencies, from 'decibels' to 'metres per second squared'. This was done with the aid of the calibration graph, Figure 10, and the results are produced in Figure 11 and Figure 12.

The first conclusion is that the 'X' axis does not present a problem for the driver in respect of either his efficiency or discomfort.

Figure 11, the 'Y' axis, shows that the 'reduced comfort boundary' is the only one infringed, since the highest level occurs at 1Hz and coincides with the 4 hour curve on the higher fatigue-decreased proficiency boundary. Work procedures do not normally exceed 4 hour periods without a meal break, if not a tea-break, therefore the limits of these fatigue-decreased proficiency boundaries are not exceeded.

On the graph, the 'reduced comfort boundary' is shown to be 10dB lower for each period of time. The effect of this is to place each acceleration value, for frequencies below 2.5Hz, at or above the 4 hour limit. Use of the overlay to Figure 11 shows this, and more particularly the discomfort which will be experienced after working for as short a time as 25 minutes.



Transmissibility of vertical vibration to a seated human. (After Dieckmann)

Figure 13

The frequency response of the seat in the 'Z' axis, Figure 12, again indicates that only the 'reduced comfort boundary' is infringed. However, five separate frequencies are above the four hour limit with the levels at 2 Hz and 2.5Hz causing problems in under two hours. Reference to Figure 13 shows that vibrations in these frequency ranges, received by a seated person, will be amplified at the shoulder causing discomfort in this area of the body.

It can be seen from this discussion that the driver of this type of vehicle will experience discomfort if driving over rough ground is required. This discomfort will be most likely to manifest itself in the shoulders and upper-arms and although not likely to influence the driver's efficiency may, over a long period of time, advance the onset of muscle weakness and perhaps arthritis.

Returning to the particular reasons for using the landrover, as stated on page 2.3, the following conclusions can be made:

1) Road surface roughness appears not to influence the frequency response of the vehicle. The vehicle's suspension system filters each type of vibratory input and responds in a manner peculiar to each axis.

2) It is not necessary to predetermine the forcing characteristics of the road surface. The randomness of undulations in the surface will influence only the amplitude of the signal generated within the vehicle.

3) The response of the vehicle in the vertical direction, ie 'Z' axis in ISO2631:1978, is the principal area of concern and more likely to lead to driver discomfort than either the 'Y' axis or the 'X' axis.

Addendum, following Examiner's Comments

The exposure time lines on Figures 11, 12 and 28 to 32 correspond to "frequency or centre frequency of one-third octave band, Hz" of ISO2631: 1978(E). The International Standard also requires acceleration levels of broad band vibration to be evaluated with respect to the centre frequency of each one-third octave band. On these Figures the black dotted lines show the narrow band, 0.25 Hz, acceleration levels for the seat and the red lines show the derived one-third octave band levels appropriate to the centre frequencies. The higher levels, in red, result in infringement of the 4 hr exposure line extending into higher frequencies to a maximum of 12.5 Hz and principally in the 'Z' axis direction.

Plate 2

JCB 3C Excavator-Loader : note the position of the driver's seat, vertically over the large diameter drive wheels.

CHAPTER 3

Excavator/Loader Tests

3.0 Introduction

The excavator/loader, Plate 2, is the 'work-horse' of construction sites. In addition to the variety of attachments which can be fitted to the front or rear telescopic arms for excavating, loading, scraping or chipping operations, the vehicles may be equipped with self-propelling tracks or rubber tyred wheels. When excavating or chipping operations are required, the vehicle is usually supported by its front loading bucket and by two hydraulic, telescopic legs at the rear thus raising the wheels above the ground. It will be readily appreciated that, in this position, the vibrations received by the driver will have their source or sources within the particular combination of operating mode, supporting system and tracked/wheeled motive arrangement.

3.1 Excavator-Loader Characteristics

From a study of the many possible operations it was considered that three different conditions could be identified with respect to the generation of vibrations:

(i) Excavating or chipping whilst stationary and supported on front bucket and rear telescopic legs.

(ii) Front-end scraping or loading travelling by means of tracks, and

(iii) Front-end scraping or loading, or rear-end loading and travelling by means of rubber-tyred wheels.

In all three conditions the front or rear actuating arms with bucket or scraper blade attachment would be brought into use. The energy required in their use would be determined by the material in which they were to work, therefore the transmitted vibrations would be too operation-specific for the study.

3.1.1 Tracked Vehicles

The vehicles which are equipped with self-propelling tracks are generally slower moving than tyred vehicles. In addition, the action of moving over their own tracks makes them less responsive to irregularities in the terrain over which they travel therefore, any induced vibrations will be less important.

3.1.2 Rubber-tyred Vehicles

With rubber-tyred vehicles however, it is a common observation and complaint from drivers that head, neck and shoulder pains are caused by bounce at the rear end. The survey carried out as part of this study confirms this. There is a far greater number of 'wheeled' excavator loaders employed on construction and associated work sites than tracked vehicles, therefore it was decided that a study of these vehicles had the greatest merit.

As previously stated these vehicles are capable of carrying out many operations yet the driver has just two seating positions to control the machine:

1) Facing forwards for (a) normal driving of the vehicles,
   (b) pushing material, etc using the scraper blade attachment, or
   (c) lifting and loading loose granular type materials, eg sand or gravel, using the front loading bucket.
2) Facing the rear for excavating or chipping using the hydraulic telescopic arm.

In the second position the vehicle needs to be raised onto the legs and front bucket for stability. These operations are carried out using the mass of the vehicle as an anchor, hence the need to remove the resilient effects of the tyres. When considering the vibrations transmitted to the driver their properties will be more specific to the work operation than in the case of the forward facing position. For example, digging in loose sandy soil will require less mechanical effort than where old building foundations or fissured rock is encountered below ground level. It was shown by McNulty and Douglas

(1983) that the vibration generated and transmitted to the driver, from work in each ground condition, is likely to furnish data specific only to itself, this is endorsed in the present work.

When the vehicle is required to be driven in either direction a common feature of each task is the effect of tyre stiffness and damping upon the vibrations produced. Whether the vehicle is stationary, eg during loading operations, or travelling forwards or backwards, tyre effects will be present. The design and construction of these vehicles results in the following relevant details:-

a) the driving wheels axle is rigidly fixed to the chassis,
b) the driver's cab is mounted on to the body vertically above the driving wheels, and, therefore,
c) the position of the driver's seat is also vertically above those wheels.

A consequence of these facts is that the entry of vibrational energy into the chassis, from whichever source, is certain to enter these wheels also. When the vehicle is travelling, the wheels will be the first point of entry for most of the vibrations, consequently their influence is important.

3.2 Selection of Test Surfaces

3.2.1 The ground profile on a construction site can vary widely in irregularity of shape, dimension of projections or depressions and texture of material. Driving across a site can result in a vehicle encountering different terrain conditions. Such rapid changes in profile obviously make it difficult, if not impossible, to determine the individual effect on the vehicle in the measurement of its frequency response. Also the randomness of these surfaces would prevent any correlation between the results and consequently the data would be relatively meaningless.

Consideration of these facts resulted in an approach being made to JCB Research Ltd, Rocester, Staffordshire, for permission to use their test roads, which was very readily granted.

3.2.2 Test Surface Description

The test surfaces used were constructed by the Company and are used regularly to assess the performance of their machines.

There are four test tracks, each with a different profile and all constructed in reinforced concrete. These tracks are arranged in a rectangular plan shape with two tracks on each long side. Alongside each track is a perimeter road for use by any vehicle accompanying the one under test. The tracks and roads are connected at each end by a continuation of the perimeter road to enable continuous testing to be carried out for as long as is required.

Each test track is 40m long by 3m wide and has a different profile to all the others. The profiles were chosen by the Company to give the vehicles a vigorous shaking when being driven over them but in four different ways.

3.2.3 The Test Tracks

(i) The Quarry Floor Track : This was constructed to provide a surface profile characteristic of that which could be expected on the ground within a stone quarry. Over the area of the track irregular shaped stones had been set onto the concrete, at random intervals, to project up to 100mm above the surface.

In addition, depressions of a similar nature and size were formed into the concrete to give a very irregular surface over which the tyres had to travel.

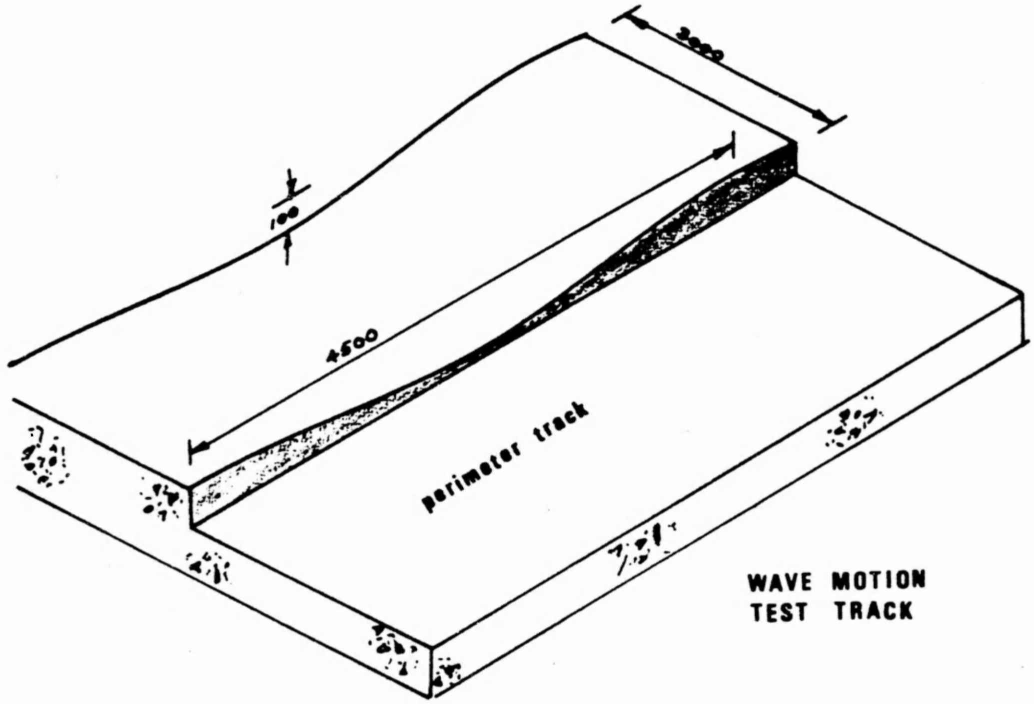


Figure 14

Plate 3

View of Wave Motion test track with the perimeter road.

Plate 4

Plate 5

Views of the Regular Kerb test track and perimeter road.

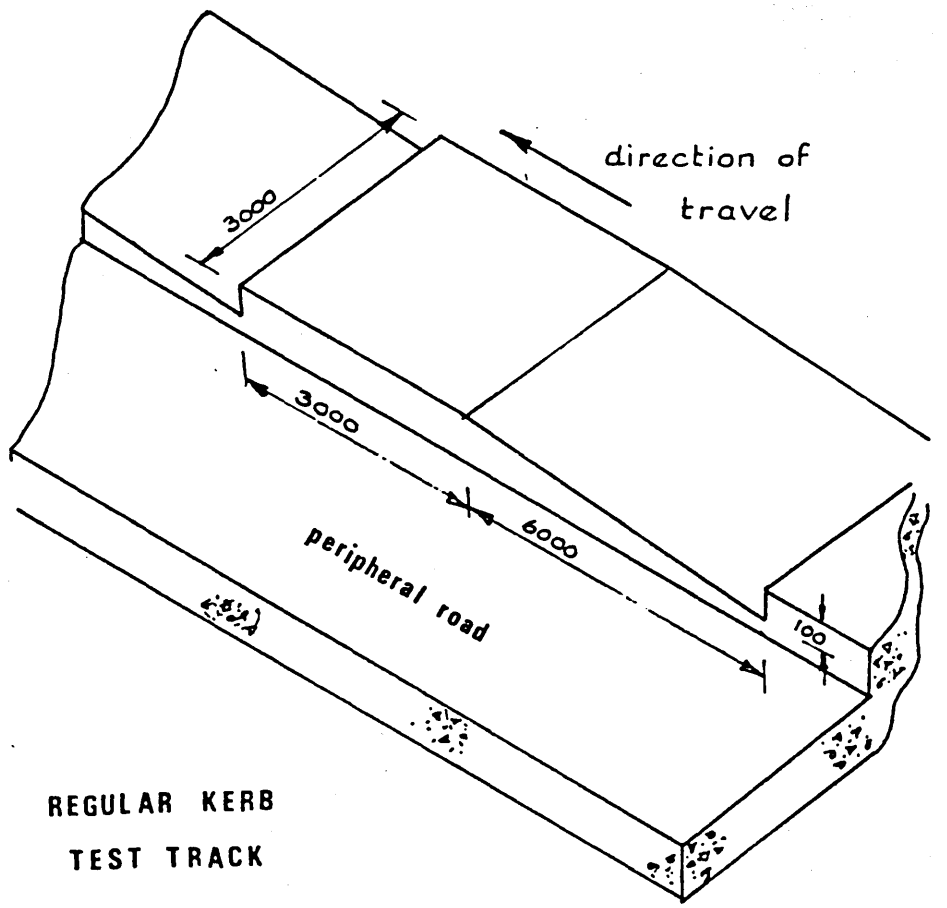


Figure 15

Diagram to show shape and dimensions of the test track.

Plate 6

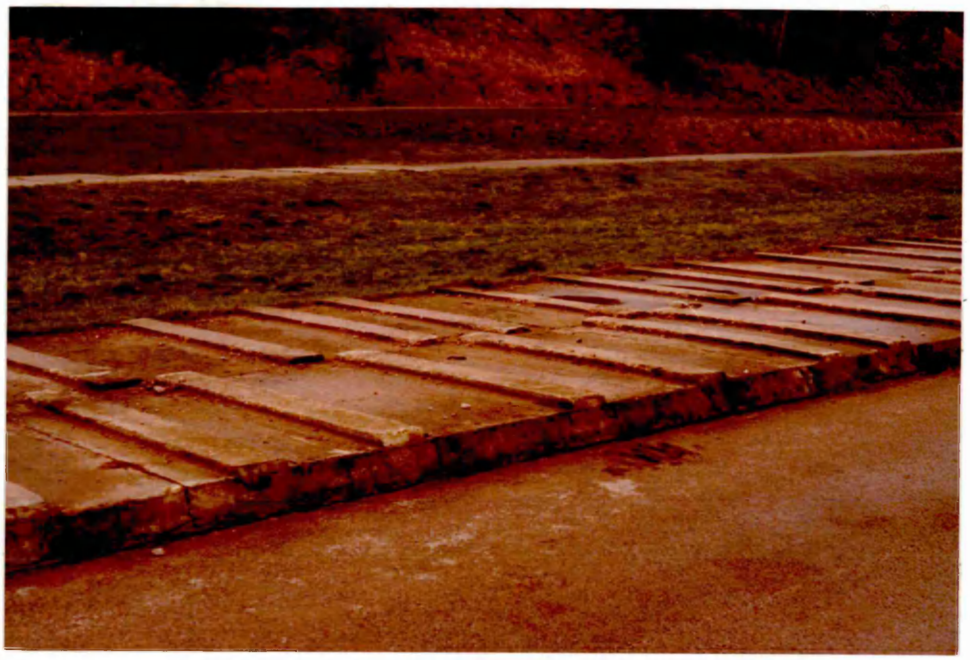
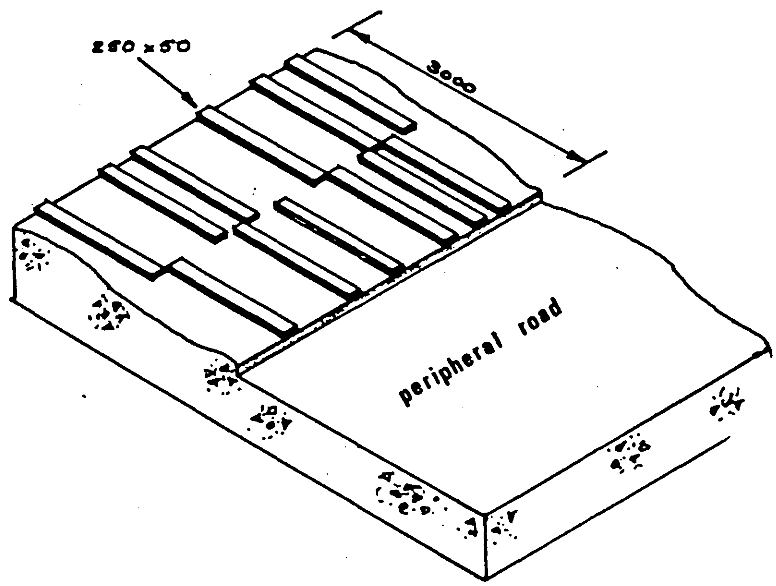


Plate 7

Views of the Random Kerb test track and its perimeter road



RANDOM KERB TEST TRACK

Figure 16

Diagram to show the random spacing of the kerbs in relation to the pair of wheels on each axle.

(ii) <u>The Wave Motion Track</u> : Figure 14 and Plate 3 show the shape of this track which produces repetitive motions in the vehicle as it travels across the surface.

(iii) <u>The Regular Kerb Track</u> : Figure 15 and Plates 4 and 5 illustrate this test track which again has a repetitive surface profile. As can be seen, the direction of travel intended for this track is from right to left. This results in a sudden drop of 100mm for the vehicle from the top surface. Both sets of wheels experience this shock but the greater response is from the large drive wheels at the rear, even though they have a bigger radius of curvature.

(iv) <u>The Random Kerb Track</u> : This track, shown in Figure 16 and Plates 6 and 7, is considered by JCB Research Ltd to provide the most severe test for their vehicles. It is adapted from tracks used to test fighting vehicles and consequently the excavator/loaders are subjected to vibrations greater than are expected from normal use. The drivers of the vehicles consider this track to be the most uncomfortable one to drive over.

3.3 <u>Test Procedure</u>

The instrumentation used in the test area was that described in Appendix A

Prior to commencing the test certain parameters were established to enable the results to be related to construction site conditions. These were:-

(i) that the vehicle should be driven at speeds commensurate with typical site speeds, ie 4 m.p.h. and 8 m.p.h,. and

(ii) that due to there being vehicles of differing age used on sites two vehicles would be used, ie a new machine and a used machine about 18 months old.

3.4 Test Vehicles

Both vehicles were ex-production machines as would be supplied to contractors.

3.4.1 The 'New' vehicle had been transferred from the works to the test area two weeks previously to undergo the standard proving tests required by the Company. It was fortunate for this study that the vehicle had not been introduced into their test programme therefore all the transmission paths for vibration between 'road' surface and driver, ie rigid and resilient connections, could be considered to be unstrained.

The importance of this was that the performance of these connections could be considered to be the most relevant since they were in their optimum condition. Also comparison of response and transmission data could be made with that from a used vehicle and any significant details studied.

Plate 8

View showing test arrangement of JCB 3C Excavator-Loader and attendant vehicle to carry the vibration measuring and recording instruments.

3.4.2 The 'Not New' vehicle had undergone many tests for endurance and stability which included:-

(i) forty eight hour continuous travel over the four test tracks,

(ii) inclined surface and stability tests, and

(iii) excavation and loading tests in a range of natural soil and rock materials.

It was due to these continuous and very stringent tests, over a comparatively short period of time, which resulted in the vehicle achieving the wear condition of a typical site vehicle about three years older.

3.5 Test Arrangement

It can be seen from Plate 8 that an accompanying vehicle was used on the test programme, this was necessary for two reasons:-

(i) The cab of the excavator/loader is designed to allow the driver to sit facing forwards or backwards and have optimum access to the controls. However, there is insufficient space for other equipment, such as that required for the test, particularly when room for another person is needed also.

(ii) The measurement and/or recording of vibration data requires the instrumentation to be itself insulated from vibrations, which will influence the results. This was

Plate 9

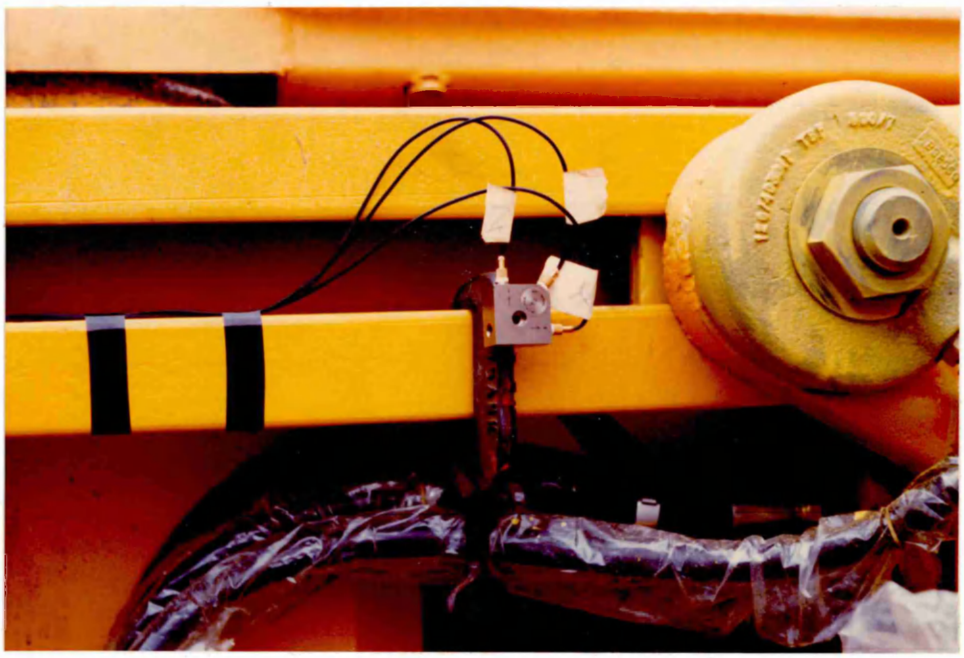
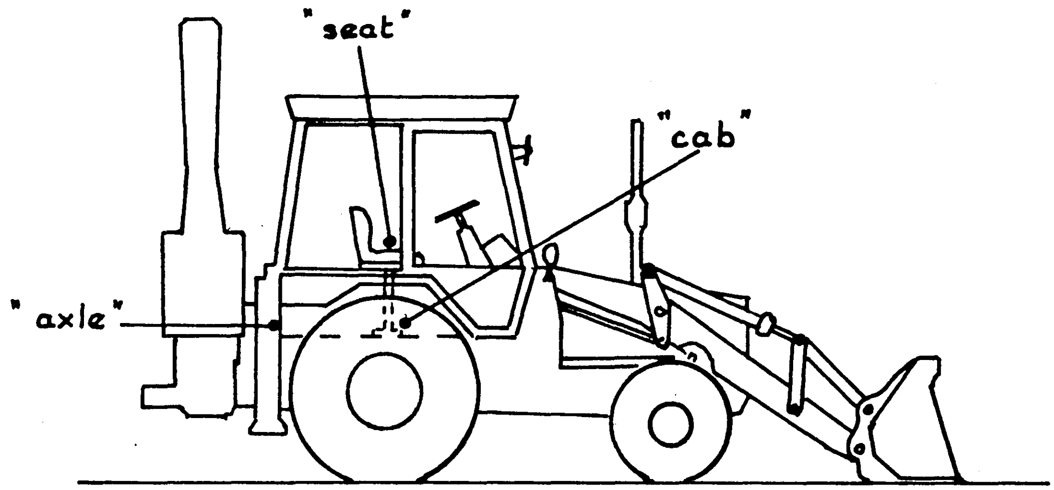


Plate 10

Views showing accelerometer location for 'axle' recordings. Actual axle fixing was not possible, this fixing has direct connection to axle via main frame.



J C B EXCAVATOR–LOADER

Accelerometer locations. Figure 17

Vibrations recorded in 'X', 'Y', 'Z' axes by triaxial accelerometer at axle, cab and seat on excavator-loader.

achieved by cushioning the instruments on the rear seat of the accompanying car which also allowed the operator to monitor the data and control the equipment during the tests.

The use of an accompanying vehicle also necessitated longer-than-normal accelerometer cables between the two vehicles. This required great care during the tests to ensure,

a) that the cables did not sustain damage, and also

b) that they were so attached at each end and supported in-between that spurious signals were not generated nor conditions caused which would influence the signals received from the accelerometer.

3.6 Accelerometer Locations

Three positions were chosen for the accelerometer, Figure 17, which correspond with those for the Landrover.

3.6.1 'AXLE' - Plates 9 and 10.

Fixed to a cross-member on the body of the vehicle which was adjacent to and rigidly connected to the axle fixing point. Actual fixing to the axle was not possible but this location was considered to be equally suitable since the signals received by the accelerometer would be the same as if fixed to the axle.

Plate 11

View showing accelerometer fixed to cab floor to record the vibrations transmitted from the axle to the seat.

Plate 12

Plate 13

'SITBAR', with accelerometer attached, in position on driver's seat to record the vibrations entering the body.

3.6.2 'CAB' - Plate 11

Clamped to the base of the driver's seat pillar where it bolted to the cab floor. The driver's cab is attached to the machine body by four bolts which pass through specially designed rubber suspension mounts between the two components.

3.6.3 'SEAT' - Plates 12 and 13

Finally, the accelerometer is located on the top of the driver's seat cushion at the point of entry of any vibrations into the driver. To achieve satisfactory transmission of the vibrational energy from seat to driver it was necessary to use the 'SITBAR' referred to in 2.2.4.

Figure 18

Brüel & Kjær | Time Function Start: seconds | End: seconds | Not Expanded: ☐ Expanded

Full Scale Level: As Below. dB

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Quarry Floor."

'X' axis vibrations

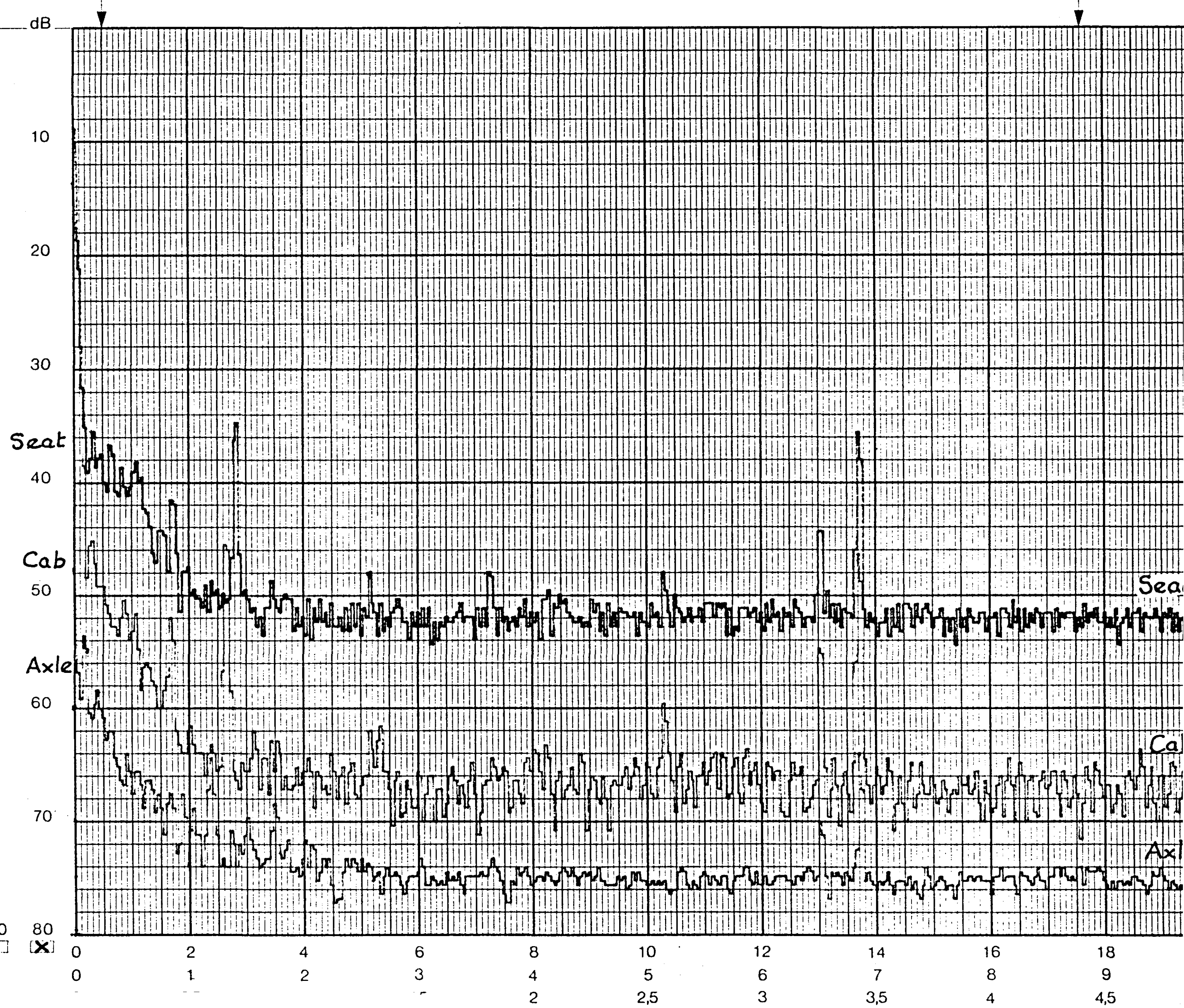
SEAT : FSL 100dB

CAB : FSL 110dB

AXLE : FSL 130dB

Each FSL = 10^{-1} m/s^2.

JCB '3CX'
Excavator - Loader (new)
speed ≈ 4mph.



Record No.: QF1X

Date: 12-8-82

Sign.: D. Douglas

20 ☐ 40 ☐ 80 ☒

Figure 18

Figure 19

Brüel & Kjær — Time Function Start: seconds — End: seconds — Not Expanded: ☐ Expanc

Full Scale Level: As Below dB

F. S. Frequency: 100 Hz

Weighting: Hanning.

Average Mode: Linear

No. of Spectra: 15

Comments: "Quarry Floor"

'Y' axis vibrations

SEAT : FSL 90dB

CAB : FSL 90dB

AXLE : FSL 120dB

Each FSL = $1 m/s^2$

JCB '3CX' (new)

speed ≈ 4mph.

Record No.: QF1Y

Date: 12-8-82

Sign.: D. Douglas

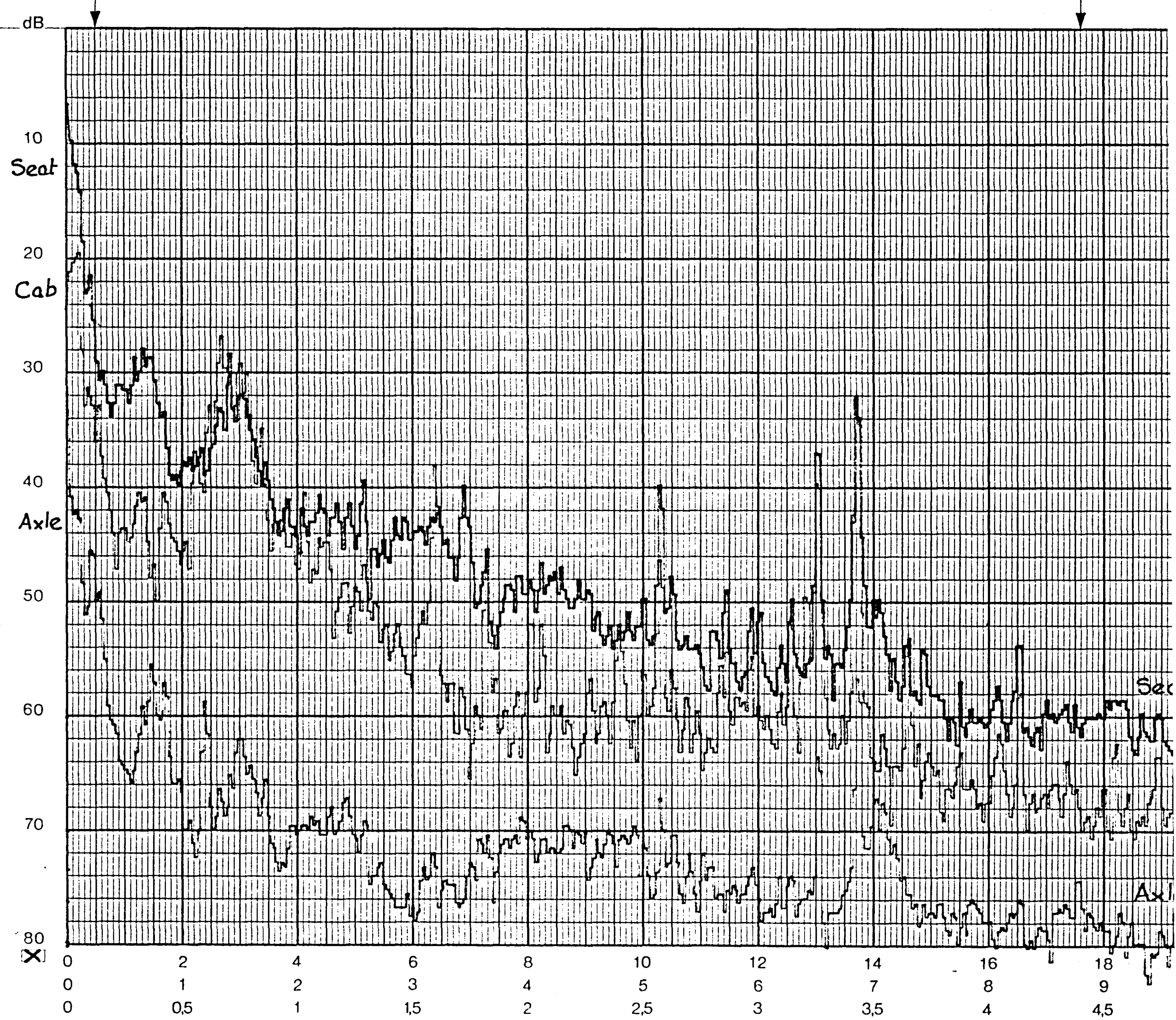


Figure 19

. igure _0

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As BELOW. dB

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Quarry Floor"

"Z axis vibrations

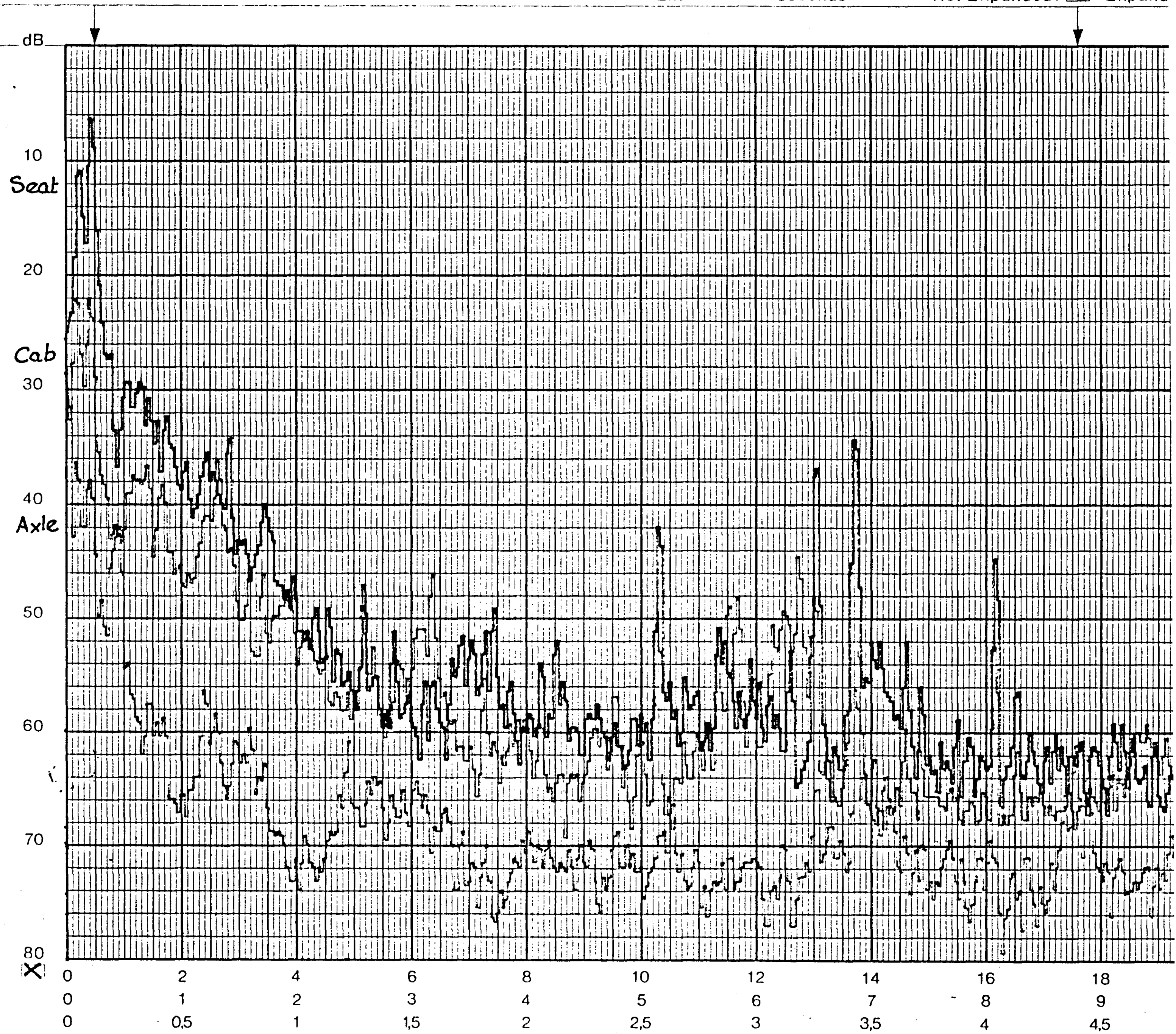
SEAT : FSL 90dB

CAB : FSL 100dB

AXLE : FSL 120dB.

Each FSL = $10 m/s^2$

JCB 3CX (new)



Record No.: QF1Z

Date: 12-8-82

Sign.: Douglas

Figure 20

QP 1002

Measuring Object:

CHAPTER 4

Excavator/Loader Test Results

4.0 Introduction

The displacement-frequency spectra of the vehicle at axle, cab and seat at each of the three axes of vibration ie 'X', 'Y' and 'Z', over the four test tracks are shown in Appendix C. Figures 18, 19, and 20 show examples of these graphs. It is important to note that the positions of the curves do not relate to their respective acceleration levels. The curves are deliberately separated on each sheet and the full scale level, in decibels, re 1μV RMS relevant to each curve was recorded for later conversion to metres per second squared. The position of each curve is also representative of the location of the accelerometer on the machine

eg: Seat; at top,

Cab; at centre, and

Axle; at bottom of the sheet

This allows the activity in any group of frequencies to be read upwards or downwards on each sheet and hence an indication of transmissibility of vibration to be obtained.

4.1 Frequency Domain

4.1.1 Seat, Cab and Axle responses : When the frequency response at the seat is compared with that at the cab and the axle, the similarity between them is readily apparent. This characteristic is evident at each axis of vibration, 'X', 'Y', 'Z', even though the frequency response of each is quite different to that of the others, see Figures 18, 19 and 20, eg Record Nos QF1X, QF1Y and QF1Z. As previously stated, it was considered important to determine the influence of the condition of the machine, as a function of its age and use, and the speed of travel on the frequency response. It can be seen from the graphs that neither of them affects the results for the characteristic responses appear with each machine and at each speed of travel.

4.1.2 Profile of Test Surface : The profile irregularity of each test surface, ie 'wave motion', 'quarry floor' etc, is uniquely different to any of the others. As a consequence of this, the movement of the machine over each surface was also expected to be different. It can be seen, however, that the frequency responses in each axis are again characteristically similar. The influence of the surface profile and 'roughness' appears to be only in the level of acceleration recorded and not in the frequency domain. Visual inspection of two test surfaces, ie 'quarry floor' and 'random kerb' suggested that there may be similarities in the machine responses over these tracks. However, the 'wave motion' and 'regular kerb' tracks were so different in profile that machine responses could not be readily predicted.

Figure 21

Brüel & Kjær — Time Function Start: seconds — End: seconds — Not Expanded: ☐ Expanded

Full Scale Level: As BELOW.
F. S. Frequency: 100 Hz
Weighting: Hanning.
Average Mode: Lin.
No. of Spectra: 7
Comments: 'X' axis

Quarry Floor test
faster speed ≃ 8 mph.
JCB '3CX' (not new)

SEAT: 100 dB FSL
FSL = 1.0 m/s²

CAB: 120 dB FSL
FSL = 3.0 m/s²

AXLE: 120 dB FSL
FSL = 1.0 m/s²

Record No.: QF/F/2X
Date: 15/10/82
Sign.: Douglas

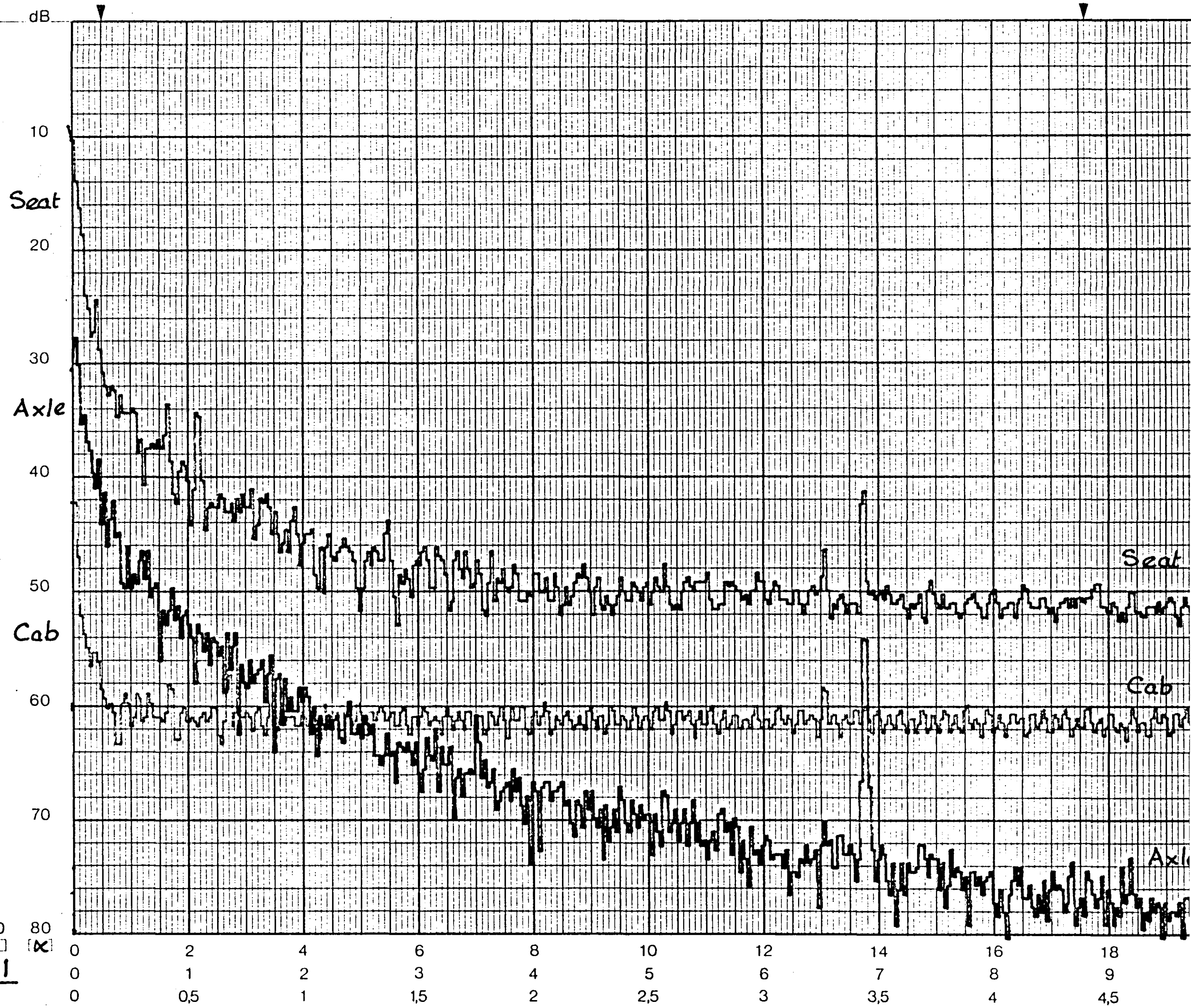


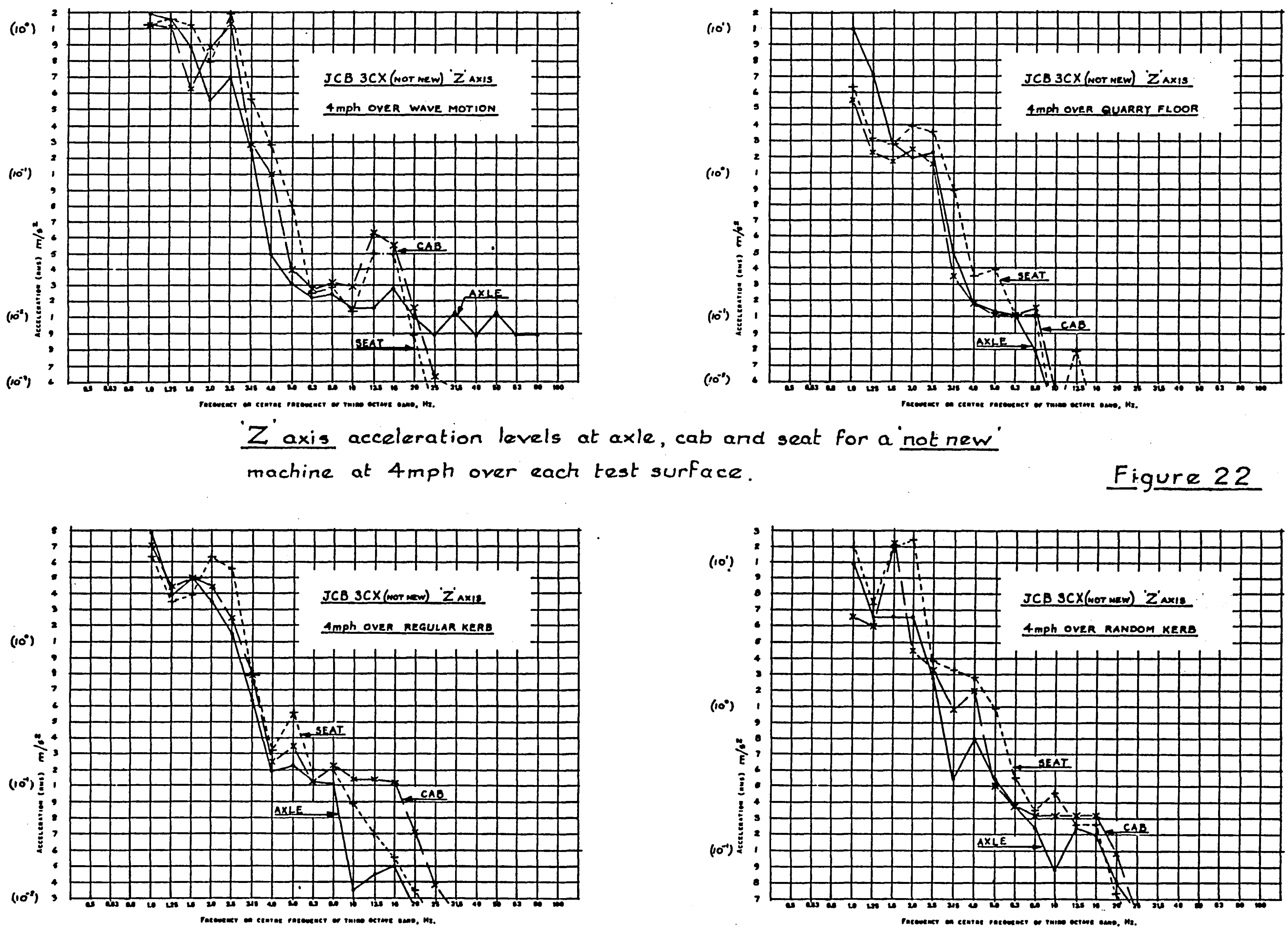
Figure 21

4.1.3 Axes of Vibration : Of the three axes the 'X' axis, ie fore and aft movement, exhibit the least amount of activity over the whole 100Hz frequency domain. Initially the response falls by 25 to 30dB over the first 20Hz but after that becomes relatively 'flat' over the remaining frequencies. In this axis an increase in speed, 4 mph to 8 mph, appears to influence the responses at axle and seat particularly, eg see Figure 21, Record No QF/F/2X. It is noticeable in this situation that the dB range over which the decay occurs extends to around 35Hz at the seat.

In the 'Y', lateral and 'Z', vertical axes a more gradual decay of acceleration occurs over most of the frequency range. However, there is a far higher degree of activity in the frequency domain and this activity is quite specific to the respective axes, eg see Figures 19 and 20, Record Nos QF1Y and QF1Z. As a consequence of this the relationship of problem frequencies with axis of vibration is more readily identified. Also the risk of discomfort for a driver is increased due to the greater range of frequencies over which higher acceleration levels occur.

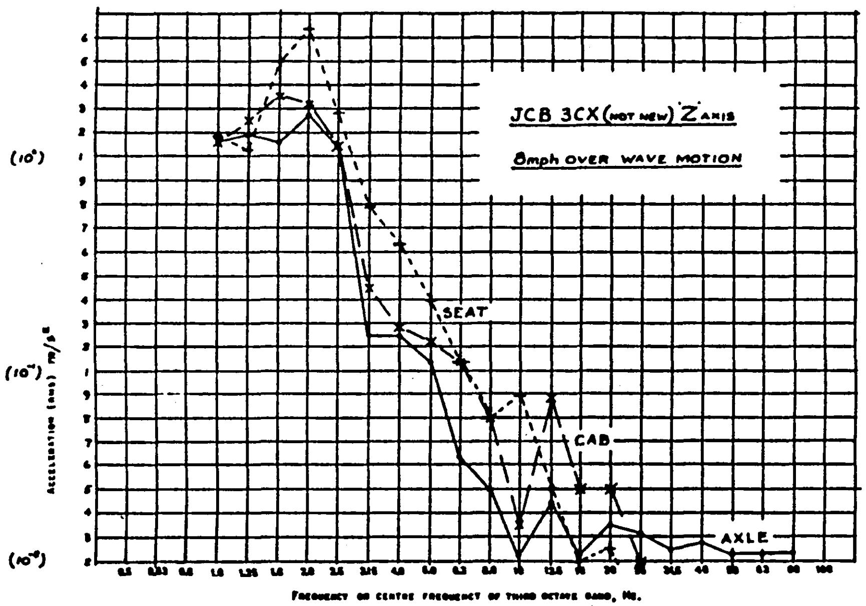
4.2 Acceleration Levels

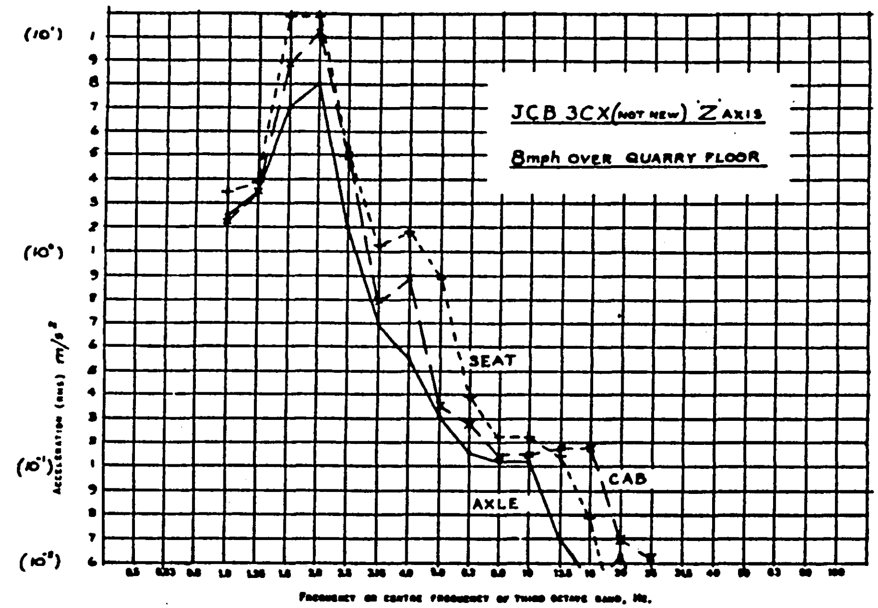
For an assessment of discomfort risk it is necessary to give frequency and acceleration levels, in metres per second



'Z' axis acceleration levels at axle, cab and seat for a 'not new' machine at 4mph over each test surface.

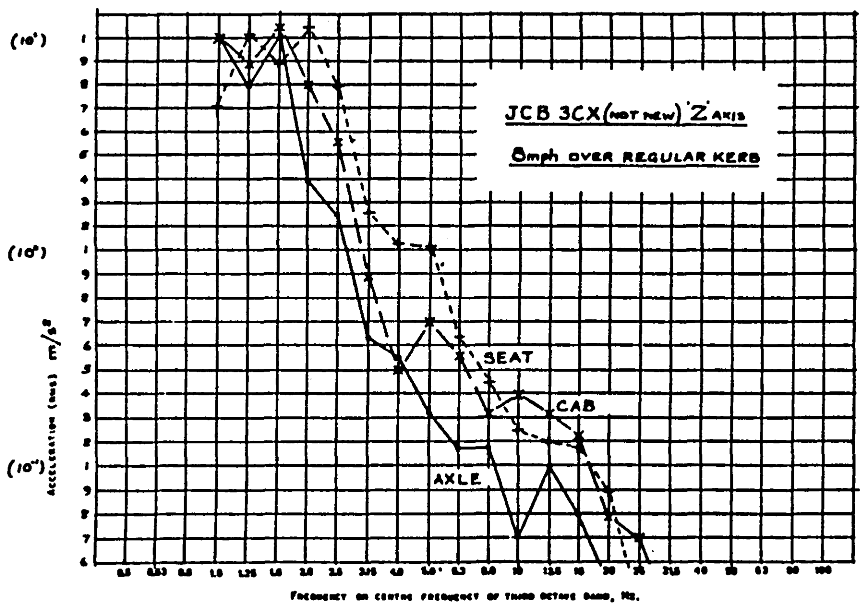
Figure 22

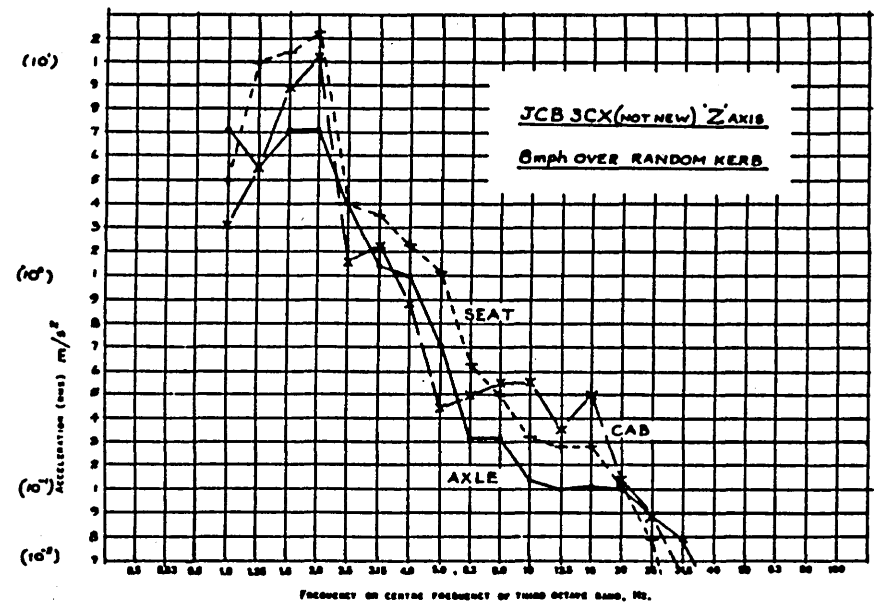


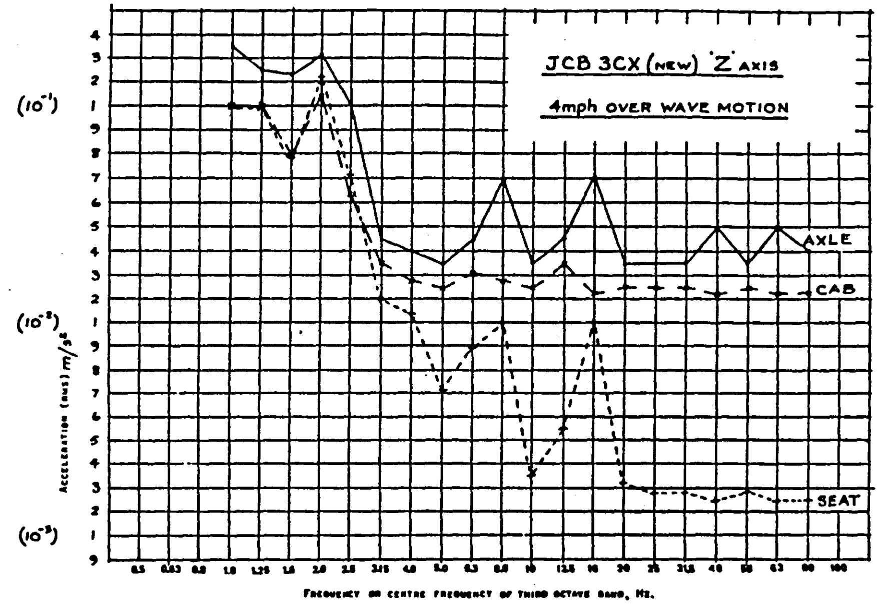


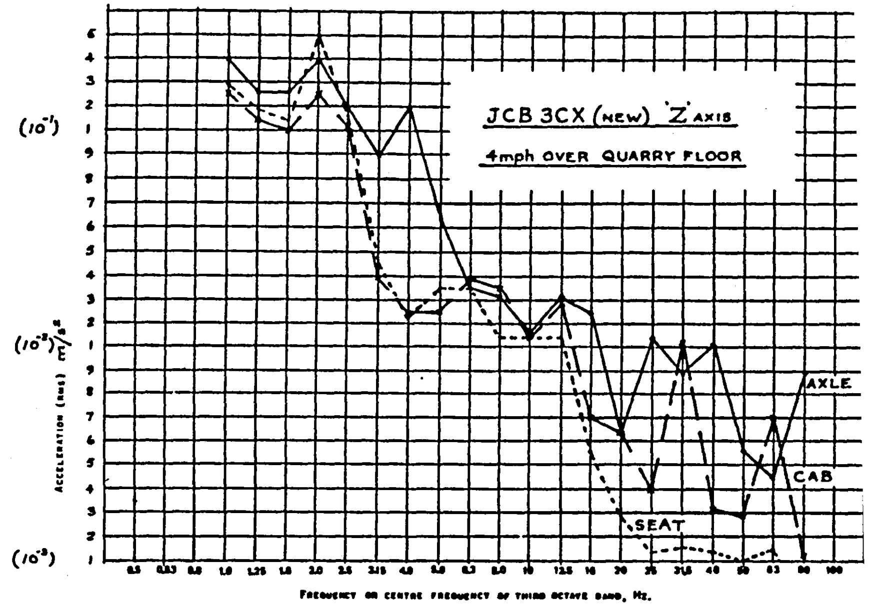
'Z' axis acceleration levels at axle, cab and seat for a 'not new' machine at 8mph over each test surface.

Figure 23



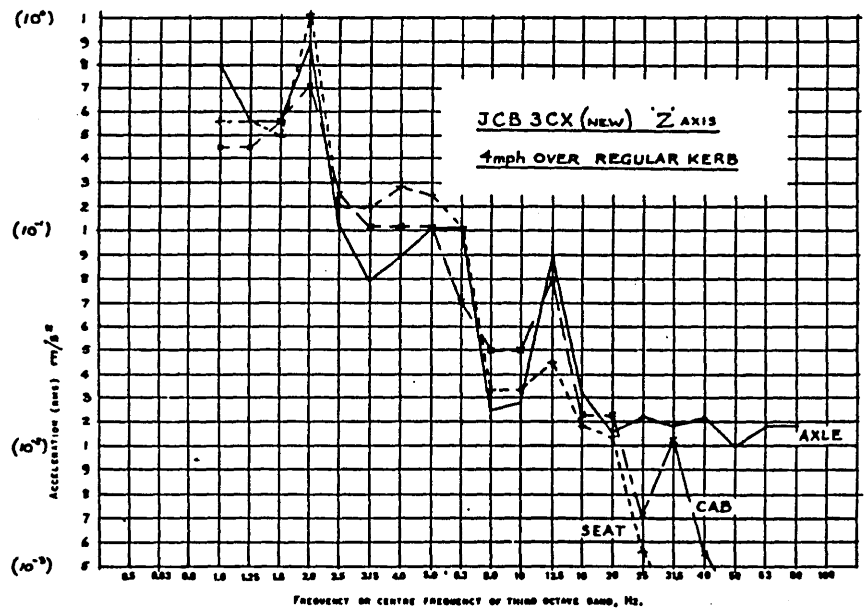


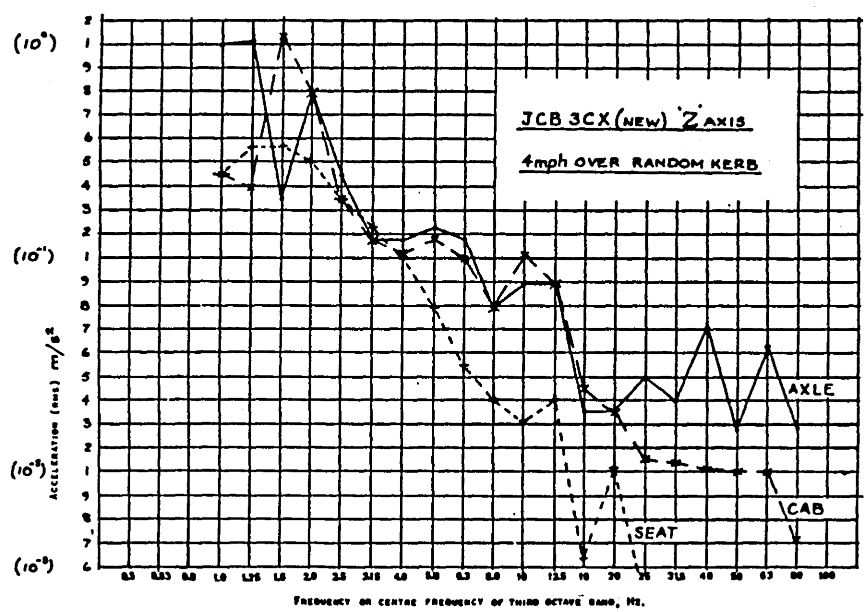




'Z' axis acceleration levels at axle, cab and seat for a new machine at 4mph over each test surface

Figure 24



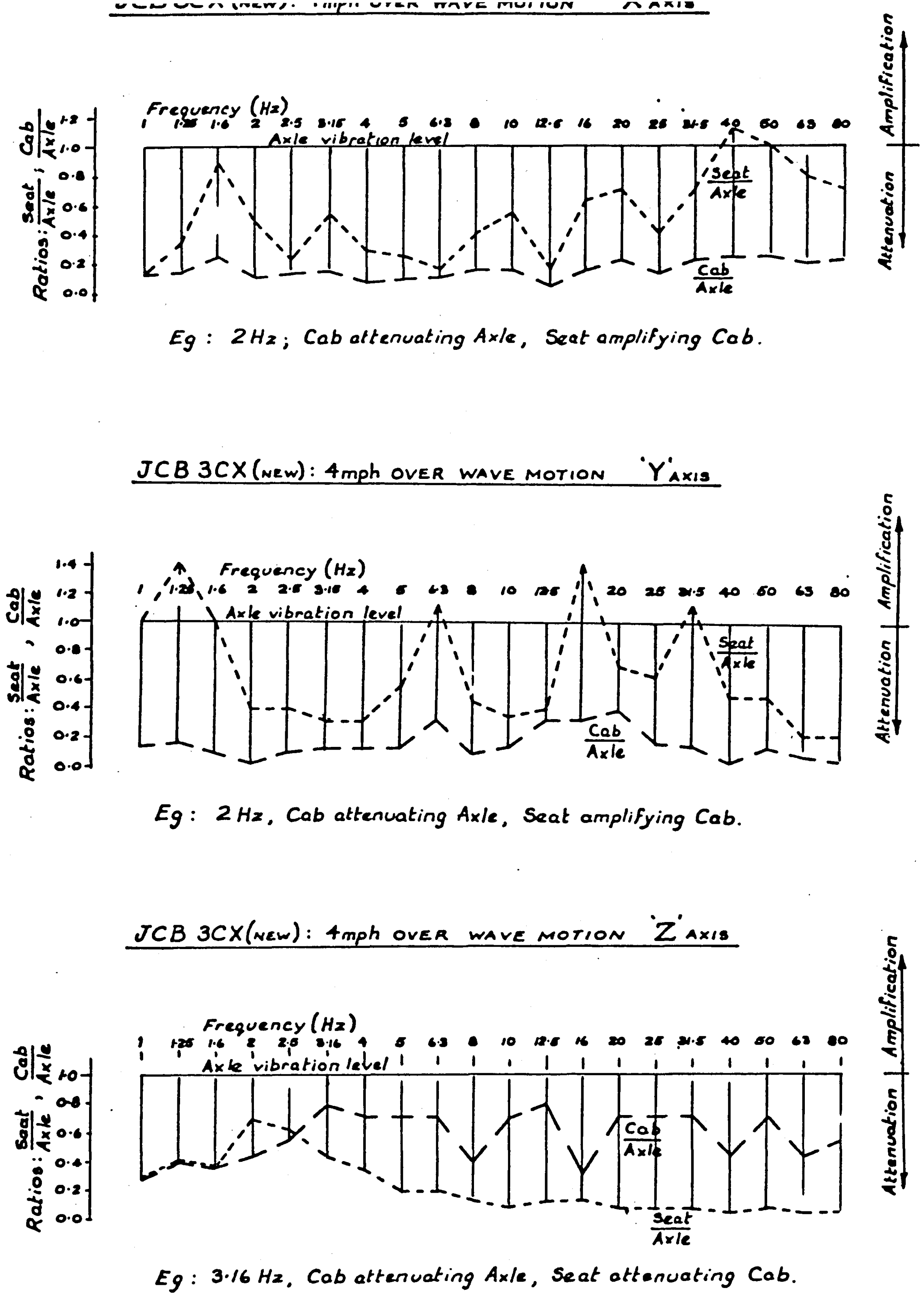


squared, to the recommendations in International Standards ISO2631:1978(E). The conversions from dB to m/s2, at the relevant centre frequency of the one-third octave bands, were produced from the computer programme in Appendix D.

When these acceleration levels are plotted against the centre frequencies, Figures 22, 23 and 24, the necessity to separate the initial curves, plotted from the narrow band spectrum analyser, is obvious. The true acceleration levels at axle, cab and seat are so similar, if not the same, at many frequencies that neither comparison of frequencies or identification of acceleration values would have been possible.

In each of the three axes of vibration the similarity of frequency response over each test surface is readily apparent. Note that Figures 22, 23 and 24 show only 'Z' axis results; the graphs for the 'X' and 'Y' axes are shown in Appendix E. As was expected, the acceleration levels at axle, cab and seat fluctuate at each frequency but the trend of the curves and the close association of levels is maintained over the important frequency range of 1 to 16HZ.

A general observation from the 36 graphs in Appendix E is the predominance of the acceleration levels at the seat over both cab and axle. This is particularly so in the low frequencies, ie below 16Hz and in the 'Z' axis direction. It appears to be a reasonable assumption that one of the design principles for these machines is that vibrations which are generated during work operations should be attenuated in all paths leading to



Attenuation or amplification of axle vibration as the energy travels to the driver. Ratios of seat-to-axle and cab-to-axle plotted at each centre frequency for 'X', 'Y' and Z axes.

Figure 25

the driver's seat. From Figures 22 and 23 etc it is obvious that such attenuation does not occur in many cases. These results, Figures 22 and 23 are from a machine considered to be typical, in mechanical condition, to the majority of machines in use on construction sites and the contrast, in seat activity level, with that of a new machine, Figure 24, is very great.

4.3 Transmission of Vibration from Axle to Seat

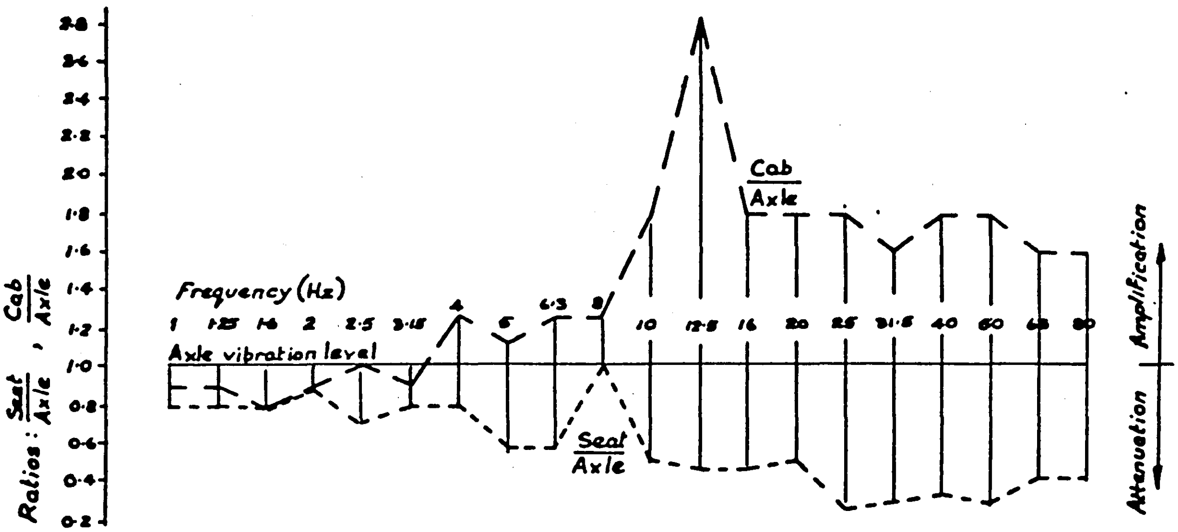
4.3.1 Introduction

The attenuation or acceleration of the axle vibration as the energy travels towards the driver can be displayed and compared by plotting Seat-to-Axle and Cab-to-Axle ratio's against frequency, eg Figures 25, 26 and 27. These graphs are provided to facilitiate the discussion and the corresponding graphs for other test tracks are shown in Appendix F.

4.3.2 Consideration of the Axes of Vibration

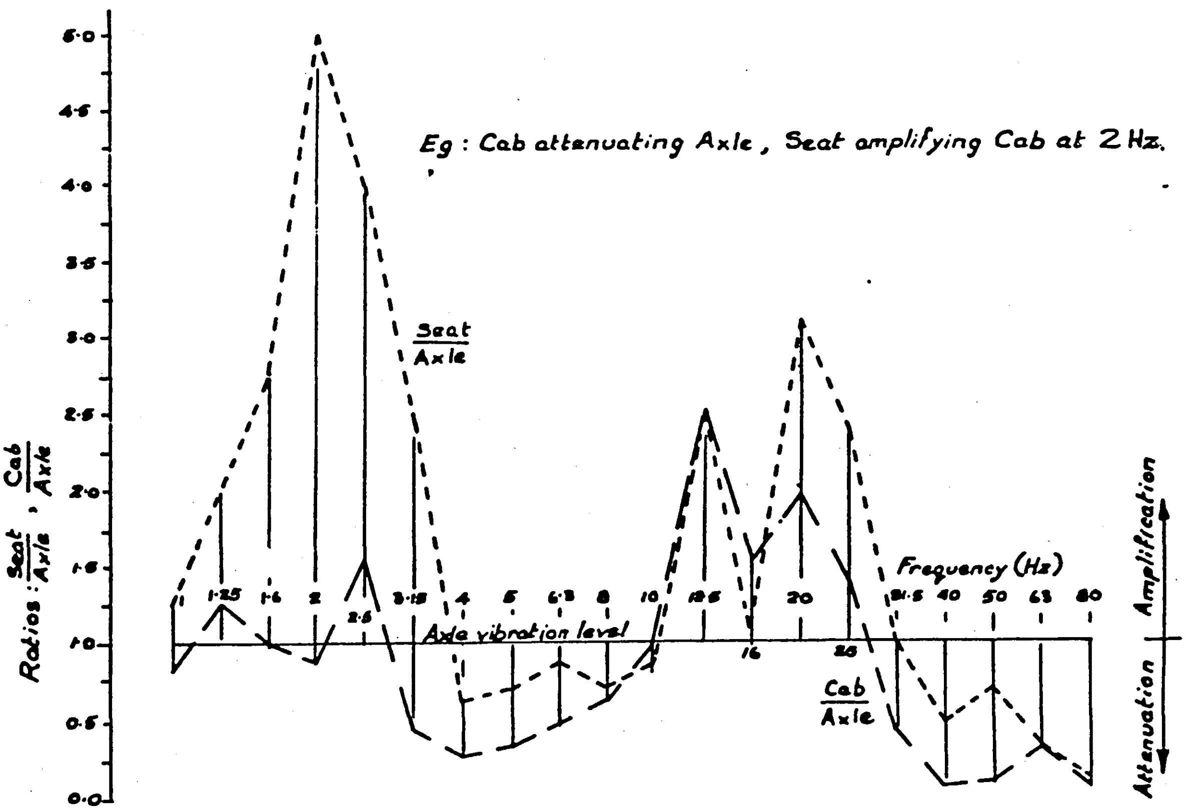
(i) 'X' Axis : Appendix F graphs show that some effective attenuation does take place but principally in the 'X' axis direction. It is important to note that in this axis the attenuation is mainly in the frequencies below 16Hz and this has important implications for discomfort risk for drivers. This is explained at 4.4.2 where acceleration levels are related to the recommendations of ISO2631:1978(E).

JCB 3CX(NOT NEW): 4mph OVER WAVE MOTION 'X' AXIS



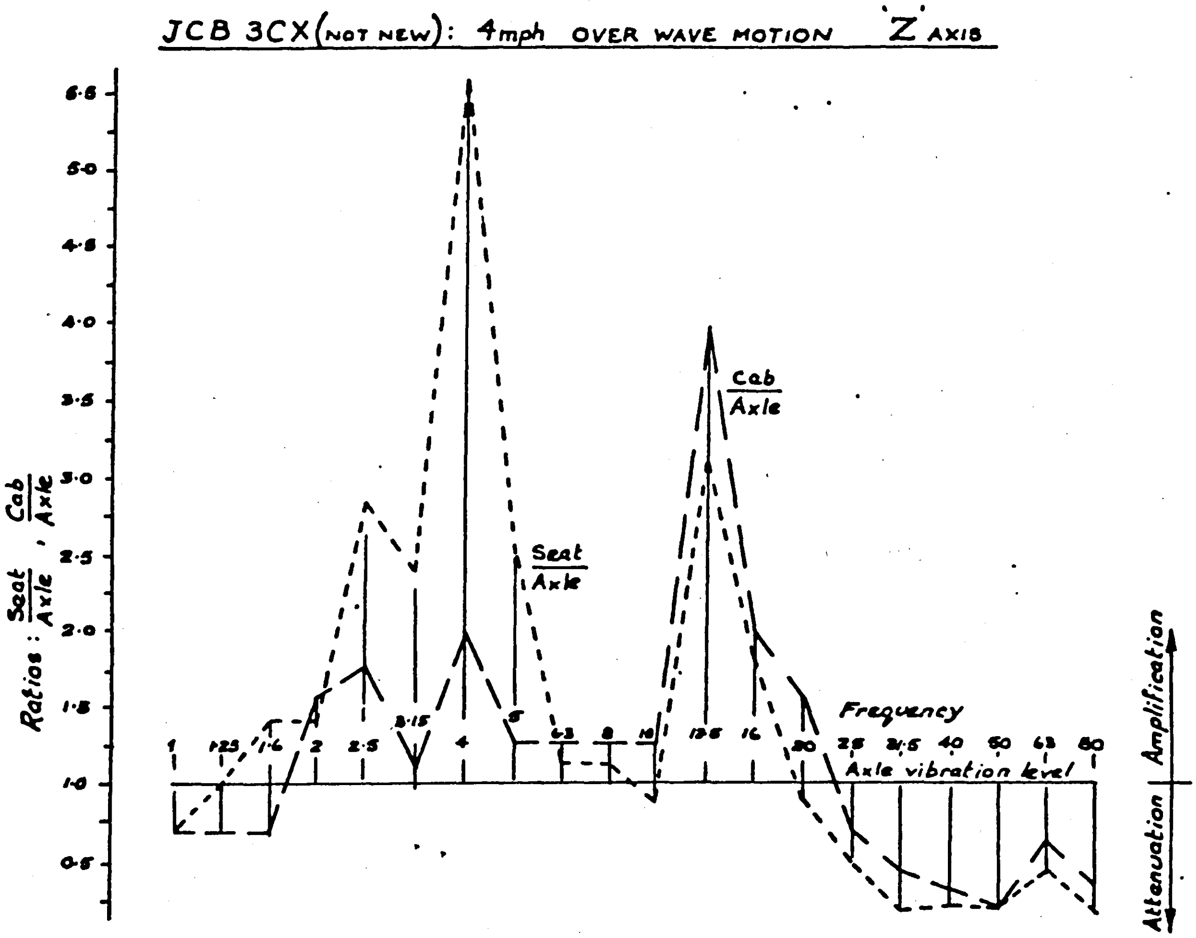
Eg: 3·15 Hz; Cab attenuating Axle, Seat attenuating Cab.

JCB 3CX(NOT NEW): 4mph OVER WAVE MOTION 'Y' AXIS



Attenuation or amplification of axle vibration as the energy travels to the driver. Ratios of seat-to-axle and cab-to-axle plotted at each centre frequency for 'X' and 'Y' axes.

Figure 26



Attenuation or amplification of axle vibration as the energy travels to the driver. Ratios of seat-to-axle and cab-to-axle plotted at each centre frequency for 'Z' axis.

Figure 27

(ii) <u>'Y' Axis</u> : The amplification of vibrations at cab and seat at about 2.5Hz and 20Hz are strong features of the 'Y' axis graphs. It can be seen from ISO2631:1978(E) that acceleration values at frequencies above 2Hz have a decreasing influence on the risk of driver discomfort. Consequently, the amplification which occurs around 20Hz has little importance. Once again the influence of machine 'ageing' as a function of use and maintenance, on the transmission of vibrations to the seat is evident when the results from the 'not new' machine are compared with those from the'new'one, ie Figures 25, 26 and 27.

(iii) <u>'Z' Axis</u> : It is shown in Chapter 2 that the seat acceleration levels, in the 'Z' axis, constitute the greatest risk for driver discomfort on these machines. The amplification provided by both cab and seat, at many frequencies, is apparent from Figure 27 and the graphs in Appendix F. The deterioration in vibration isolation on the 'not new' machine is again very obvious. However, the damping provided on the 'new' machine still results in acceleration levels at the seat being significantly high in the important frequencies below 8Hz.

4.4 Comparisons with ISO2631:1978 (E)

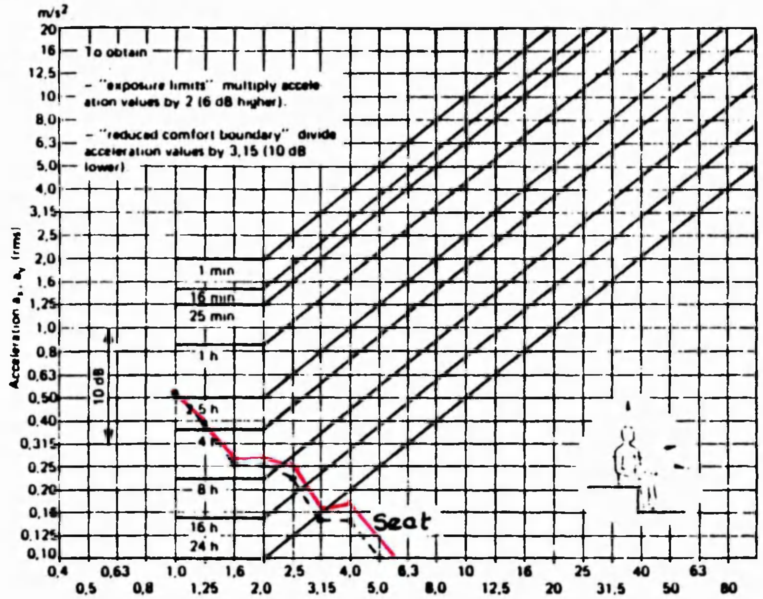
4.4.1 Introduction

It has been shown in the previous section that significantly high levels of acceleration can occur at the seat in the earth moving vehicles tested. However, to assess the relevance of these in relation to comfort, the ability to perform work tasks, and the concomitant driver safety, the accelerations at their associated frequencies are compared to the guidelines of ISO2631:1978(E).

In addition to intensity, frequency and direction, the standard defines boundaries for exposure in terms of duration. Normal working days are four hours without a meal break, consequently the four hour boundary is the one to which all recorded values are here related.

4.4.2 Fatigue - Decreased Proficiency Boundaries

Figures 28 to 33 inclusive show the acceleration levels recorded at axle and/or seat which actually register on the ISO2631 'fatigue-decreased proficiency' boundary curves. In the two horizontal axes only two situations in the 'X' direction and four in the 'Y' direction are recorded and only in one of these, Figure 30(b), is there any significant infringement of the 4 hour F.D.P. boundary.

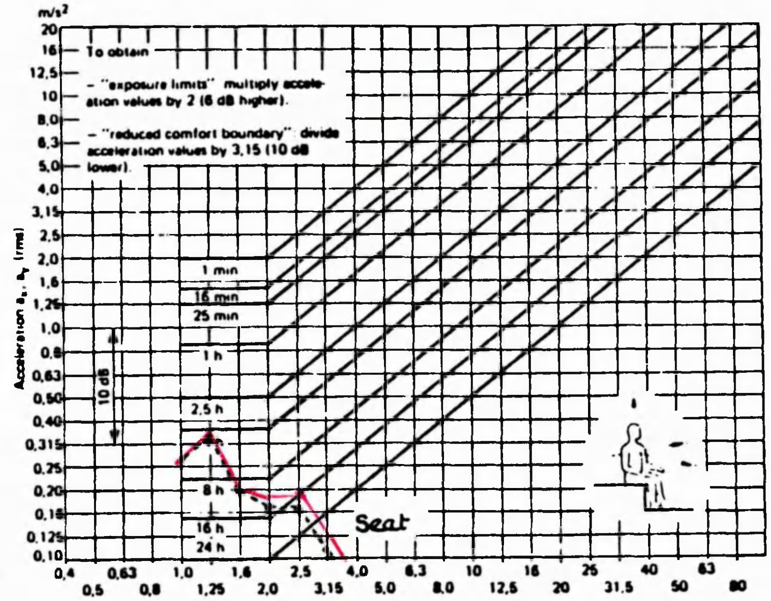


Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631 : 1978

'X' AXIS, 8mph OVER REGULAR KERB.

(b)



Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631 : 1978

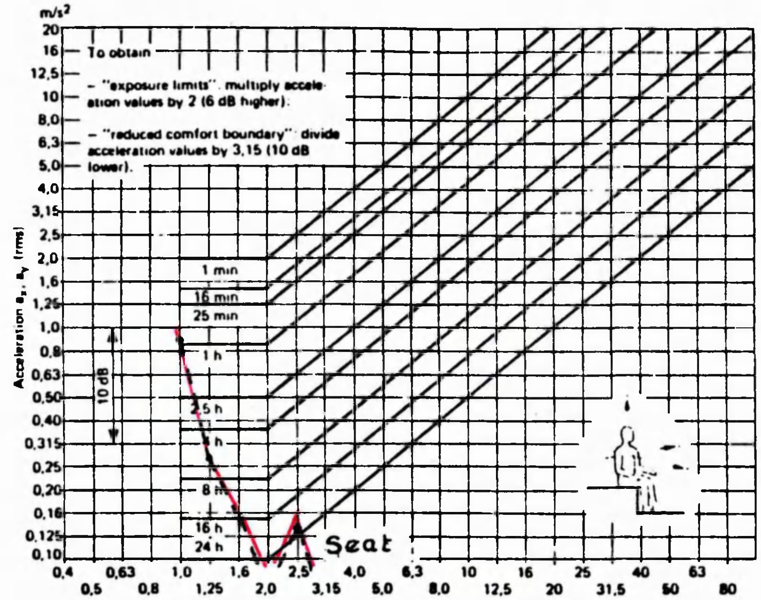
'X' AXIS, 4mph OVER REGULAR KERB.

(a)

—— see page 30

'X' axis acceleration levels, at the seat of a 'not new' machine, which infringe fatigue-decreased proficiency boundaries.

Figure 28

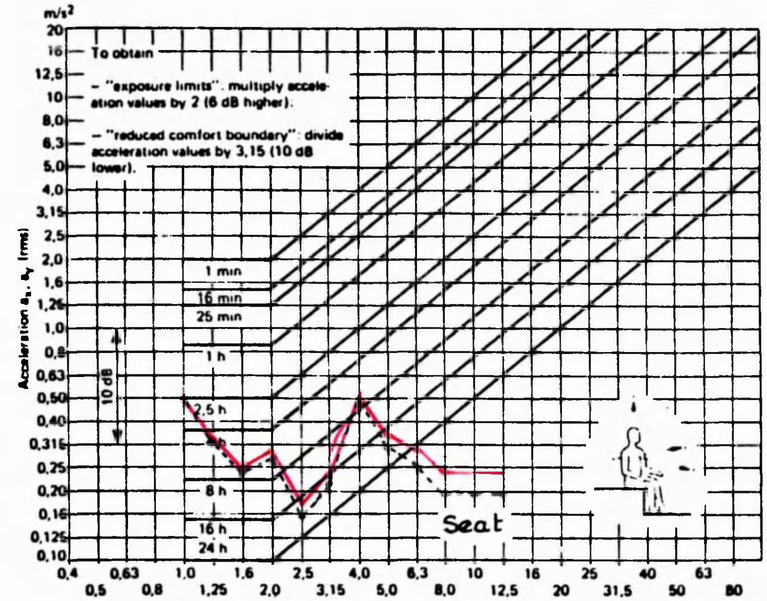


Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NEW) COMPARED WITH ISO 2631:1978

'Y' AXIS, 4mph OVER RANDOM KERB

(b)



Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631:1978

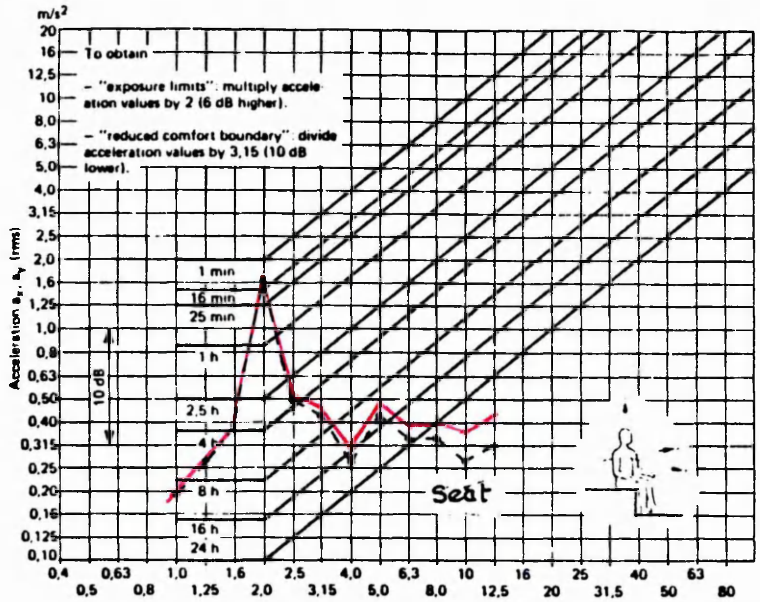
'Y' AXIS, 4mph OVER RANDOM KERB.

(a)

— see page 30

'Y' axis acceleration levels, at the seat of a new machine, which infringe fatigue-decreased proficiency boundaries.

Figure 29

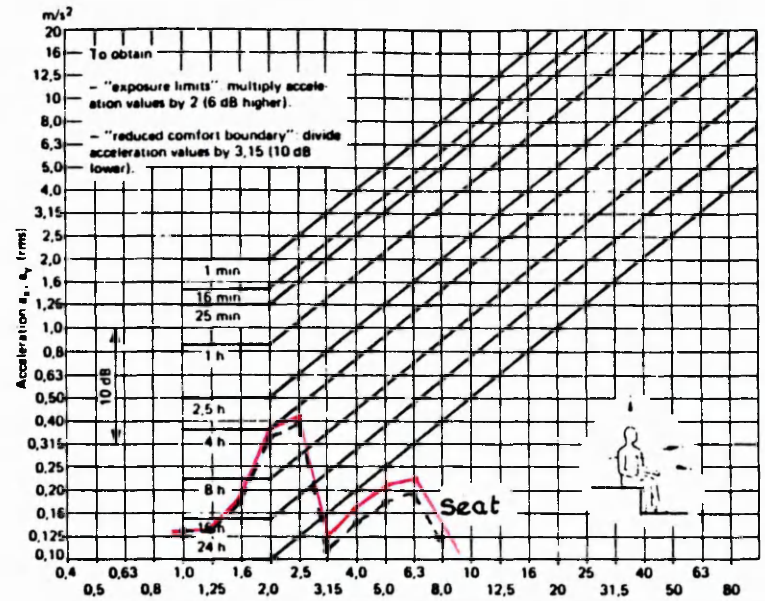


Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631 : 1978

'Y' AXIS 8mph OVER RANDOM KERB.

(b)



Lateral vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631 : 1978

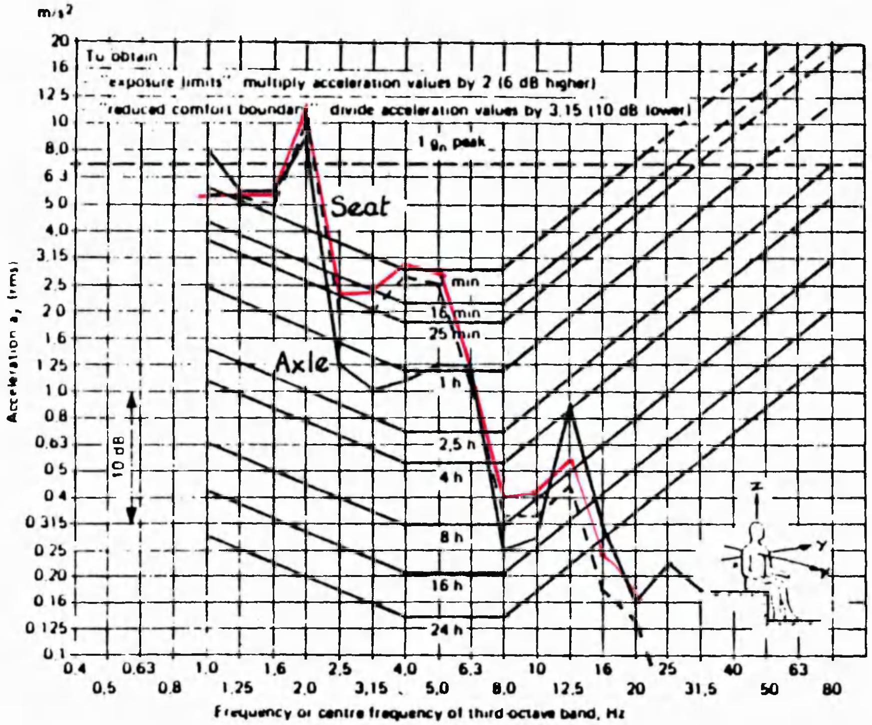
'Y' AXIS, 8mph OVER QUARRY FLOOR

(a)

—— see page 30

'Y' axis acceleration levels, at the seat of a 'not new' machine, which infringe fatigue-decreased proficiency boundaries.

Figure 30

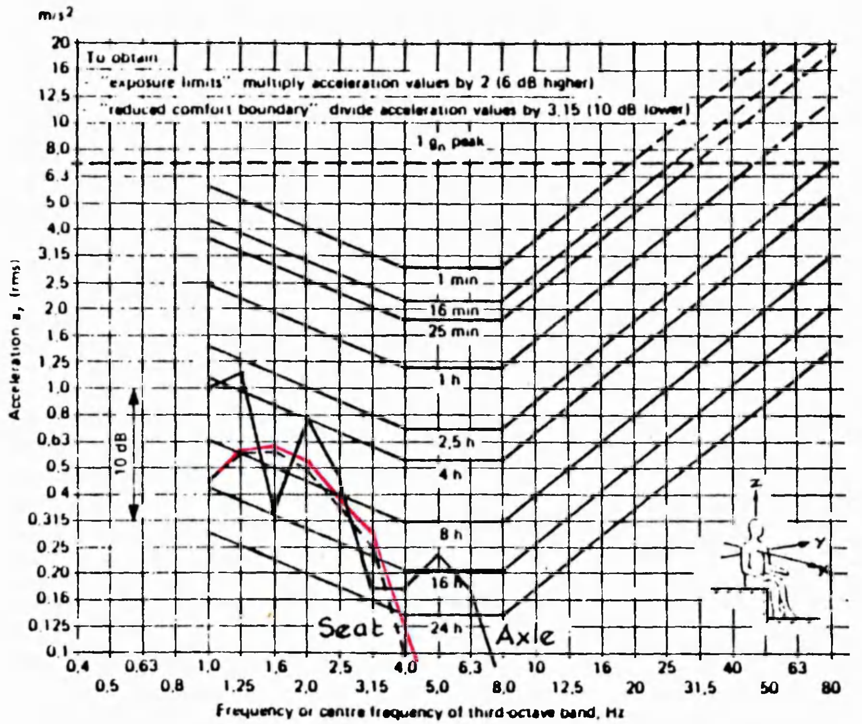


Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NEW) COMPARED WITH ISO 2631 : 1978

'Z' AXIS, 4mph OVER REGULAR KERB.

(b)



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NEW) COMPARED WITH ISO 2631 : 1978

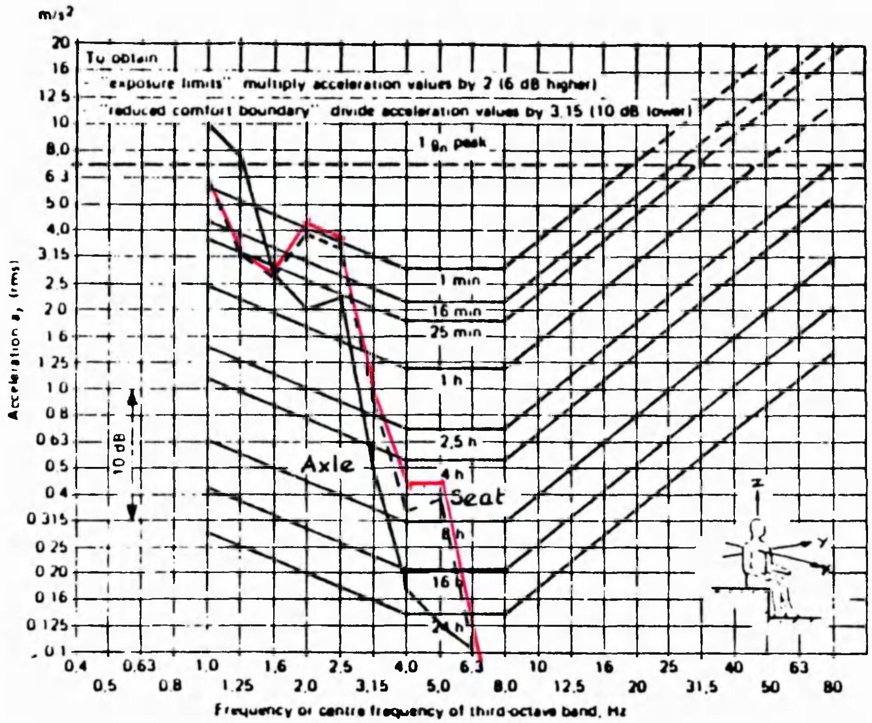
'Z' AXIS, 4mph OVER RANDOM KERB.

(a)

—— see page 30

'Z' axis acceleration levels, at the seat of a new machine, which infringe fatigue-decreased proficiency boundaries. Also the axle acceleration levels for the same machine.

Figure 31

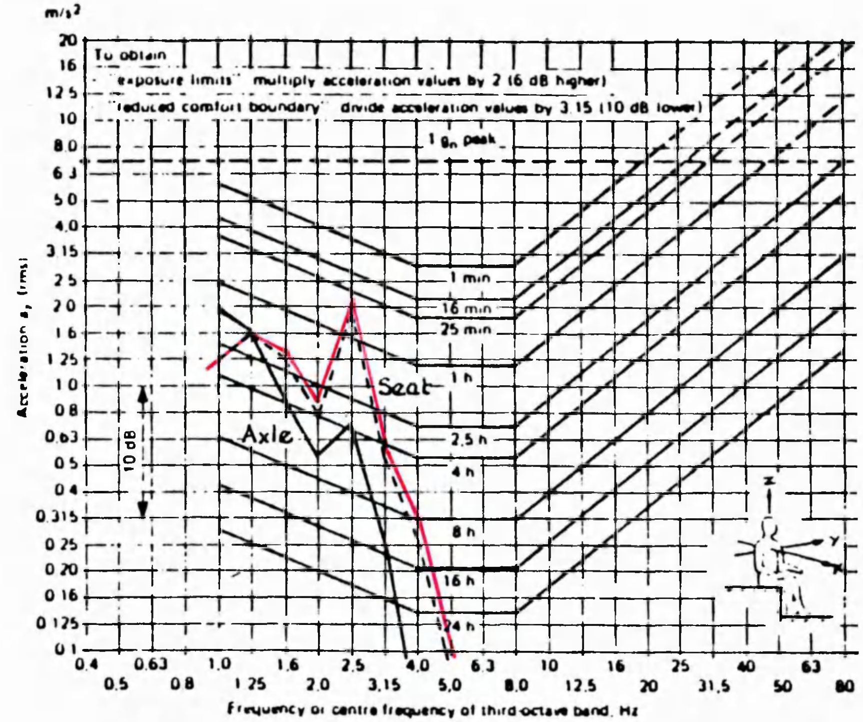


Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB (NOT NEW) COMPARED WITH ISO 2631 : 1978

'Z' AXIS, 4mph OVER QUARRY FLOOR

(b)



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631 : 1978

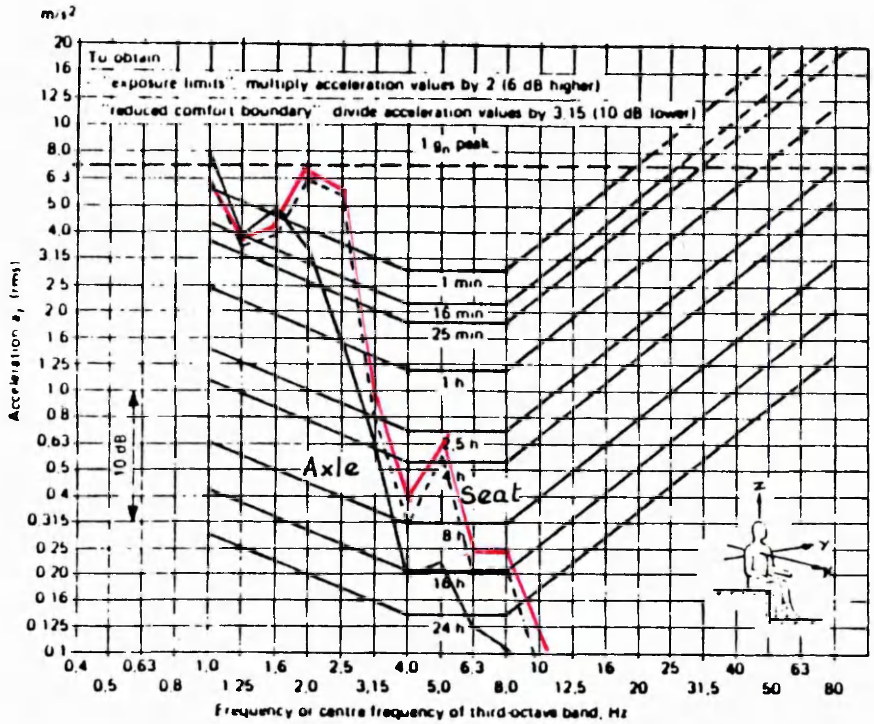
'Z' AXIS, 4mph OVER WAVE MOTION.

(a)

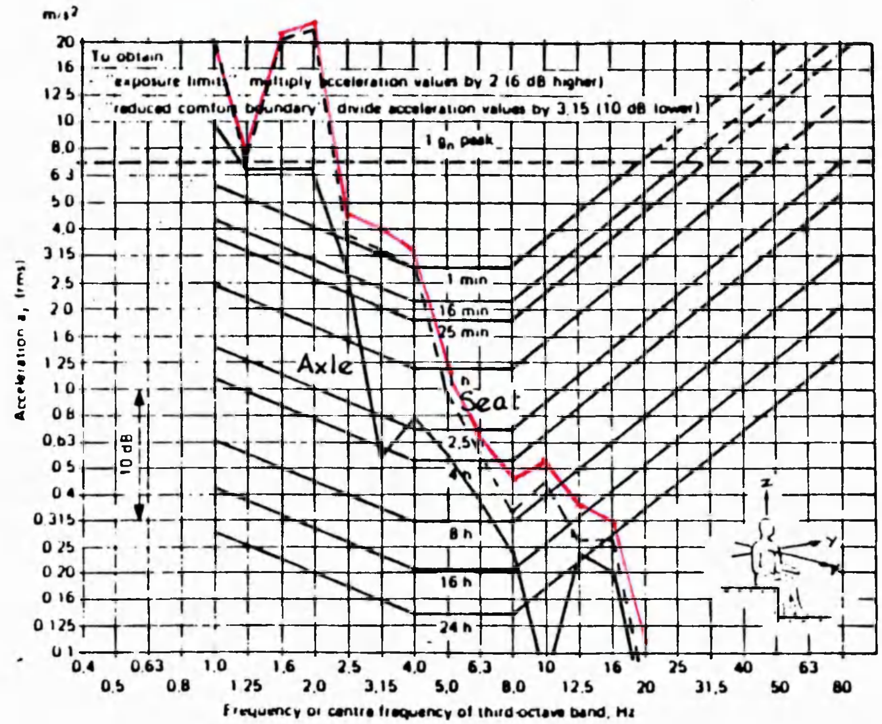
—— see page 30

'Z' axis acceleration levels, at the seat of a 'not new' machine, which infringe fatigue-decreased proficiency boundaries. Also the axle acceleration levels for the same machine.

Figure 32



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631 : 1978

'Z' AXIS, 4mph OVER REGULAR KERB.

(d)

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631 : 1978

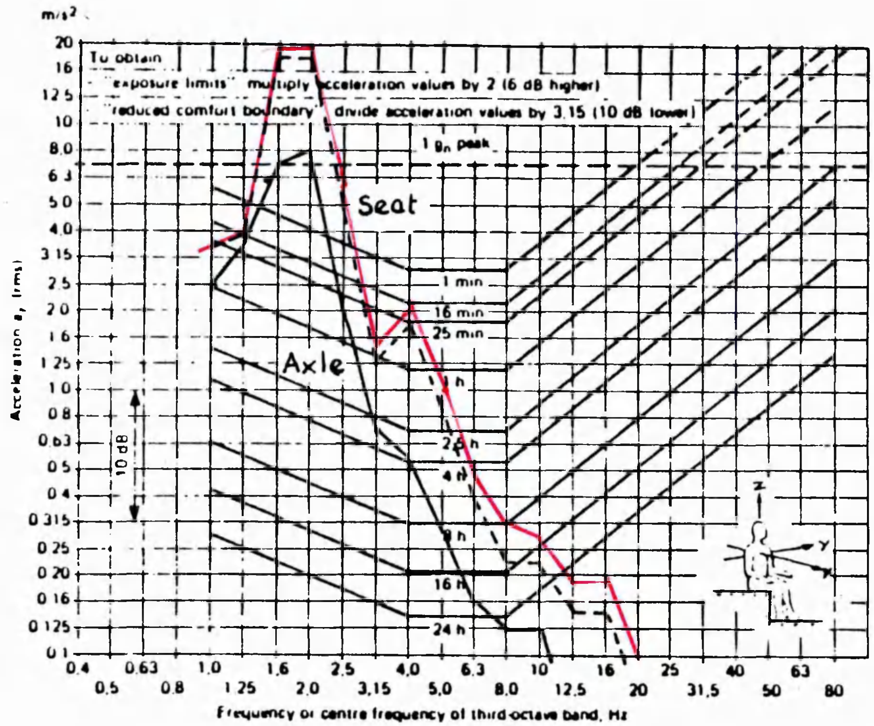
'Z' AXIS, 4mph OVER RANDOM KERB

(c)

—— see page 30

'Z' axis acceleration levels, at the seat of a 'not new' machine, which infringe fatigue - decreased proficiency boundaries. Also the axle acceleration levels for the same machine.

Figure 32

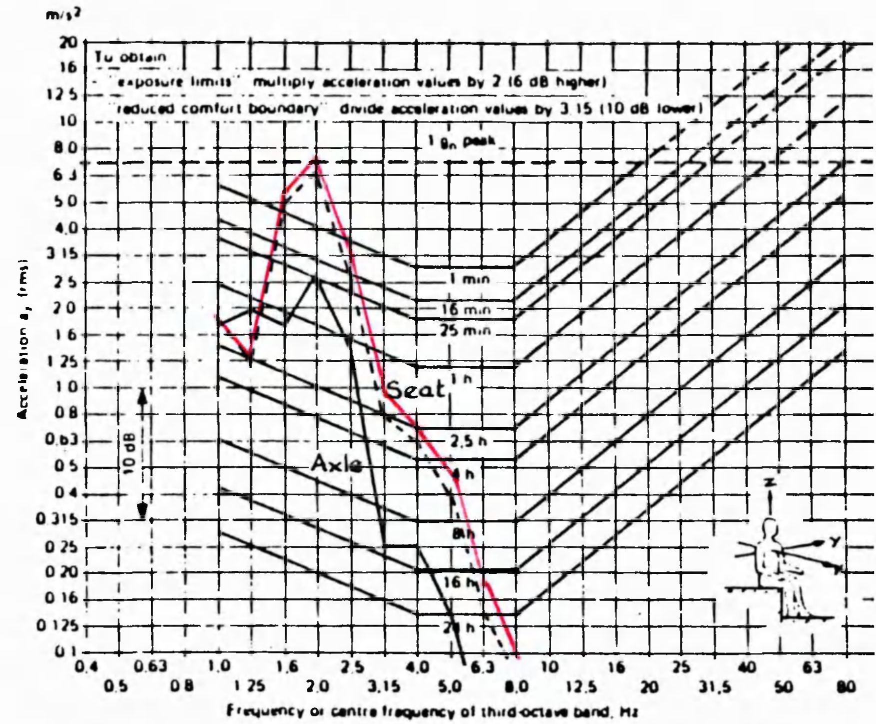


Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631:1978

'Z' AXIS, 8mph OVER QUARRY FLOOR.

(b)



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631:1978

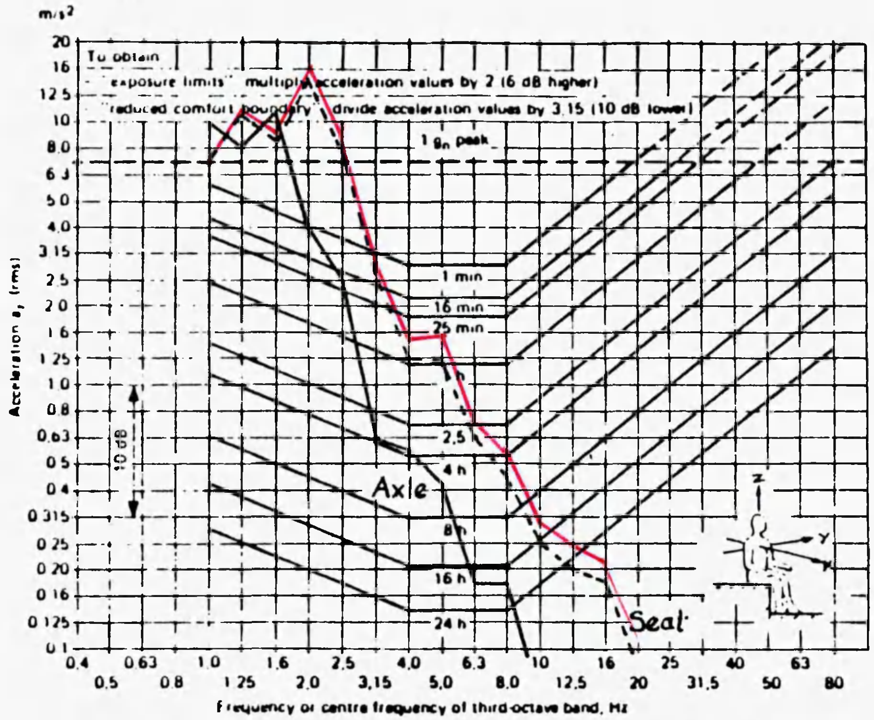
'Z' AXIS, 8mph OVER WAVE MOTION.

(a)

—— see page 30

'Z' axis acceleration levels, at the seat of a 'not new' machine, which infringe fatigue-decreased proficiency boundaries. Also the axle acceleration levels for the same machine.

Figure 33

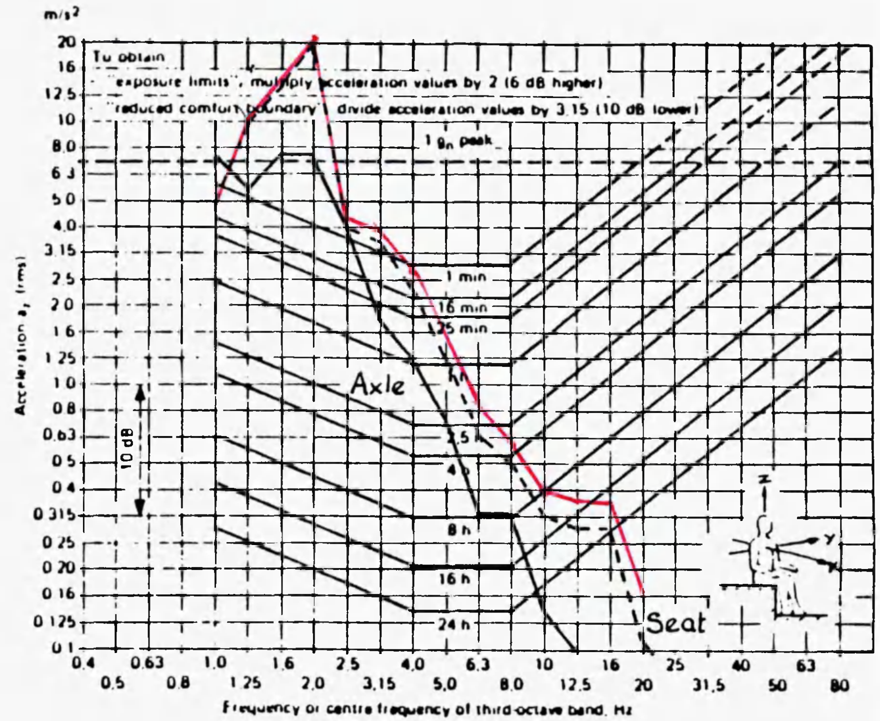


Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631: 1978

'Z' AXIS, 8mph OVER REGULAR KERB

(d)



Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries

JCB 3CX (NOT NEW) COMPARED WITH ISO 2631: 1978

'Z' AXIS, 8mph OVER RANDOM KERB.

(c)

— see page 30

'Z' axis acceleration levels, at the seat of a 'not new' machine, which infringe fatigue-decreased proficiency boundaries. Also the axle acceleration levels for the same machine.

Figure 33

Figures 29(a) and (b) clearly show the effect of increased speed over a particular surface profile and this results in an increase in acceleration levels by about 3dB.

Figures 29(a) and (b) demonstrate effects to be expected from use as a machine 'ages'. Although both machines were subjected to the same test the older machine transmits significantly higher levels of vibrational energy at higher frequencies to the seat. These levels do not infringe this 4 hour F.D.P. boundary but do infringe the lower, reduced comfort (R.C.) boundary, see Figure 34.

Where irregular projections occur in surfaces over which these machines travel strong, lateral, ('Y' axis), movements are certain to be produced. Figures 30(a) and (b) also show, in this axis, the influence of increased speed and indicate the reduction in comfort level to be experienced by the driver. It is interesting to see that only seat acceleration levels are significant in the 'X' and the 'Y' directions. This results from amplification of cab energy transmitted from the axle.

The remaining curves of Figures 31, 32 and 33 are for both seat and axle and the significance of the axle values are explained on page 4.32. Initially it can be seen that, with the exception of two test track

JCB 3CX: FREQUENCIES WHERE ISO 2631:1978 INFRINGEMENT OCCURS.
4hr "REDUCED COMFORT BOUNDARY" 'o' = Seat.

X AXIS

Surface	Condition	Speed	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20
REGULAR KERB	NEW	4mph														
	NOT NEW	4mph	o	o	o	o	o									
		8mph	o	o	o	o	o									
QUARRY FLOOR	NEW	4mph														
	NOT NEW	4mph														
		8mph	o	o	o	o										

Y AXIS

Surface	Condition	Speed	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20
QUARRY FLOOR	NEW	4mph														
	NOT NEW	4mph														
		8mph	o	o	o	o	o									
RANDOM KERB	NEW	4mph	o	o	o											
	NOT NEW	4mph	o	o	o	o	o	o	o	o						
		8mph	o	o	o	o	o	o	o	o						

Figure 34

JCB 3CX: FREQUENCIES WHERE ISO 2631:1978 INFRINGEMENT OCCURS.
4hr "REDUCED COMFORT BOUNDARY" 'o' = Seat ; '+' = Axle

Z AXIS

Surface	Condition	Speed	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20 (Hz)
QUARRY FLOOR	NEW	4mph				+	o		+							
	NOT NEW	4mph	o +	o +	o +	o +	o +	o +	o +	o						
		8mph	o +	o +	o +	o +	o +	o +	o +	o +	o	o	o			
WAVE MOTION	NEW	4mph				+										
	NOT NEW	4mph	o +	o +	o +	o +	o +	o +	o							
		8mph	o +	o +	o +	o +	o +	o +	o +	o						
REGULAR KERB	NEW	4mph	o +	o +	o +	o +	o +	o +	o +	o +	o +	o +	o +	o +		
	NOT NEW	4mph	o +	o +	o +	o +	o +	o +	o +	o +	o	o				
		8mph	o +	o +	o +	o +	o +	o +	o +	o +	o +	o +				
RANDOM KERB	NEW	4mph	o +	o +	o +	o +	o +	o	+	+	+					
	NOT NEW	4mph	o +	o +	o +	o +	o +	o +	o +	o +	o +	o +	o	o		
		8mph	o +	o +	o +	o +	o +	o +	o +	o +	o +	o +	o	o		

Figure 35 (a)

Frequencies where acceleration levels at seat and axle exceed the I.S.O. 2631: 1978 4hr. maxima.

results for the new machine, ie 'quarry floor' and 'wave motion', all vertical (Z) axis results are represented.

It is also noted that serious vibration transmission occurs in the vertical direction, for at many frequencies infringement of even the exposure limit boundary is evident. In this axis of vibration the exposure limit for shorter durations than 4 hours is infringed and this has important implications for the physical well-being of the driver. These implications are discussed in Chapter 6 which is concerned with the survey of drivers and their assessment of the physical effects of seat vibration in these machines.

4.4.3 Reduced Comfort and Exposure Limit Boundaries

To compare the frequency response of a vehicle with either the reduced comfort or exposure limit boundaries requires the acceleration values of each duration line to be moved 10dB lower or 6dB higher respectively. To facilitate this process and allow comparisons to be made between the machines speeds and test tracks Figures 34 and 35(a) (b) and (c) are presented. It is immediately obvious that, with these machines, the horizontal vibrations, ie 'X' and 'Y' axes of Figure 34, are only likely to cause a reduction in the level of comfort for the driver. Also this discomfort will be predominantly associated with the older machines.

JCB 3CX: FREQUENCIES WHERE ISO 2631:1978 INFRINGEMENT OCCURS.

'Z' 4hr 'FATIGUE-DECREASED PROFICIENCY' 'o' = Seat '+' = Axle

			1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20 (Hz)
QUARRY FLOOR	NEW	4mph														
	NOT NEW	4mph	o +	o +	o +	o +	o +	o								
	NOT NEW	8mph	o +	o +	o +	o +	o +	o +	o +	o						
WAVE MOTION	NEW	4mph														
	NOT NEW	4mph	o	o +	o	o	o +									
	NOT NEW	8mph	o +	o +	o +	o +	o +	o	o							
REGULAR KERB	NEW	4mph	o +	o +	o +	o +	o +	o +	o +	o +						
	NOT NEW	4mph	o +	o +	o +	o +	o +									
	NOT NEW	8mph	o +	o +	o +	o +	o +	o +	o +	o	o					
RANDOM KERB	NEW	4mph		+												
	NOT NEW	4mph	o +	o +	o +	o +	o +	o	o +	o +						
	NOT NEW	8mph	o +	o +	o +	o +	o +	o +	o +	o +	o					

Figure 35 (b)

JCB 3CX: FREQUENCIES WHERE ISO 2631:1978 INFRINGEMENT OCCURS.

'Z' AXIS 4hr 'EXPOSURE LIMITS' 'o' = Seat '+' = Axle

			1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20 (Hz)
QUARRY FLOOR	NEW	4mph														
	NOT NEW	4mph	o +	o +	o +	o +	o +									
	NOT NEW	8mph	o +	o +	o +	o +	o +	o +	o +							
WAVE MOTION	NEW	4mph														
	NOT NEW	4mph					o									
	NOT NEW	8mph			o +	o +	o +									
REGULAR KERB	NEW	4mph	o +	o +	o +	o +	o +	o	o +	o +						
	NOT NEW	4mph	o +	o +	o +	o +	o +									
	NOT NEW	8mph	o +	o +	o +	o +	o +	o	o	o						
RANDOM KERB	NEW	4mph														
	NOT NEW	4mph	o +	o +	o +	o +	o +	o	o							
	NOT NEW	8mph	o +	o +	o +	o +	o +	o +	o +	o +						

Figure 35 (c)

Frequencies where acceleration levels at seat and axle exceed the I.S.O. 2631:1978 4hr maxima.

The charts of Figures 35(a) (b) and (c) show that at frequencies below 5Hz even the exposure limits are likely to be exceeded. Particularly with a machine which is not a new one. The new machine shows the least activity, at seat level, which may infringe the boundaries in the Standard. It appears to be the surfaces with greatest amplitude or irregularity of profile which create discomfort or a reduction in work effectiveness for the driver due to fatigue, eg Figure 35(a) Random Kerb, or Figure 35(a) and (b) Regular Kerb.

The 'not new' machine equates with typical construction site machines and Figures 35(a) (b) and (c) demonstrate their susceptability to damaging vibrations in the vertical, 'Z', axis. The frequencies where acceleration values occur in excess of the exposure limits, Figure 35(c), are seen to range from 1 to 5Hz. The problems resulting from such vibrations are due to the high transmissibility (resonant characteristics) of the human body at frequencies between 3 and 7Hz, Gillespie et al, (1982).

Throughout this discussion the great similarity in acceleration level and low frequency response between seat and axle, via the cab, has been stressed. This is the reason for the frequency response at the axle being included on the ISO2631:1978(E) charts of Figures 34 and 35. Although it is the response of the seat which is needed to assess driver discomfort risk the high acceleration levels produced at the axle are an important aspect of this study. They clearly show that the problems experienced at the driver's seat originate from vibrations produced by the tyres during travel.

4.5 Summary and Conclusions

4.5.1 Frequency Response

This study shows that pneumatic-tyred earthmoving vehicles exhibit specific and different filtering characteristics, for random vibration inputs, in each of the three co-ordinate axes, ie 'X', 'Y' and 'Z'. Irrespective of the profile, or 'roughness', of a surface, as defined by the irregularity, angularity and dimensions of any projections, the frequency response in each axis will be retained. These responses have distinctive low frequency components corresponding to those frequencies acknowledged to be responsible for human experiences ranging from simple discomfort to interference with work procedures due to fatigue.

4.5.2 Acceleration Levels

The vehicles also exhibit high levels of acceleration, particularly in the vertical axis, which are closely related to the angularity and dimensions of surface projections, eg Quarry Floor and Random Kerb test surfaces. As previously stated, these test surfaces equate to typical construction site terrain, consequently the risk of driver discomfort or fatigue in such conditions is great. This conclusion is endorsed when the results from the two machines are related to their age, ie through use. It also emphasises the need for regular and correct maintenance of the machines otherwise the deterioration in ride quality will be increased.

4.5.3 Tyre Influence

The final and most important conclusion to this part of the study is that the tyre on the large diameter drive wheel is the source of the vibrations received at the seat. Due to the absence of springing or damping mechanisms between the wheel's axle and the chassis of the vehicle, vibrations generated by the tyre travel direct to the cab mounting points. These mounts, four in number, consist of bolts through natural rubber isolation blocks separating the cab from the chassis. Any effectiveness in vibration attenuation appears to be when the blocks are in their 'new' condition or at frequencies above 20Hz on older machines. Consequently, vibrational energy is transferred, with little attentuation, to the driver's seat leaving the cushion as the principal means of avoiding discomfort conditions.

Upon consideration of the above conclusions it was decided to subject a typical driver-wheel to a series of static and dynamic tests to determine whether low frequencies would be a dominant feature of its frequency response to vibration.

CHAPTER 5

5.0 Excavator/Loader Drive Wheel Tests

5.1 Introduction

The conclusion that the tyres on the large diameter wheel were the source of the vibration required endorsement from the static and dynamic properties of the tyre and wheel combination. A typical rubber-tyred wheel was obtained from JCB Research Ltd, an 'A' frame support constructed in the laboratory and forces applied via a hydraulic ram to a non-rolling tyre. The design of the 'A' frame allowed it to be modified to accommodate vertical movement of the wheel during the dynamic tests.

5.2 The 'A' Frame Figure 36, Plates 14 and 15.

For the static tests the wheel and its simulated axle were supported by the 'A' frame in such a manner that neither rotation of the wheel or movement in any other direction was possible. The complete unit was positioned and fixed into a large independent test frame with the axle horizontal and vertically below the hydraulic ram.

The dynamic tests required not only free vertical movement for the wheel and axle, but also the facility to apply an initial static load to the wheel. These were accommodated by

Plate 14

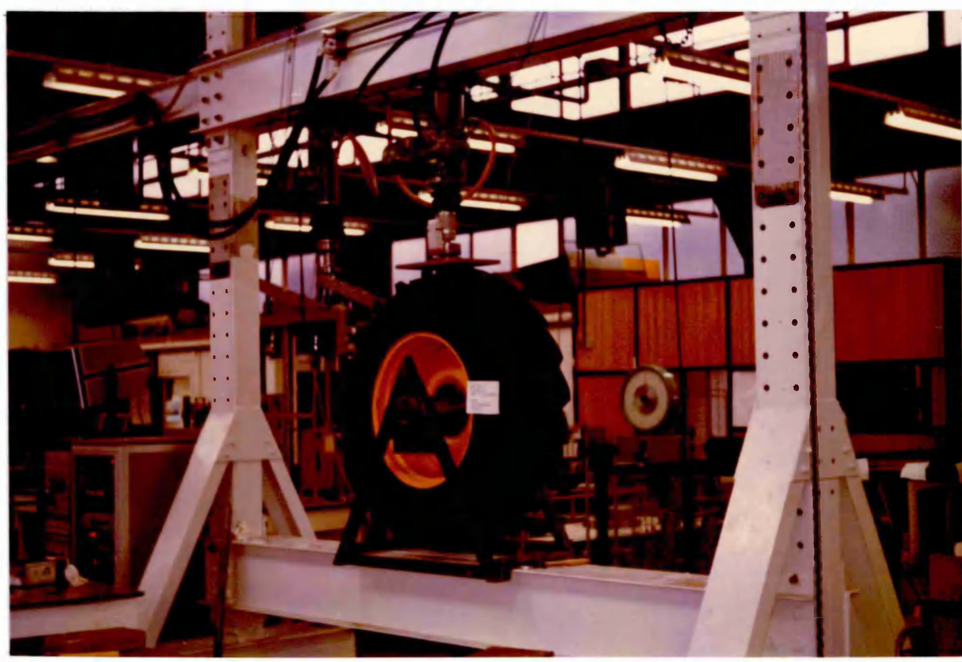
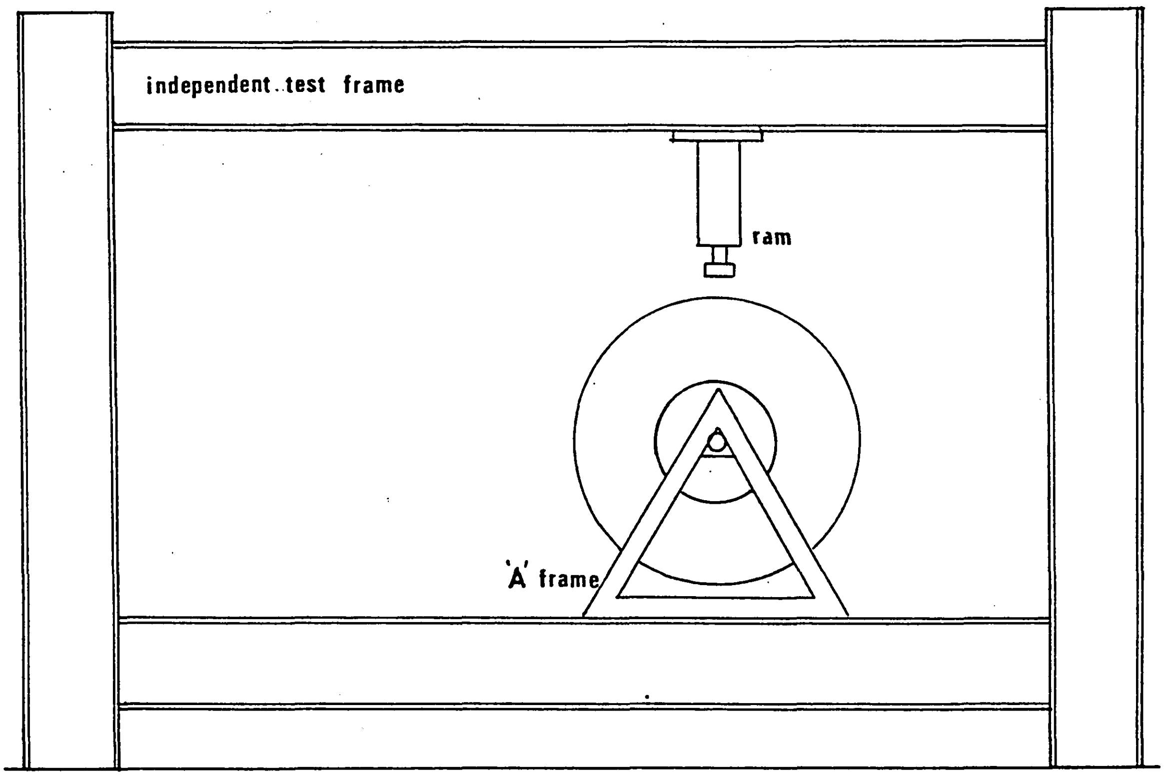


Plate 15

Views showing the drive wheel in the 'A' frame for the series of static tests.



DRIVEWHEEL TEST RIG (fixed axle) **Fig 36**

LOCATION OF WHEEL IN TEST FRAME FOR STATIC STIFFNESS AND MODE SHAPE TESTS ON THE TYRE.

(SEE APPENDIX I FOR DETAILED DRAWING)

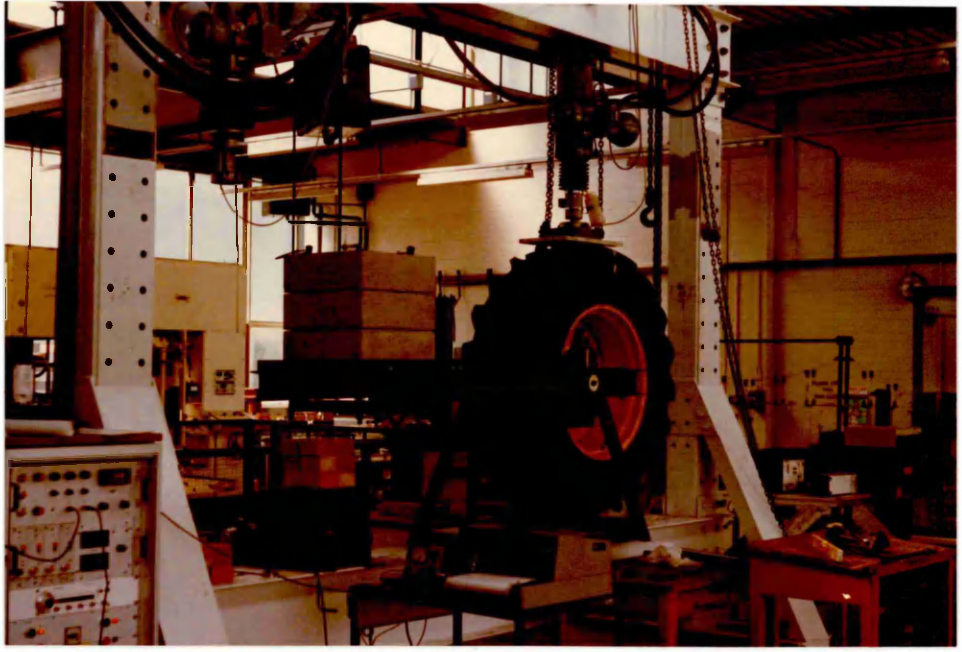
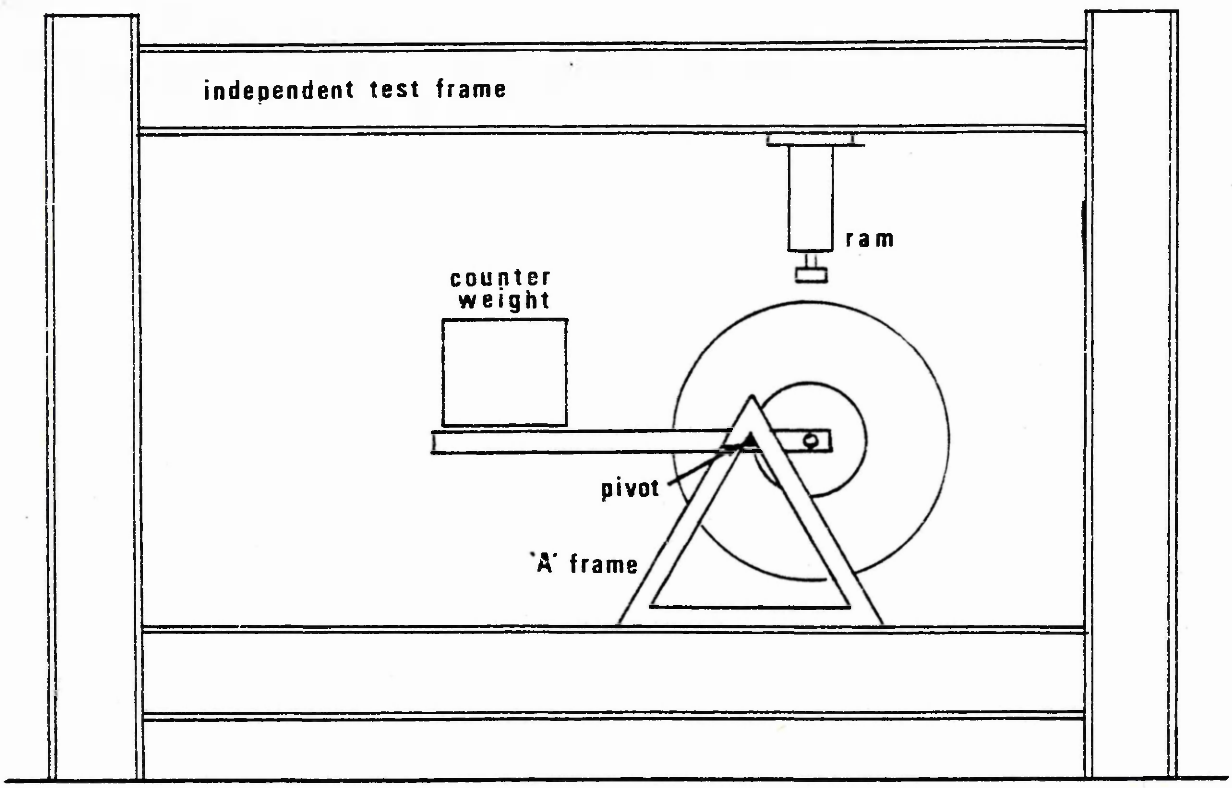


Plate 16



DRIVEWHEEL TEST RIG

Fig 37

LOCATION OF WHEEL IN TEST FRAME FOR DISPLACEMENT AND ACCELERATION MEASUREMENTS ON AXLE FREE TO MOVE IN VERTICAL AXIS.

using the 'A' frame as support and fulcrum for two cantilever beams. The wheel and axle were supported between the beams at one end and concrete blocks were securely bolted across the beams at the opposite end, Figure 37, Plate 16. This arrangement kept the axle horizontal and allowed free vertical movement whilst the moment arm to the concrete blocks provided a realistic static load of 1 tonne at the tyre-to-ram interface.

An important consideration for the dynamic tests was that the natural frequency of the cantilever system should be significantly different to the low frequencies identified during the tests on the moving vehicle.

Comprehensive analysis of the tyre vibration characteristics was outlined by McNulty and Douglas (1985).

5.3 Cantilever Test Frame, and Determination of Natural Frequency

5.3.1 Introduction

To determine the possible existence of vibration modes within the range of frequencies from 1Hz to 8Hz the computer programme package PAFEC 75 was employed.

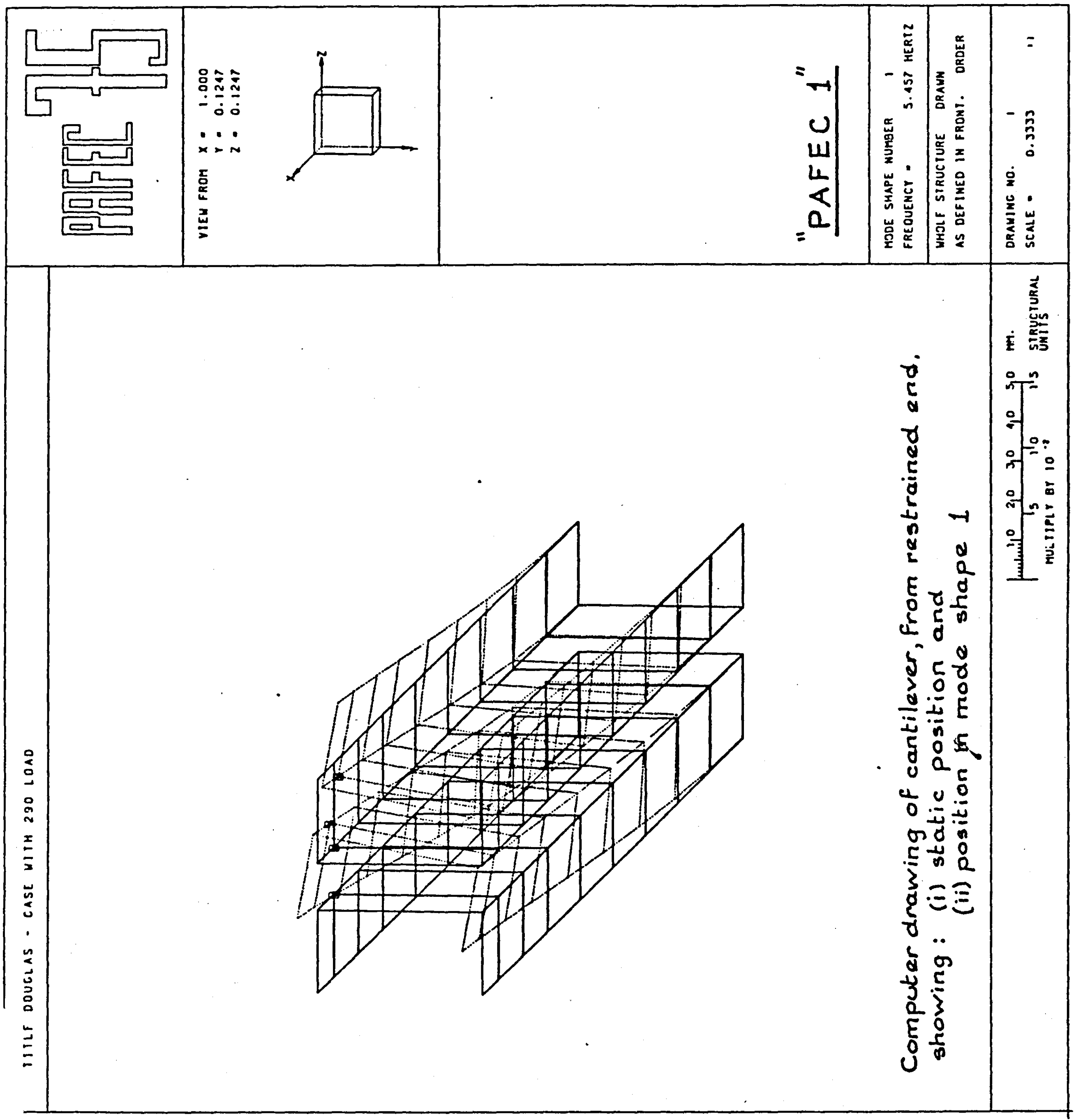
PAFEC 75 is a versatile and powerful group of programme modules which allow many structures, such as beams, frames, flat or curved plates or solid elements, to be statically or dynamically analysed. The theory underlying these programmes is too lengthy to be included in this report, as also is the detail of preparing the data for insertion into the programme.

However, an explanation of the process used is provided to facilitiate the discussion of results and assist with identification of the modes in Figures PAFEC 1, 2 and 3.

5.3.2 Data Preparation

The test frame of two channels had first to be identified for the computer by numbered node points around the structure. It was decided to employ only the longer cantilever for analysis and to consider it constrained at its fulcrum. The justification for this was that the smaller lever arm would be too stiff to influence the test results.

Sixteen node points identified each channel, as shown in the diagram below, eight nodes for the outline and four nodes, eg 5, 20, 6 and 21 for the load position.



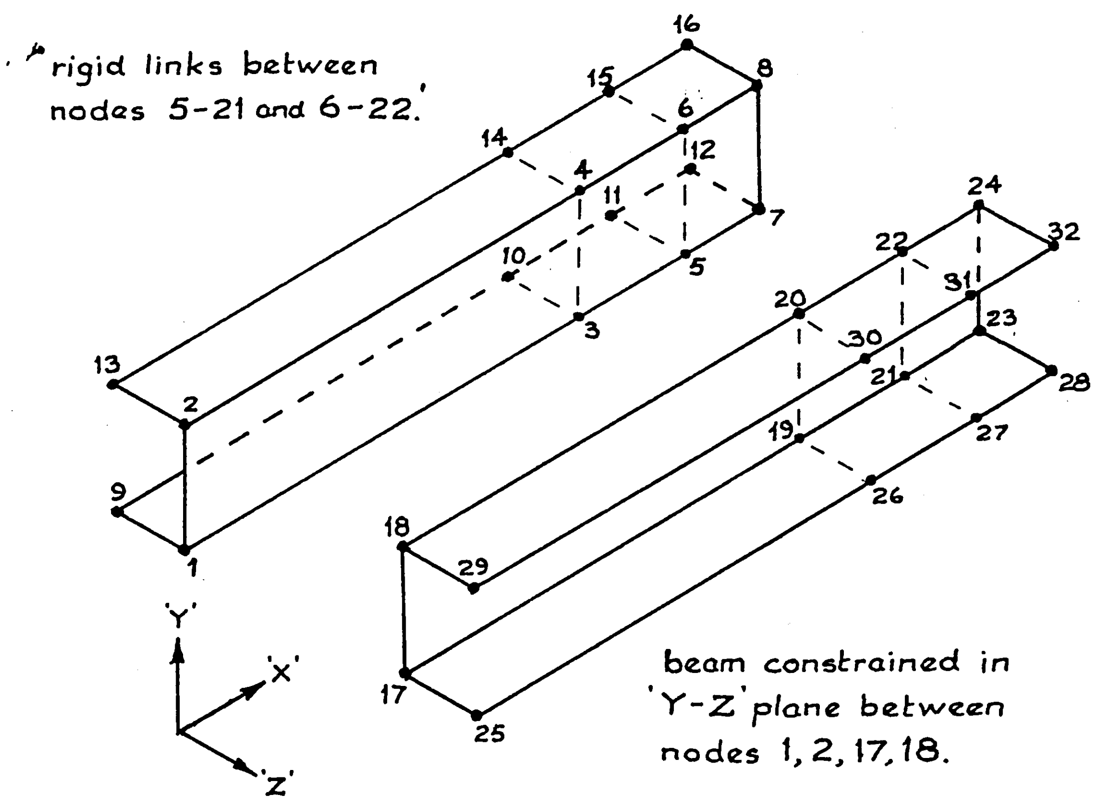
Computer drawing of cantilever, from restrained end, showing: (i) static position and (ii) position in mode shape 1

User E452 File GDOAGLAS CALCOMP plotted on 31/10/85 at 18:04:49
Plot file 5289 for GUNSON

5.3.2 Data Preparation

The test frame of two channels had first to be identified for the computer by numbered node points around the structure. It was decided to employ only the longer cantilever for analysis and to consider it constrained at its fulcrum. The justification for this was that the smaller lever arm would be too stiff to influence the test results.

Sixteen node points identified each channel, as shown in the diagram below, eight nodes for the outline and four nodes, eg 5, 21, 6 and 22 for the load position.



Representation of cantilever test frame by numbered node points for determination of natural frequency by finite element method using PAFEC 75.

These nodes were also rigid links between the channels. The intermediate lines on PAFEC 1, 2 and 3, which subdivided the beams into extra elements were obtained from a built-in facility of the programme known as PAFBLOCKS. This facility removed the need to 'write-in' the number of elements by providing a selection of identifiers which the programme recognised and acted upon. Web and flange thicknesses had to be provided but the material properties, such as Young's Modulus and Moment of Inertia, for common materials like mild steel or aluminium were automatically selected. From instructions concerning the data required the programme calculated the natural frequencies and drew the beam in its stationary and 'mode number' deflected shapes.

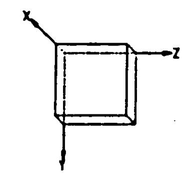
5.3.3 Discussion of Results

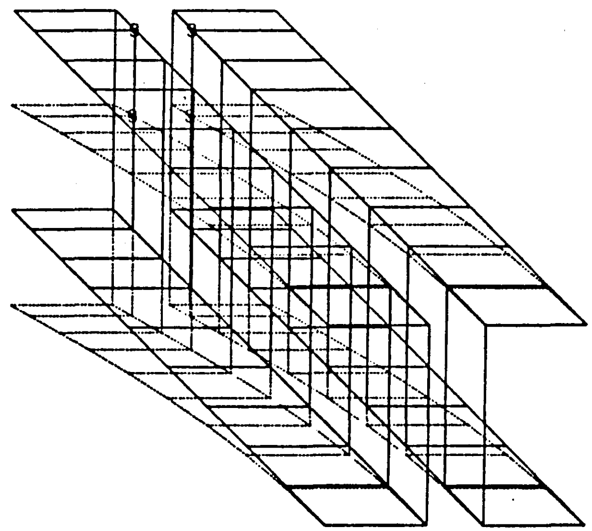
Four views of the beam are shown for each mode number in Appendix J. Figures PAFEC 1, 2 and 3 illustrate the conclusion that the vibration in this part of the test frame did not influence the response of the wheel-tyre system to applied excitation. The first mode occurred at 5.457Hz and this is outside the principal group of frequencies, ie 1.6 to 3.15Hz, under consideration at the drive wheel. In addition, the movement is shown in a horizontal direction, therefore at right angles to the axle's movement. A slight twisting action at the free end is indicated at this frequency but this is considered ineffective.

TITLE DOUGLAS - CASE WITH 29? LOAD

PAFEC 75

VIEW FROM X = 1.000
Y = 0.1247
Z = 0.1247





"PAFEC 2"

Computer drawing of cantilever, from restrained end, showing : (i) static position and
(ii) position in mode shape 2

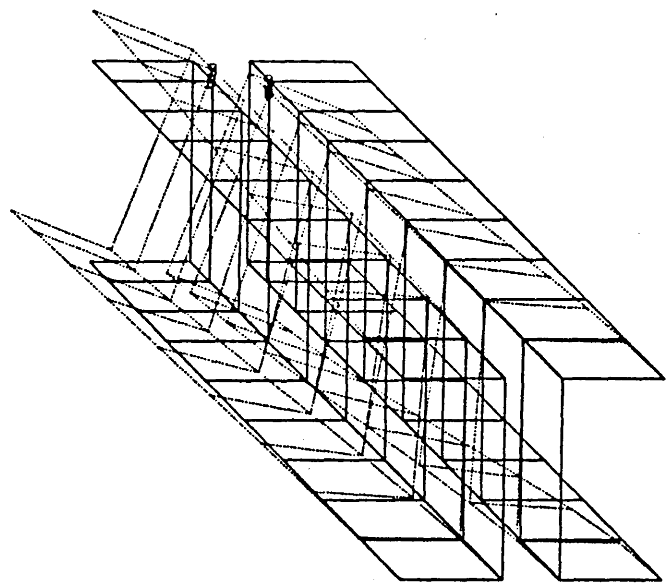
MODE SHAPE NUMBER 2
FREQUENCY = 11.79 HERTZ

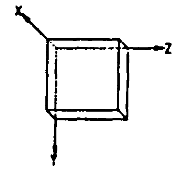
WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

10 20 30 40 50 MM.
5 10 15 STRUCTURAL UNITS
MULTIPLY BY 10 $^{-2}$

DRAWING NO. 2
SCALE = 0.3333 :1

TITLE DOUGLAS - CASE WITH 290 LOAD





VIEW FROM X = 1.000
Y = 0.1247
Z = 0.1247

"PAFEC 3"

Computer drawing of cantilever, from restrained end,
showing : (i) static position and
(ii) position in mode shape 3.

MODE SHAPE NUMBER 3
FREQUENCY = 31.00 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

10 20 30 40 50 MM.
5 10 15 STRUCTURAL UNITS
MULTIPLY BY 10 ⁻¹

DRAWING NO. 3
SCALE = 0.3333 :1

Mode 2 shows a flexing action in the vertical plane, which is the plane of the wheel response. The frequency of this mode, however, is higher still at 11.79Hz and further removed from the low frequencies under consideration. Reference to Figure 44 of the dynamic tests shows that from 5Hz upwards the displacement of the axle was minimal and decreasing towards an extrapolated zero at 11Hz to 12Hz. Also, in Figure 39, the tyre is shown to be absorbing the vibrational energy at frequencies between 11Hz and 12Hz to produce a circular mode shape. It is concluded, therefore, that even though the cantilever may have flexed at 11.79Hz in the vertical plane the action would not have adversely influenced the wheels response at lower frequencies.

Mode 3 once again shows similar, unimportant end rotation response as observed in Mode 1, but the associated frequency has now increased to 31Hz. Therefore this mode can also be discounted due to being too far removed from the frequencies of the drive wheel response.

It is concluded, from this analysis, that the construction of the cantilever test frame did not generate response frequencies to invalidate the results obtained from the drive wheel tests.

5.4 Drive Wheel Tests

5.4.1 Static Wheel Tests : Introduction

The focus of these tests was the tyre and its air content to ascertain their frequency responses to applied vibration and the correlation of these responses with those on the vehicle. To keep the test conditions consistent, pneumatic pressures within the recommended working range only were used, that is 193kPa to 214.3kPa (28 psi to 35 psi). It has been shown that frequency and tyre stiffness are related, Hooker (1980); also stiffness can vary with pneumatic pressure (Matthews and Talamo (1965). Consequently, the stiffness of the tyre within the above inflation pressures was measured.

5.4.2 Tyre Stiffness

With the wheel and ram axially aligned the mass of the ball-seating and load-spreader plate were tared on the machine to allow true applied force to be recorded. On initial contact of the ram a dial gauge, reading 50mm x 0.01mm, was positioned to register the tyre deflection relative to the axle. Force was then applied to the tyre to

JCB Drive-wheel tests: results of static deflection tests on the tyre at four inflation pressures. Tabulated values of ram force and resulting tyre deflection at 1mm increments of ram displacement. (Ref. Figure 38) Table 1

RAM DISPL^T (mm)	TYRE INFLATION PRESSURES															
	200kPa (29psi)				214kPa (31psi)				228.5kPa (33psi)				241.3kPa (35psi)			
	FORCE (kN) RAM		DEFLECT^N (mm) TYRE		FORCE (kN) RAM		DEFLECT^N (mm) TYRE		FORCE (kN) RAM		DEFLECT^N (mm) TYRE		FORCE (kN) RAM		DEFLECT^N (mm) TYRE	
	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP
0	0·00	0·03	0·00	0·15	0·00	0·01	0·00	0·12	0·00	0·00	0·00	0·02	0·00	0·01	0·00	0·00
1	0·21	0·03	0·91	1·10	0·15	0·01	0·96	0·60	0·01	0·00	0·95	0·96	0·04	0·05	0·94	0·98
2	0·46	0·11	1·84	2·01	0·42	0·06	1·88	2·00	0·02	0·00	1·90	1·90	0·30	0·05	1·77	1·91
3	0·70	0·32	2·76	2·93	0·69	0·26	2·80	2·89	0·30	0·00	2·82	2·87	0·59	0·15	2·72	2·83
4	0·95	0·52	3·68	3·84	0·95	0·48	3·72	3·80	0·61	0·10	3·73	3·79	0·86	0·37	3·66	3·74
5	1·21	0·76	4·63	4·78	1·20	0·72	4·63	4·72	0·90	0·31	4·68	4·67	1·15	0·59	4·58	4·62
6	1·48	1·00	5·53	5·70	1·49	0·96	5·58	5·66	1·15	0·55	5·56	5·64	1·42	0·82	5·46	5·58
7	1·74	1·23	6·47	6·63	1·77	1·22	6·49	6·58	1·47	0·80	6·51	6·59	1·70	1·07	6·38	6·47
8	2·01	1·46	7·39	7·53	2·03	1·47	7·43	7·50	1·76	1·03	7·47	7·49	1·99	1·31	7·32	7·34
9	2·27	1·71	8·32	8·46	2·31	1·74	8·34	8·44	2·05	1·30	8·39	8·44	2·29	1·57	8·26	8·30
10	2·53	1·96	9·22	9·38	2·60	1·97	9·30	9·34	2·34	1·61	9·33	9·37	2·55	1·85	9·16	9·20
11	2·80	2·22	10·14	10·30	2·87	2·23	10·18	10·27	2·64	1·83	10·27	10·31	2·83	2·12	10·06	10·12
12	3·11	2·46	11·00	11·22	3·18	2·49	11·11	11·21	2·91	2·09	11·17	11·23	3·12	2·39	11·00	11·01
13	3·43	2·72	11·96	12·16	3·49	2·77	12·03	12·11	3·20	2·35	12·14	12·16	3·42	2·66	11·90	11·98
14	3·77	3·02	12·86	13·08	3·84	3·07	12·96	13·00	3·51	2·64	13·06	13·12	3·74	2·93	12·77	12·87
15	4·10	3·29	13·82	13·95	4·17	3·36	13·85	13·95	3·83	2·89	13·94	14·06	4·11	3·22	13·73	13·76
16	4·45	3·63	14·71	14·91	4·55	3·69	14·76	14·88	4·17	3·18	14·88	14·94	4·47	3·56	14·61	14·71
17	4·83	3·97	15·63	15·82	4·90	4·03	15·67	15·79	4·53	3·52	15·78	15·88	4·86	3·91	15·51	15·62
18	5·15	4·31	16·52	16·72	5·27	4·36	16·62	16·69	4·91	3·84	16·74	16·81	5·20	4·25	16·46	16·52
19	5·52	4·64	17·47	17·69	5·63	4·74	17·51	17·64	5·29	4·21	17·67	17·73	5·54	4·58	17·32	17·37
20	5·86	4·98	18·33	18·59	6·01	5·11	18·49	18·55	5·64	4·56	18·52	18·64	6·00	4·98	18·28	18·33
21	6·24	5·33	19·26	19·50	6·38	5·45	19·29	19·46	6·06	4·94	19·50	19·58	6·32	5·36	19·13	19·27
22	6·64	5·68	20·19	20·41	6·78	5·85	20·22	20·41	6·43	5·29	20·42	20·48	6·71	5·71	20·04	20·15
23	7·02	6·06	21·10	21·28	7·18	6·23	21·17	21·29	6·81	5·69	21·30	21·40	7·09	6·08	20·90	21·09
24	7·39	6·46	21·99	22·23	7·59	6·64	22·10	22·21	7·22	6·09	22·60	22·32	7·49	6·50	21·81	22·01
25	7·78	6·83	22·97	23·12	7·99	7·03	23·01	23·15	7·66	6·51	23·21	23·27	7·92	6·93	22·82	22·89
26	8·17	7·19	23·91	24·03	8·41	7·46	23·96	23·99	8·04	6·91	24·10	24·20	8·35	7·34	23·74	23·79
27	8·57	7·61	24·84	25·00	8·85	7·86	24·88	25·00	8·48	7·35	25·07	25·12	8·75	7·78	24·63	24·75
28	8·97	8·00	25·76	25·90	9·29	8·29	25·85	25·95	8·92	7·77	26·02	26·00	9·19	8·23	25·55	25·67
29	9·40	8·39	26·69	26·85	9·70	8·71	26·78	26·87	9·34	8·23	26·98	27·02	9·63	8·66	26·54	26·58
30	9·78	8·82	27·62	27·77	10·12	9·13	27·69	27·80	9·77	8·67	27·90	27·98	10·06	9·10	27·46	27·51
31	10·22	9·17	28·54	28·69	10·56	9·54	28·64	28·72	10·20	9·10	28·86	28·86	10·52	9·53	28·38	28·42
32	10·64	9·57	29·48	29·59	10·97	10·00	29·54	29·66	10·63	9·56	29·80	29·82	10·95	9·99	29·29	29·37
33	11·03	9·98	30·40	30·53	11·41	10·41	30·46	30·59	11·05	9·99	30·72	30·78	11·42	10·43	30·22	30·29
34	11·44	10·40	31·31	31·43	11·86	10·85	31·38	31·51	11·55	10·48	31·67	31·74	11·84	10·90	31·09	31·21
35	11·88	10·83	32·27	32·40	12·26	11·29	32·31	32·39	11·99	10·92	32·60	32·65	12·33	11·36	32·08	32·15
36	12·33	11·31	33·24	33·38	12·78	11·80	33·34	33·39	12·44	11·41	33·54	33·60	12·73	11·78	32·96	32·99
37	12·76	11·75	34·12	34·29	13·17	12·29	34·22	34·34	12·82	11·89	34·47	34·52	13·14	12·32	33·84	33·96
38	13·16	12·20	35·07	35·22	13·63	12·78	35·16	35·23	13·34	12·44	35·50	35·54	13·65	12·80	34·87	34·90
39	13·61	12·72	36·02	36·14	14·12	13·30	36·13	36·16	13·81	12·97	36·40	36·45	14·13	13·36	35·82	35·83
40	14·03	13·22	36·94	37·05	14·56	13·86	37·03	36·98	14·25	13·51	37·37	37·39	14·56	13·90	36·73	36·76
41	14·45	13·76	37·90	37·97	15·00	14·45	37·97	38·00	14·47	14·13	38·28	38·33	15·03	14·49	37·64	37·66
42	14·84		38·83		15·42		38·85		15·15		39·24		15·44		38·56	

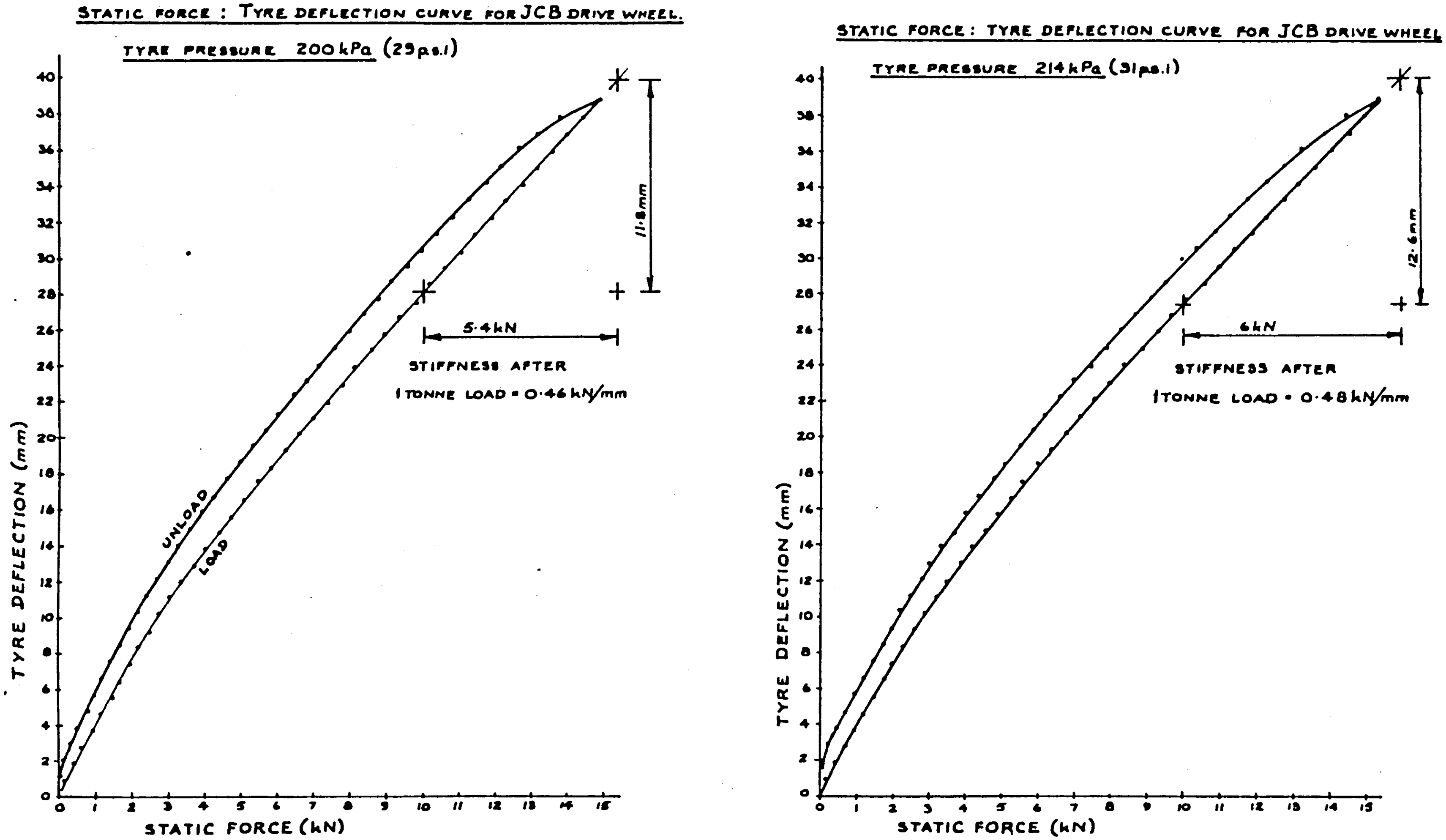
produce 1mm incremental movements of the ram. The applied force and tyre deflection were then recorded and the procedure repeated until the maximum available force from the ram, 16kN, was approached. At this point the force was reduced by similar decrements and deflections recorded, Table 1.

5.4.3 Frequency Effects

From the results of the force : deflection tests it was concluded that the tests for frequency effect need to be carried out at one pneumatic pressure only, that is 214kPa (31 psi). This pressure is a mid-range value and, more significantly, a tyre pressure relevant to construction site use.

The wheel was retained in its axial position with the ram and a simulated vehicle load of 1 tonne applied before the ram was oscillated at single frequencies up to 25Hz with an amplitude of ± 1mm. It was important that only the tyre was influenced by these vibrations, consequently this amplitude was the maximum which could be applied.

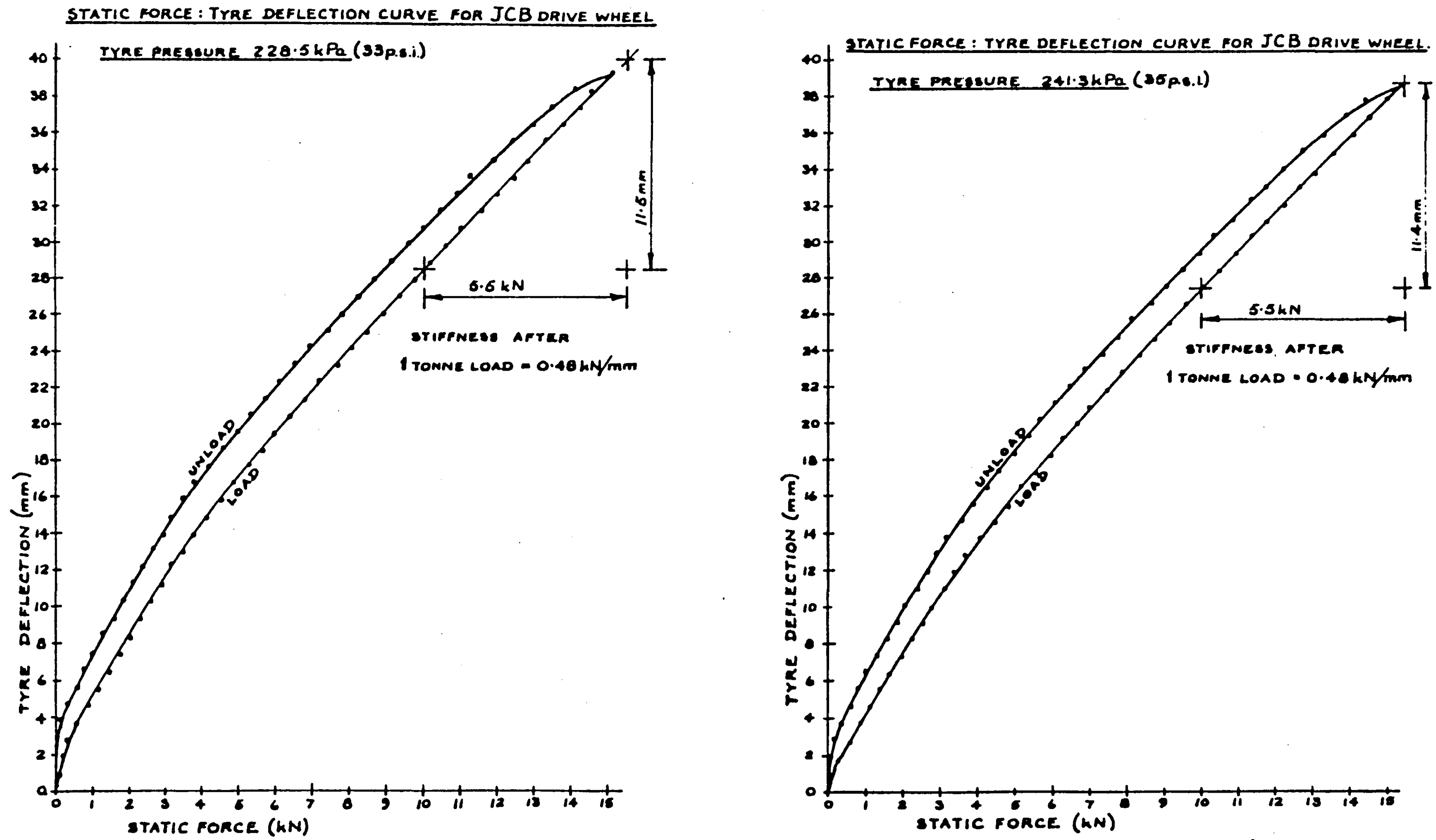
The response of the tyre was to be obtained from the mode shapes, therefore, information concerning radial movements of the tyre were required. Chiesa, Oberto and Tambourini (1964) concluded



(a) (b)

Static deflection and stiffness of drive wheel tyre at 200kPa and 214kPa inflation pressures.

Figure 38



(c) (d)

Static deflection and stiffness of drivewheel tyre at 228·5 kPa and 241·3 kPa inflation pressures.

Figure 38

that, for radial movements, the side walls always oscillate out of phase with respect to the tread, that is, when one is expanded the other is contracted and vice versa. Consequently, transverse movements of the tyre wall were measured at intervals around the tyre for each frequency as this would represent the movement of the tyre under the vertical forcing.

5.5 Discussion of Results

5.5.1 Tyre Stiffness

The static force : deflection curves for the tyre, at four different inflation pressures, are shown in Figure 38(a),(b),(c) and (d). These illustrate the non-linearity associated with pneumatic tyres but also a high level agreement between the results for each pressure. On each graph the change of slope is particularly evident after a deflection of about 12mm, but thereafter the results show an acceptable level of linearity. If cognisance is taken of the need to relate results to the conditions under which these vehicles operate, then the region above 12mm deflection becomes significant. An axle load of 1 tonne has been used for reference in this study, and when the tyre stiffness above this value is calculated a figure of 0.48kN/mm results for three of the four

JCB DRIVE WHEEL TYRE DEFLECTION TEST : TRANSVERSE MOVEMENTS OF TYRE WALL

DEFLECTION DIFFERENCE - V- FREQUENCY   Ref. Table 2

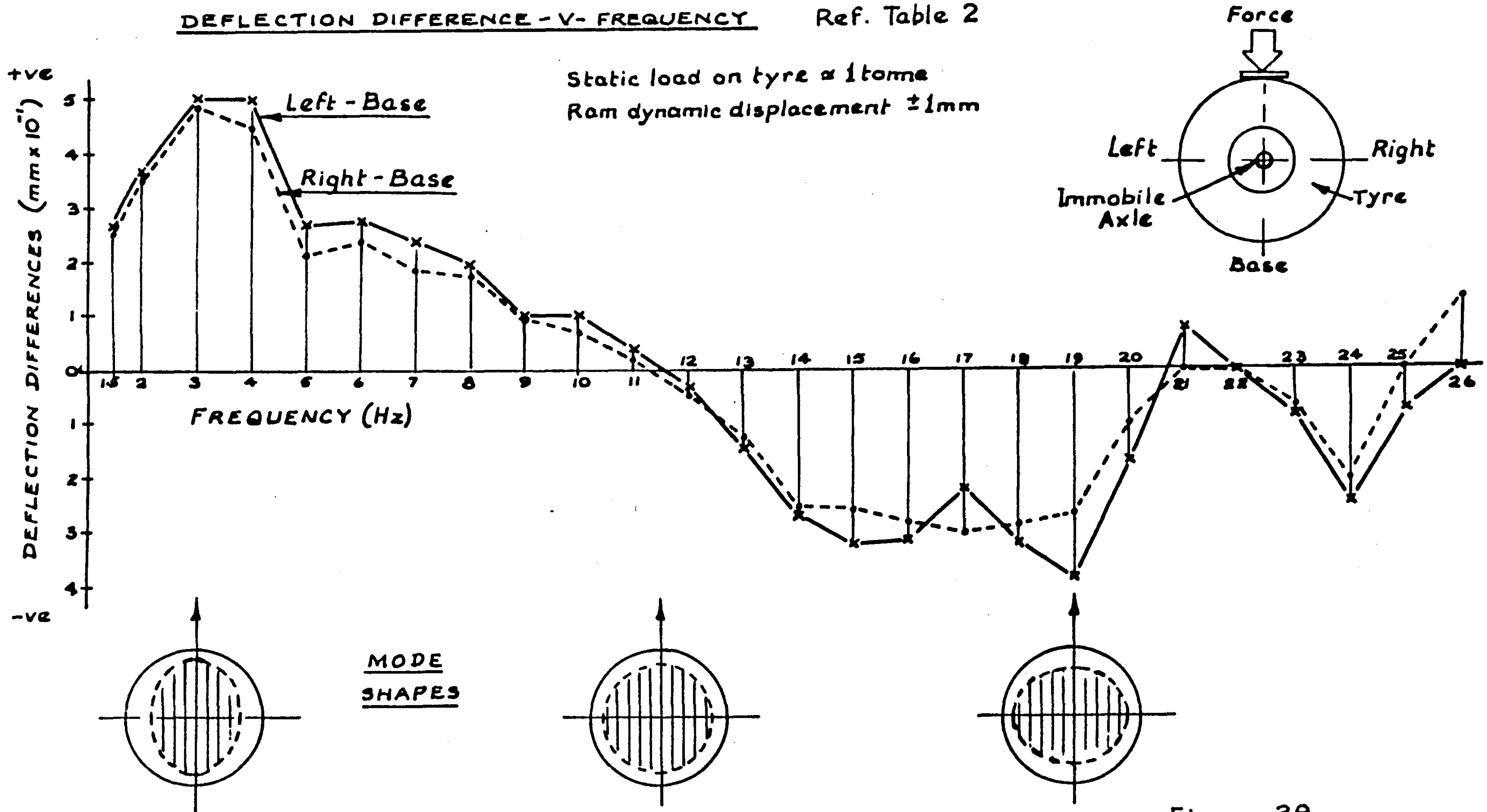


Figure 39

STATIC LOAD ON TYRE = 1 TONNE. RAM DISPLACEMENT ±1mm

Hz	WHEEL AXES				
1·5	0·5	0·485	(0·265)	(0·25)	0·235
2	0·6	0·585	(0·365)	(0·35)	0·235
3	0·65	0·635	(0·5)	(0·485)	0·15
4	0·7	0·65	(0·5)	(0·45)	0·2
5	0·72	0·66	(0·27)	(0·21)	0·45
6	0·7	0·66	(0·28)	(0·24)	0·42
7	0·71	0·66	(0·235)	(0·185)	0·475
8	0·75	0·73	(0·195)	(0·175)	0·555
9	0·835	0·825	(0·1)	(0·09)	0·735
10	0·75	0·72	(0·1)	(0·07)	0·65
11	0·735	0·72	(0·085)	(0·02)	0·7
12	0·685	0·675	(-0·035)	(-0·045)	0·72
13	0·475	0·5	(-0·15)	(-0·125)	0·625
14	0·3	0·325	(-0·27)	(-0·245)	0·57
15	0·235	0·3	(-0·32)	(-0·255)	0·555
16	0·2	0·235	(-0·315)	(-0·28)	0·515
17	0·235	0·235	(-0·22)	(-0·3)	0·535
18	0·235	0·27	(-0·32)	(-0·285)	0·555
19	0·27	0·385	(-0·38)	(-0·265)	0·65
20	0·45	0·42	(-0·17)	(-0·1)	0·52
21	0·42	0·345	(0·075)	(0·0)	0·345
22	0·405	0·405	(0·0)	(0·0)	0·405
23	0·385	0·405	(-0·085)	(-0·07)	0·475
24	0·405	0·45	(-0·245)	(-0·2)	0·65
25	0·46	0·535	(-0·075)	(0·0)	0·635
26	0·42	0·555	(0·0)	(0·135)	0·42

'EXPLANATION'

Transverse displacement of tyre wall in m.m.

Wheel Axes

0·42	0·555
(0·0)	(0·135)

0·42

Difference between horizontal and vertical tyre displacement values in m.m.

Ref: Figure 39

TABLE 2

Transverse displacements of tyre wall for the determination of mode shapes.

inflation pressures. The lowest pressure having a stiffness of 0.46kN/mm.

5.5.2 Frequency Effects

The transverse displacements of the tyre wall in the top quadrant, between 315° through 0° to 45° clockwise, would be influenced by the initial load of 1 tonne and the presence of the spreader plate. Consequently, the displacements outside this region are considered to be relative to the radial movements at the equatorial line of the tread. As expected, the movements of the tyre wall were small and to facilitate this discussion the values recorded at the 90°, 180° and 270° positions around the tyre for each frequency are shown in Table 2. It is obvious that the deflections at the horizontal plane differ from those at the vertical plane, and also that the relative magnitudes change between them. This change in magnitude is shown more clearly when the displacement at the bottom of the tyre is subtracted from each horizontal value, as indicated in brackets eg (0.265) on Table 2. Figure 39 shows these displacement differences plotted against frequency and also the mode shapes of the tyre which can be deduced from them. For the purpose of clarity, these mode shapes are drawn for the complete tyre by allowing the deflection at the bottom of the tyre to represent a value for the top, ignoring the influence on tyre shape of the static load. These vibration tests result in the tyre adopting three distinct mode shapes as the frequency increases. From being a circular shape the mode shape of the tyres vibration becomes elliptical with the major axis vertical. As the frequency increases above 3.5Hz the tyre reverts to a circular shape at around 11 or 12Hz then continues the contraction of the vertical axis and elongation of the horizontal axis until a horizontal ellipse is formed at about 19Hz.

5.6 Dynamic Tests

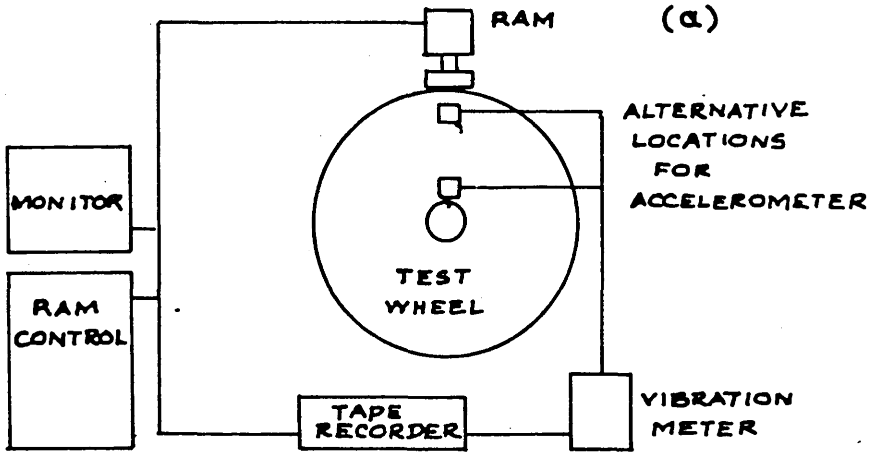
5.6.1 Introduction

The particular response of the tyre at frequencies below 12Hz, on a rigid, immovable axle, required confirmation on a wheel free to move in its vertical axis. Comparisons could then be made with the results of the analyses from the moving vehicle to which actual site conditions are related. To obtain the necessary data the wheel was mounted in the cantilever, Figure 37, and vibrated by the hydraulic ram. The responses at both tyre and axle were analysed, at the relevant frequencies, to provide information concerning the relationship between:

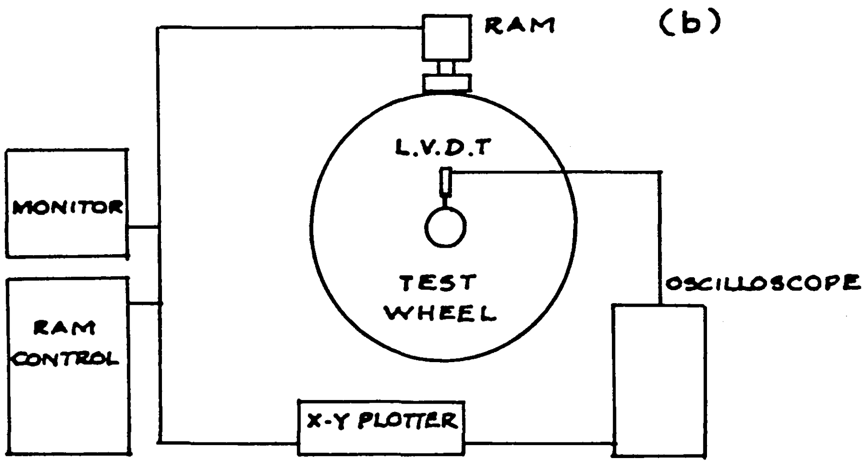
- tyre acceleration and ram force,
- axle acceleration and ram force, and
- axle displacement and ram displacement.

Two important considerations influenced the choice of ram displacement control for the adopted procedure for these tests. First was the four-to-one amplification of ram displacement which would occur at the counterweight end of the double cantilever beam. A ram displacement of ± 10mm would result in 290kg of concrete moving through ± 40mm, at various frequencies, with the inherent risk of danger to people and equipment. The other consideration was related to the alternative control modes available for the ram movement, ie force control or displacement control.

Using force control in this situation could lead to problems if the necessary resistance was either not offered by the wheel, or encountered by the ram late in its travel sequence. If the force set for the ram was not opposed then impact forces and possibly damaging forces, would be exerted within the hydraulic system once the ram reached the end



BLOCK DIAGRAM FOR ACCELERATION AND FORCE MEASUREMENTS.



BLOCK DIAGRAM FOR DISPLACEMENT MEASUREMENTS.

FIGURE 40

of its maximum travel. Whilst opposition to the ram force late in travel would result in the excessive displacement of the counterweight, referred to above.

Displacement control was selected because problems would be avoided if care was exercised regarding the resulting counterweight displacement.

5.6.2 Tests Procedure

In all of the tests to investigate the above relationships, the beam of the cantilever was fist held horizontal by applying force to the wheel via the ram. This ensured that the wheel and ram were axially aligned in the vertical plane, and also simulated a vehicle static force on the tyre. The control of ram movement was by displacement mode with sine wave movement at the selected frequencies. Figure 40 (a) and (b) shows block diagrams of the instrumentation.

The relevant values for force, displacement and acceleration, shown in Tables 3 to 9, were obtained from the following conversion data:

- Ram force; 10 volts output = 16kN
- Ram displacement; 10 volts output = 50mm

- Axle displacement via LVDT; 10 volts output = 12.7mm
- Tyre acceleration; refer to calibration graph in Appendix G.

(i) <u>Details specific to tyre acceleration test</u>

The activity of the tyre was obtained from the triaxial accelerometer fixed to the side of the rubber lug of the tread band below the ram. An output for radial movement was taken to the vibration meter which was also connected to the tape recorder. The completed tape was later processed via a narrow band frequency analyser and permanent records of the results produced from an X-Y plotter, Appendix G.

(ii) <u>Details specific to axle tests</u>

The acceleration of the axle was measured as for the tyre with the exception that the accelerometer was securely connected to the top of the axle.

Displacements of the axle were obtained by use of a linear ~~voltage digital~~ variable differential transducer (LVDT) mounted above the axle. The output was to a

JCB DRIVE WHEEL: DYNAMIC TEST.

VIBRATION TEST TO DETERMINE TYRE ACCELERATION AND FORCE REQUIRED TO MAINTAIN A PARTICULAR RAM DISPLACEMENT AT EACH FREQUENCY.

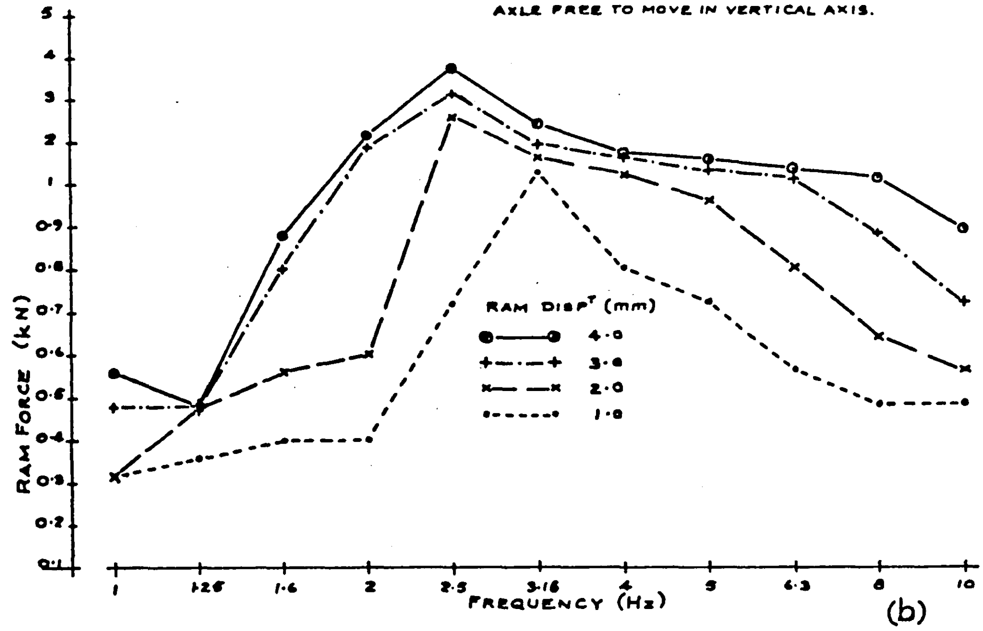
TABLE 3 (Ref. Fig 41)

RAM DISPLAY: 1cm = 0·16kN.

RAM DISPLACEMENT (m.m. peak - peak)		FREQUENCY (Hz)	1	1·25	1·6	2	2·5	3·16	4	5	6·3	8	10
1·0	RAM	DISPLAY (cm)	2	2·25	2·5	2·5	4·5	8	5	4·5	3·5	3	3
		FORCE (kN)	0·32	0·36	0·4	0·4	0·72	1·28	0·8	0·72	0·56	0·48	0·48
	TYRE	APPEND^x G (dB)	91·3	90	92	92·2	104·3	107·4	106	105·5	103	101	94·6
		ACCEL^N (m/s²)	0·015	0·013	0·016	0·017	0·063	0·09	0·08	0·075	0·056	0·045	0·021
2·0	RAM	DISPLAY (cm)	2	3	3·5	3·75	16	10	7·5	6	5	4	3·5
		FORCE (kN)	0·32	0·48	0·56	0·6	2·56	1·6	1·2	0·96	0·8	0·64	0·56
	TYRE	APPEND^x G (dB)	107·2	106·6	107·8	107·6	119·2	116·3	114	113·3	112·3	110·5	103·7
		ACCEL^N (m/s²)	0·09	0·085	0·096	0·094	0·36	0·26	0·2	0·18	0·165	0·13	0·06
3·0	RAM	DISPLAY (cm)	3	3	5	11·5	19	12	10	8	6·5	5·5	4·5
		FORCE (kN)	0·48	0·48	0·8	1·84	3·04	1·92	1·6	1·28	1·04	0·88	0·72
	TYRE	APPEND^x G (dB)	110·7	111·8	117·7	116·5	120·2	117·3	115	115	113·6	112·9	105·1
		ACCEL^N (m/s²)	0·145	0·155	0·3	0·265	0·41	0·29	0·225	0·225	0·185	0·175	0·07
4·0	RAM	DISPLAY (cm)	3·5	3	5·5	13	23	15	10·5	9·5	8·5	7	5·5
		FORCE (kN)	0·56	0·48	0·88	2·08	3·68	2·4	1·68	1·52	1·36	1·12	0·88
	TYRE	APPEND^x G (dB)	111·8	112·3	108·6	113·4	121·7	117	117	115·8	115·3	114	106·4
		ACCEL^N (m/s²)	0·155	0·165	0·11	0·19	0·48	0·28	0·28	0·245	0·23	0·2	0·085

JCB DRIVE WHEEL : DYNAMIC TESTS.

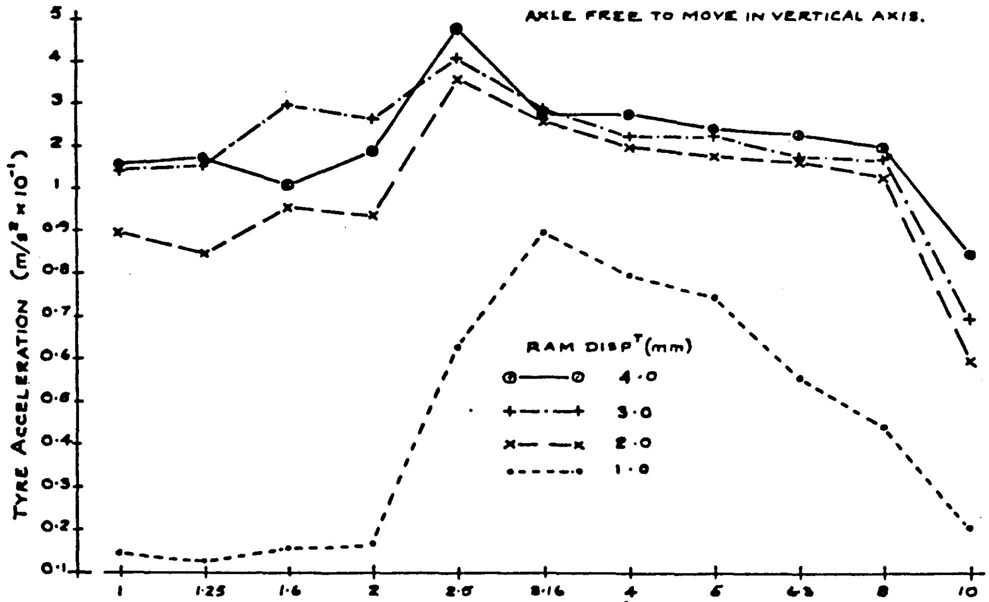
RAM FORCE -V- FREQUENCY FOR FOUR DIFFERENT DISPLACEMENTS OF RAM. AXLE FREE TO MOVE IN VERTICAL AXIS.



(b)

JCB DRIVE WHEEL : DYNAMIC TESTS.

TYRE ACCELERATION -V- FREQUENCY FOR FOUR DIFFERENT DISPLACEMENTS OF RAM. AXLE FREE TO MOVE IN VERTICAL AXIS.



(a)

Figure 41 Ref. Table 3

digital storage oscilloscope for monitoring from which permanent records were produced by the X-Y recorder, Appendix H.

5.7 Discussion of Results

5.7.1 Tyre acceleration and frequency relationships

Table 3 summarises the test results and Figures 41(a) and (b) show the relationships of force and acceleration to frequency for each of the four ram displacements.

On Figure 41(a) each curve displays only small variations in tyre acceleration in the first four frequencies. After 2Hz the levels increase significantly, particularly 1mm ram displacement. The procedure in each test was to first set the required displacement and then to increase the frequency. However, in every case it was found necessary to modify this after the 2Hz readings had been taken, due to excessive movement of the wheel when the frequency was again increased. To obtain readings at 2.5Hz and above, the ram displacement first had to be reduced to zero, next the frequency increased to 2.5Hz, and then the ram frequency from 2Hz to 2.5Hz without removing the ram displacement appeared to result in the tyre and ram movements becoming out of phase with each other. This condition ceased at 2.5Hz, even with the smallest ram displacement, where the acceleration increased to a maximum at 3.16Hz. The acceleration levels for 2mm, 3mm and 4mm ram displacements return close to their initial values, at 3.16Hz, and remain little changed up to 8Hz when a significant reduction occurs.

5.7.2 Ram force and frequency relationship

When the ram force was investigated it was apparent that a considerable increase was required at each frequency up to 2.5Hz to maintain a particular displacement. The increase was not of the same order for all ram displacement, however, there was similarity between the curves for 1 and 2mm and 3 and 4mm displacements.

During the tests on the tyre the movement of the wheel and axle was observed and an increase of activity was noted as the frequency was raised to 2Hz. As previously reported, the oscillation of the tyre and wheel between 2Hz and 2.5Hz was such that great care was necessary to avoid damage. However, once the frequency was increased to 2.5Hz the activity of the wheel gradually reduced until after 6.3Hz wheel movement could not be seen or

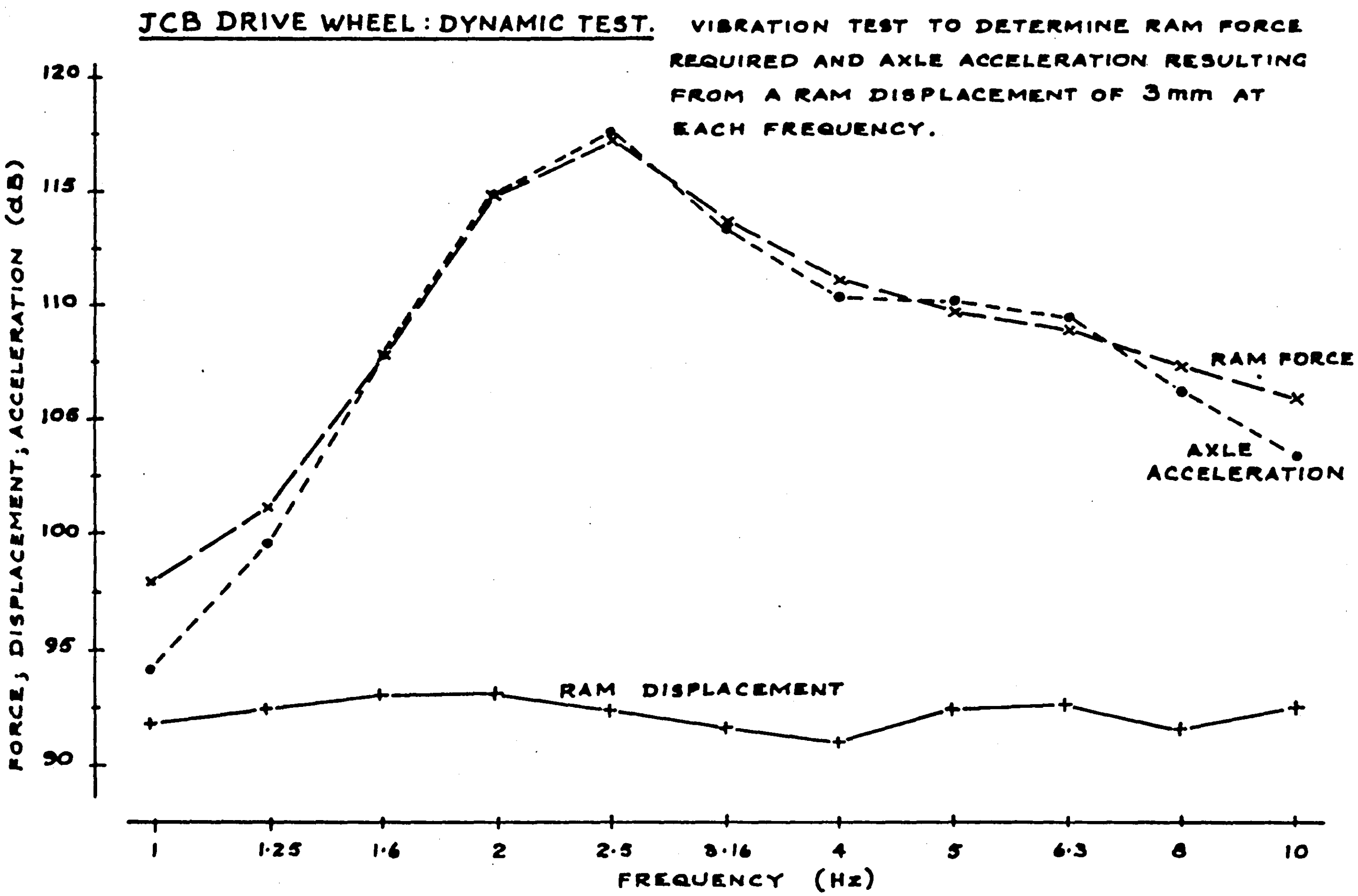


Figure 42
(Ref: Table 4 & Appendix H)

JCB DRIVE WHEEL : DYNAMIC TEST

Vibration Test to determine, at each frequency:-

(i) the force produced by the ram to maintain a displacement of 3mm peak-to-peak, and

(ii) the resulting acceleration of the drive wheel's axle due to the ram force and displacement at the tyre's surface.

Ram Frequency (Hz)	Ram Displacement (dB)	Ram Force (dB)	Axle Acceleration (dB)
1.0	91.7	98	94.1
1.25	92.4	101.2	99.6
1.6	93.0	107.8	107.7
2.0	93.0	114.8	114.9
2.5	92.2	117.2	117.5
3.15	91.5	113.5	113.2
4.0	90.8	111.0	110.2
5.0	92.3	109.6	110.1
6.3	92.5	108.8	109.4
8.0	91.3	107.3	106.1
10.0	92.4	105.9	103.3
12.5	91.5	101.9	95.0

TABLE 4
(Ref Figure 42 and Appendix H)

sensed by touch. The force required by the ram at 6.3Hz, 8Hz and 10Hz, at all displacements, is higher than that required at frequencies up to 1.6Hz and yet this energy does not appear to be transmitted from the tyre to the wheel.

5.7.3 Axle acceleration and ram force relationships

It was necessary to move the site of the investigation to the axle because, on the excavator/loader vehicle, the omission of a suspension system between axle and chassis main frame allows direct transmission of vibrations arriving at the axle. Figure 42,Table 4 show the relationships resulting from the analyses in Appendix H and to assist with comparisons the amplitudes are retained as dB units.

In addition to the ram force curve, which mirrors that of the tyre tests in Figure 41(a), the results show that the ram displacement has, as intended, very little variation across the measured frequency range. This suggests that the ram is meeting with higher resistance, particularly at frequencies between 1.6Hz and 4Hz, in maintaining the required displacement. It is important to note how the axle's acceleration levels follow the ram force as frequencies change. Also that the frequencies with

JCB DRIVE WHEEL DYNAMIC TEST

(Ref Figure 43 & 44)

Vibration test to determine the displacement of the axle and relevant ram force for a constant ram displacement of 2mm (peak to peak) at each frequency.

FREQUENCY. (Hz)

	Details	1	1.25	1.6	2	2.5	3.16	4	5	6.3	8	10
Digital Storage	Ram (mV/cm)	100	100	100	100	100	100	100	100	100	100	100
Oscilloscope setting	Axle (mV/cm)	200	200	1000	1000	500	200	200	50	20	10	10
Graphical Record	Ram display (cm)	3.6	3.7	4.0	5.1	5.4	5.3	5.0	4.4	4.1	3.8	3.2
Figure	Axle display (cm)	2.8	3.1	1.8	3.1	2.2	3.1	3.5	2.8	2.5	2.0	1.3
Calculate Results	Ram Force (kN)	0.58	0.59	0.64	0.82	0.86	0.85	0.80	0.70	0.66	0.61	0.51
	Axle displacement (mm.pk-pk)	0.71	0.79	2.29	3.94	1.4	0.79	0.89	0.18	0.06	0.03	0.02

Conversion data : Ram force:- 625mV = 1kN

Axle displacement : 787mV = 1mm

TABLE: 5

(Ref Figures 43 & 44)

JCB DRIVE WHEEL : DYNAMIC TEST.

(Ref. Table 3)

AMPLITUDES OF RAM FORCE AND AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT = 2 mm pk-pk

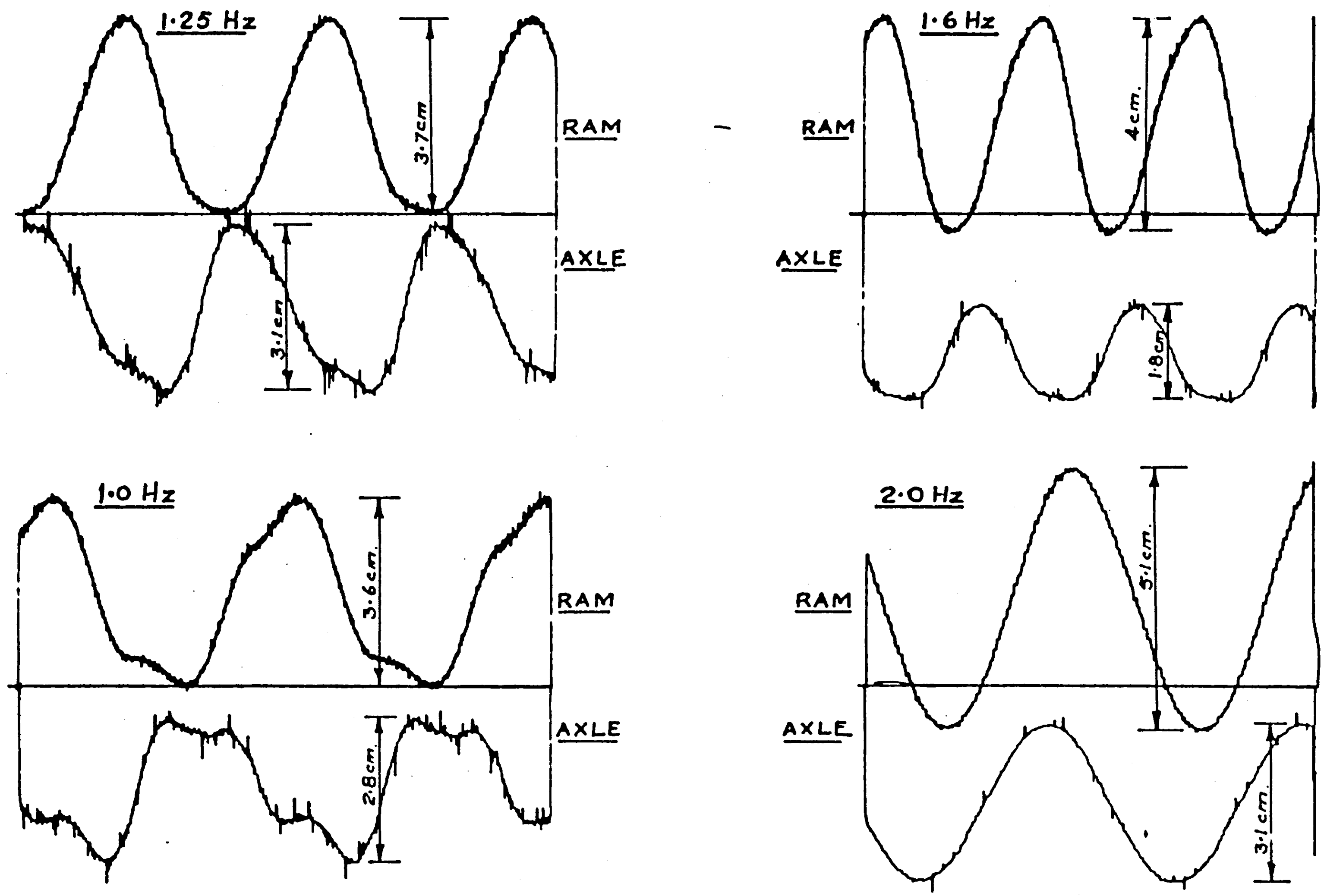


Figure 43 (a)

JCB DRIVE WHEEL : DYNAMIC TEST

(Ref. Table 3)

AMPLITUDES OF RAM FORCE AND AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT = 2 mm pk-pk

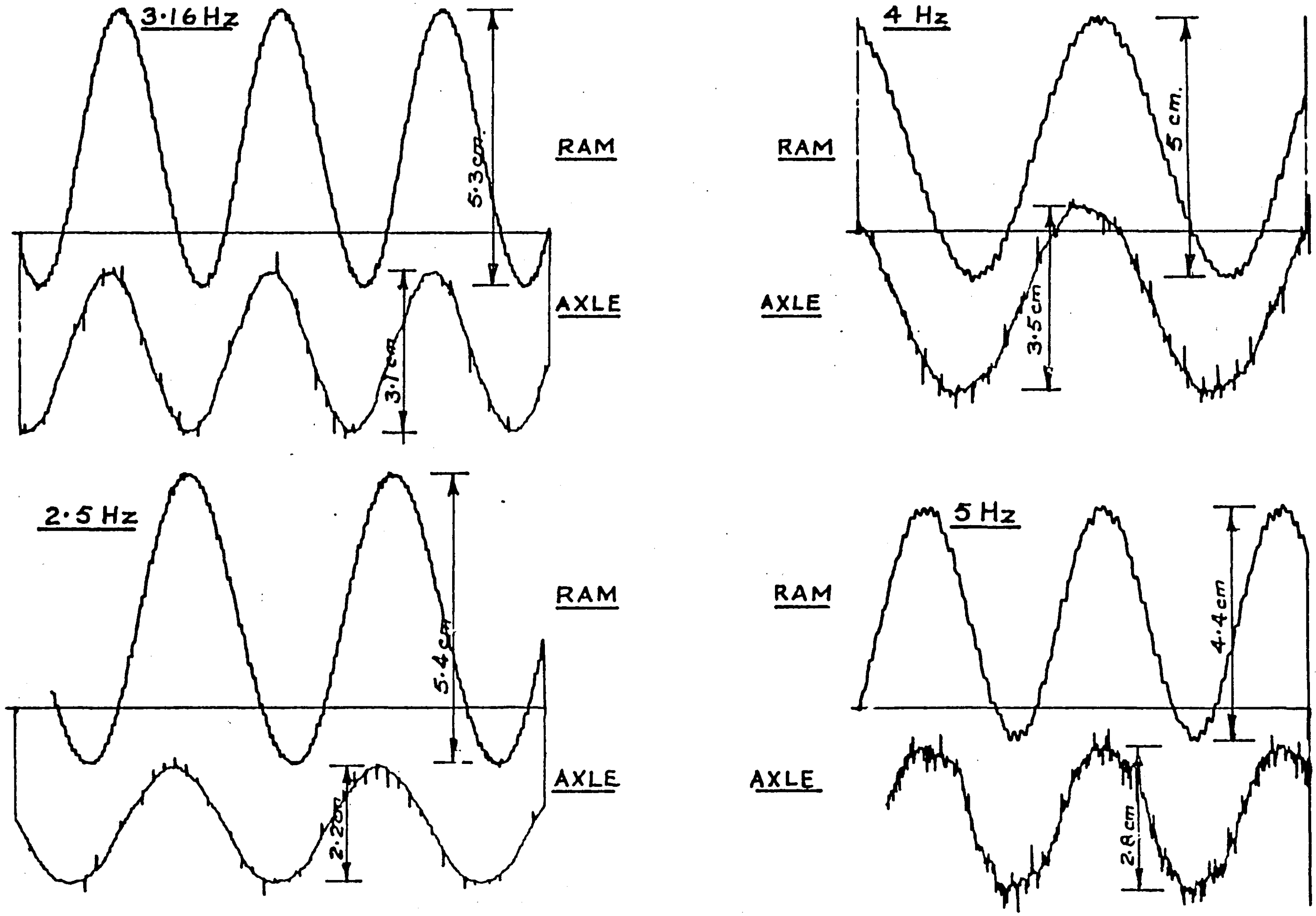


Figure 43 (b)

JCB DRIVE WHEEL : DYNAMIC TEST.
(Ref. Table 3)

AMPLITUDES OF RAM FORCE AND AXLE DISPLACEMENT
AT EACH FREQUENCY FOR RAM DISPLACEMENT = 2 mm pk-pk

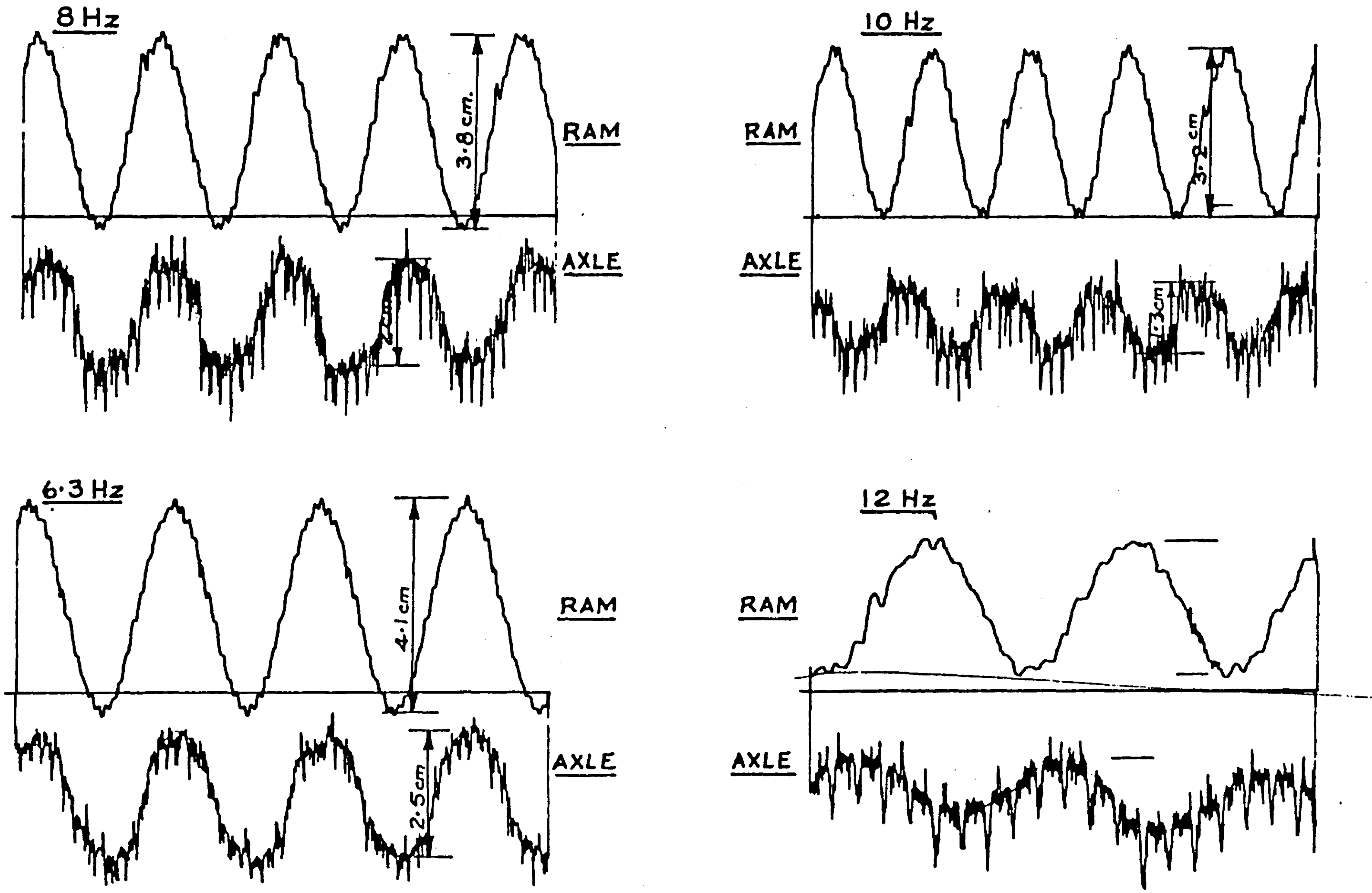


Figure 43 (c)

JCB DRIVE WHEEL : DYNAMIC TEST (REF. TABLE 5)

VIBRATION TEST TO DETERMINE AXLE DISPLACEMENT AND RELATED RAM FORCE FOR A RAM DISPLACEMENT OF 2mm AT EACH FREQUENCY.

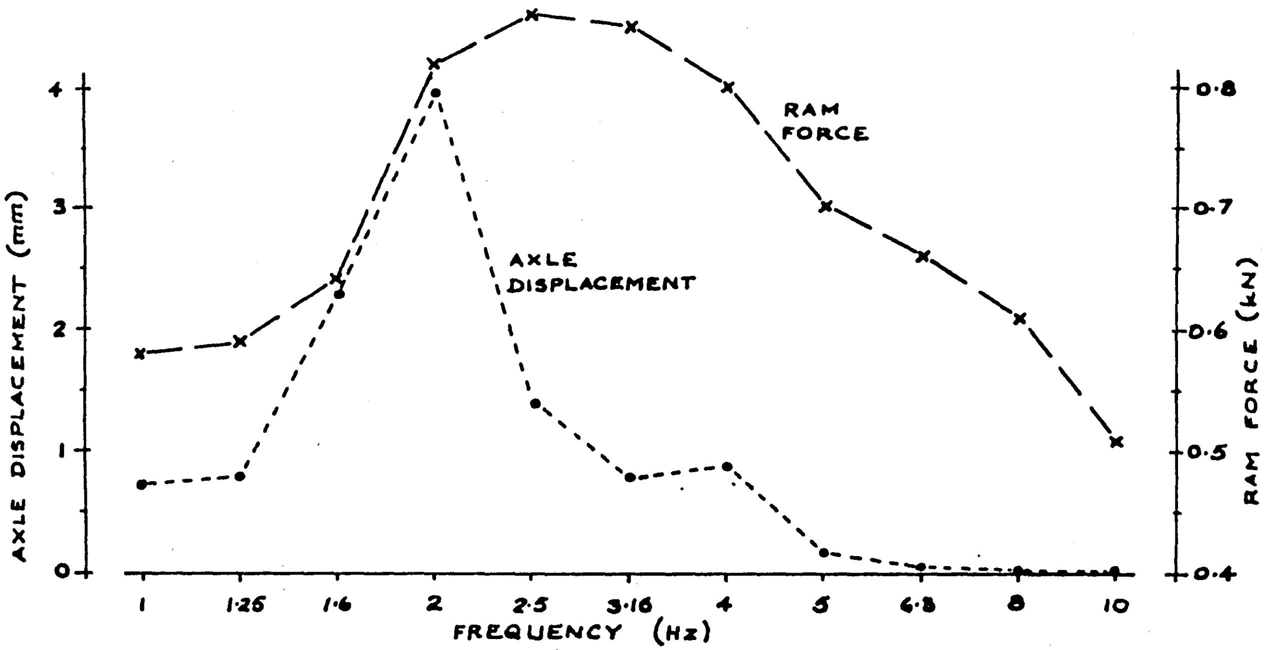


Figure 44

the highest values, correspond to those at the tyre in relation to acceleration and mode shape. The axle's acceleration continued to decrease at frequencies above 6.3Hz demonstrating that energy is being transferred from the tyre, although the resulting displacement at the axle appeared to be comparatively small.

5.7.4 Axle displacement and ram force relationships

The results of the previous tests on the tyre and axle led to the decision to change the instrumentation to allow the signals from the ram and axle to be recorded simultaneously. Figure 43(a) (b) (c) illustrate these resultant curves and Table 5 shows the calibration and calculated values. When these values are plotted against frequency, Figure 44, the high displacement of the axle at about 2Hz, previously referred to, is evident. Also the decrease in displacement at 2.5Hz is shown along with confirmation of the negligible movement of the axle at 6.3Hz and above.

The resistance offered to the ram whilst travelling the set distance is demonstrated by the amplitude of the ram force curve. Up to 2Hz the increasing ram force is accompanied by a corresponding increase in the distance travelled by the axle, whilst above 2Hz the energy appears to have little effect on this aspect of wheel movement. Reference to Figure 42 shows that the axle's acceleration continues at a high level after 2Hz. This is significant for the effects of transmitted energy for it is the acceleration received by the human body which creates the discomfort risk.

The phase relationships of ram force and axle movement during this test were considerations in the decision to introduce the instrumentation which produced the diagrams in Figures 43(a) (b) and (c). It is evident from these figures that ram force and axle displacement are out of phase by almost 180° at certain frequencies, ie 1, 1.25, 1.6 and 10Hz. However, these are not the frequencies at which a high force was recorded, see Figure 44.

The high ram forces occur at the intermediate frequencies, particularly between 2Hz and 5Hz inclusive, and here correspond to an in-phase relationship between the two signals.

5.7.5 Axle and ram displacement relationships

(Tables 6, 7, 8 & 9, and Figures 45, 46, 47 & 48)

This series of tests completes the bank of data relating to the wheel's displacement response to

JCB DRIVE WHEEL : DYNAMIC TEST

(Ref Figure 45)

Vibration test to determine the displacement of the axle at each frequency for a nominal ram displacement of 0.5mm (peak-to-peak) .

FREQUENCY. (Hz)

	Details	1	1.25	1.6	2	2.5	3.16	4	5	6.5	8	10
Digital Storage Oscillator	Ram (mV/cm)	50	50	50	50	50	50	50	50	50	50	50
	Axle (mV/cm)	100	100	100	200	200	200	100	20	10	10	10
Graphical Display (Figure)	Ram (cm)	2.1	2.3	2.7	3.0	3.2	3.2	3.2	3.4	3.4	3.4	3.3
	Axle (cm)	2.2	2.6	3.1	1.8	3.8	2.8	3.1	2.9	1.0	0.8	0.6
Calculated Results	Ram Displacement (mm)	0.55	0.58	0.68	0.75	0.8	0.8	0.8	0.85	0.85	0.85	0.83
	Axle Displacement (mm)	0.28	0.33	0.39	0.46	0.97	0.71	0.39	0.07	0.06	0.5	0.04
	$\frac{\text{Axle}}{\text{Ram}}$ ratio	0.51	0.57	0.57	0.61	1.23	0.89	0.49	0.08	0.07	0.06	0.05

Conversion Data : Ram displacement : 200mV = 1mm

Axle displacement : 787mV = 1mm

TABLE 6

(Ref Figure 45)

JCB DRIVE WHEEL: DYNAMIC TEST.
(Ref. Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 0·5 mm pk-pk (NOM)

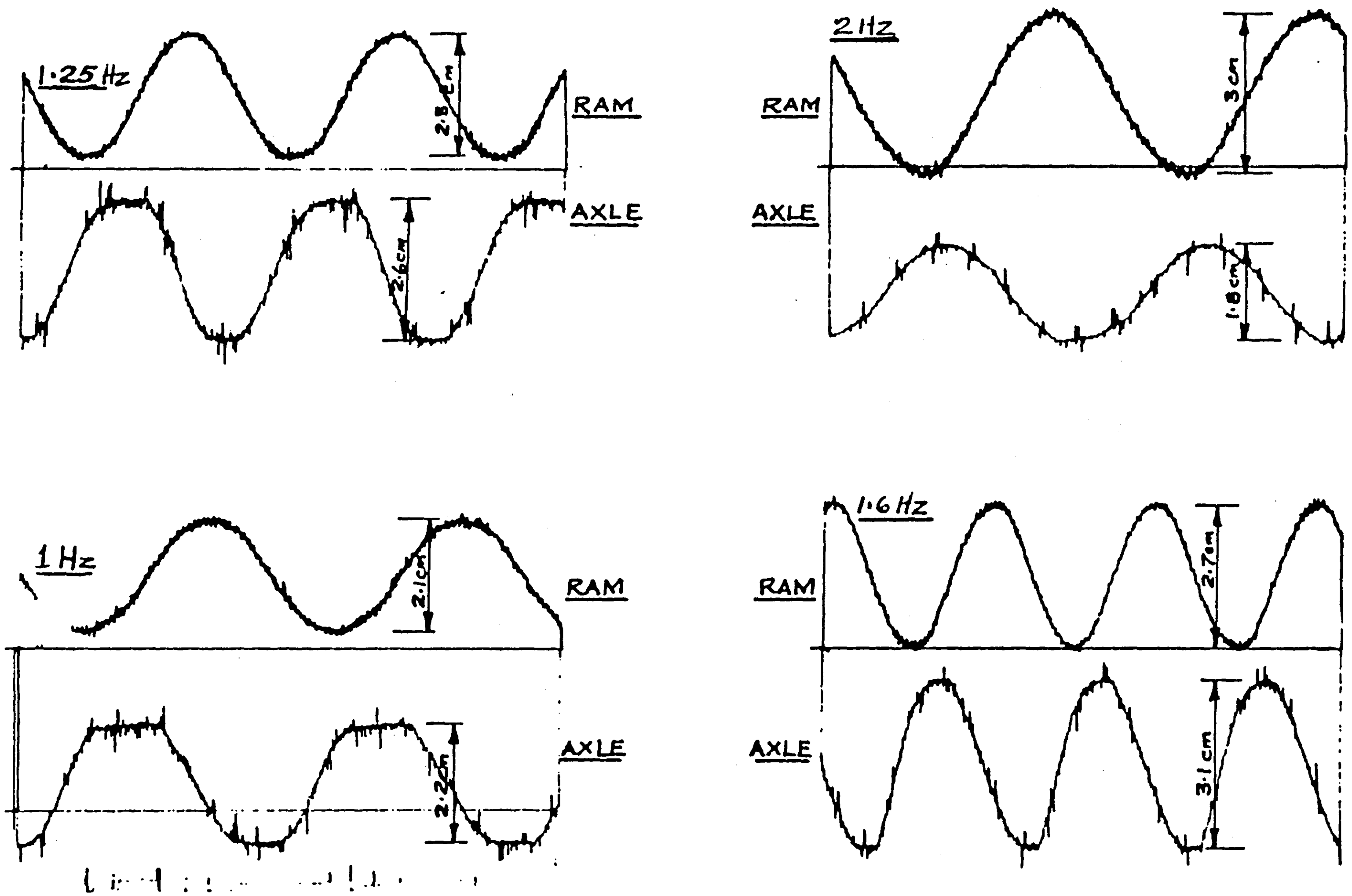


Figure 45 (a) Ref. Table 6

JCB DRIVE WHEEL : DYNAMIC TEST. (Ref. Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 0·5mm pk-pk (NOM)

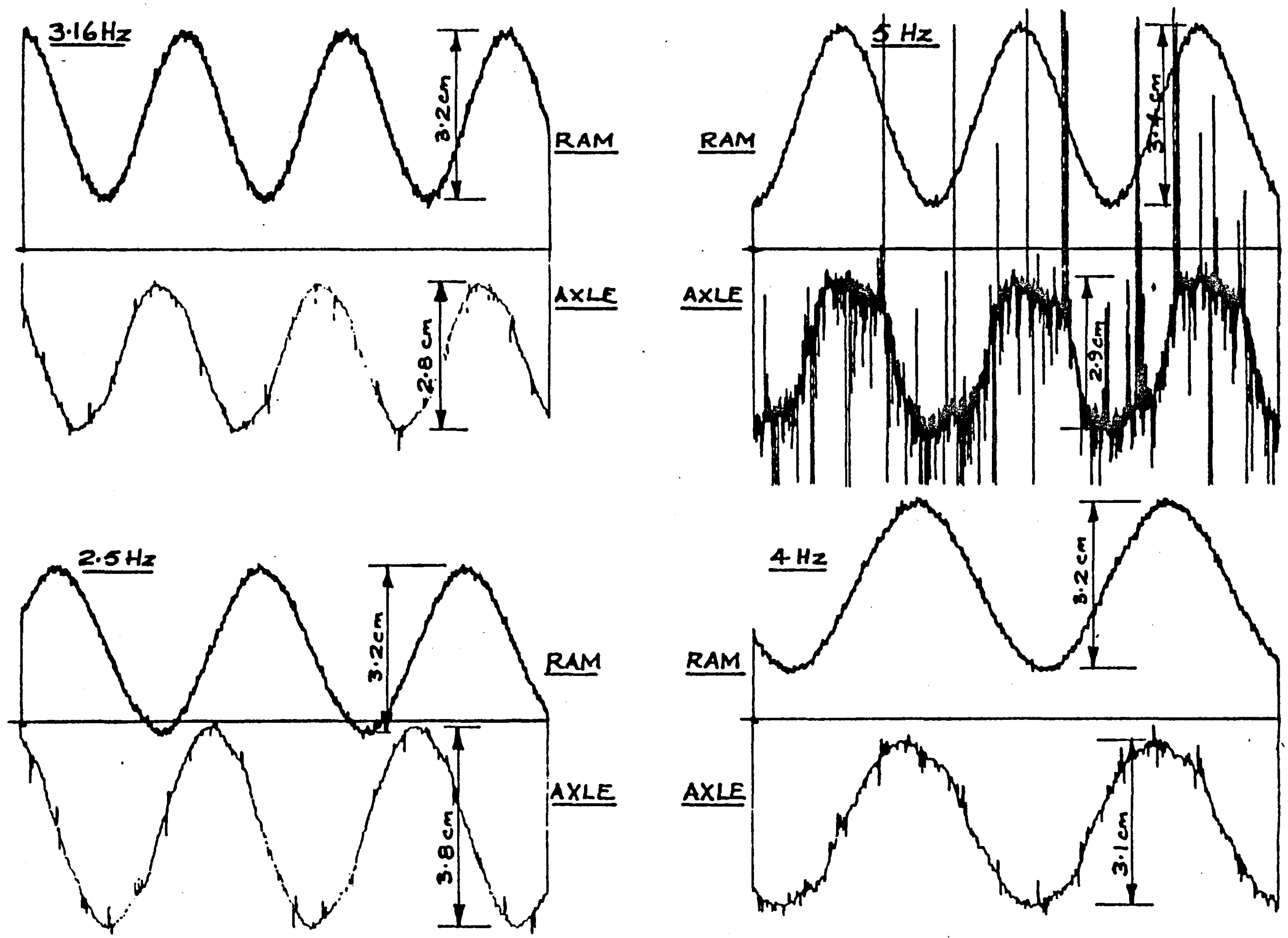


Figure 45 (b) Ref. Table 6

JCB DRIVE WHEEL: DYNAMIC TEST.
(Ref. Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 0·5mm pk-pk.

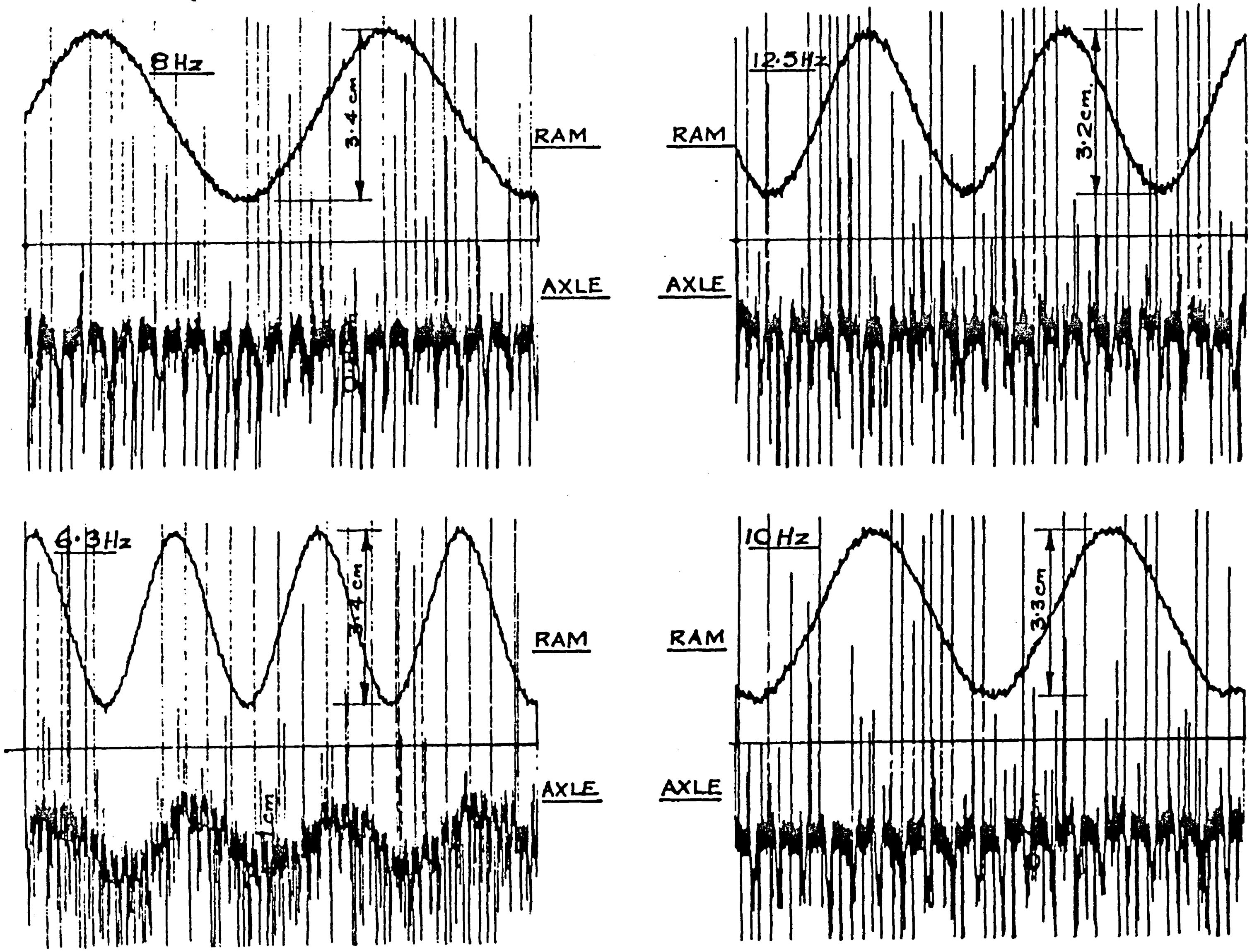


Figure 45 (c) Ref. Table 6

JCB DRIVE WHEEL : DYNAMIC TEST

(Ref Figure 46)

Vibration test to determine the displacement of the axle at each frequency for a nominal ram displacement of 1.0mm (peak-to-peak)

FREQUENCY. (Hz)

	Details	1	1.25	1.6	2	2.5	3.16	4	5	6.3	8	10
Digital Storage Oscilloscope	Ram (mV/cm)	100	100	100	100	100	100	100	100	100	100	100
	Axle (mV/cm)	200	200	1000	1000	500	200	200	50	20	10	10
Graphical Display (Figure)	Ram (cm)	2.1	2.2	3.0	2.8	2.9	3.1	3.2	3.2	3.3	3.3	3.2
	Axle (cm)	3.4	4.1	3.2	2.4	2.6	4.0	2.3	2.5	2.3	0.6	0.4
Calculated Results	Ram Displacement (mm)	1.05	1.1	1.5	1.4	1.45	1.55	1.6	1.6	1.65	1.65	1.6
	Axle Displacement (mm)	0.86	1.04	4.07	3.05	1.65	1.02	0.58	0.15	0.06	0.008	0.005
	$\frac{\text{Axle}}{\text{Ram}}$ ratio	0.82	0.96	2.7	2.18	1.14	0.66	0.36	0.09	0.04	0.005	0.003

Conversion Data : Ram displacement : 200mV = 1mm

Axle displacement : 787mV = 1mm

TABLE 7

(Ref Figure 46)

JCB DRIVE WHEEL: DYNAMIC TEST.
(Ref Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 1 mm pk-pk

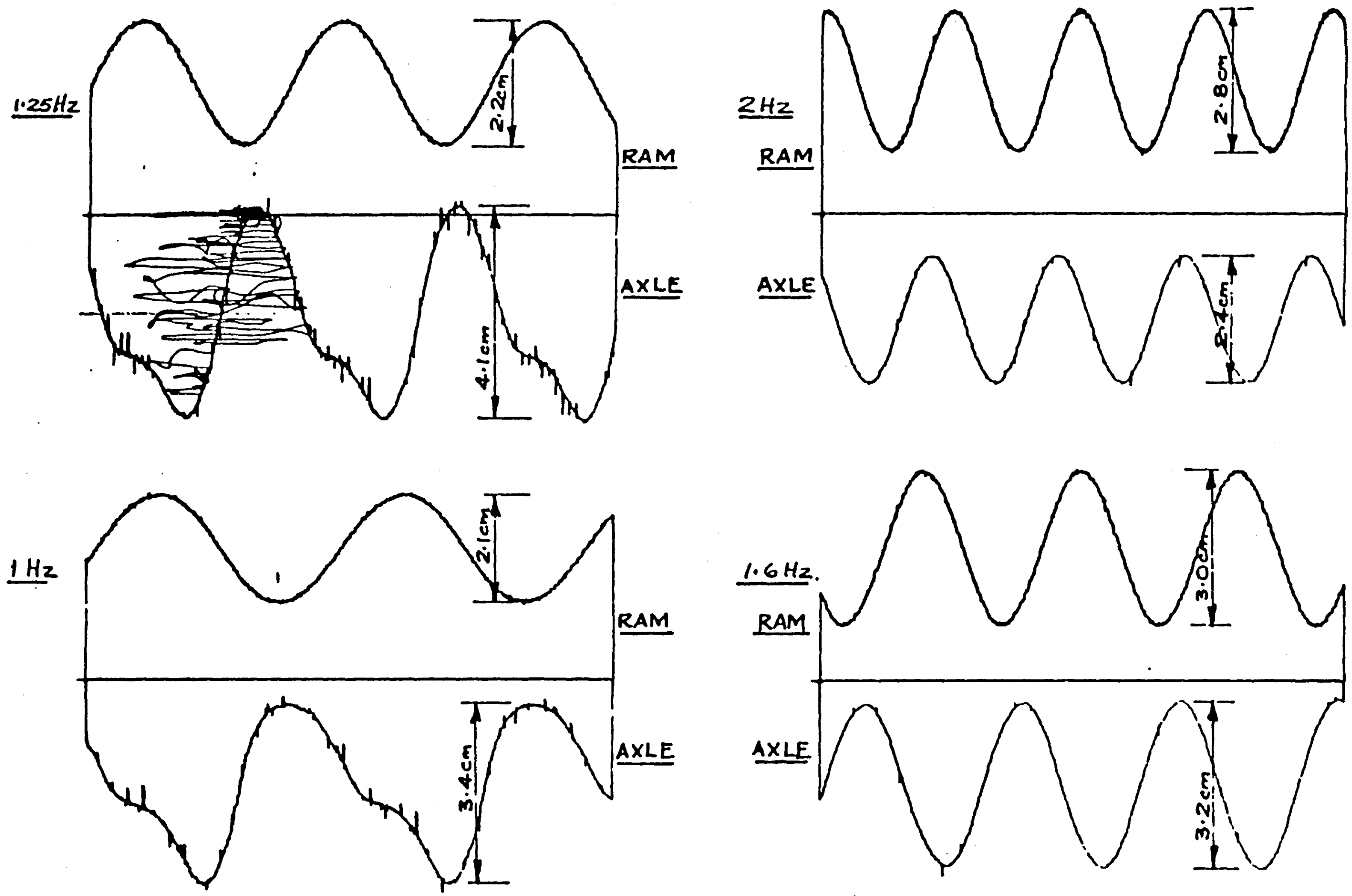


Figure 46 (a) Ref. Table 7

JCB DRIVE WHEEL: DYNAMIC TEST.

(Ref. Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 1 mm pk-pk.

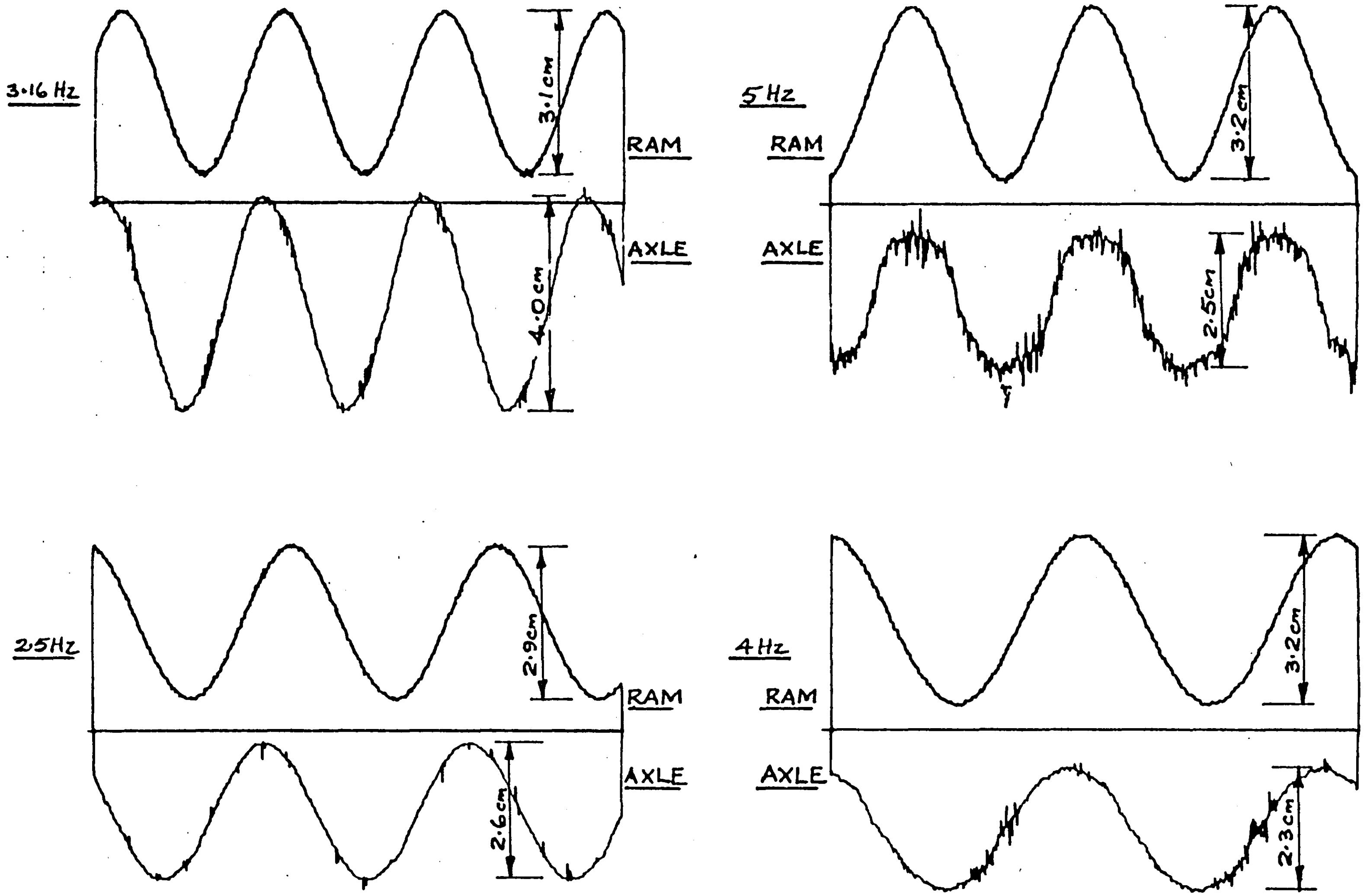


Figure 46 (b) Ref. Table 7

JCB DRIVE WHEEL: DYNAMIC TEST.
(Ref. Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 1mm pk-pk.

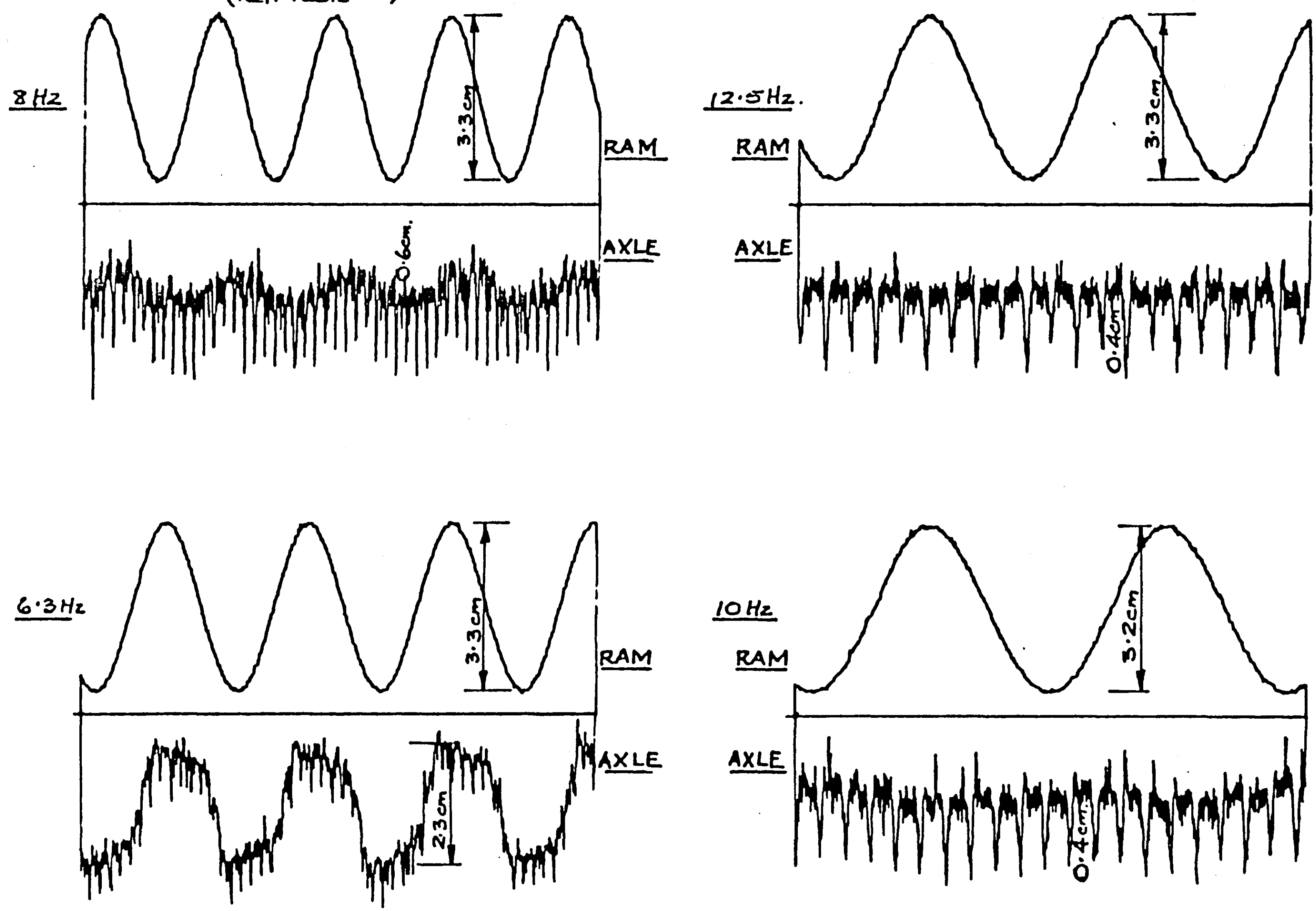


Figure 46 (c) Ref. Table 7

JCB DRIVE WHEEL : DYNAMIC TEST

(Ref Figure 47)

Vibration test to determine the displacement of the axle at each frequency for a nominal ram displacement of 1.5mm (peak-to-peak)

FREQUENCY. (Hz)

	Details	1	1.25	1.6	2	2.5	3.16	4	5	6.3	8	10
Digital Storage Oscillator	Ram (mV/cm)	100	100	200	200	100	100	100	100	200	200	200
	Axle (mV/cm)	500	500	1000	1000	200	200	200	20	10	5	5
Graphical Display (Figure)	Ram (cm)	3.2	3.8	2.2	2.0	4.3	4.5	4.7	4.7	2.5	2.4	2.4
	Axle (cm)	2.3	3.4	4.1	1.7	4.0	2.3	1.3	3.8	3.4	2.7	1.3
Calculated Results	Ram Displacement (mm)	1.6	1.9	2.2	2.0	2.15	2.25	2.35	2.35	2.25	2.2	2.2
	Axle Displacement (mm)	1.46	2.16	5.21	2.16	1.02	0.58	0.33	0.10	0.04	0.02	0.008
	$\frac{\text{Axle}}{\text{Ram}}$ ratio	0.91	1.14	2.37	1.08	0.47	0.28	0.14	0.04	0.02	0.009	0.004

Conversion Data : Ram displacement : 200mV = 1mm

Axle displacement : 787mV = 1mm

TABLE 8

Ref Figure 47)

JCB DRIVE WHEEL: DYNAMIC TEST. (Ref. Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 1·5 mm pk-pk

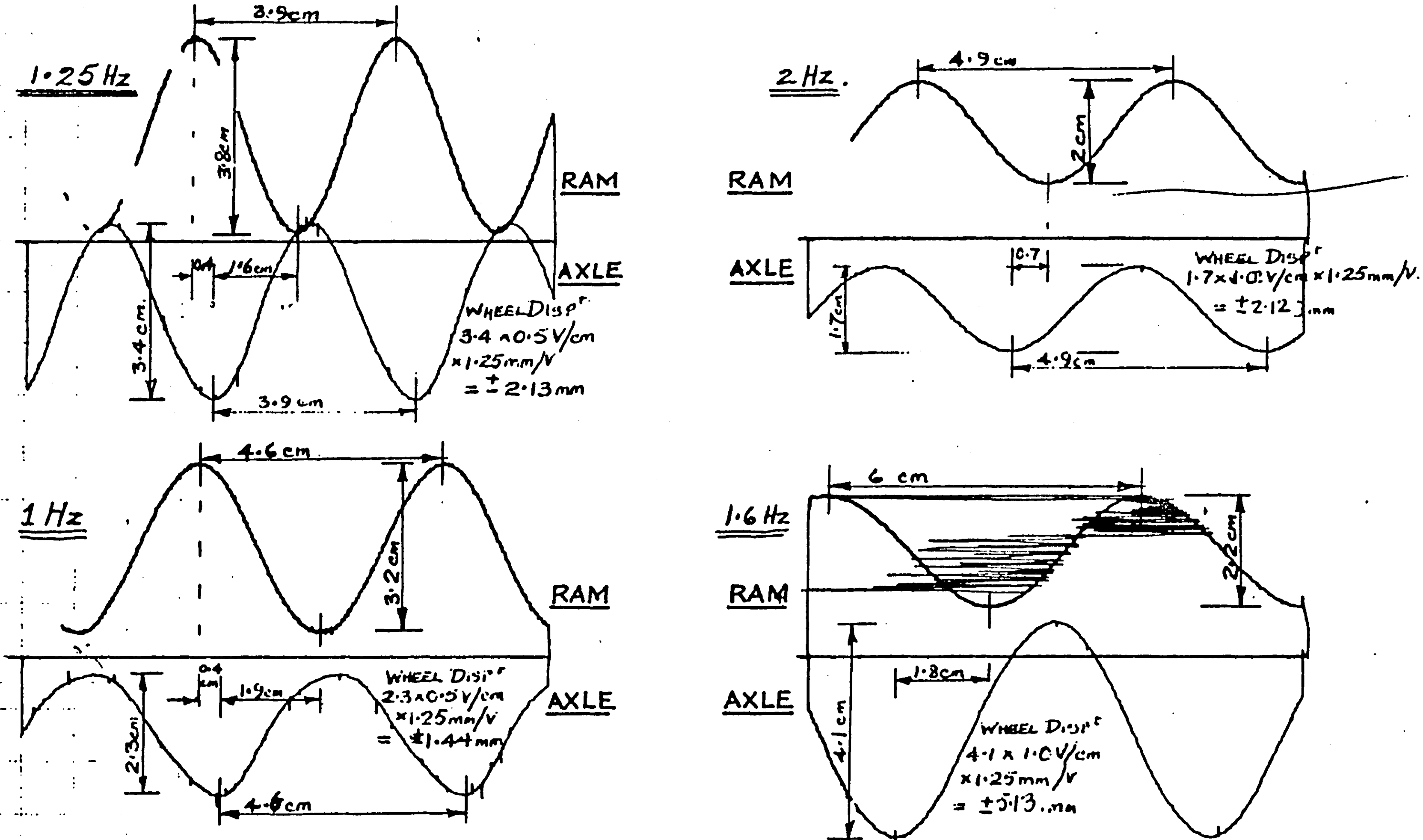


Figure 47 (a) Ref. Table 8

(Ref. Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 1·5mm pk-pk

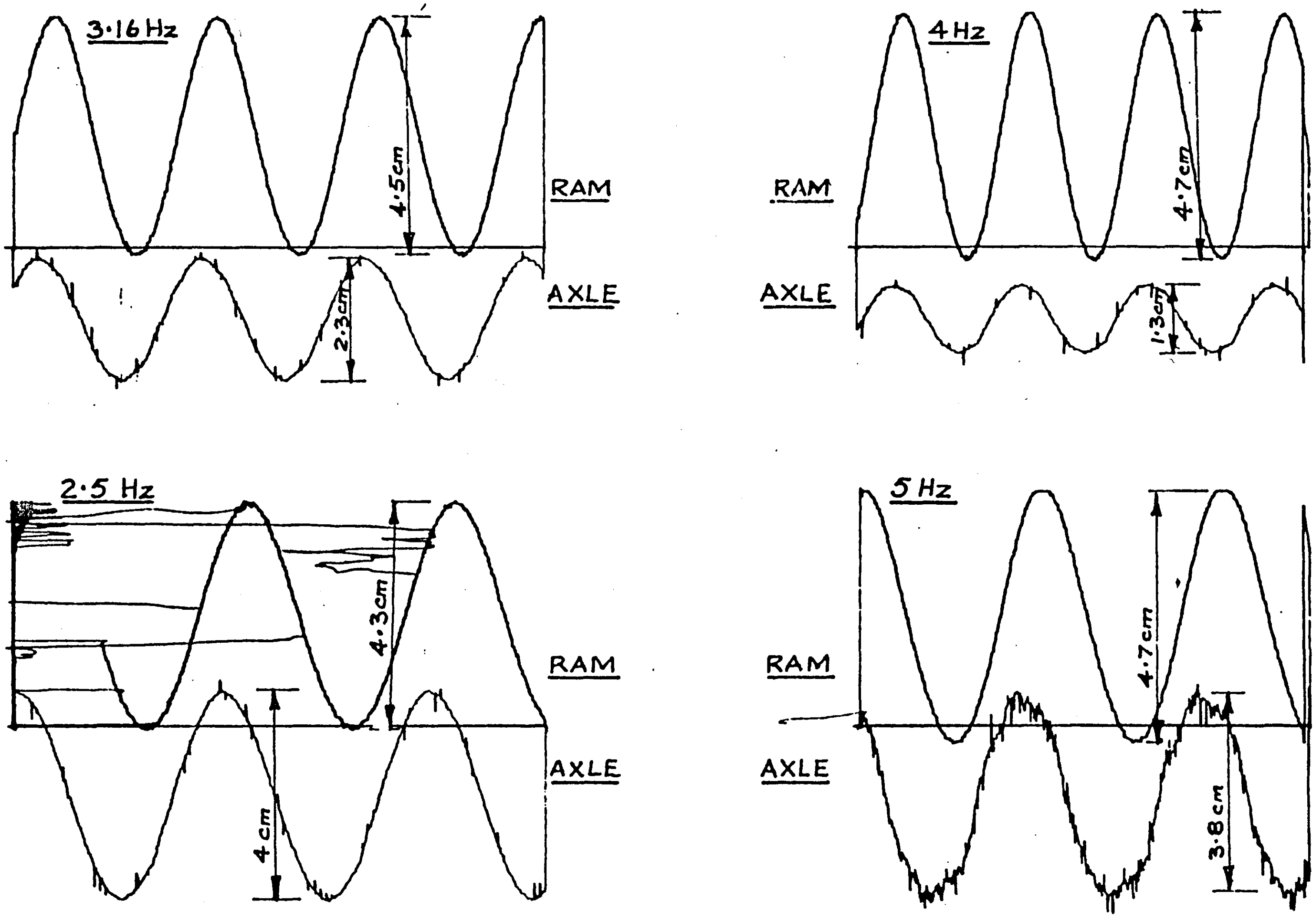


Figure 47 (b) Ref. Table 8

JCB DRIVE WHEEL : DYNAMIC TEST.
(Ref Table)

AMPLITUDE OF AXLE DISPLACEMENT AT EACH FREQUENCY FOR RAM DISPLACEMENT OF 1·5 mm pk-pk.

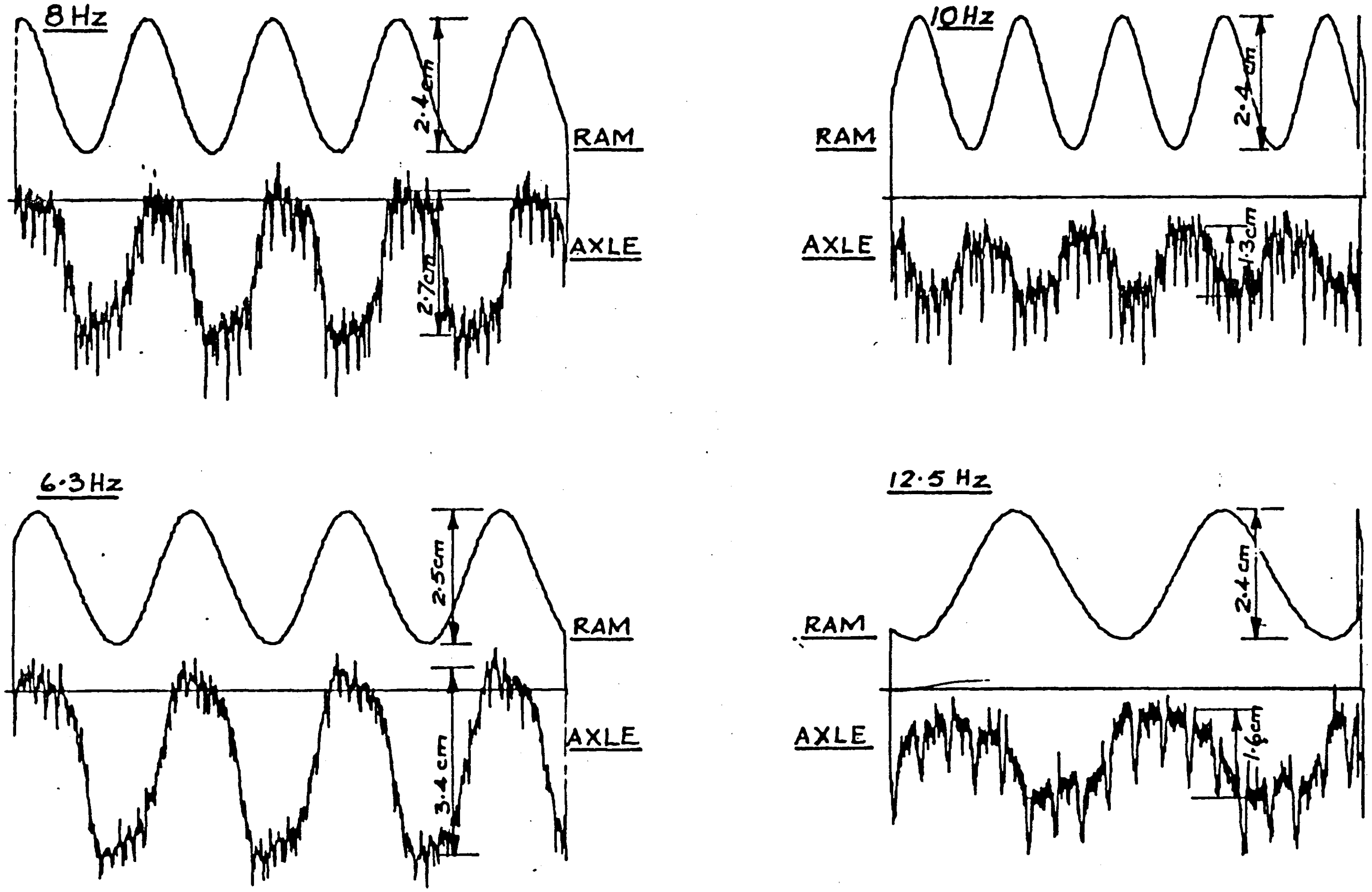


Figure 47 (c) Ref. Table 8

JCB DRIVE WHEEL : DYNAMIC TEST

Vibration test to determine the displacement of the axle at each frequency for a nominal ram displacement of 2mm (peak-to-peak)

FREQUENCY. (Hz)

	Details	1	1.25	1.6	2	2.5	3.16	4	5.6	6	8	10
Digital Storage Oscillator	Ram (mV/cm)	100	100	100	100	100	100	100	100	100	100	100
	Axle (mV/cm)	500	1000	2000	1000	500	200	200	100	100	100	100
Graphical Display	Ram (cm)	4.4	4.95	6.65	5.6	4.1	6.25	6.75	6.6	6.65	6.75	6.75
	Axle (cm)	6.2	3.85	7.75	4.8	5.9	6.7	2.9	2.45	0.95	0.55	0.55
Calaculated Results	Ram Displacement (mm)	2.2	2.48	3.33	2.8	2.05	3.13	3.38	3.3	3.33	3.38	3.38
	Axle Displacement (mm)	3.94	4.89	19.7	6.1	3.75	1.7	0.74	0.31	0.12	0.07	0.07
	$\frac{\text{Axle}}{\text{Ram}}$ ratio	1.79	1.97	5.9	2.18	1.83	0.54	0.22	0.09	0.04	0.02	0.02

Conversion Data : Ram displacement : 200mV = 1mm

Axle displacement : 787mV = 1mm

TABLE 9

JCB DRIVE WHEEL: DYNAMIC TEST.

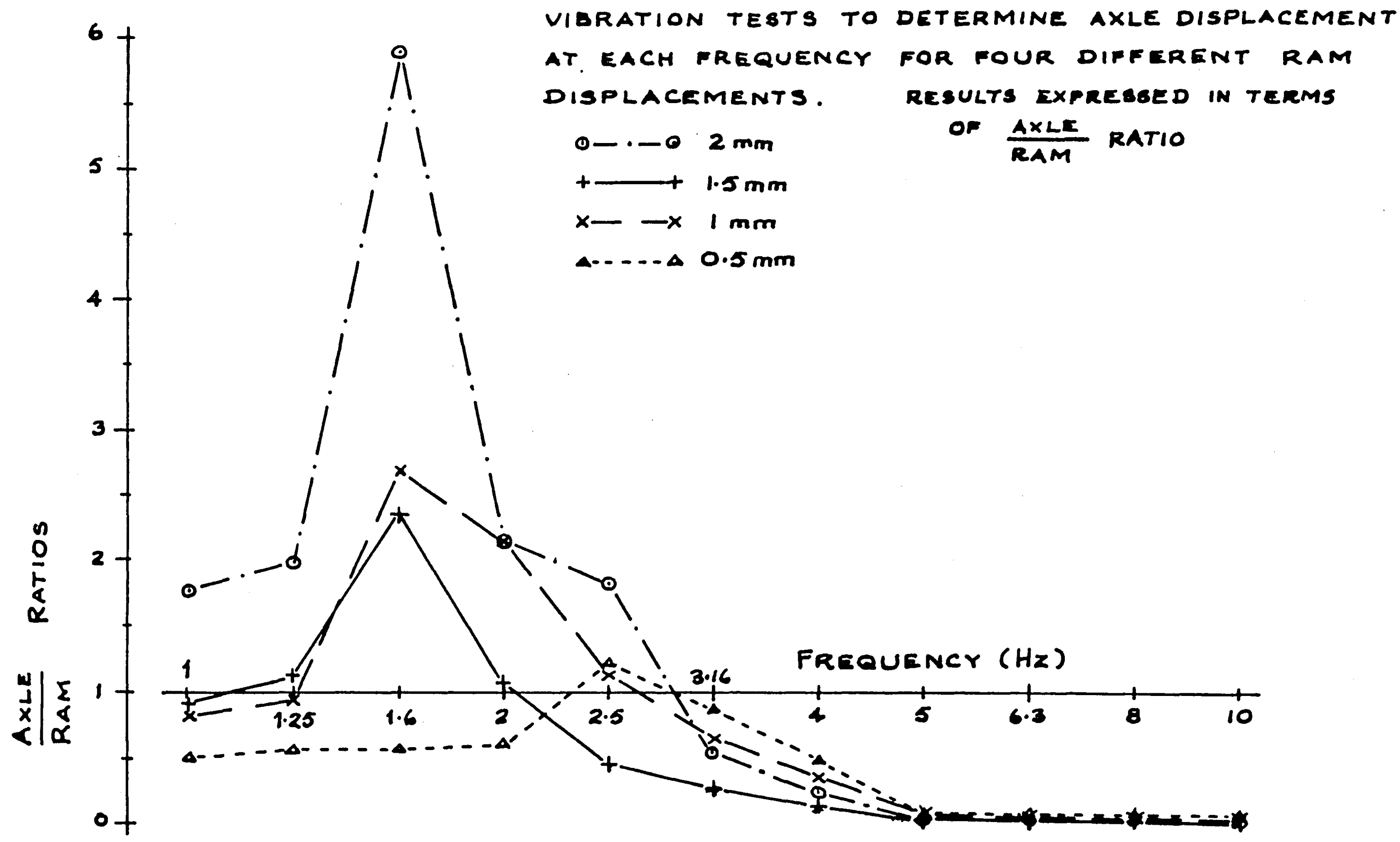


Figure 48
(Ref: Tables 6,7,8,9)

vibration and provides information concerning the nature of the signals between ram and axle.

It is apparent, for each ram displacement setting, that the actual travel of the ram increases with frequency rise. In each case this increase is some 50% greater at 10Hz than at 1Hz, yet in terms of the displacements used they are not large. Study of the displacement produced at the axle by the ram needs to take this increase into account, consequently the relationship is shown on the graph in ratio terms, ie Axle ÷ Ram, Figure 48. The results of the four tests are displayed in this Figure and they confirm the observations made during the tyre acceleration tests, paragraph 5.7.1. The attenuation at frequencies above 4Hz is high for all ram displacements and an amplification at the axle of vibration input to the tyre can be predicted at frequencies from 1.25Hz to 2.5Hz. In terms of displacement the response of the wheel is shown to be most active at 1.6Hz in three of the four tests. Also, comparison of the trend of each curve with that of axle displacement in Figure 44 confirms that force transmitted to the axle from the tyre will result in greatest disturbance at frequencies below 2.5Hz.

The phase differences between the displacements of ram and axle agree with those between ram force and axle displacement in Figures 43(a) (b) (c). This indicates that the amplification of the vibration at the axle has some other source or sources than that of phase difference. Observations of the axle and tyre during these tests support this and a more detailed investigation of the following conditions is necessary for clarification. The apparent absence of axle movement at 6.3Hz and above, previously reported and now shown to be minimal, had accompanying tyre effects. These were that the sidewalls of the tyre immediately below the ram had very little lateral movement, even at 5Hz and this decreased with increasing frequency. Also that tyre movement at these frequencies appeared to be concentrated in the band directly below the tread chevrons.

To summarise, as frequency increases above 5Hz the energy imparted by the ram concentrates in the tyre's tread band which becomes much more active. This activity appears to have a damping effect on the movement experienced by the axle with a consequent diminishing of displacement.

5.8 Drive wheel tests conclusions

Within the recommended range of inflation pressures the non-rolling tyre exhibits a constant static stiffness when under an applied load analagous to the load from an excavator/loader vehicle, Figure 38(a)(b). As a consequence, the varying acceleration levels in the tyre's frequency response to vibration, Figure 41(a), cannot be the effect of changes in static siffness. This is consistent with Hooker (1980) who also concluded that the frequency effect was independent of inflation pressure and could be considered to be a casing effect.

It has been shown in Figure 39, that when a static tyre is vibrated specific mode shapes are induced in it which are identifiable with narrow frequency bands centring on 3Hz, 11Hz and 19Hz. Since the pneumatic pressure did not have any effect on the tyre's static stiffness it is considered that these frequency mode shapes are further evidence of the casing effect. The resistance of the tyre to external excitation is demonstrated in Figure 41(b), where ram force rises to a maximum at 2.5Hz before decaying at each frequency down to 10Hz. The tyre's acceleration level generally mirrors this ram effect, therefore the geometry of the mode shape is concluded to be responsible for these frequency-related levels. The maximum frequency for these tests was restricted to 10Hz because of the irrelevance of higher frequencies in the comparisons with ISO2631:1978(E), and reference to Figures 31 to 33 will show that the decay in acceleration, at the axle, continues to about 25Hz.

The frequency response recorded for the axle, Figure 42, bears similar features to that for the tyre in Figure 41(a), particularly at 2.5Hz and above. The analysis of acceleration levels at the axle on the vehicle also shows the same frequency effect, therefore the tyre's characteristic response to vibration appears to be the source of low frequency problems transmitted to the chassis via the axle.

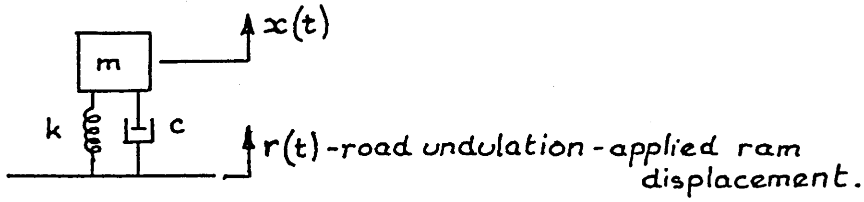
Excitation applied to the tread results in relatively high displacements of the axle at 1.6Hz, Figure 44. This displacement, combined with the correspondingly high acceleration levels in this frequency region, will have resulted in the test control difficulties reported in section 5.7.1. The reduction in axle displacement after 2Hz correlates with the drop in wheel activity and the minimal displacement at 6.3Hz and above with the stillness of the axle at the same frequencies. This emphasises the need to reduce the transmission of acceleration into the vehicle because the level continues to be high even though axle displacement falls.

The contribution of phase difference, between ram and axle movement, to the transmission of vibration is not proved here. However, further investigation into these relationships should be undertaken because the behaviour of the tyre casing below the chevrons indicates that an intermediate phase may exist to aid transmission of energy.

The tyre as a vibration isolator

1 Displacement transmissibility theory

The excavator-loader and its suspension, the tyre, can be approximated by a mass-spring-damper model:-



The displacement at the vehicle is $x(t) = kx + c\dot{x}$. Due to kx and $c\dot{x}$ being 90° out of phase the displacement magnitude $|x(t)| = \sqrt{k^2x^2 + c^2\dot{x}^2}$. The ratio of vehicle displacement to road undulation can be expressed in terms of transmissibility T;

i.e. $\frac{|x|}{|r|} = T\sin(\omega t - \psi)$, where ω = frequency

t = time

ψ = phase angle.

Consequently:

(i) $$T = \sqrt{\frac{1 + (2\zeta\omega/\omega_n)^2}{(1 - \omega^2/\omega_n{}^2)^2 + (2\zeta^2\omega/\omega_n)^2}}$$

and

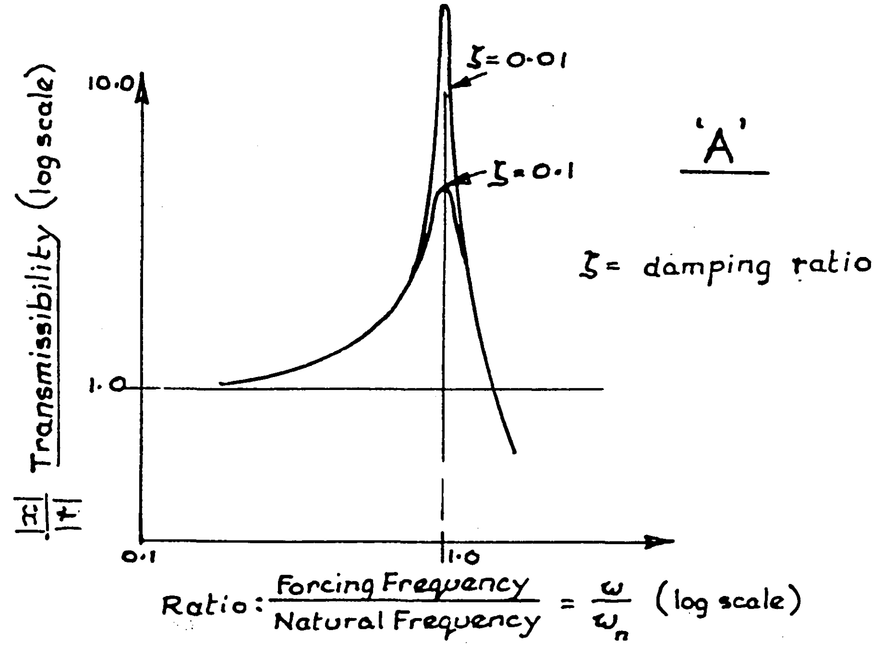
(ii) $$\psi = \tan^{-1}\frac{2\zeta(\omega/\omega_n)^3}{(1 - \omega^2/\omega_n{}^2)^2 + 4\zeta^2\omega^2/\omega_n{}^2}$$

The following graphs, 'A' and 'B', show transmissibility T and phase angle ψ as functions of the frequency ratio ω/ω_n for two values damping ratio, ζ, where ω_n = natural frequency.

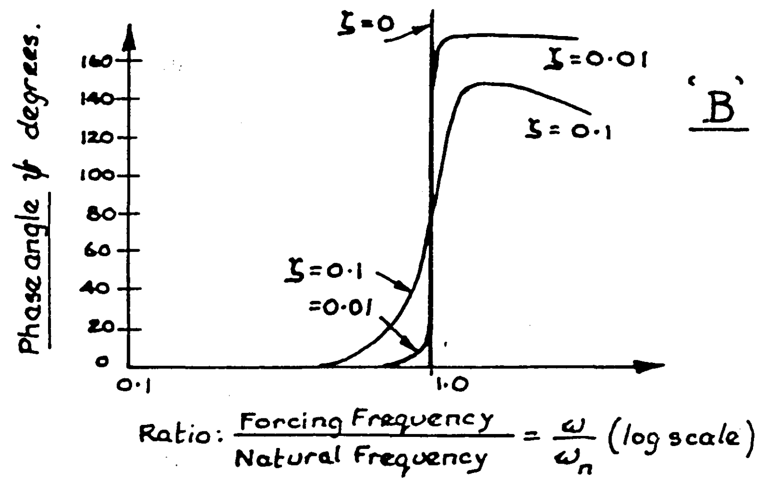
These graphs show that:-

(i) at resonance, i.e. $\omega/\omega_n = 1.0$, the transmissibility is limited only by the presence of damping C, and

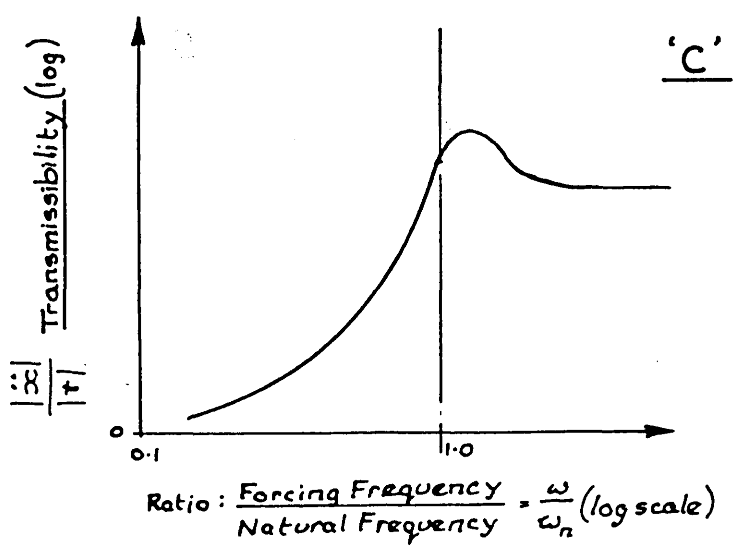
(ii) only where $\omega/\omega_n > \sqrt{2}$ does vibration isolation become effective. It is desirable to make $\omega/\omega_n >> \sqrt{2}$.



'A'
ζ = damping ratio
ζ=0·01
ζ=0·1
10·0
1·0
0·1
1·0
$\frac{|x|}{|+|}$ Transmissibility (log scale)
Ratio: Forcing Frequency / Natural Frequency = ω / ω_n (log scale)



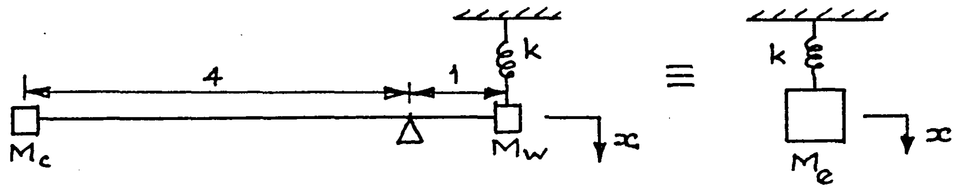
'B'
ζ=0
ζ=0·01
ζ=0·1
ζ=0·1
=0·01
160
140
120
100
80
60
40
20
0
0·1
1·0
Phase angle ψ degrees.
Ratio: Forcing Frequency / Natural Frequency = ω / ω_n (log scale)



'C'
0
0·1
1·0
$\frac{|\ddot{x}|}{|+|}$ Transmissibility (log)
Ratio: Forcing Frequency / Natural Frequency = ω / ω_n (log scale)

2 Natural frequency of the test rig

The test rig used to simulate the vehicle-tyre system can be represented by the following diagram:-



where M_c = concrete, 290 kg

M_w = wheel, 155 kg

M_e = equivalent mass = 4795 kg

For a dynamically equivalent system, kinetic energy must be equal to that of the actual system.

$$\therefore \frac{1}{2}M_e\dot{x}^2 = \frac{1}{2}M_w\dot{x}^2 + \frac{1}{2}M_c(4\dot{x})^2$$

$$\therefore M_e = M_w + 16M_c$$

$$= \underline{\underline{4795 \text{ kg}}}$$

Using the established tyre stiffness, k = 0.48 kN/mm, page 106, the natural frequency, $f_n = \frac{1}{2\pi}\sqrt{\frac{0.48 \times 10^6}{4795}} = \underline{1.6 \text{ Hz}}$

3 Relationship of model to test rig

The displacement of a mass is directly related to the force received therefore Figures 43, 46, 47 and 48 can be referred to for confirmation that the test system's natural frequency is at about 1.6 Hz. Figure 48 in particular shows how the response of the axle follows the classic transmissibility curve in 'A'. The existence of the natural frequency at about 1.6 Hz is also confirmed in Figures 43(a), 46(a), 47(a) where the two curves are 90° out of phase at this frequency. Graph 'C' illustrates transmissibility by reference to the acceleration of a mass and, by relating $\left|\frac{\dot{x}}{r}\right|$ to ω/ω_n shows that the maximum value occurs at a higher frequency than ω_n. In Figure 42 the axle's acceleration is a maximum at 2.5 Hz and then decays to a more constant value after 4 Hz. This again follows the classic case and confirms the natural frequency at about 1.6 Hz.

It is noticeable in Figure 48 that the maximum value for the 0.5 mm displacement occurs at 2.5 Hz. This indicates that the tyre does not respond linearly at small displacements; that the peak values will occur at higher frequencies and consequently the mass-spring-damper model is not relevant in this case.

4 Conclusions

(i) The test rig for the wheel was a true simulation of the excavator-loader system.

(ii) At the large displacements to which the vehicle will be subjected the natural frequency will be about 1.6 Hz.

(iii) The tyre acts as a simple spring in transmitting energy from the road to the chassis.

CHAPTER 6

Questionnaire to drivers of earthmoving vehicles

6.0 Introduction

Ride discomfort is a subjective sensation, consequently the results from the objective measurements needed to be supplemented by ride-assessments from the drivers of such vehicles. Humans often tolerate large variations in environmental conditions at their work place before complaining of discomfort. Also, long-term familiarity with work situations often results in particular environmental conditions being identified with the work procedures. This relationship of task to environment can become accepted as normal consequently conscious monitoring of the environment may not take place. Drivers of earthmoving vehicles expect to experience vibrations when working, therefore an assessment of their discomfort awareness, via a questionnaire, had to be related to the more intense or longer-lasting physical effects.

6.1 Procedure

To obtain the co-operation of the drivers and their employers it was necessary to avoid lengthy interruptions of the work tasks. A questionnaire was prepared and the study area condensed into eight questions structured around considerations such as:-

(i) if discomfort was experienced would it be in the parts of the body identified with low frequency vibration?

(ii) would the effects of any vibration on the body persist after work ceased?

(iii) would the driver's sensitivity to vibration be heightened or suppressed by the overall period of such driver experience?

With the exception of the drivers at JCB Research Ltd, where postal arrangements were made, the driver's surveyed were selected at random from the many sites around Sheffield. The drivers were interviewed and their answers and other relevant observations noted on the questionnaire sheets, See Appendix 'K'.

6.2 Discussion of results

Assistance with answers to this questionnaire was obtained from fifteen of the twenty drivers or employers approached. It is acknowledged that for statistical purposes the sample number is small. However, the information provided does strongly support the conclusions here and from other sources, about discomfort risk from low frequency vibration.

TABLE 10 (reference Appendix K)

Summary of the replies to the questionnaire from drivers of JCB3C Excavator-Loaders.

(Note: the number of replies relating to a question is shown in inverted commas, eg '2'.)

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total:

Years	3½	6	6½	8½	10	12	15	16	18
Drivers	'2'	'1'	'2'	'2'	'1'	'4'	'1'	'1'	'1'

(b) in your present employment; "Answers widely varying"

Ques 2 On average, how many days each week do you drive such a vehicle?

5 days per week = '14'

3 " " " = '1'

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement?

Yes = '15' No = 'NIL'

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
'1'	'13'	'11'	'3'	'8'	'10'	'2'	'2'

Ques 5 Is this disturbance still noticeable after you have finished work?

Yes = '12' No = '3'

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

Minutes	10	15	20	30	varies
Answers	'2'	'5'	'1'	'2'	'1'

Ques 7 Please state the approximate age of the vehicle which you drive most often.

Years (approx)	2	3	4	5
Answers	'2'	'6'	'3'	'4'

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

"Please see individual questionaire sheets for responses"

Table 10 summarizes these answers.

All the drivers agreed that some degree of discomfort was experienced when these vehicles are being driven on construction sites, ref Question 3. It was not possible to relate the severity of discomfort to the period of driving experience, ref Question 1, however, 80% of the drivers were conscious of the discomfort for at least ten minutes after stopping work, ref Questions 5 and 6. This confirms that vibration discomfort was a physiological and not a psychological effect. Further support for this was provided by the answers to Question 4 where all drivers identified vibration discomfort with some part or parts of their body. Analysis of these answers showed strong correlation with Dieckmann's results, Figure 13, that low frequency vibration is transmitted to the upper body and neck without attenuation.

It is concluded that low frequency vibration discomfort, from these vehicles, is confirmed by this survey and by the correlation with the other studies as given below:-

(i) ISO2631:1978(E) - that frequencies up to 4Hz in the 'Z' axis provided the greatest risk of vibration discomfort.

(ii) Excavator-loader vibrations, D Douglas - that discomfort inducing acceleration levels are generated at frequencies up to 4Hz.

(iii) Dieckmann - that low frequency vibration in the body transmits readily to the neck and head region.

(iv) Driver discomfort survey, D Douglas - that the upper body and neck will experience most discomfort when these vehicles are driven over rough terrain.

CHAPTER 7

7 SUMMARY

7.1 Introduction

Human comfort is a subjective condition which is dependent upon one or more environmental factors influencing the person concerned at that particular time. The mental and/or physical health of the person can also influence their assessment of comfort, consequently the specification of environmental factors can only provide guidelines towards conditions acceptable to a majority of people. International Standard IS02631:1978(E) provides the guidelines to which this study relates and uses frequency-related acceleration levels to indicate discomfort and disability risk. The results of this work show that the drivers of pneumatic tyred earth moving vehicles are exposed to these risks from vibrations produced as a consequence of the vehicle's construction and the nature of the terrain over which they travel.

7.2 Discussion

It has been demonstrated that these vehicles respond to vibration in a characteristic manner in each of the three axes. The frequency response and acceleration levels associated with the vertical, 'Z', axis identify this as the critical direction with respect to driver discomfort. The problem frequencies are those below 10Hz, however this conclusion is dependent upon the period of time associated with the risk. A normal working day is usually divided into two four-hour periods separated by a meal break, hence the four-hour limit in the Standard has been adopted in this study. When the acceleration levels from the seat's frequency analysis are compared to this limit it is shown that serious infringements occur, particularly in the frequencies below 5Hz.

The fact that these infringements result from travel over particular concrete surfaces does not detract from their significance. Construction site terrain is noted for its changeable nature which makes identity measurements impractical. However the influence which such surfaces can have on the vibration induced in vehicles can be predicted from experience and it was from such experience that the four test surfaces were considered to produce results analogous to those from typical construction sites. The vehicle acts as a low frequency filter to any form of vibration input, therefore the frequency response is characteristic of the axis concerned whilst the acceleration amplitude will be conditioned by the amplitude of the surface irregularities.

New vehicles are shown to be associated with driver discomfort when used over very rough terrain, but it is the older vehicles which produce discomfort, or even fatigue, over most surfaces. This situation highlights the necessity for regular and efficient maintenance of the vehicles if driver discomfort is to be prevented or at least kept to a minimum.

Acceleration levels apertaining to the driver's seat were the values for application to ISO2631:1978(E) but the similarity of the frequency response to that at cab and axle indicated that these values were generated elsewhere. To identify this source cognisance was taken of the vehicle's construction and the apparent requirement that the tyres should provide suspension as well as traction. Tests on the tyre demonstrated that when vibrated, it responded by adopting different mode shapes identifiable with certain narrow frequency bands. These mode shapes are shown to be related to the acceleration because the changes occur in mode shape and acceleration as the frequency rises.

In terms of the spectral densities the frequency response at the tyre is comparable to that at the axle, consequently the energy is transmitted from the axle to the cab and seat resulting in the identified risk of driver discomfort. Large displacements of the axle at 1.6Hz to 2Hz were measured and observed and, although displacements do not appear in the Standard, they are physically experienced in the cab. This is confirmed by the drivers' reference to the 'rear end bounce' ie high displacement amplitude at low frequency, in the survey, Appendix J . The survey answers also confirm the existence of unacceptably high acceleration levels at the seat. When questioned about any physical effects from operating the vehicle the drivers complained of discomfort in the neck, shoulders and upper arms. These statements agree also with the conclusions of Dieckmann, illustrated in Figure 13, Chapter 2.

7.3 Conclusions

General conclusions have been outlined at the end of each chapter and the main findings of this investigation are summarised as follows:

(i) Drivers of earthmoving vehicles suffer high levels of vibration discomfort varying from around 0.6 $m.s^{-2}$ to 6 $m.s^{-2}$, as defined by International Standard 2631:1978, when traversing irregular terrain.

(ii) The disturbance due to vibration is predominantly low frequency, <10 Hz, and this vibration is shown to emanate from the large diameter drive wheels.

(iii) The vehicles tested had resilient seats and cab mounts to isolate the driver from the induced vibration and the results show that these are clearly ineffective for this purpose. Some preliminary work on this has been described in Hilyard, Collier, McNulty and Douglas (1983).

(iv) The investigation suggests that to attenuate the energy prior to its entering the chassis is a possible solution.

Recommendations

It has been stated in (ii) above that the tyre is the dominant source of disturbance therefore future investigations should concentrate attention on the interface between the chevron tread band and the tyre main structure.

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APPENDICES

HUMAN RESPONSE TO VIBRATION FROM EARTHMOVING MACHINES

by

DENNIS DOUGLAS BA, Cert Ed, MCIOB, MIOA.

A thesis submitted to the Council for National Academic Awards in partial fulfilment of the requirements for the degree of MASTER of Philosophy.

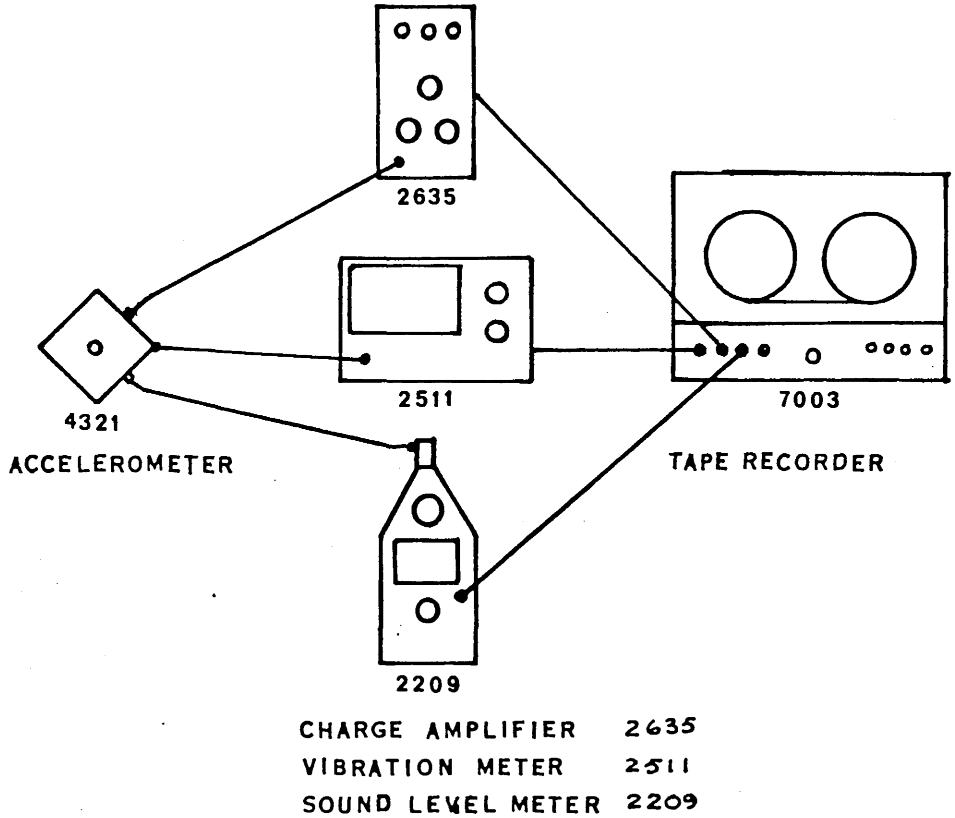
Sponsoring Establishment : Department of Building
Sheffield City Polytechnic

Collaborating Establishment : JCB RESEARCH LTD

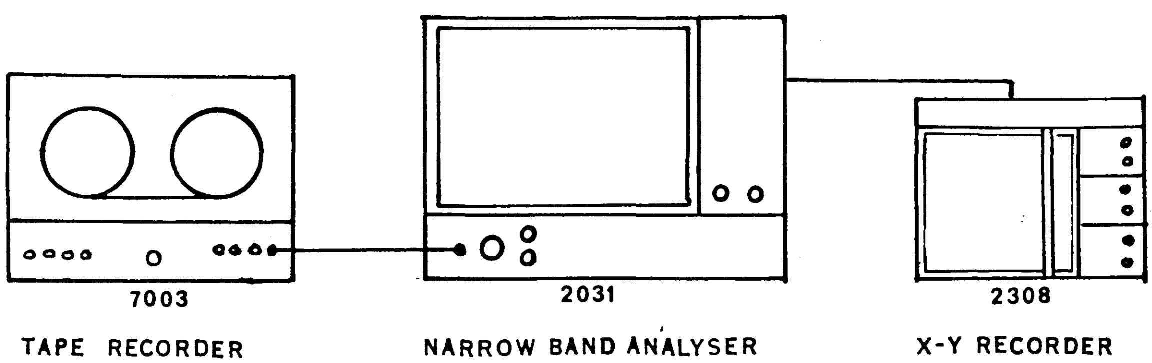
TABLE OF CONTENTS

A P P E N D I X 'A'

General details and arrangements of instruments used in the study.



SITE MEASUREMENT & RECORDING ARRANGEMENT (a)



LABORATORY ANALYSIS (b)

Figure A1

APPENDIX A

Instrumentation for Signal Measurement and Analysis

The arrangements for both measurement and analysis of the signals are shown in the block diagrams in Figure A1(a) and (b) and the instrumentation consisted of:-

(i) accelerometer, type 4321

(ii) vibration meter, type 2511

(iii) charge amplifier, type 2635

(iv) sound level meter, type 2209

(v) tape recorder, type 7003

(vi) narrow band spectrum analyser, type 2031

(vii) X-Y recorder, type 2308

all manufactured by Brüel & Kjær, Denmark.

General considerations regarding measurement instrumentation and technique

In vibration studies the three quantities of interest are:-

(i) vibratory displacement,

(ii) vibratory velocity, and

(iii) vibratory acceleration.

The relationship between them is simply explained as follows:-

Considering the oscillating motion of a body about a reference position then:-

(i) the 'instantaneous displacement' can be described mathematically by

$$x = X_{peak} \sin (2\pi \frac{t}{T})$$

$$= X_{peak} \sin (2\pi ft)$$

$$= X_{peak} \sin (wt)$$

where: X_{peak} = maximum displacement from reference position

w = $2\pi f$ or angular frequency

t = time

(ii) the velocity, 'v' of the moving body is the time rate of change of its displacement, therefore:

$$v = \frac{dx}{dt} \text{ which } = w X_{peak} \cos(wt)$$

$$= V_{peak} \cos(wt$$

$$= V_{peak} \sin (wt + \pi) \text{ and}$$

(iii) the 'acceleration', 'a', is the time rate of change of the velocity, therefore:

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2} = -w^2 X_{peak}\sin(wt)$$

$$= -A_{peak}\sin(wt)$$

$$= A_{peak}\sin(wt + \pi)$$

The relationships between the above parameters are designed into the measuring instruments used and 'acceleration' values are obtained, through 'velocity' values, from displacements by an integration procedure.

Accelerometer type 4321

1 General points

An accelerometer is an electromechanical transducer which produces either a voltage or a charge at its output terminals which is proportional to the acceleration to which it is subjected. Of the two types in common use the 'shear' configuration gives better results and is preferred to the 'compression' type.

The selection of an accelerometer obviously requires consideration of the parameters of the vibrating system to be measured, the associated environmental conditions and the particular characteristics of the accelerometer.

2 Specific points

At the start of the study it was not known in which of the three axes; 'X'; 'Y' or 'Z'; vibrations would produce the greatest problems. The type 4321 allows vibration measurements to be made in these three mutually perpendicular directions, therefore the results obtained are directly comparable for each road or track profile used.

Accelerometers and Preamplifiers

Accelerometer, type 4321, used in this study, is particularly manufactured to indicate the vibration in three mutually perpendicular directions. This makes the device ideal for these tests for the results can be readily identified with the directions of the co-ordinate system previously mentioned in ISO2631-1978(E), ie 'X', 'Y' and 'Z'. Other characteristics of this accelerometer which also illustrate it's suitability are with respect to the following:-

(i) weight

Recommended, "the weight should be at least ten times less than the effective weight of the test specimen"

Actual weight = 55 grammes

Test specimen weight ~ 6 tonnes

(ii) Linear frequency range:

Recommended, "to be within the linear frequency range of the accelerometer".

Actual linear frequency range = 1 - 8.7kHz

Test frequency range = 1 - 80Hz

(iii) maximum vibration level:

Recommended, "not to exceed one third of the maximum shock rating of the accelerometer"

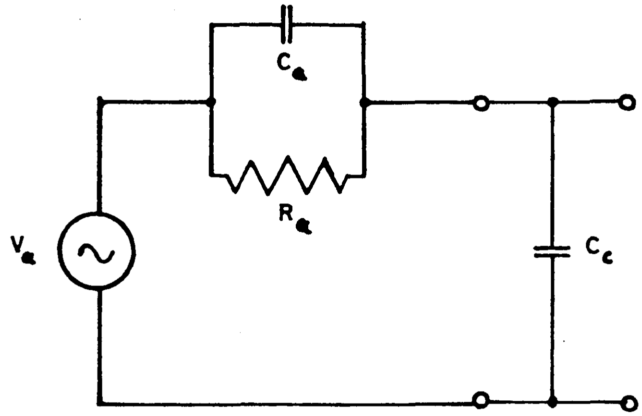
Actual maximum shock rating = $100km.s^{-2}$

Test maximum expected with respect to ISO2631-1978(E) exposure limits = $10m.s^{-2}$

(iv) operating temperature range:

Actual maximum temperature for accelerometer = 250C

Test ambient temperature 10C to 20C.



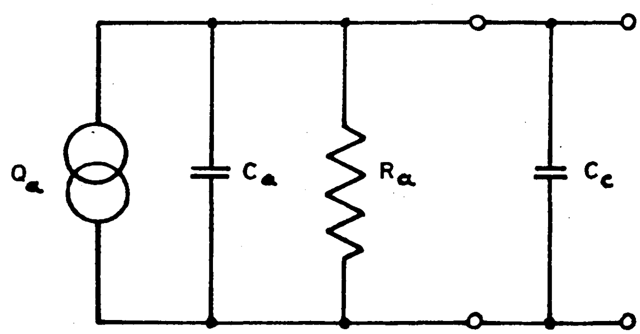
Voltage Equivalent

Note dependence of voltage output on cable capacitance ;

ie $V_a = Q_a/(C_a + C_c)$

Charge output does not depend on cable capacitance

(a)



Charge Equivalent

(b)

EQUIVALENT PIEZOELECTRIC ACCELEROMETER CIRCUITS WITH CONNECTING CABLE

Figure A2

An accelerometer's sensitivity to vibration may be defined as the ratio of its electrical output to the mechanical input and in terms of voltage or charge

ie voltage (mV) per unit of acceleration : $\frac{mV}{m.s^{-2}}$

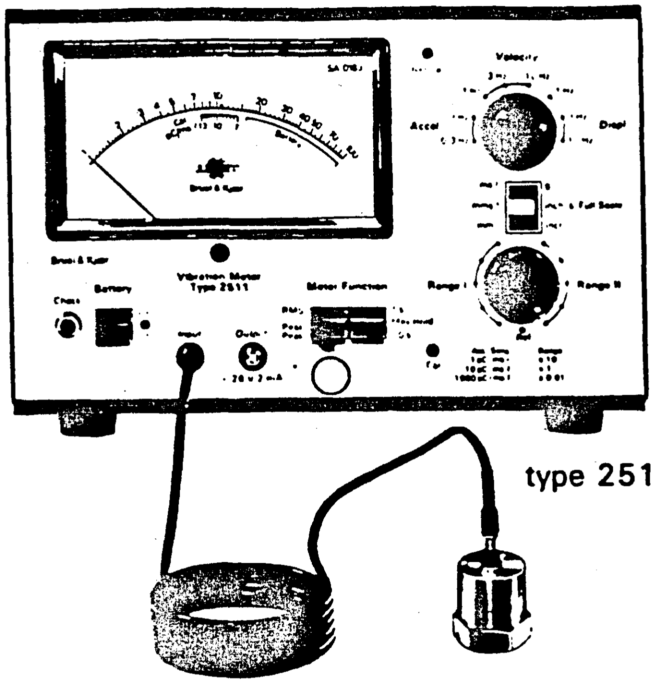
or charge (pC) per unit of acceleration : $\frac{pC}{m.s^{-2}}$

In deciding which units to adopt the influence of the connecting cables had to be considered because extra long cables from the excavator-loader to the instruments in the accompanying car were neccessary. It can be seen from Figure A2(a) and (b) that the <u>voltage</u> output is dependent upon cable capacitance but the <u>charge</u> output is not,therefore charge output was selected.

<u>Preamplifiers</u>: Vibration Meter, type 2511, Figure A3
Charge Amplifier, type 2635, Figure A4

The need to measure the vehicle's acceleration levels in three separate axes simultaneously caused an initial problem from lack of suitable instruments to accept the three connecting cables. A solution was found by using the above instruments and ensuring that they were calibrated on the same source and that their output signals correlated with each other.

General Purpose Vibration Meter



type 2511

Figure A3

Conditioning Amplifier
(Battery Operated)

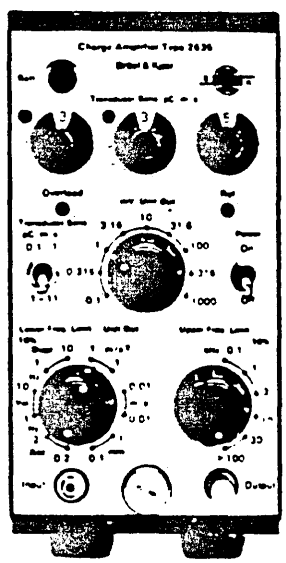


Figure A4

Vibration Meter, type 2511, Figure A3

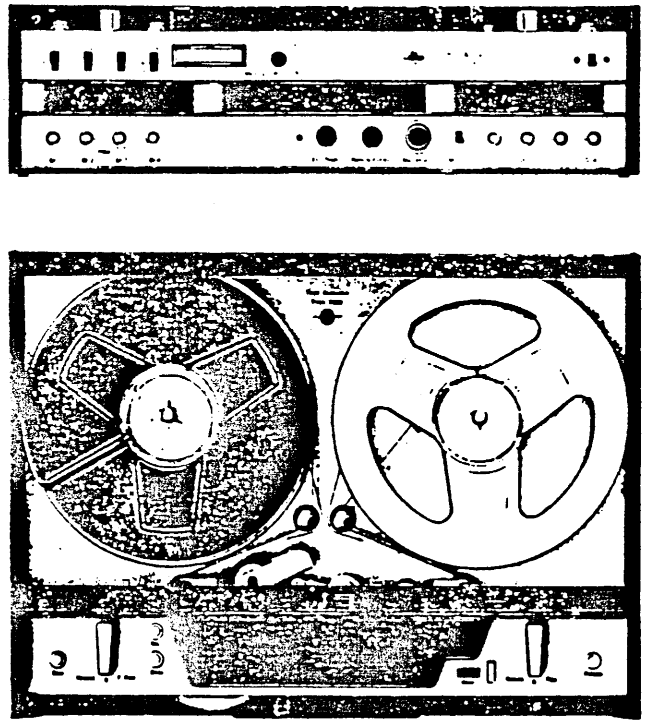
This instrument was used as the reference for the other two because of its particular design for this type of measurement. It has a frequency range from 0.3Hz to 15KHz, is fully portable and permits the use of long accelerometer cables without its sensitity being influenced by cable capacitance. Initial studies suggested that vibrations in the vertical, 'Z' axis, direction were likely to be most important, therefore the cable from this output on the accelerometer was connected to the type 2511.

Charge Amplifier, type 2635, Figure A4

This is another portable amplifier which allows the exact charge sensitivity of the accelerometer to be 'dialed-in'. It's lower frequency limit of 0.2Hz and upper frequency limits, selectable from six steps to 100kHz proved valuable for the vibration recording in the frequency range 1 to 80Hz.

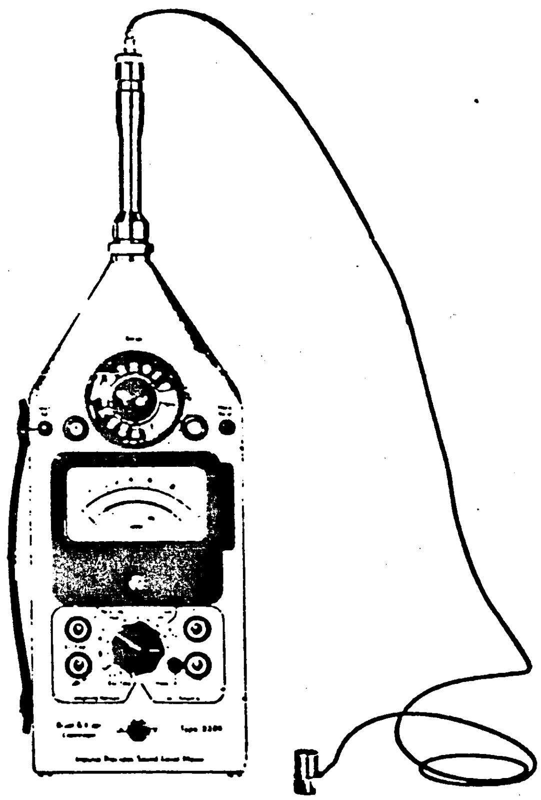
Precision Sound Level Meter, type 2209, Figure A5

Another portable meter fully adaptable for measuring vibrations by fitting an Integrator, type ZR0020, in place of the microphone and changing the attenuator scale. A disadvantage in having to use this meter for vibration measurements is that its lower frequency limit is 2Hz. However, the frequencies which can cause the greatest discomfort are generated in the vertical, 'Z' axis, direction, therefore this meter was used to measure accelerations from the front to rear mode, ie 'X' axis.



type 7003

Figure A 6



Sound Level Meter

Figure A 5

Tape Recorder, type 7003, Figure A6

Measuring vibrations in a vehicle whilst it was moving presented difficulties but analysing such signals was not possible. The output from each preamplifier was fed into a separate channel on the tape recorder and stored for later analysis in the laboratory.

The advantages from this precision recorder are:

(i) its design, particularly for vibration measurements

(ii) F.M. recording technique from D.C. to 10kHz

(iii) 1.5 ips recording speed with frequency range 0 to 1kHz

(iv) four channel recording and reproduction facility

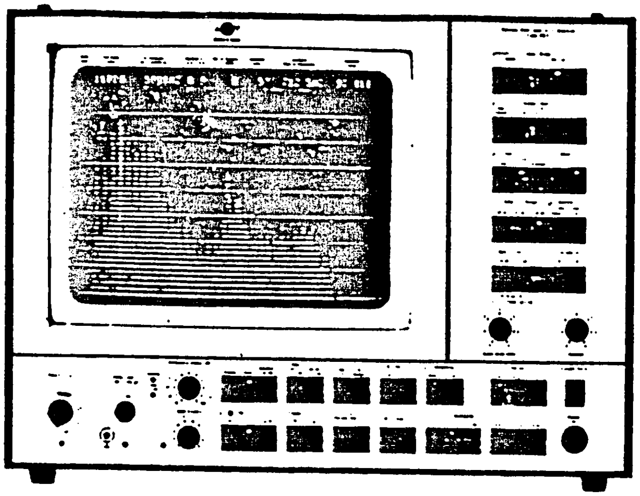
Narrow Band Spectrum Analyser, type 2031, Figure A7

Analysis of the signals required a facility to concentrate on the frequency range 1 to 80Hz which was a very small section of the possible signal received. This analyser allowed the range 0 to 100Hz to be displayed in increments of 0.25Hz constant bandwidth.

The acceleration information required, over the desired frequency range, needed to be respresentative of the surface profile concerned. A means of averaging the signal was required and the Linear Averaging function of the instrument proved ideal.

Linear averaging uses a converging algorithm which means that a correct spectrum is always displayed on the screen whether the averaging is complete or not. The advantage of this is that the maximum amount of information can be obtained from a limited amount

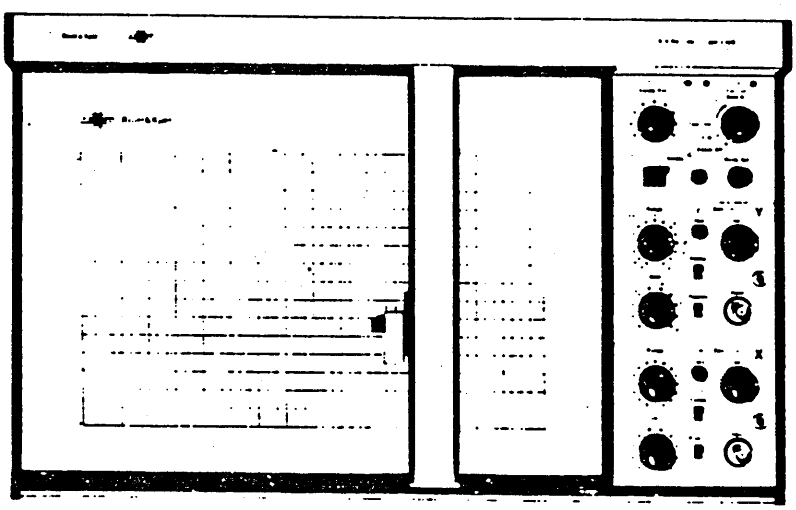
Narrow Band Spectrum Analyzer



type 2031

Figure A7

X-Y Recorder



type 2308

Figure A8

of data. Where the full scale frequency is set at 100Hz a 4 seconds record length is required for analysis of each sample. In situations like this study, where the number of spectra required to be averaged to achieve confidence is not known, Linear Averaging is valuable for the result displayed will always be a true average.

X - Y Recorder, type 2308, Figure A8

The project has resulted in one hundred separate signals to be studied, consequently the need for quick reproduction of the analysis displayed on the narrow band spectrum analyser was necessary. This recorder is designed for use with the N.B.S.A. and provides an accurate hard copy for later study.

APPENDIX 'B'

Landrover test results : graphical presentation of spectral densitities on 'X', 'Y' and 'Z' axes at axle, cab and seat over different road surfaces.

Brüel & Kjær

Time Function Start: sec E. seconds Not Expanded: ☐ Expand

Full Scale Level: As Below.

F. S. Frequency: 100 Hz

Weighting: Hanning.

Average Mode: Lin.

No. of Spectra: 35.

Comments:

Smooth Road
(Eccleshall Rd. S.)

'X' axis vibrations.

: Seat (Red) FSL 100dB.
SLM = 10 m/s² FSD.

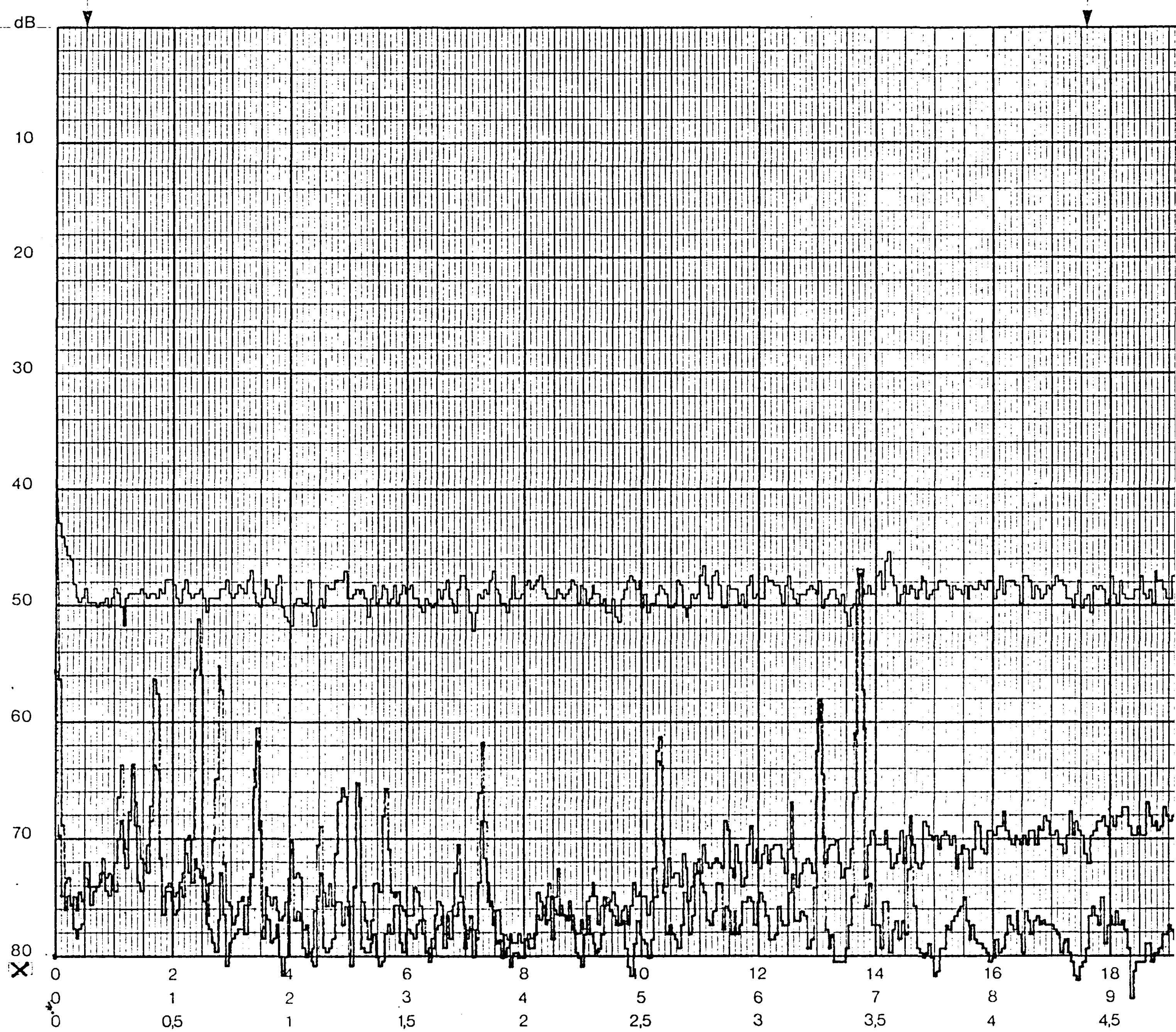
: Chassis (Green) FSL 130dB
SLM = 10 m/s² FSD.

: Axle (Black) FSL 110dB.
SLM = 10 m/s² FSD.

Record No.: LR/s/X

Date: Feb. 1982.

Sign.: [signature]



Measuring Object:

QP 1002 'LANDROVER'

Brüel & Kjær

Time Function Start: sec E. seconds Not Expanded: ☐ Expand

Full Scale Level: As Below.
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 35

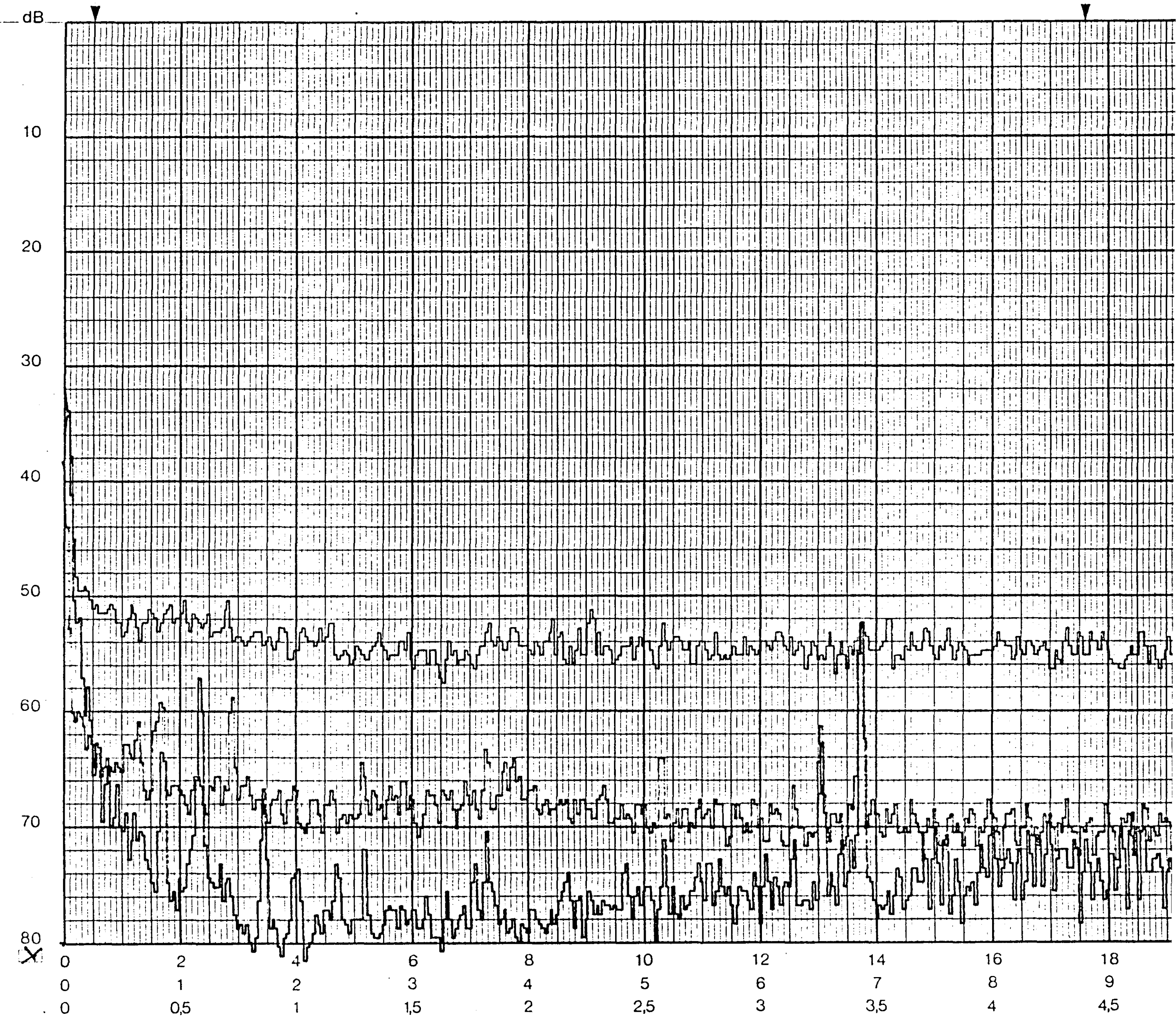
Comments:
Cobbled Road.

'X' axis vibrations.

: Seat (Red) FSL 110dB.
SLM = 10m/s² FSD.

: Chassis (Green) FSL 130dB
SLM = 10m/s² FSD.

: Axle (Black) FSL 110dB.
SLM = 10m/s² FSD.



Record No.: LR/C/X
Date: Feb 1982.
Sign.:

Measuring Object:

QP 1002 'LANDROVER'

Brüel & Kjær

Full Scale Level: As Below.

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 35

Comments:

Rough Track

(Ringinglow)

X axis vibrations.

: Seat (Red) FSL 100dB.

SLM = 30 m/s^2 FSD.

: Chassis (Green) FSL 120dB.

SLM = 10 m/s^2 FSD.

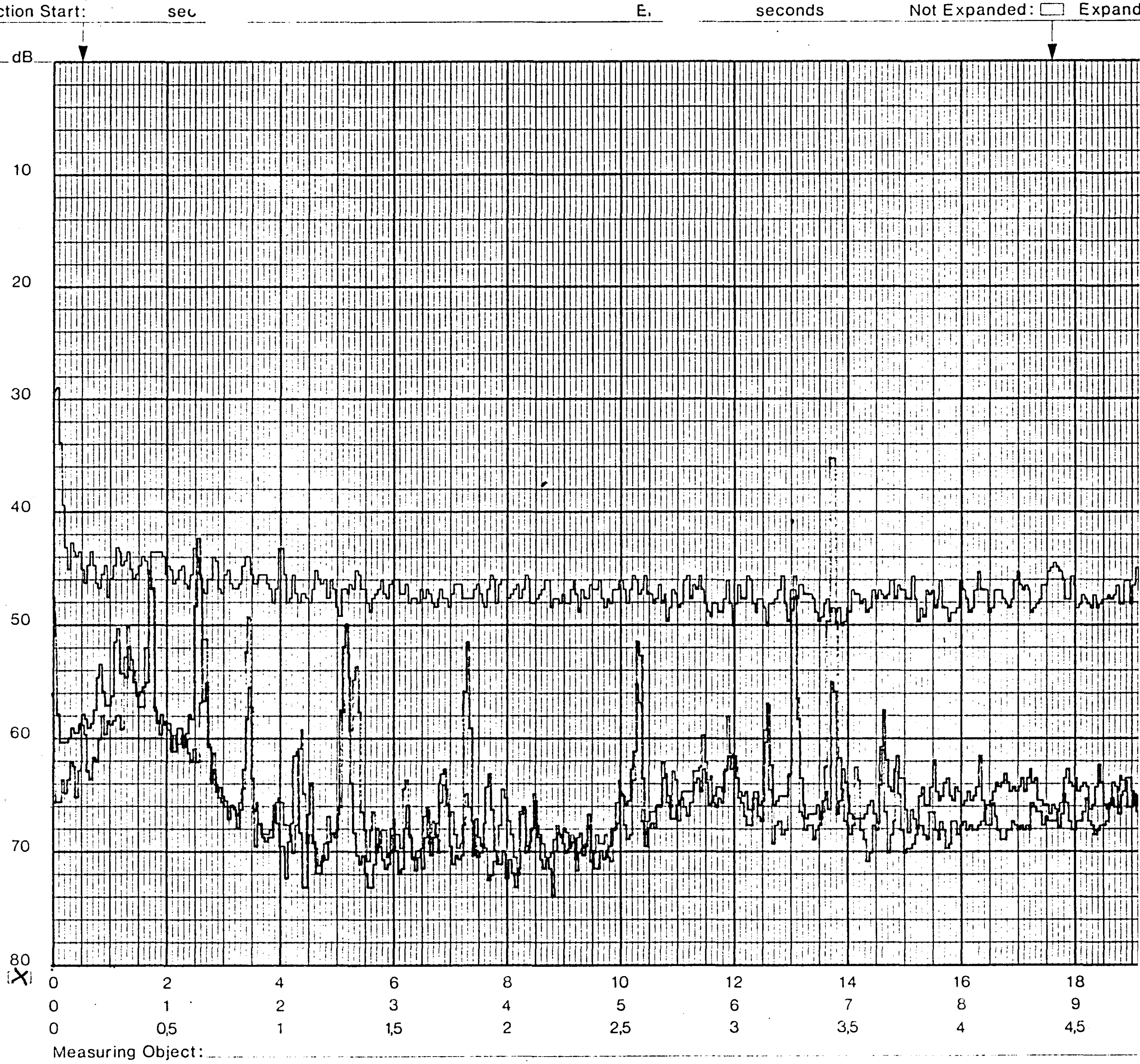
: Axle (Black) FSL 100dB.

SLM = 30 m/s^2 FSD.

Record No.: LR/R/X

Date: Feb 1982

Sign.:



QP 1002 'LANDROVER'

Brüel & Kjær

Time Function Start: sec. E. seconds Not Expanded: ☐ Expand

Full Scale Level: As Below.
F. S. Frequency: 100dB.
Weighting: Hanning.
Average Mode: Lin.
No. of Spectra: 35

Comments:
Smooth Road
(Ecceshall Rd S)

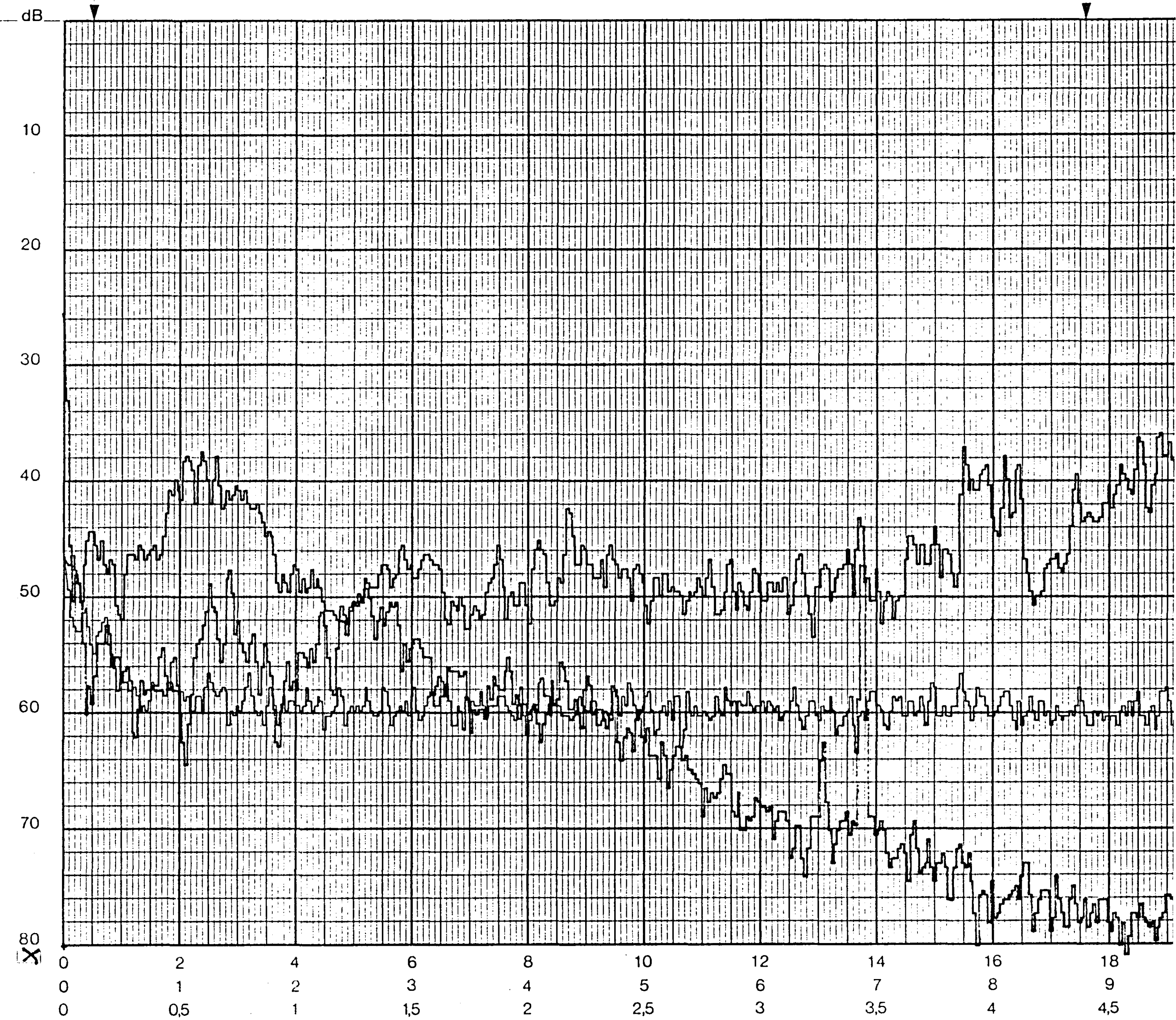
'Y' axis vibrations.

: Seat (Red) FSL 110dB.

: Chassis (Green) FSL 130dB

: Axle (Black) FSL 110dB.

Charge Amp. = 10m/s^2 FSD



Record No.: LR/S/Y
Date: Feb. 1982
Sign.:

Measuring Object:

QP 1002 'LANDROVER'

Brüel & Kjær

Time Function Start: sec End seconds Not Expanded: ☐ Expanded

Full Scale Level: As Below. dB
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 35

Comments:
Cobbled Road.

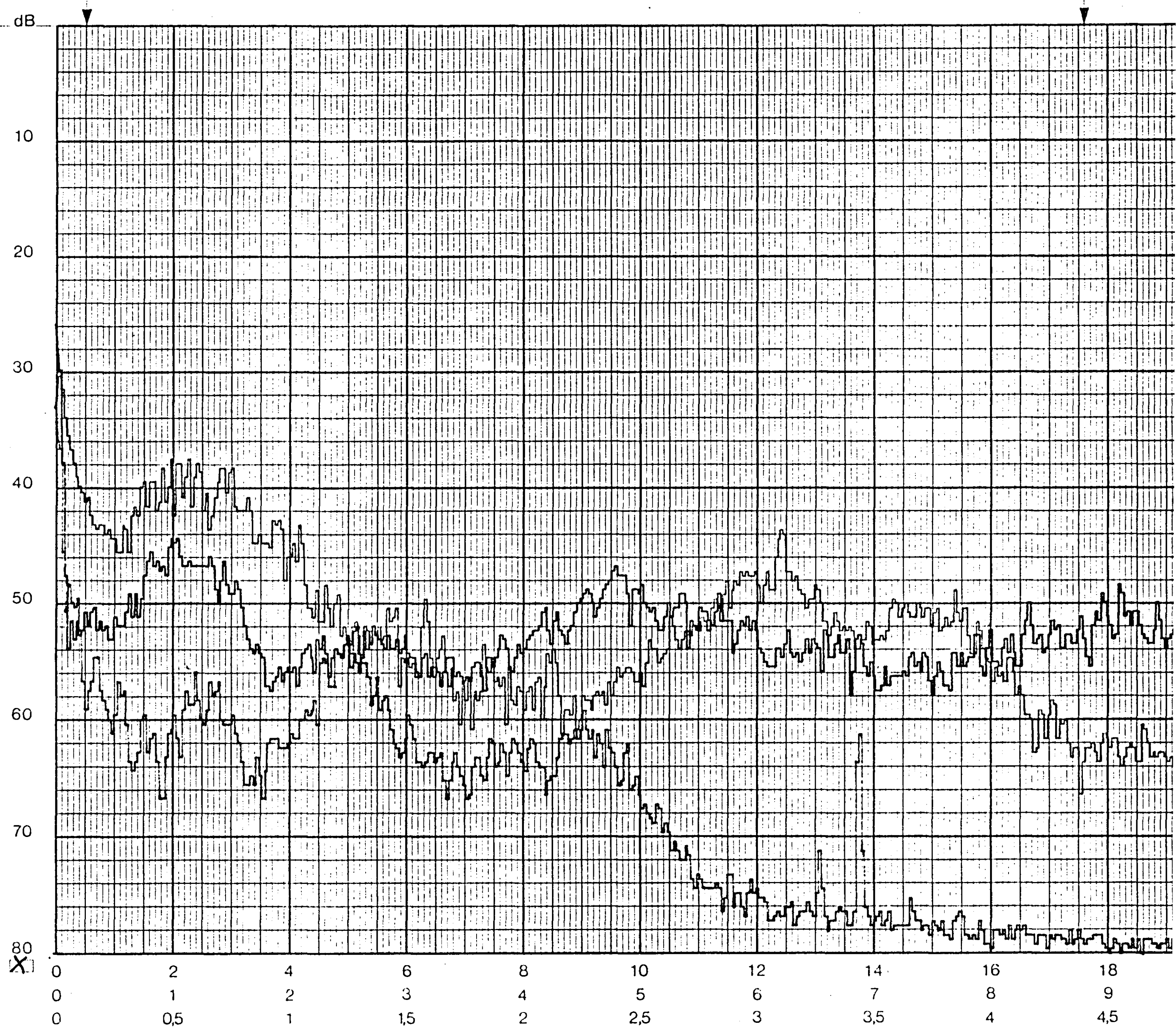
'Y' axis vibrations.

: Seat (Red) FSL 120 dB.

: Chassis (Green) FSL 130 dB.

: Axle (Black) FSL 120 dB.

Charge Amp. = 10 m/s² FSD



Record No.: LR/C/Y
Date: Feb 1982
Sign.:

Measuring Object:

QP 1002 LANDROVER

Brüel & Kjær

Time Function Start: sec seconds Not Expanded: ☐ Expand

Full Scale Level: As Below.

F. S. Frequency: 100 Hz.

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 35

Comments:

Rough Track
(Ringinglow)

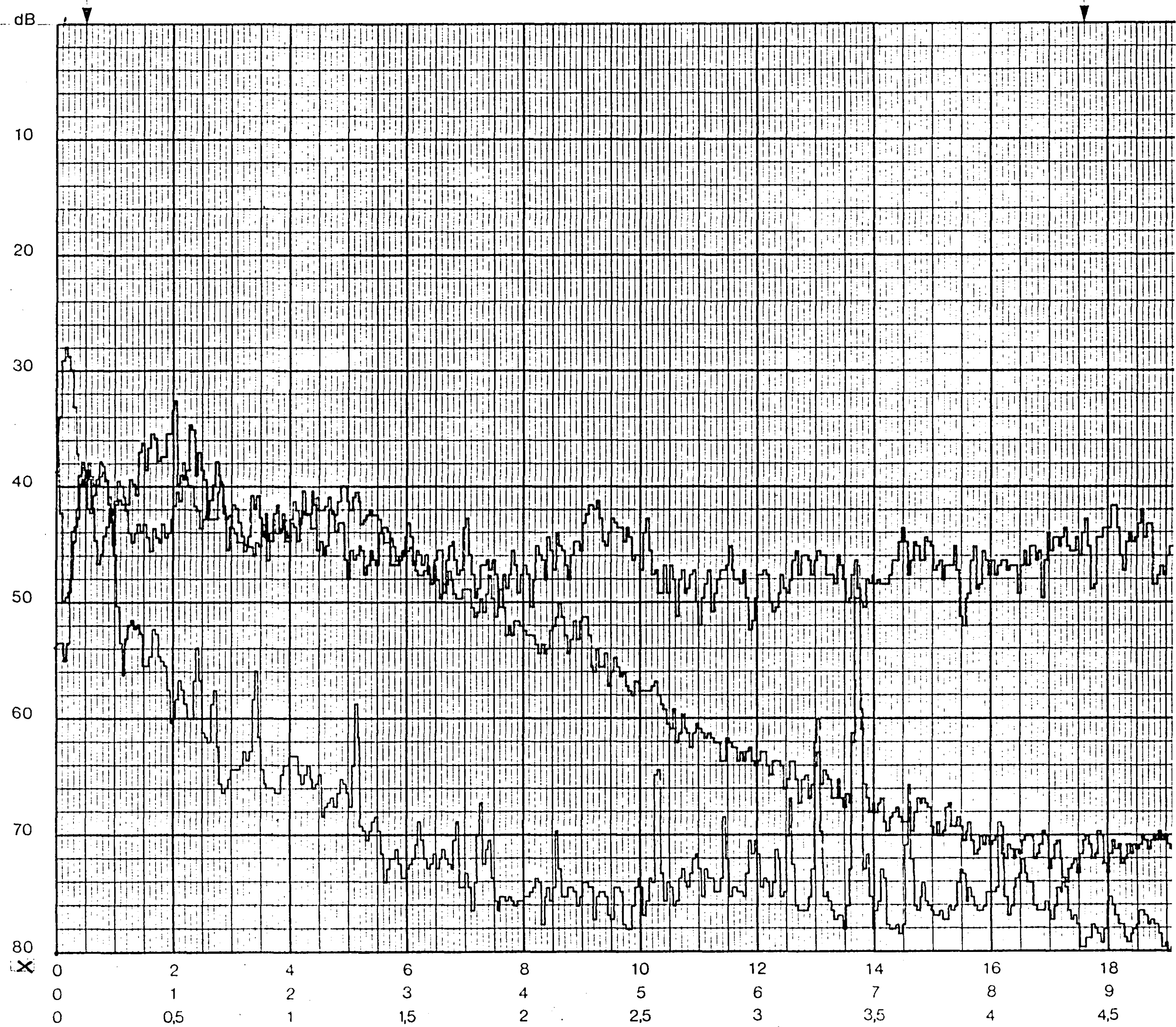
Y axis vibrations

: Seat (Red) FSL 110 dB.

: Chassis (Green) FSL 110 dB.

: Axle (Black) FSL 110 dB.

Charge Amp. = 10 m/s² F.S.D.



Record No.: LR/R/Y

Date: Feb. 1982

Sign.:

20 ☐ 40 ☐ 80 ☒

Measuring Object:

QP 1002 LANDROVER

Brüel & Kjær

Time Function Start: sec. t. seconds Not Expanded: [ ] Expanded

Full Scale Level: As Below. dB

F. S. Frequency: 100 Hz.

Weighting: Hanning.

Average Mode: Lin.

No. of Spectra: 35.

Comments:

Smooth Road.

(Eccleshall Rd. S)

'Z' axis vibrations.

: Seat (Red) FSL 110dB.

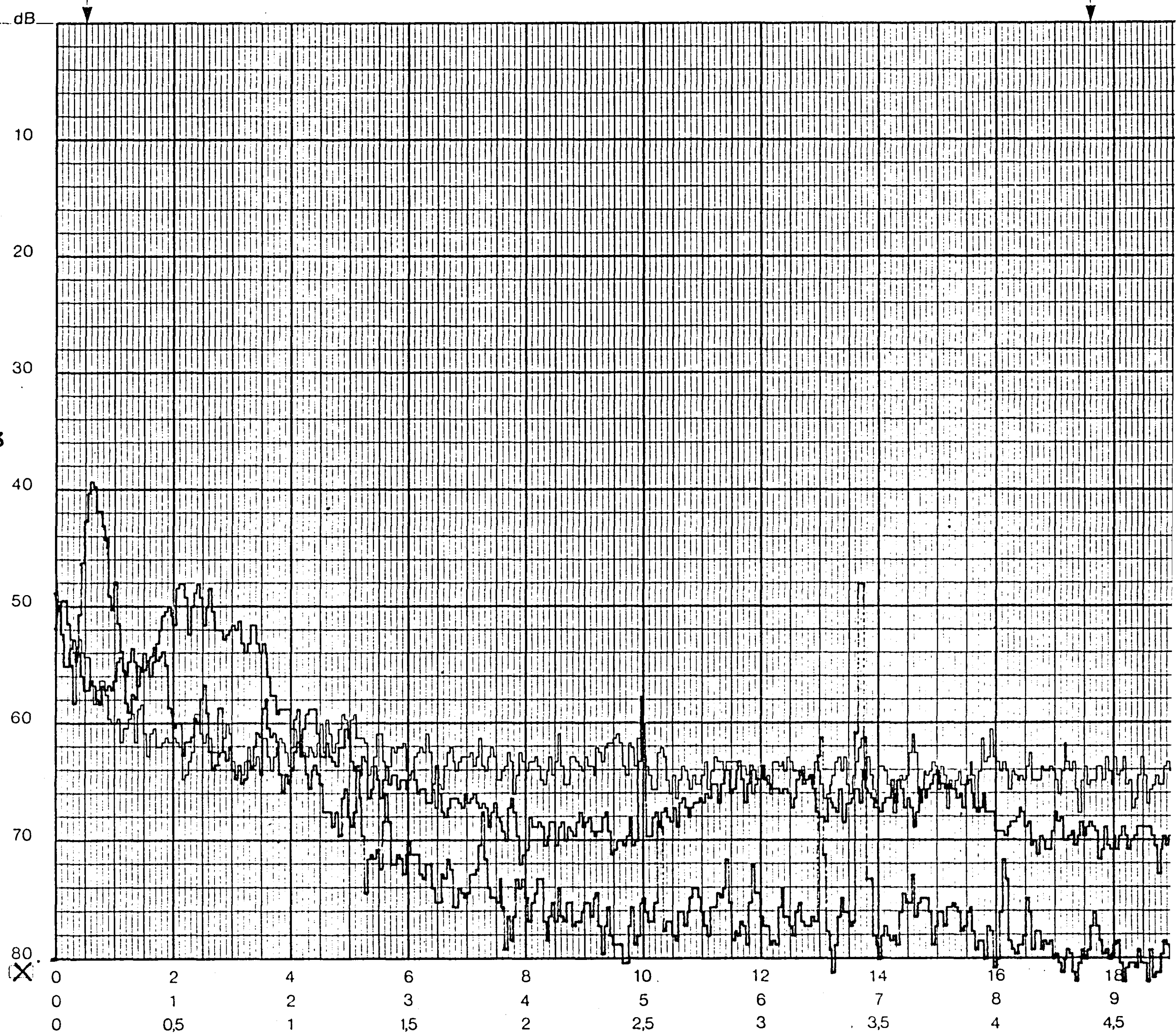
2511 = 10m/s² FSD.

: Chassis (Green) FSL 80dB

2511 = 10m/s² FSD.

: Axle (Black) FSL 70dB

2511 = 10 m/s² FSD.



Record No.: LR/S/Z

Date: Feb 1982

Sign.: SS.

Measuring Object:

QP 1002 'LANDROVER'

Brüel & Kjær

Time Function Start: secc E. seconds Not Expanded: ☐ Expan

Full Scale Level: As Below.

F. S. Frequency: 100 Hz.

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 35.

Comments:

Cobbled Road.

'Z' axis vibrations.

: Seat (Red) FSL 110dB.
2511 = 10m/s² FSD.

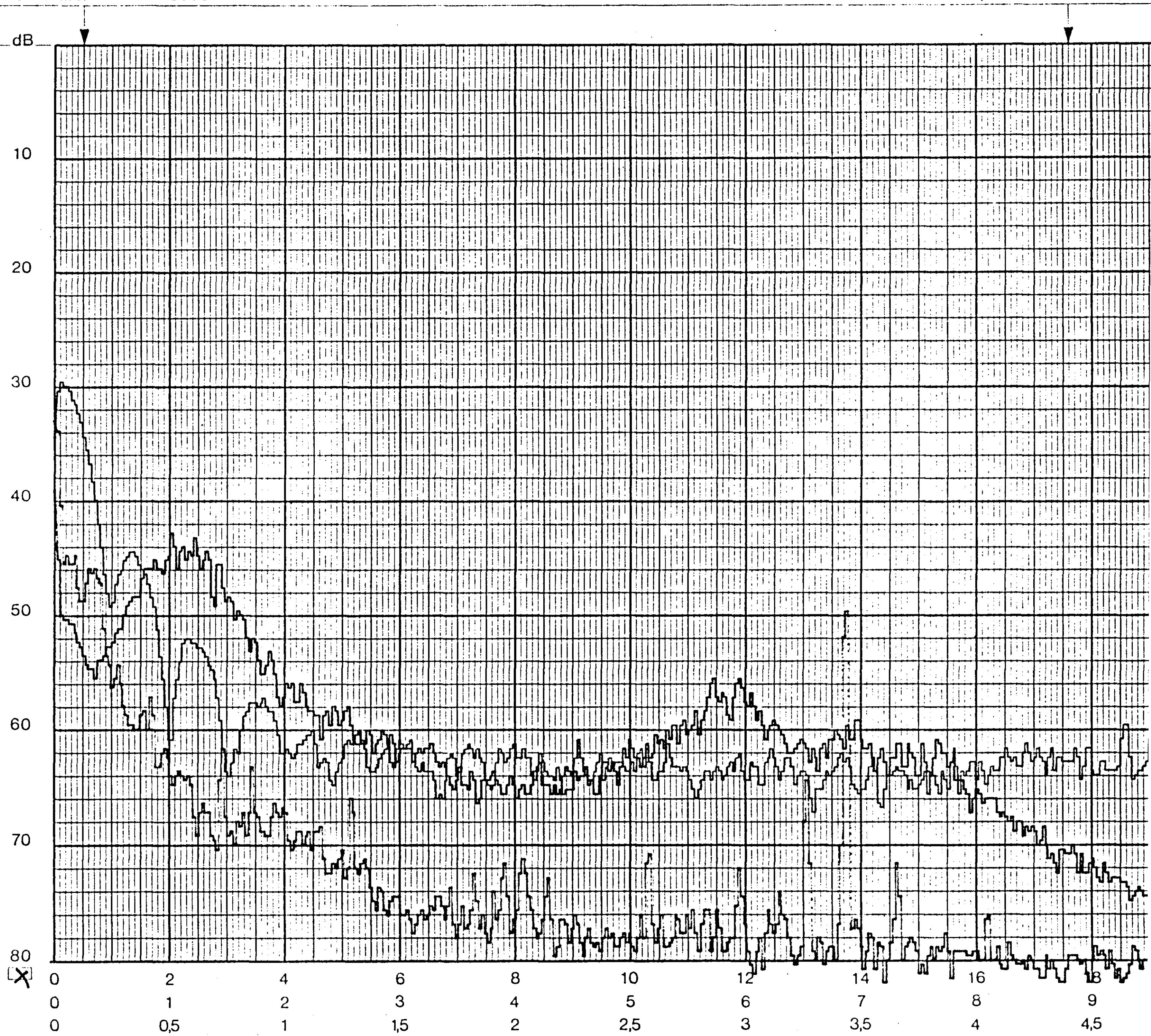
: Chassis (Green) FSL 70dB
2511 = 10m/s² FSD.

: Axle (Black) FSL 130dB.
2511 = 10m/s² FSD

Record No.: LR/C/Z

Date: Feb 1982

Sign.:



Measuring Object:

185

QP 1002 'LANDROVER'

Brüel & Kjær

Time Function Start: sec. E. seconds Not Expanded: Expand

Full Scale Level: As Below.

F. S. Frequency: 100 Hz.

Weighting: Hanning.

Average Mode: Lin.

No. of Spectra: 35

Comments:

Rough Track
(Ringinglow)

'Z' axis vibrations.

:Seat (Red) FSL 110dB.
2511 = 10 m/s² FSD.

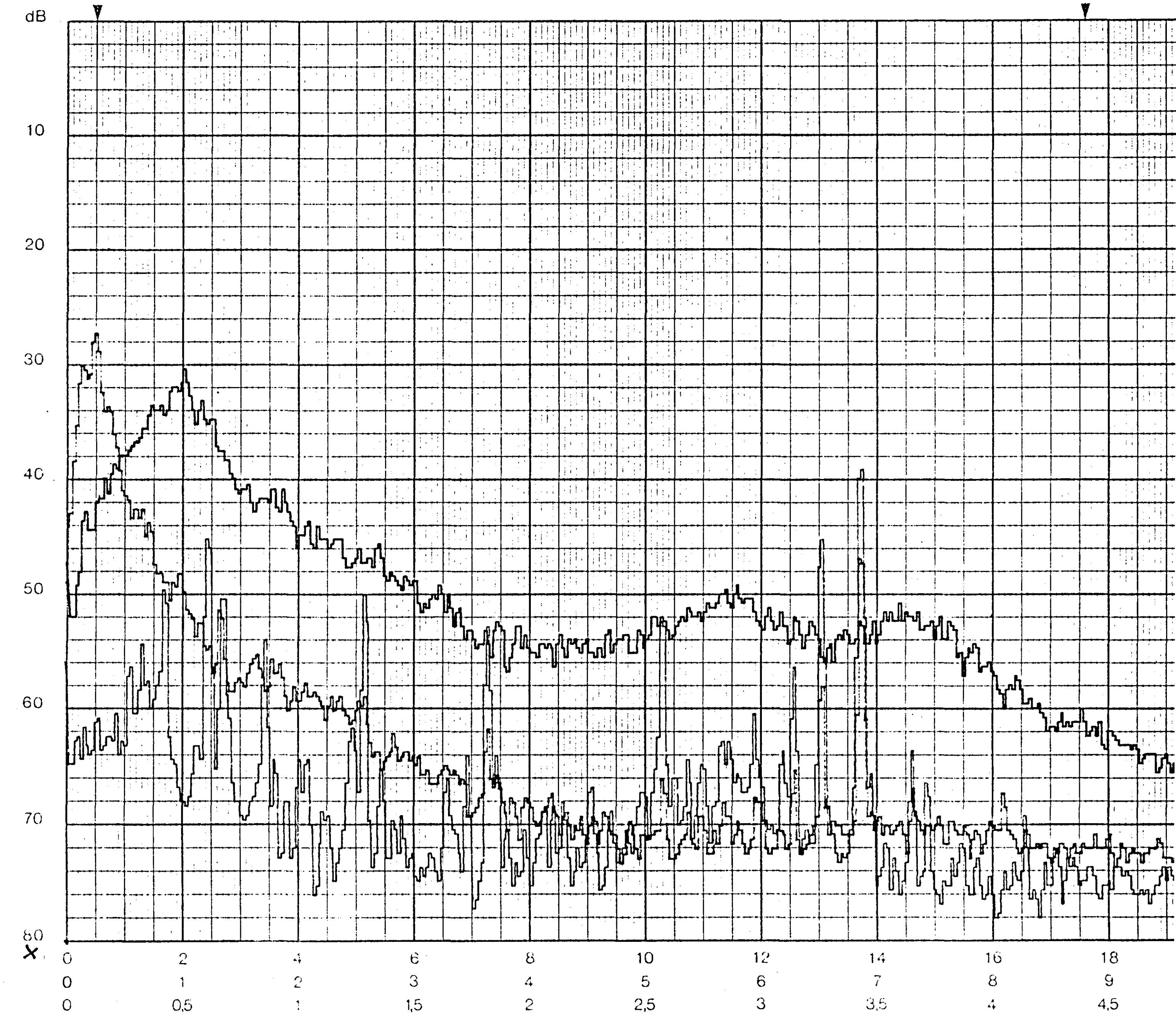
:Chassis (Green) FSL 100dB.
2511 = 10 m/s² FSD.

:Axle (Black) FSL 120dB.
2511 = 10 m/s² FSD.

Record No.: LR/R/Z

Date: Feb 1982

Sign.:



Measuring Object:

QP 100: 'LANDROVER'

APPENDIX 'C'

JCB 3CX Excavator/Loader test results : graphical presentation of spectral densities in 'X', 'Y' and 'Z' axes at axle, cab and seat over four different test tracks.

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As BELOW dB

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Wave Motion"

'X'axis vibrations.

SEAT : FSL 100dB

Cab : FSL 110dB

AXLE : FSL 120dB

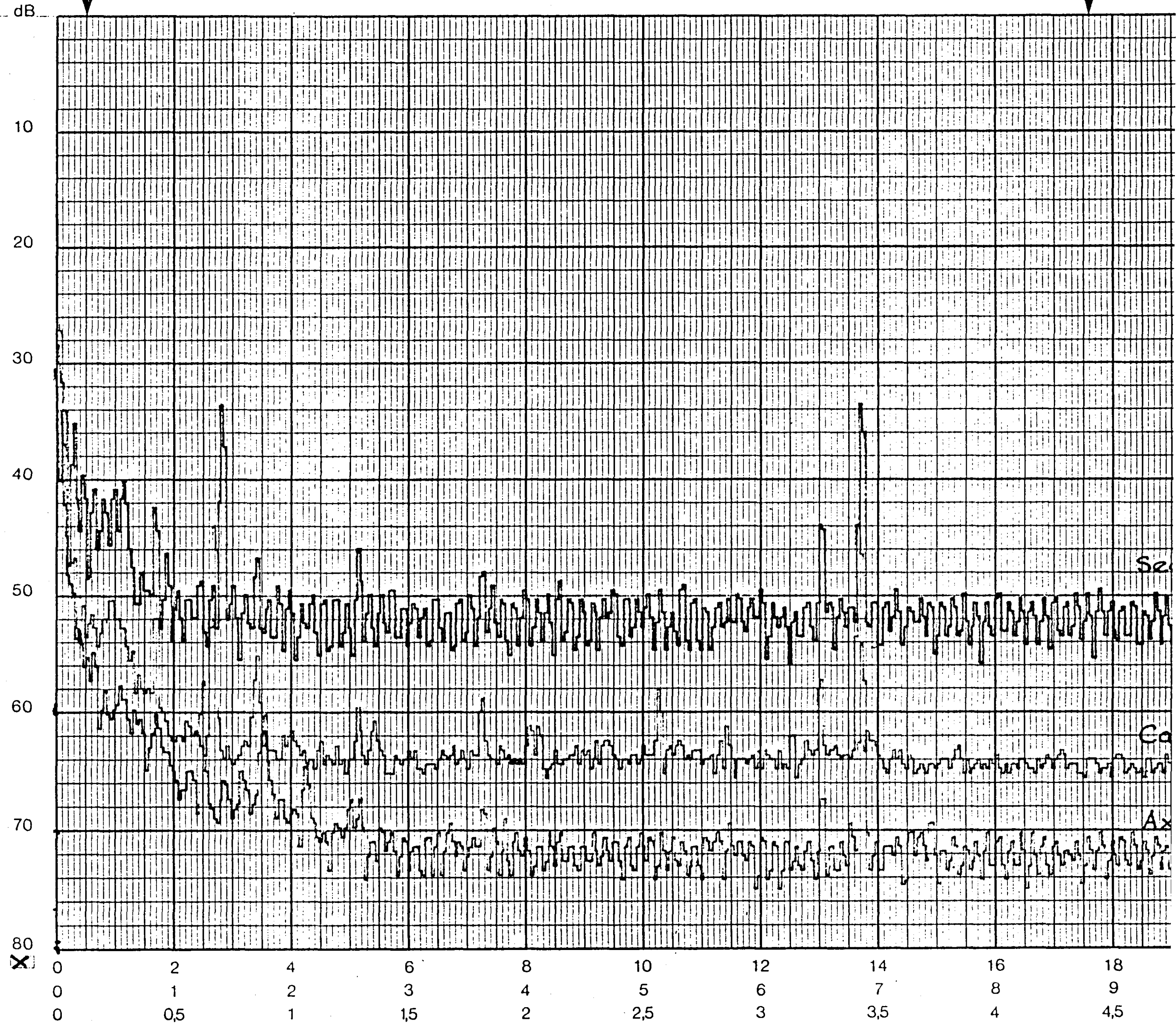
Each FSL = 10^{-1} m/s^2

JCB 3CX (new)

Record No.: WM 1X

Date: 12.8.82

Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As Below. dB

F. S. Frequency: 100 Hz

Weighting: Hanning.

Average Mode: Linear

No. of Spectra: 15

Comments: "Wave Motion"

'Y' axis vibrations

SEAT : FSL 80dB

CAB : FSL 90dB

AXLE : FSL 120dB

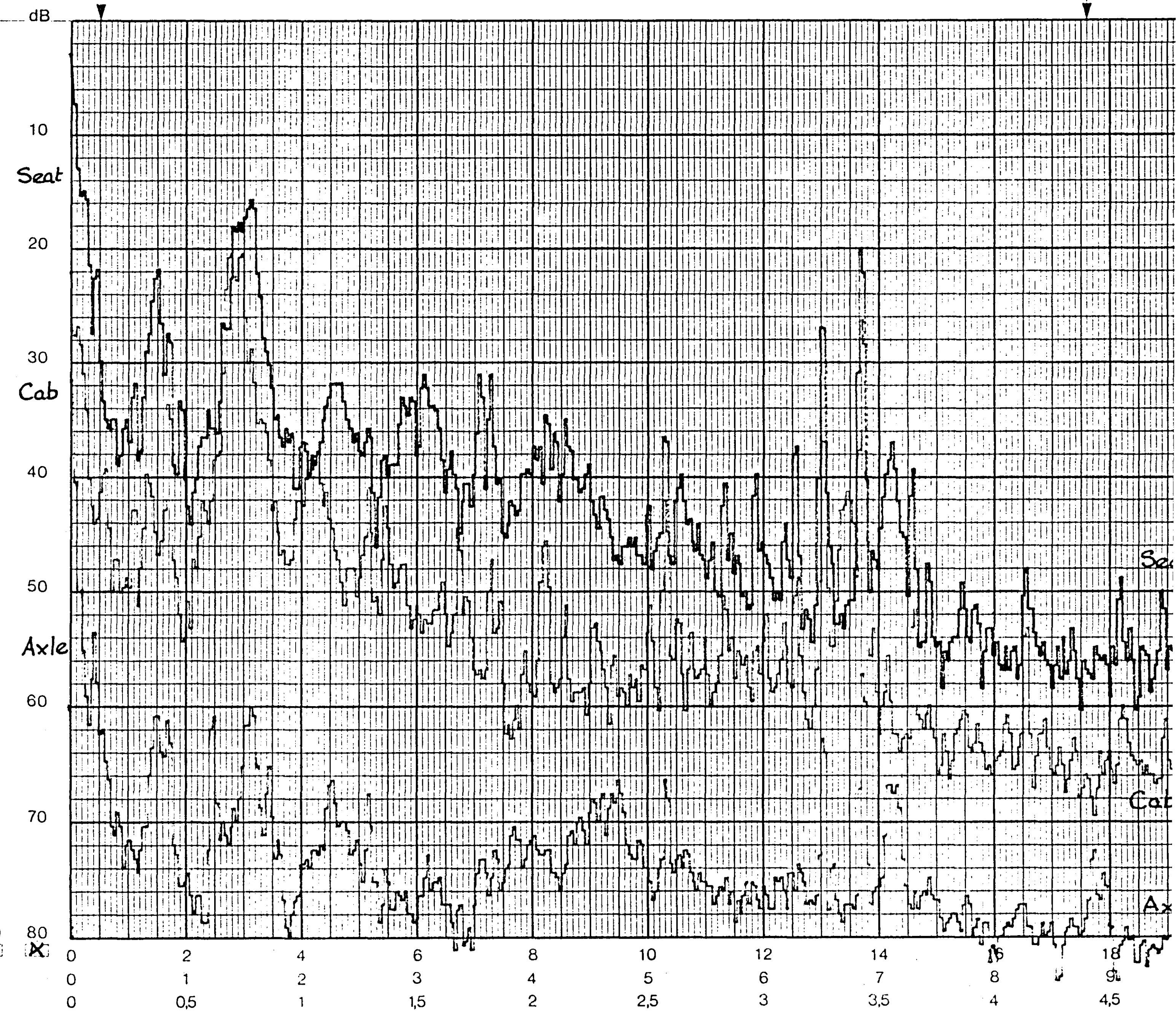
Each FSL = $1 m/s^2$

JCB 3CX (new)

Record No.: WM 1 Y

Date: 12.8.82

Sign.: [signature]



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: ______ seconds   End: ______ seconds   Not Expanded: ☐ Expanded

Full Scale Level: As Below
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 15
Comments: 'Wave Motion'

'Z axis vibrations

Seat : FSL 80dB.

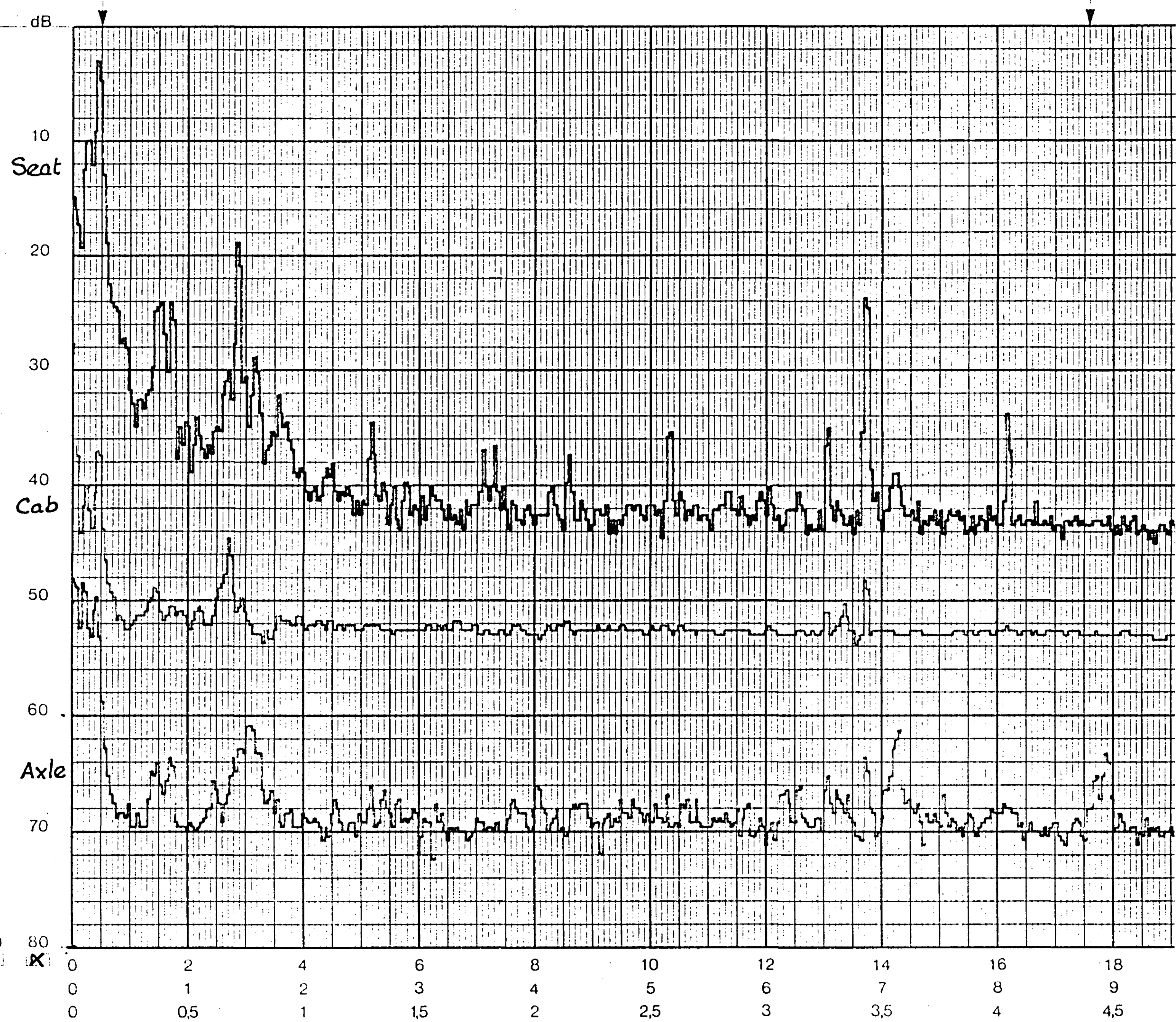
CAB : FSL 110dB

Axle : FSL 130dB.

Each FSL = 10m/s²

JCB 3CX (new)

Record No.: WM1Z
Date: 12-8-82
Sign.: D. Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Regular Kerb"

"X" axis vibrations

Seat : FSL 90dB

Cab : FSL 110dB

Axle : FSL 120dB.

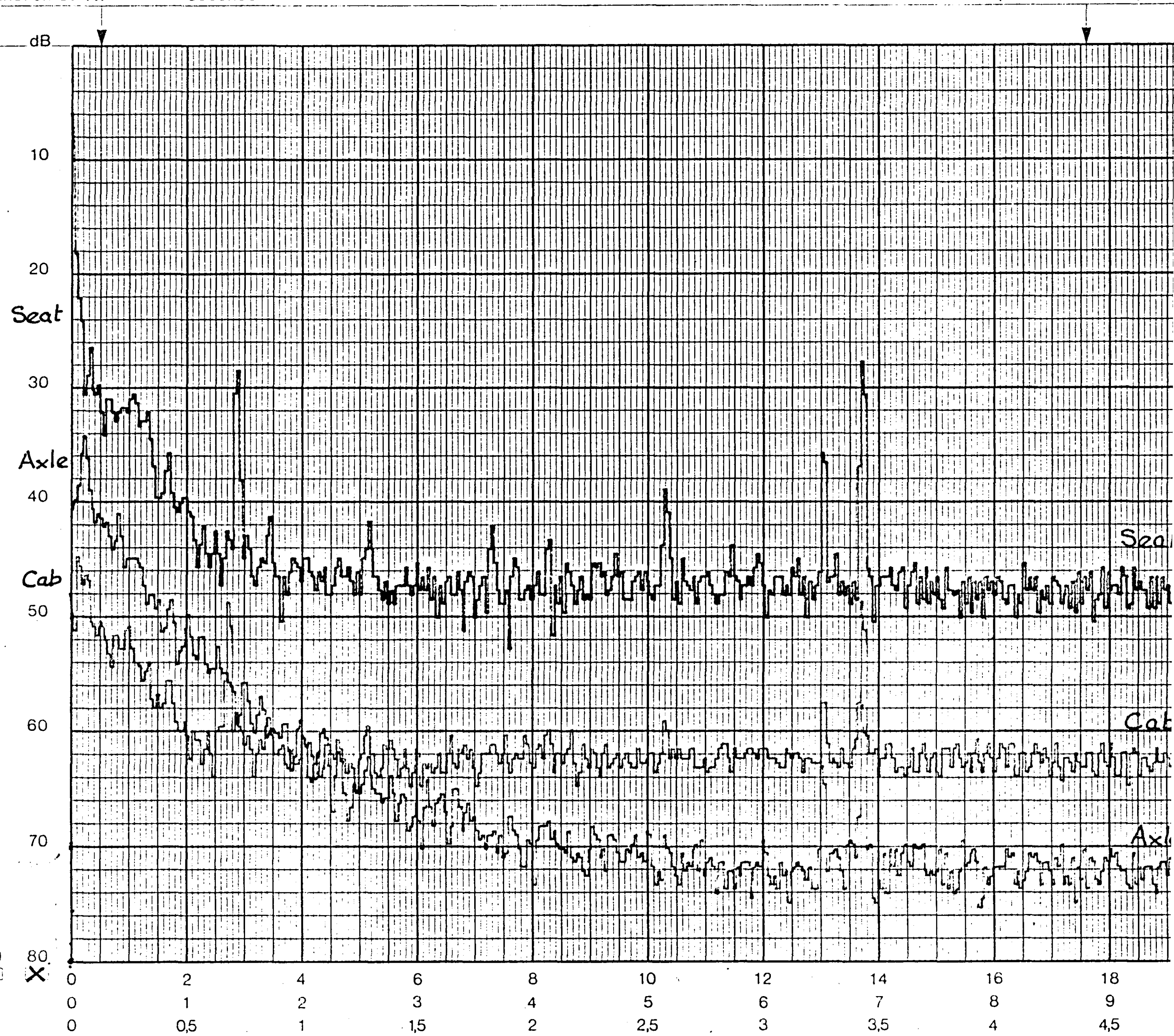
Each FSL = $10^{-1} m/s^2$

JCB 3CX (new)

Record No.: RgK 1X

Date: 12.8.82

Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: As Below dB
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Linear
No. of Spectra: 15
Comments: "Regular Kerb"

'Y' axis vibrations

SEAT : 100dB FSL

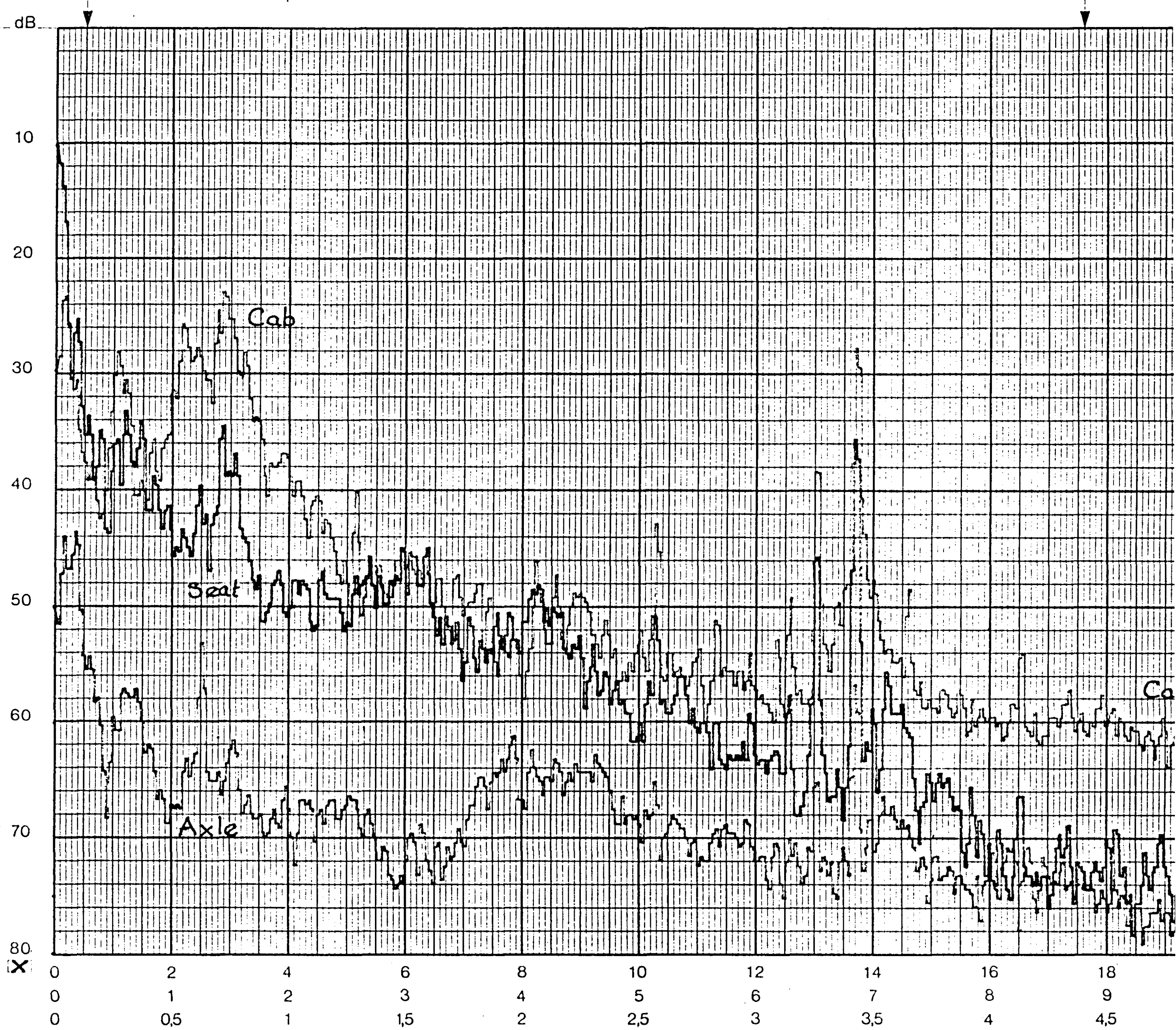
CAB : 90dB FSL

AXLE : 120dB FSL

Each FSL = $1 m/s^2$

JCB 3CX (new)

Record No.: RgK 1Y
Date: 12.8.82
Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: ______ seconds End: ______ seconds Not Expanded: ☐ Expand

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Regular Kerb."

'Z' axis vibrations

SEAT : FSL 90dB

CAB : FSL 100dB

AXLE : FSL 120dB.

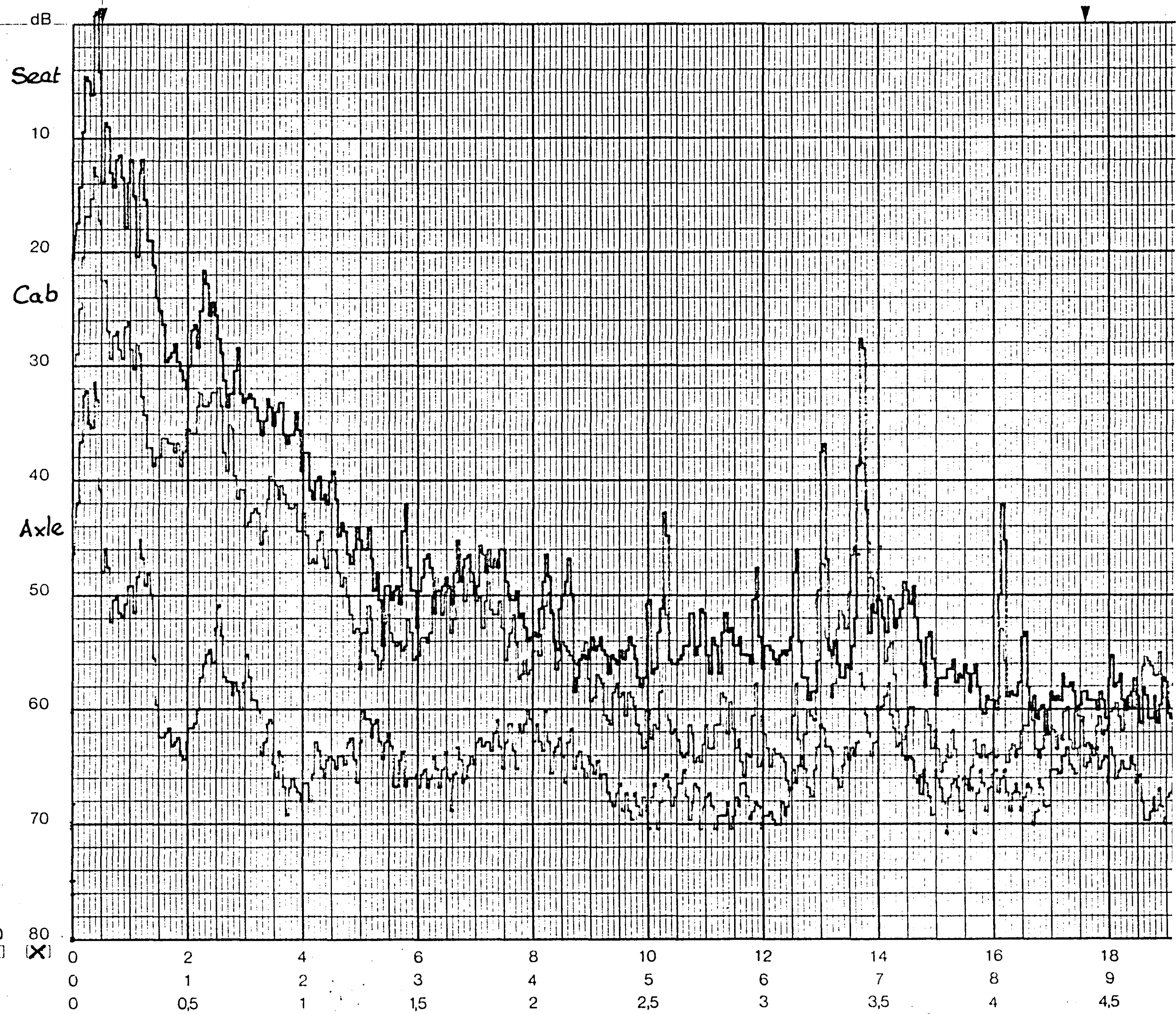
Each FSL = 10m/s²

JCB 3CX (new)

Record No.: RgK 1 Z

Date: 12.8.82

Sign.: D Douglas



Measuring Object: ______

QP 1002

Brüel & Kjær

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Random Kerb"

'Xaxis vibrations

SEAT: FSL 90dB

CAB: FSL 110dB

AXLE: FSL 120dB

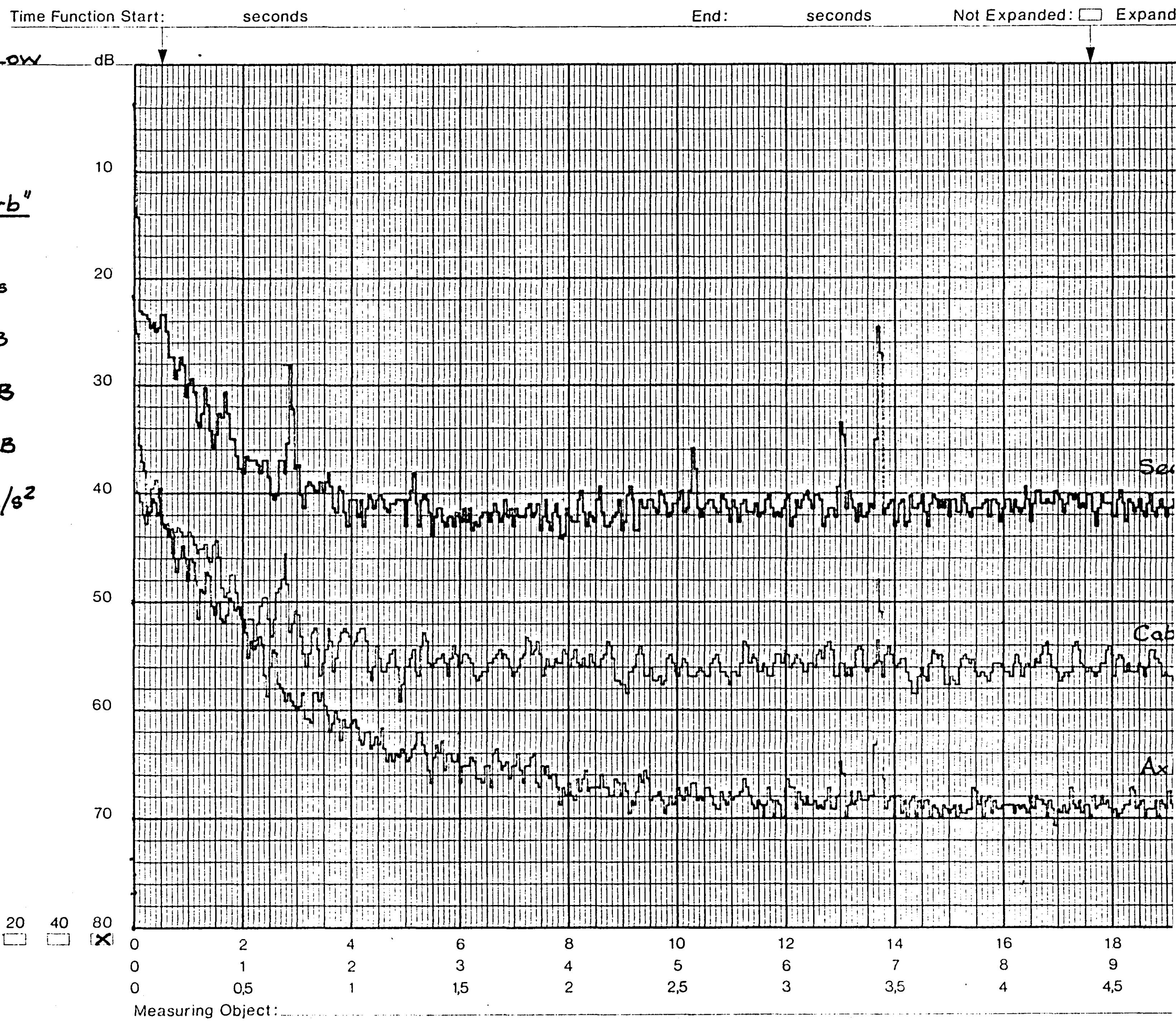
Each FSL = $10^{-1} m/s^2$

JCB 3CX (new)

Record No.: RmK 1 X

Date: 12.8.82

Sign.: Douglas



QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expanded:

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Random Kerb"

'Y axis vibrations

Seat : FSL 90dB

Cab : FSL 110dB

Axle : FSL 120dB.

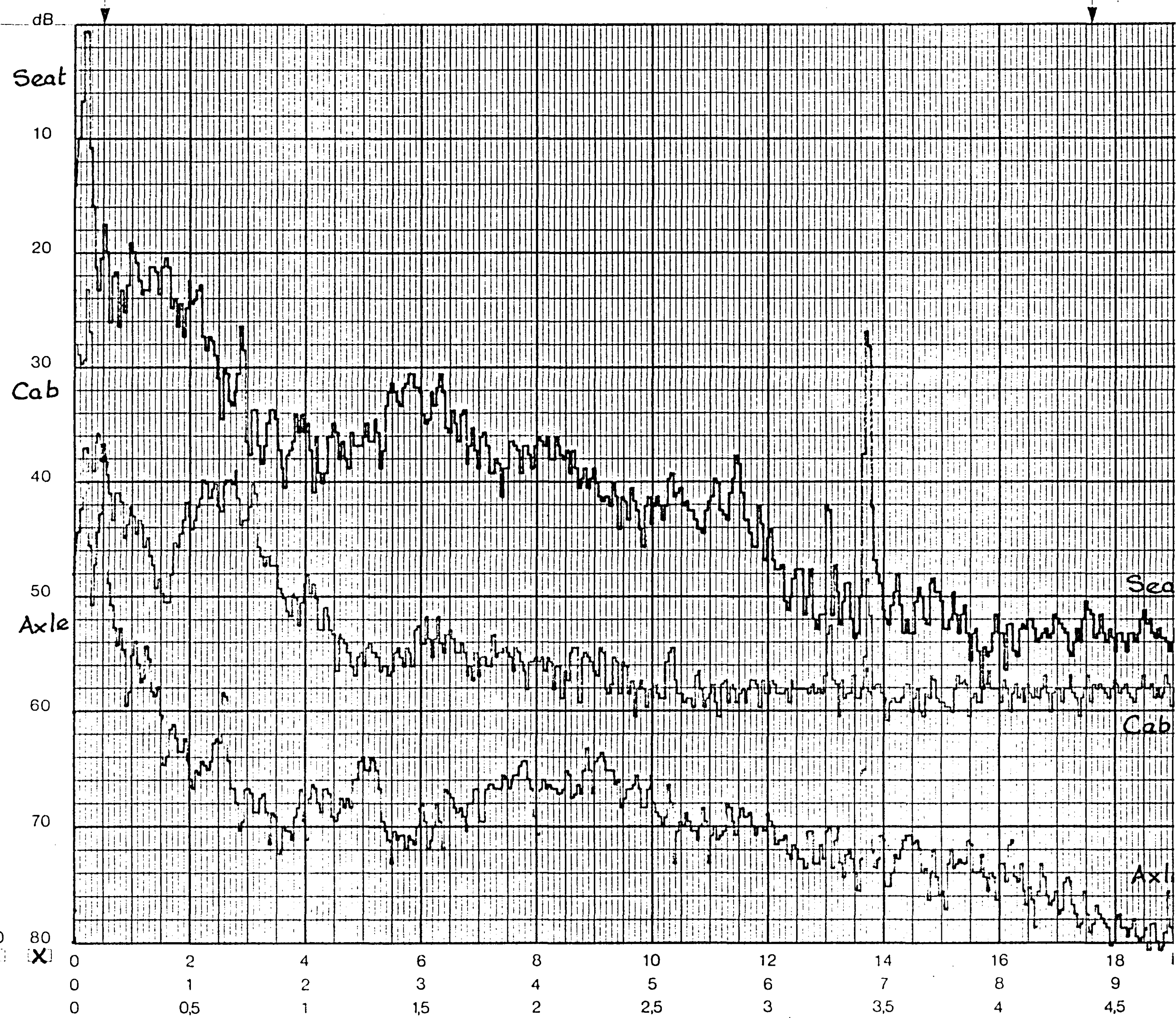
Each FSL = $1 m/s^2$

JCB 3CX (new)

Record No.: RmK 1 Y

Date: 12.8.82

Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Linear

No. of Spectra: 15

Comments: "Random Kerb."

'Z' axis vibrations

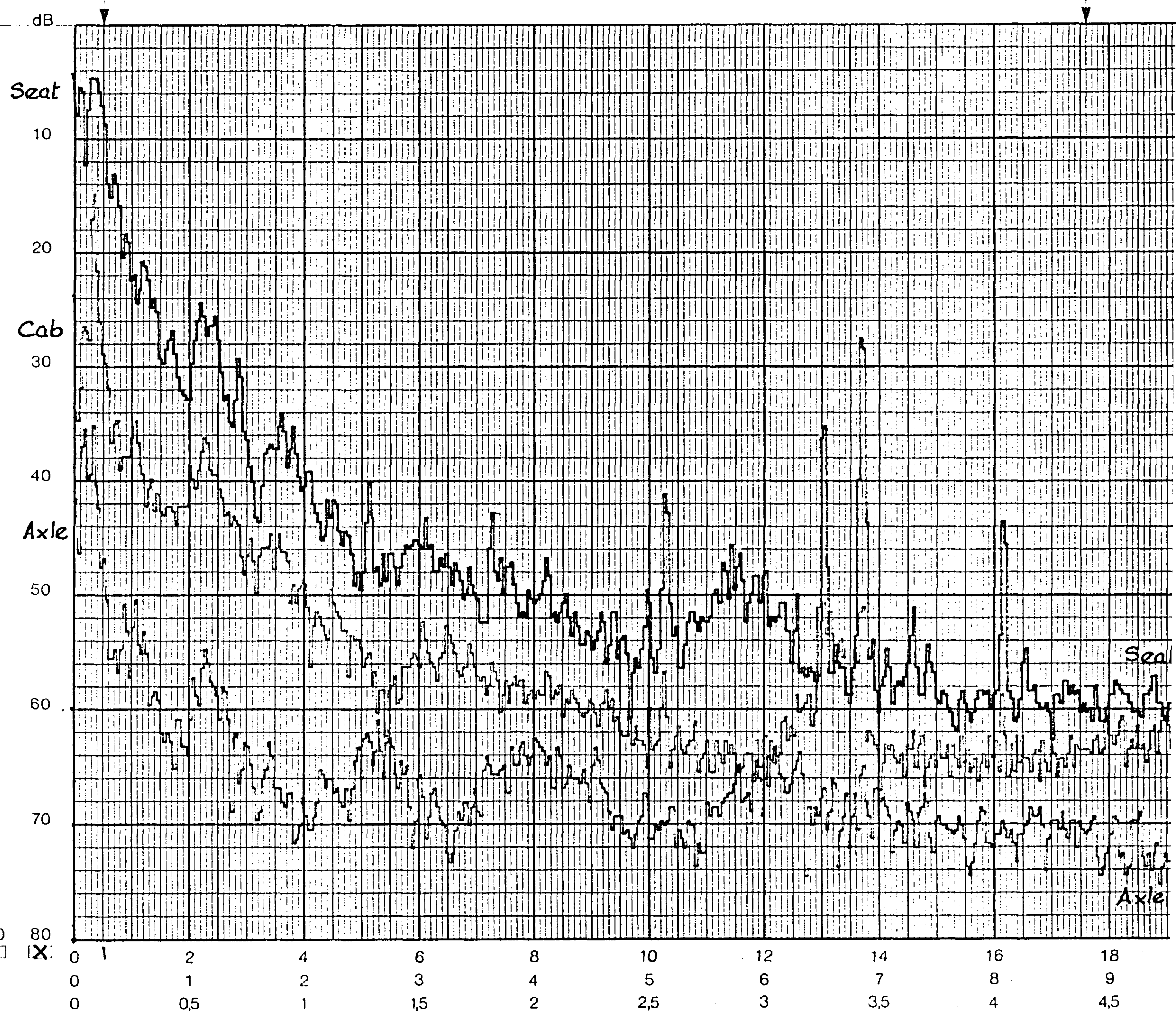
Seat : FSL 90dB

Cab : FSL 110dB

Axle : FSL 130dB.

Each FSL = 10 m/s²

JCB 3CX (new)



Record No.: RmK 1 Z

Date: 12·8·82

Sign.: D Douglas

20 ☐ 40 ☐ 80 ☒

Measuring Object:

QP 1002

Brüel & Kjær | Time Function Start: seconds | End: seconds | Not Expanded: Expand

Full Scale Level: As Below
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 9
Comments: 'Y' axis

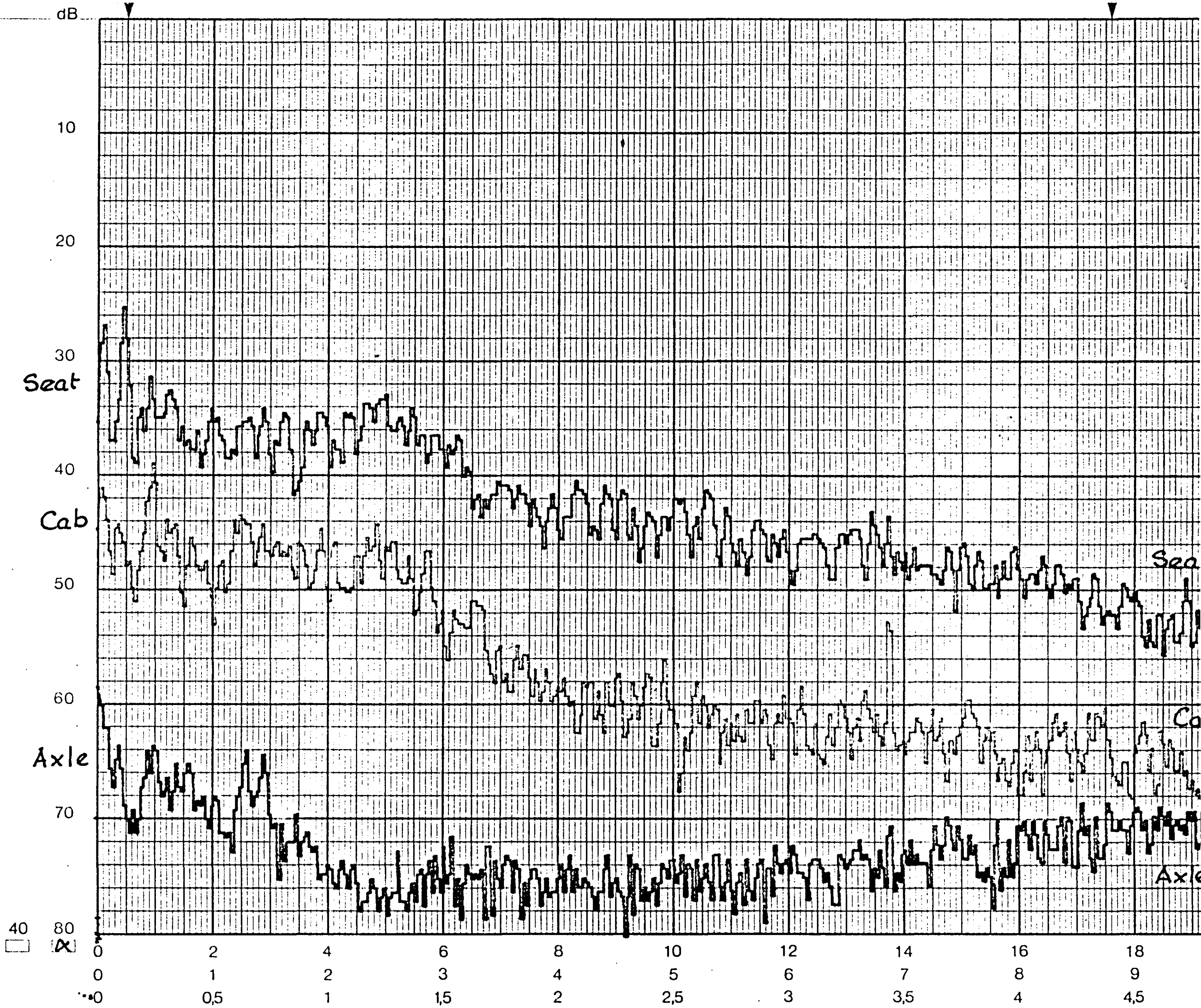
Quarry Floor test
faster speed ≃ 8 mph.
JCB '3CX', not new.

SEAT: 110 dB FSL

CAB: 120 dB FSL

AXLE: 140 dB FSL

Each FSL = $1{\cdot}0\,m/s^2$



Measuring Object:

Record No.: QF/F/2Y
Date: 15/10/82
Sign.: Douglas

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: As Below dB

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 7

Comments: 'Z' axis

Quarry Floor test.
faster speed ≃ 8 mph.
JCB '3CX', not new.

SEAT : 120dB FSL

CAB : 120dB FSL

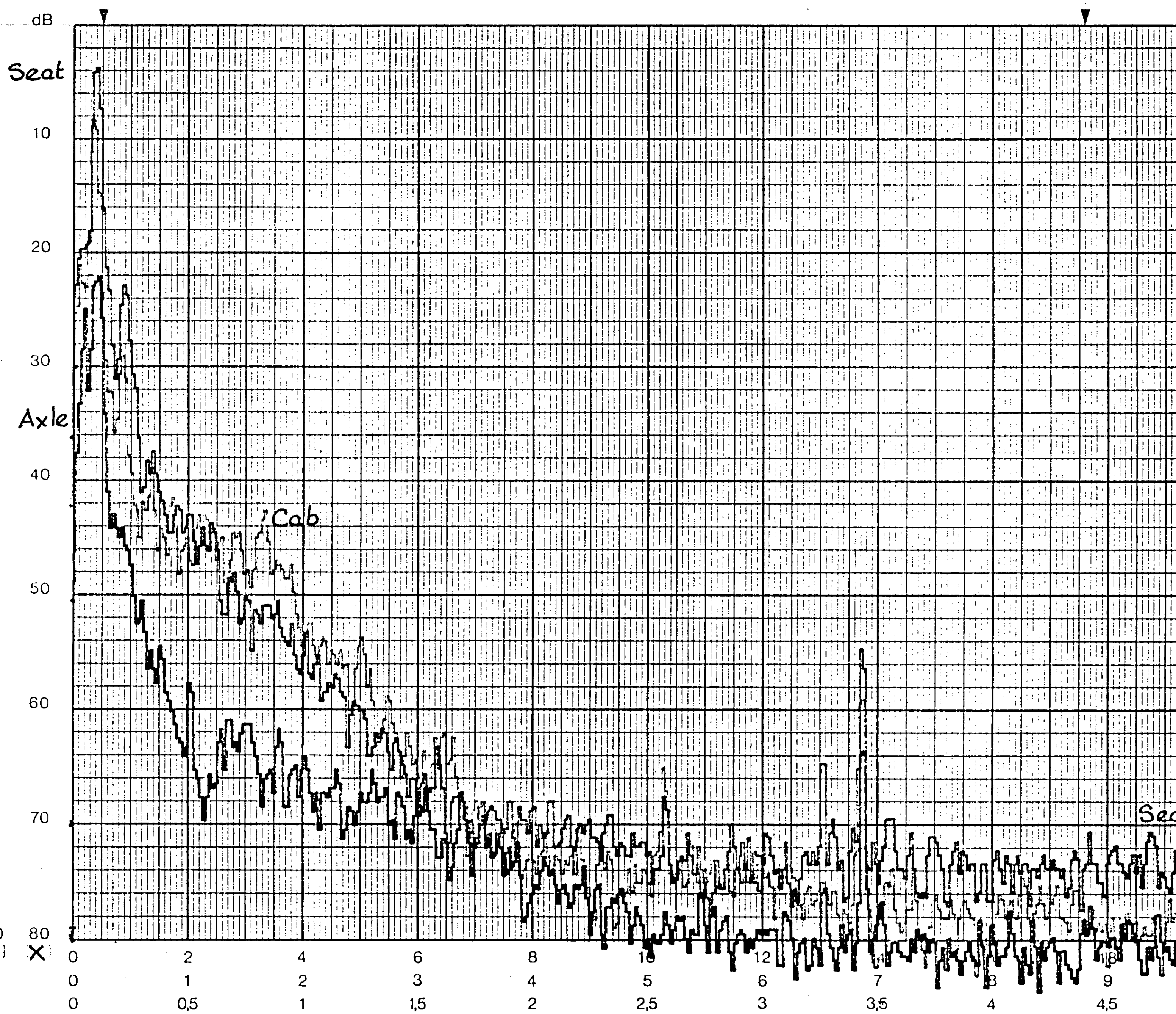
AXLE : 130dB FSL

Each FSL = 100 m/s²

Record No.: QF/F/2Z

Date: 15-10-82

Sign.: D Douglas



Measuring Object:

QP 1002

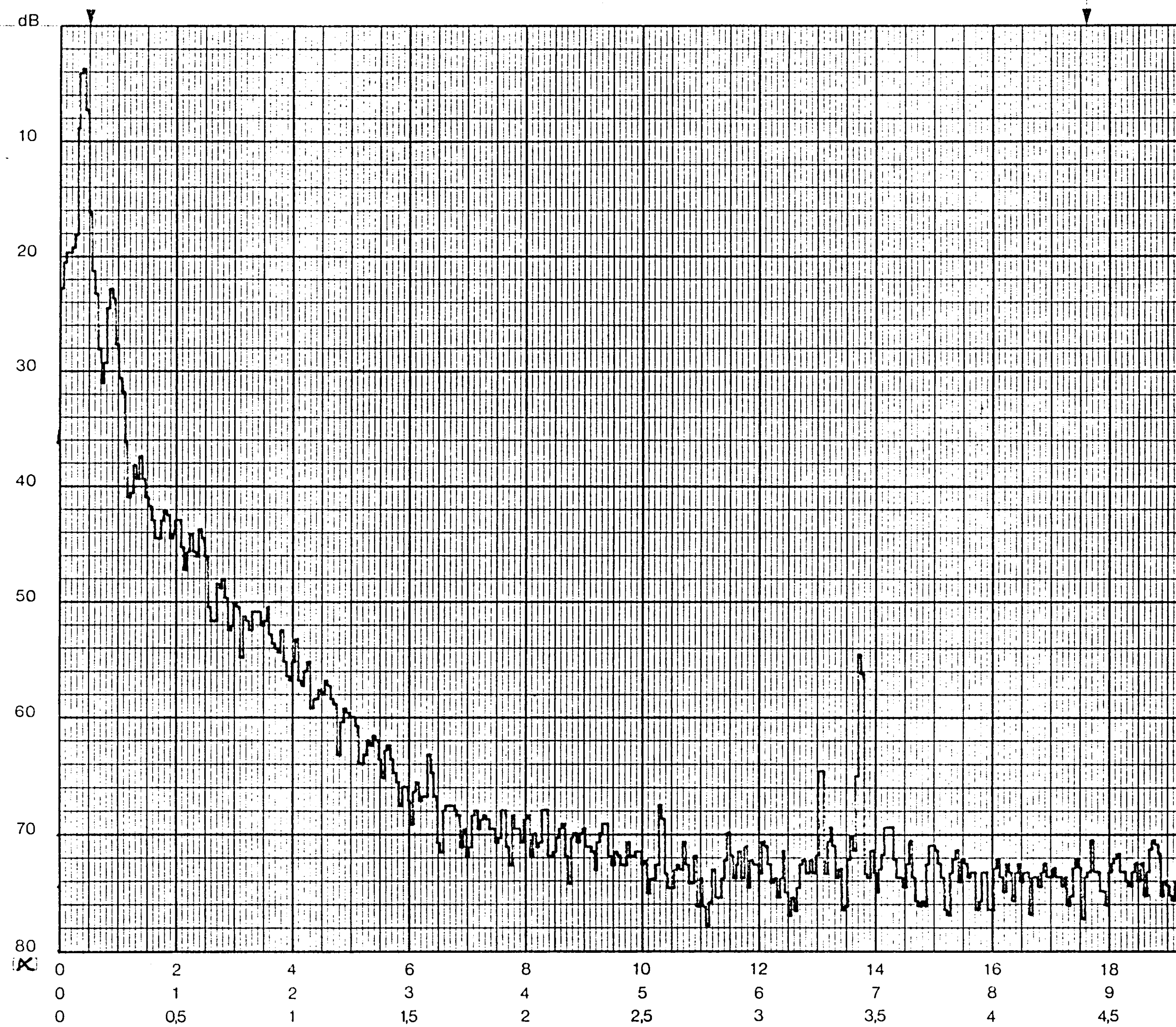
Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 120 dB
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 7.
Comments: Z axis

Quarry Floor test
faster speed ≈ 8 mph.
JCB '3CX', not new.

SEAT ONLY: for others
ie CAB & AXLE see
other sheet.



Record No.: QF/F/2Z
Date: 15-10-82
Sign.: Douglas

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: As BELOW. dB
F. S. Frequency: 100 Hz.
Weighting: Hanning.
Average Mode: Lin.
No. of Spectra: 7.
Comments: 'X' axis.

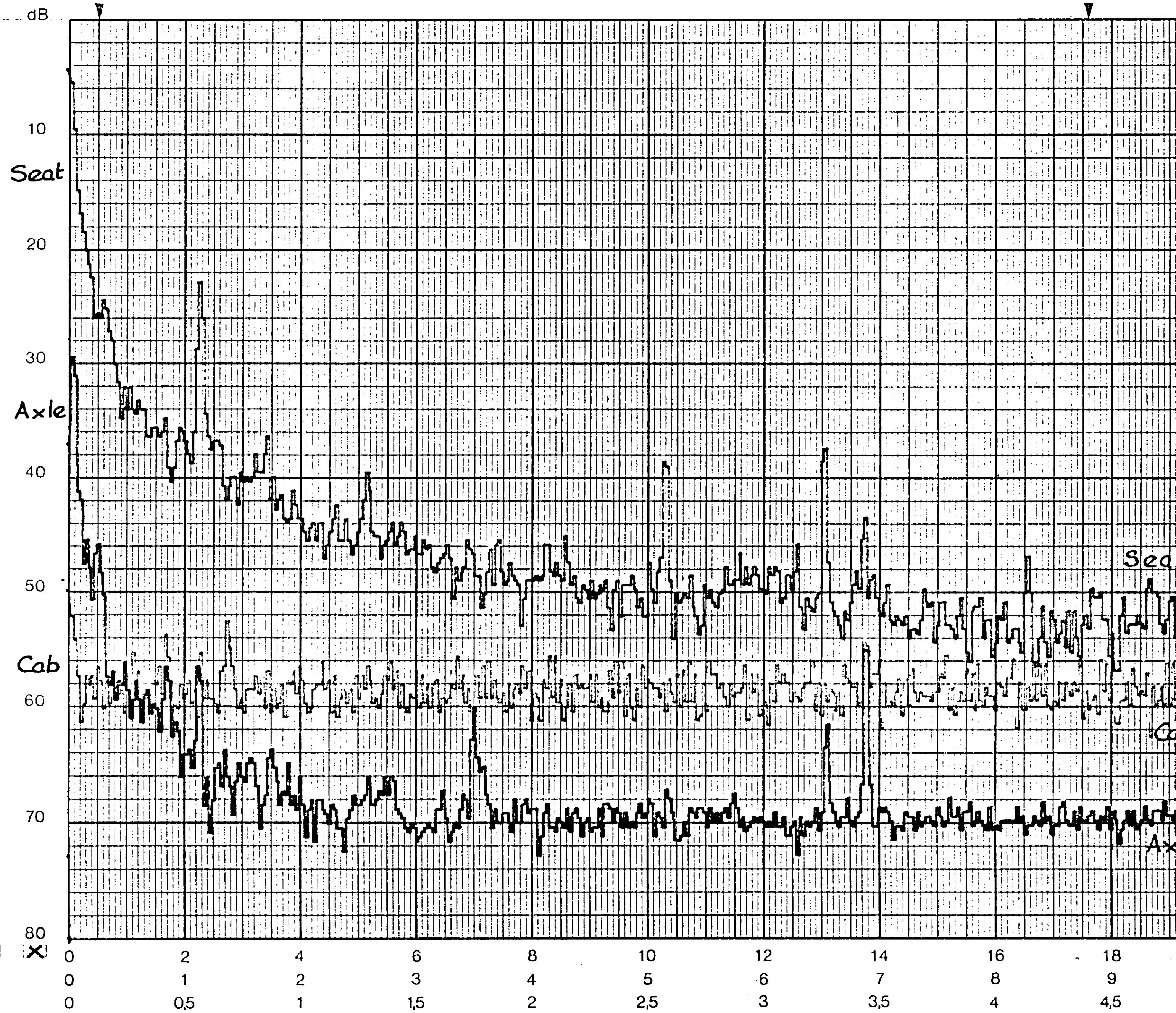
Wave Motion test.
faster speed ≃ 8 mph.
JCB '3CX', not new

SEAT: 90 dB FSL.
FSL = 1·0 m/s²

200

CAB: 120 dB FSL
FSL = 3·0 m/s²

AXLE: 120 dB FSL.
FSL = 1·0 m/s²



Record No.: WM/F/2X
Date: 15/10/82
Sign.: Douglas

20 40 80 X

Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: As Below
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 9
Comments: 'Y' axis

Wave Motion test
faster speed ≃ 8 mph
JCB '3CX', not new.

SEAT: 100 dB FSL

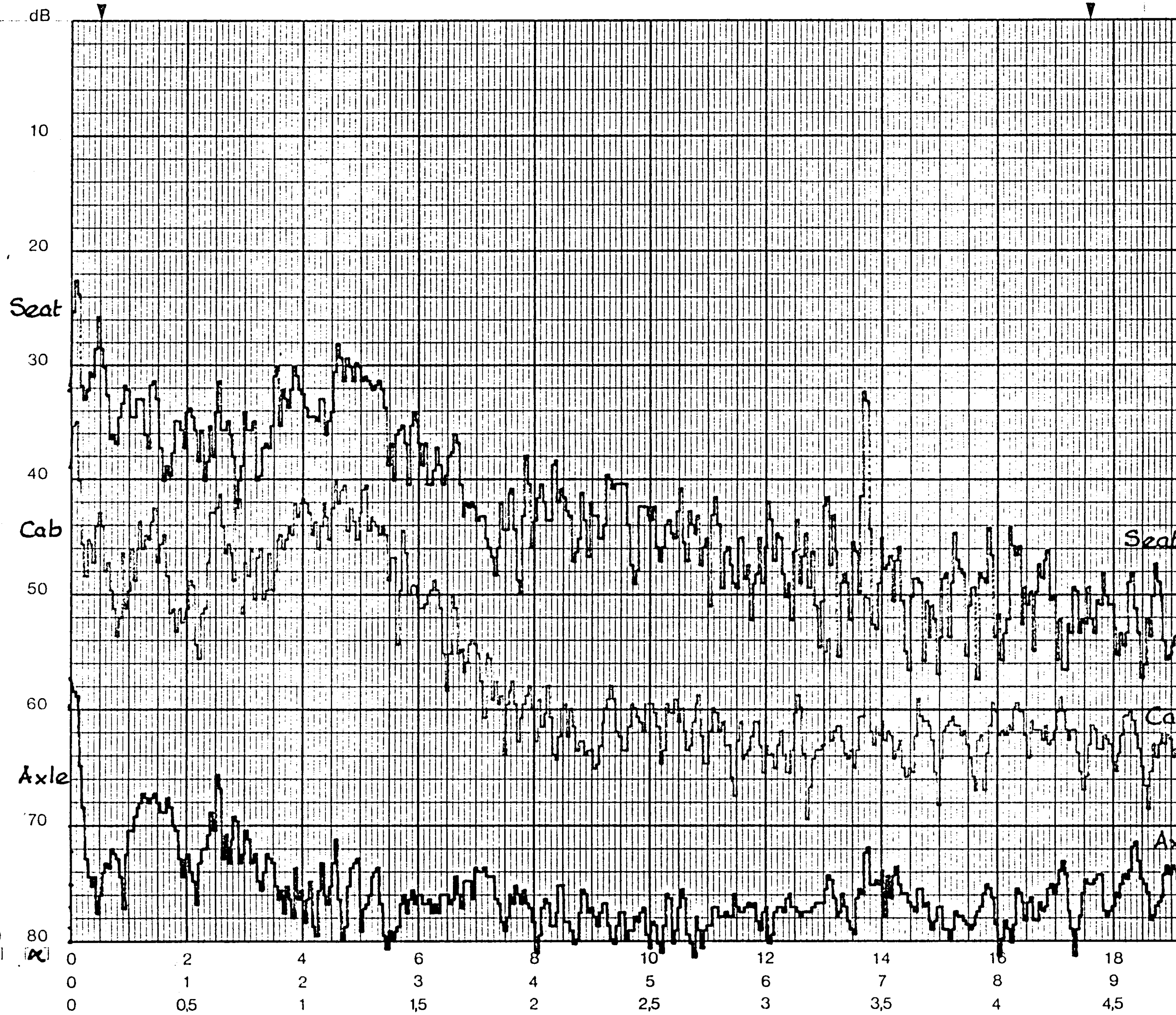
CAB: 110 dB FSL

AXLE: 130 dB FSL

Each FSL = 1·0 m/s²

Record No.: WM/F/2Y
Date: 15-10-82
Sign.: Douglas

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: ______ seconds   End: ______ seconds   Not Expanded: ☐ Expand

Full Scale Level: As Below.

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 7

Comments: 'Z' axis

Wave Motion test
faster speed ≃ 8 mph.
JCB '3CX', not new

SEAT: 110dB FSL

CAB: 120dB FSL

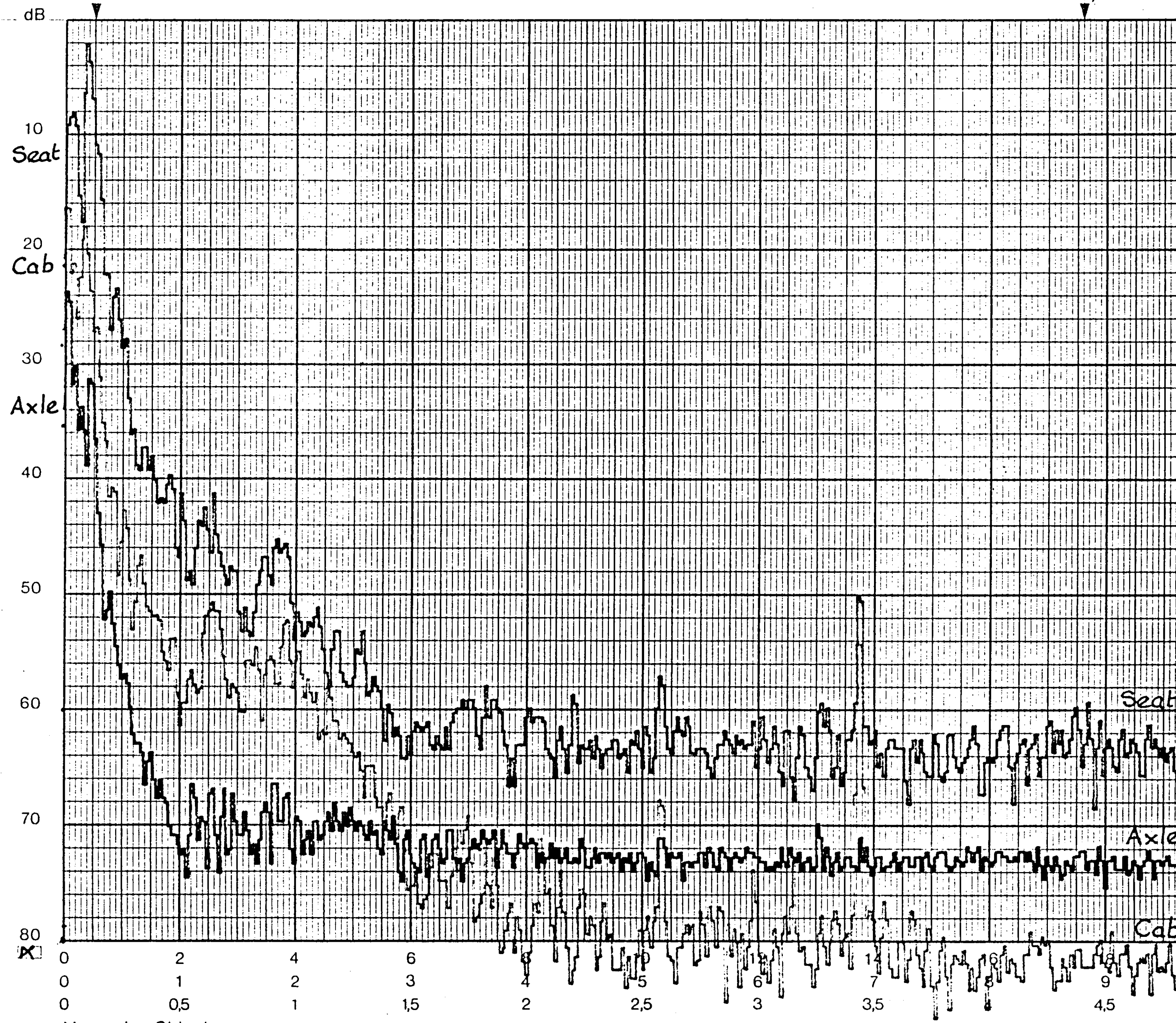
AXLE: 130dB FSL

Each FSL: $100 m/s^2$

Record No.: WM/F/22

Date: 15-10-82

Sign.: [signature]



Measuring Object: ______

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expand

Full Scale Level: As BELOW.

F. S. Frequency: 100 Hz.

Weighting: Hanning.

Average Mode: Lin.

No. of Spectra: 7.

Comments: 'X' axis.

Regular Kerb test.
faster speed ≃ 8mph.
JCB. '3CX', not new.

SEAT: 110 dB. FSL.
FSL = 1.0 m/s²

CAB: 120dB FSL
FSL = 3.0 m/s²

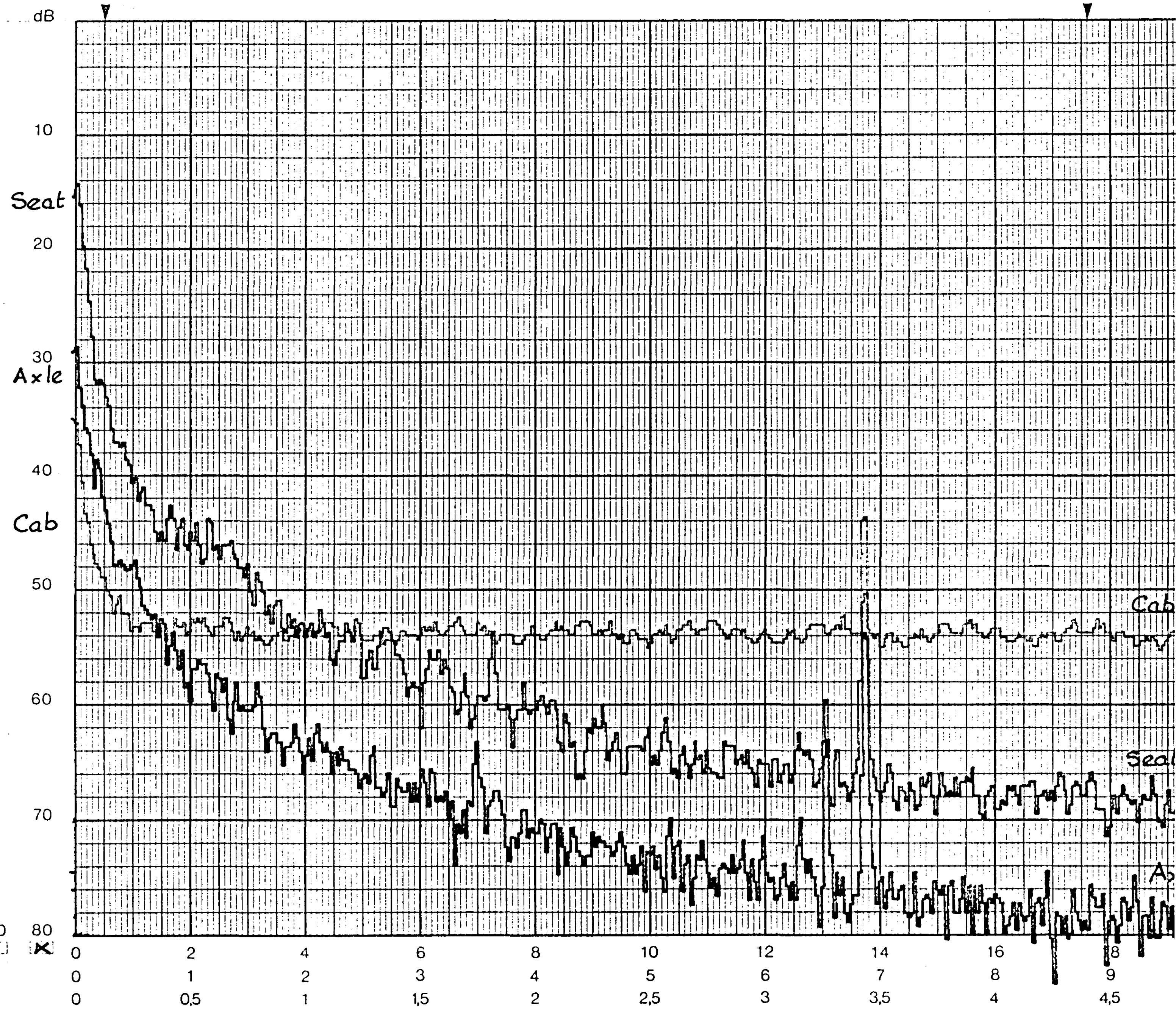
203

AXLE: 120dB FSL
FSL = 1.0 m/s²

Record No.: RgK/F/2X

Date: 15/10/82

Sign.: [signature]



Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: As Below dB

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 7

Comments: 'Y' axis

Regular Kerb test
faster speed ≃ 8 mph
JCB. '3CX', not new.

SEAT: 110 dB FSL

CAB: 120 dB FSL

204

AXLE: 130 dB FSL

Each FSL = 1 m/s²

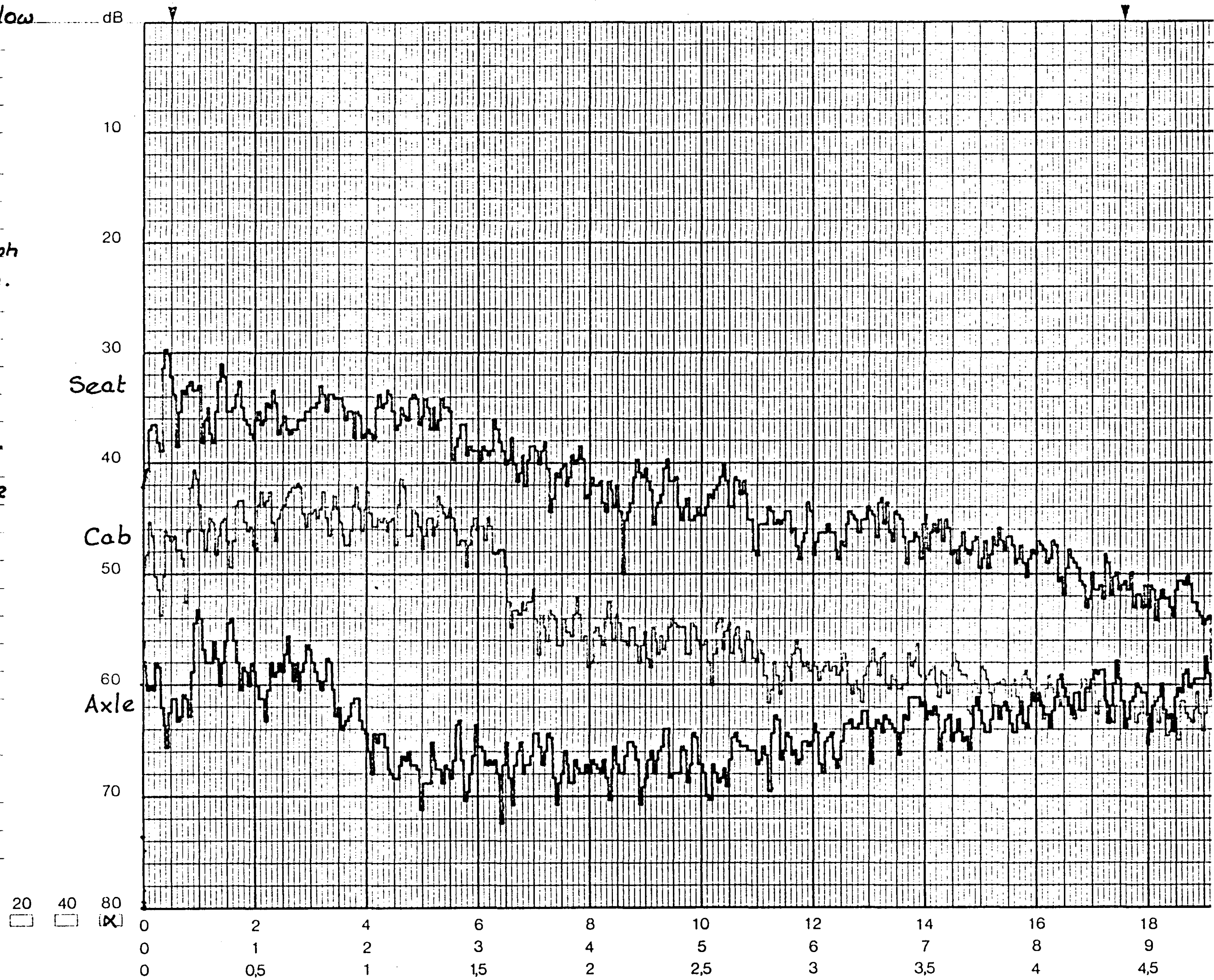
Record No.: RgK/F/2Y

Date: 15-10-82

Sign.: D Douglas

QP 1002

Time Function Start: seconds End: seconds Not Expanded: Expand



Measuring Object:

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expand

Full Scale Level: 120 dB.

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 7

Comments: Z axis

Regular Kerb test
faster speed ≃ 8 mph.
JCB, '3CX', not new.

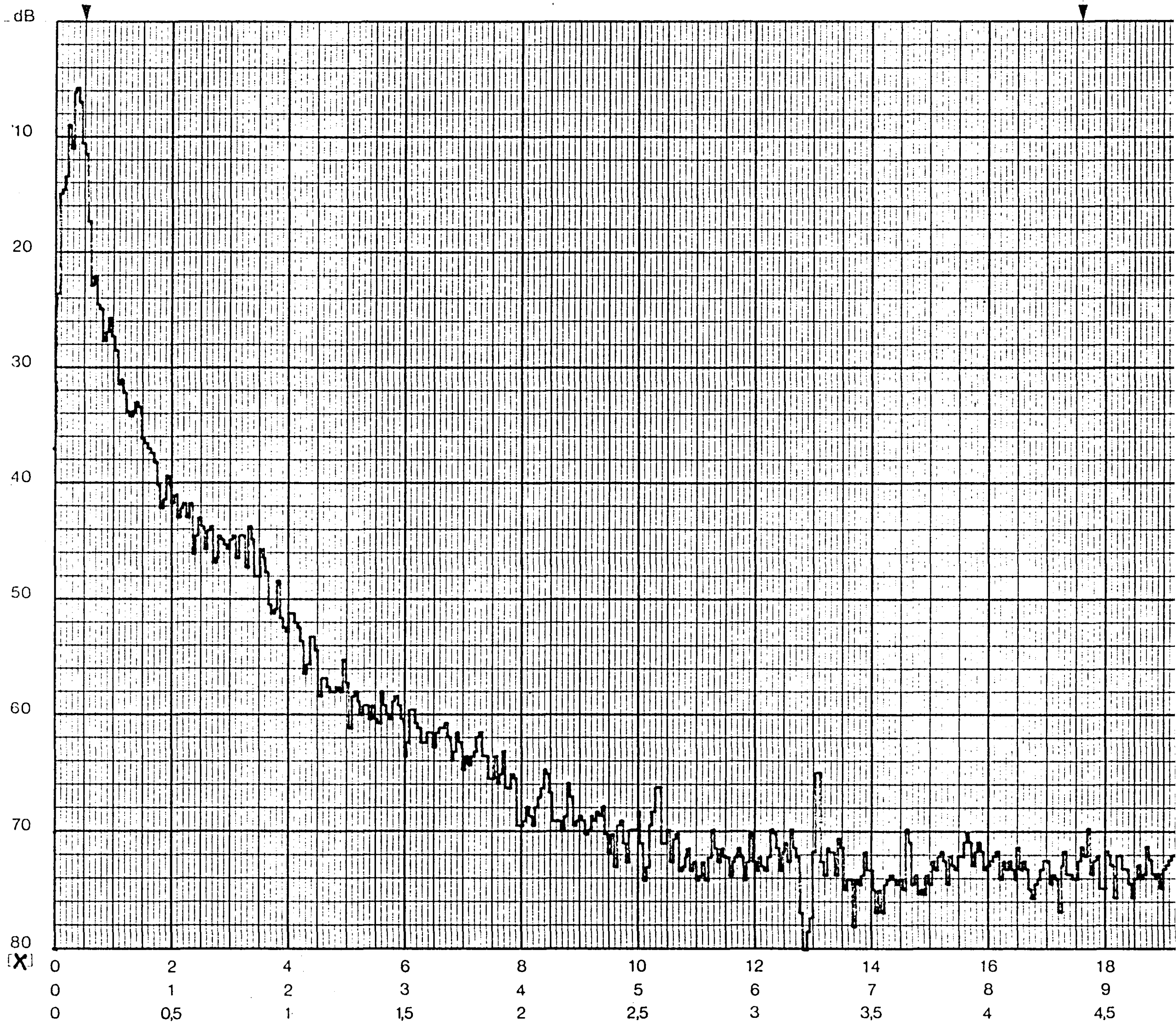
SEAT ONLY: for
CAB & AXLE see
other sheet.

FSL = 120 dB = 100 m/s²

Record No.: RgK/F/2Z

Date: 15-10-82

Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds · End: seconds Not Expanded: [ ] Expand

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 7

Comments: 'Z' axis

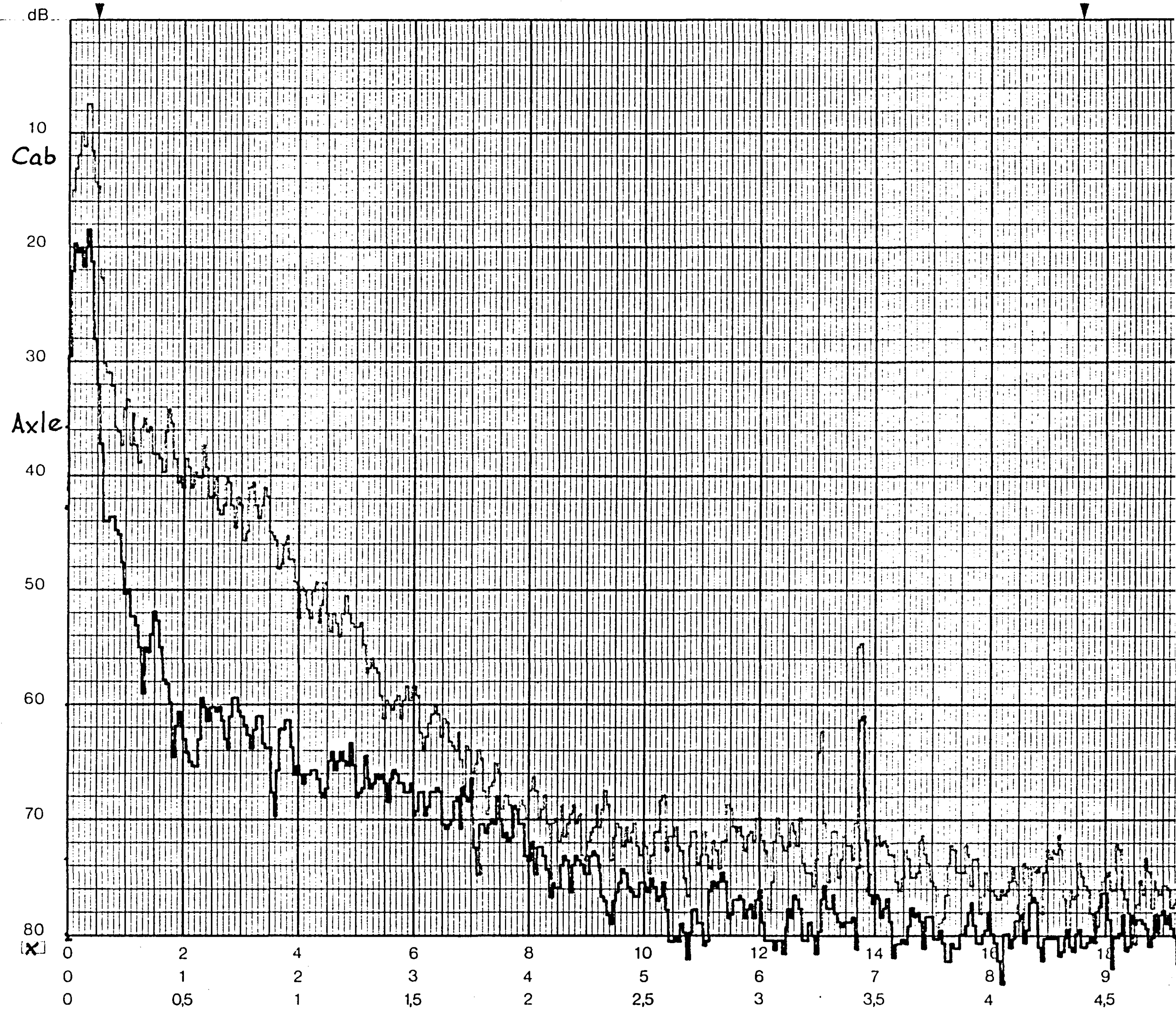
Regular Kerb test
faster speed ≃ 8 mph
JCB. '3CX', not new.

SEAT: See other sheet.

CAB: 120dB FSL

AXLE: 130dB FSL

Each FSL = 100 m/s²



Record No.: RgK/F/22

Date: 15-10-82

Sign.: D Douglas

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 7

Comments: X axis

Random Kerb test
faster speed ≃8mph
JCB 3CX, not new.

SEAT: 100dB FSL

CAB: 120dB FSL

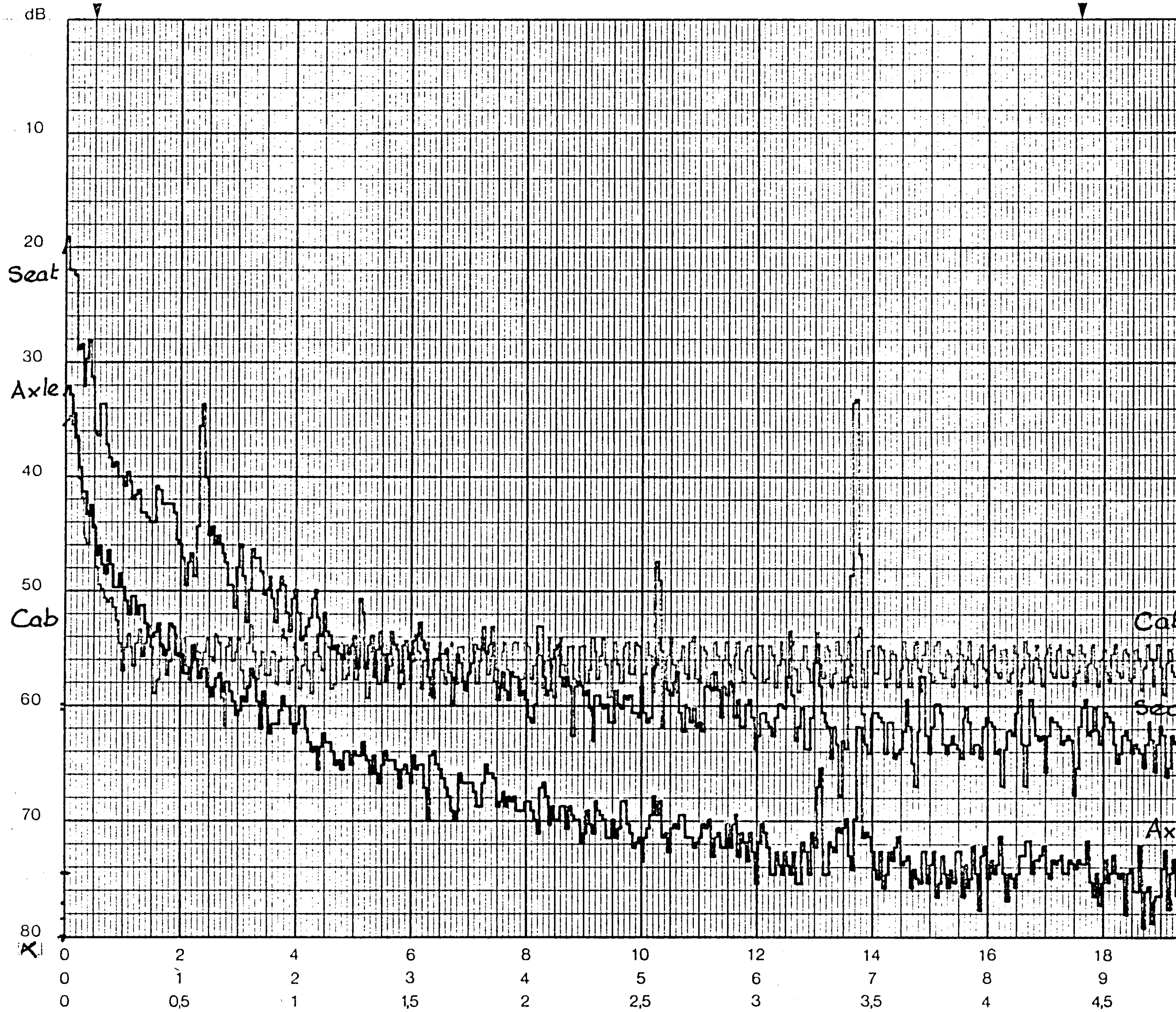
AXLE: 120dB FSL

Each FSL = 3·0m/s²

Record No.: RmK/F/2X

Date: 15-10-82

Sign.: D Douglas



Measuring Object:

QP 1002

207

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expand

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 9

Comments: 'Y' axis

Random Kerb test
faster speed ≃ 8mph.
JCB '3CX', not new.

SEAT : 110dB FSL

CAB : 120dB FSL

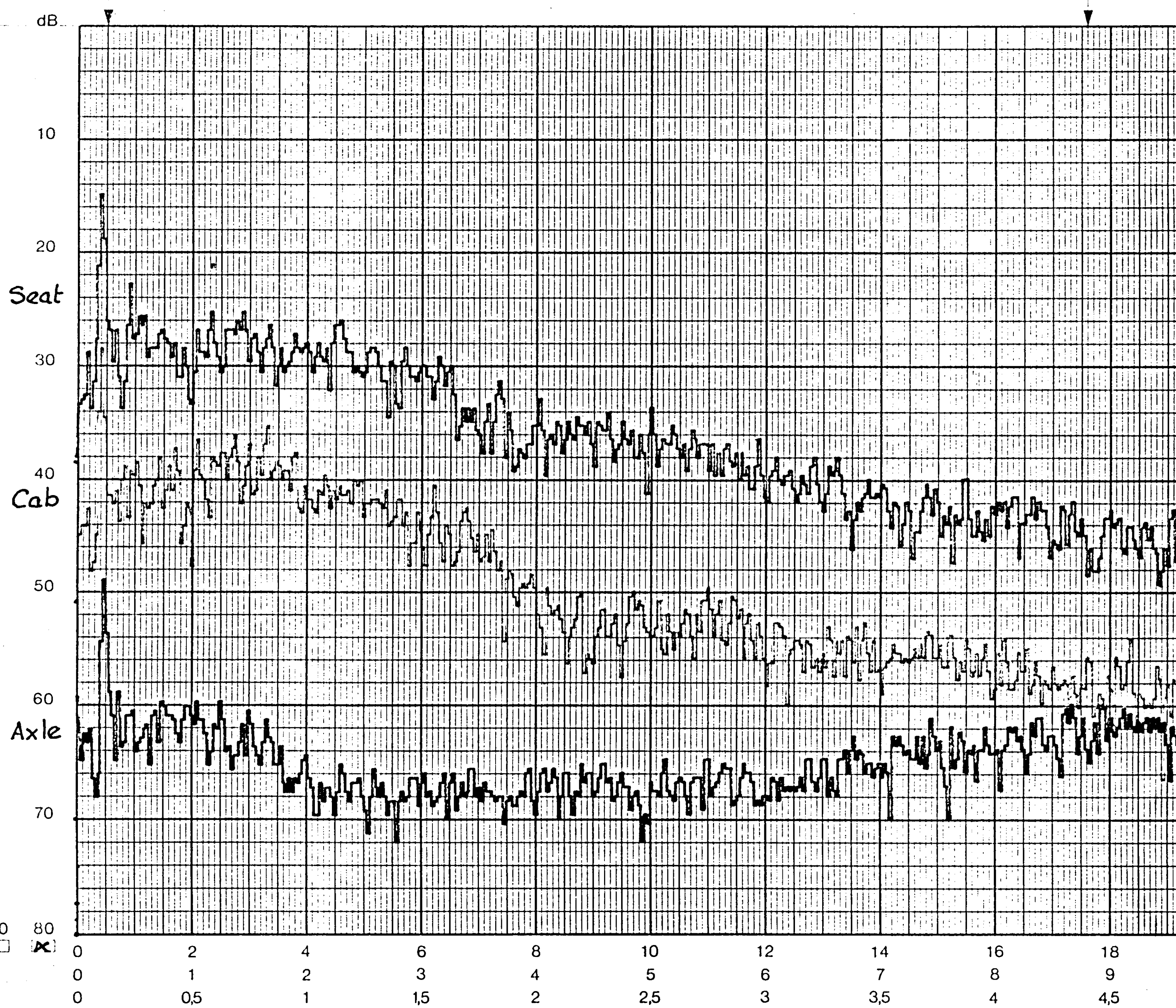
AXLE : 140dB FSL

Each FSL = 1·0m/s²

Record No.: RmK/F/2Y

Date: 15-10-82

Sign.: S Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120 dB.
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 7
Comments: 'Z' axis

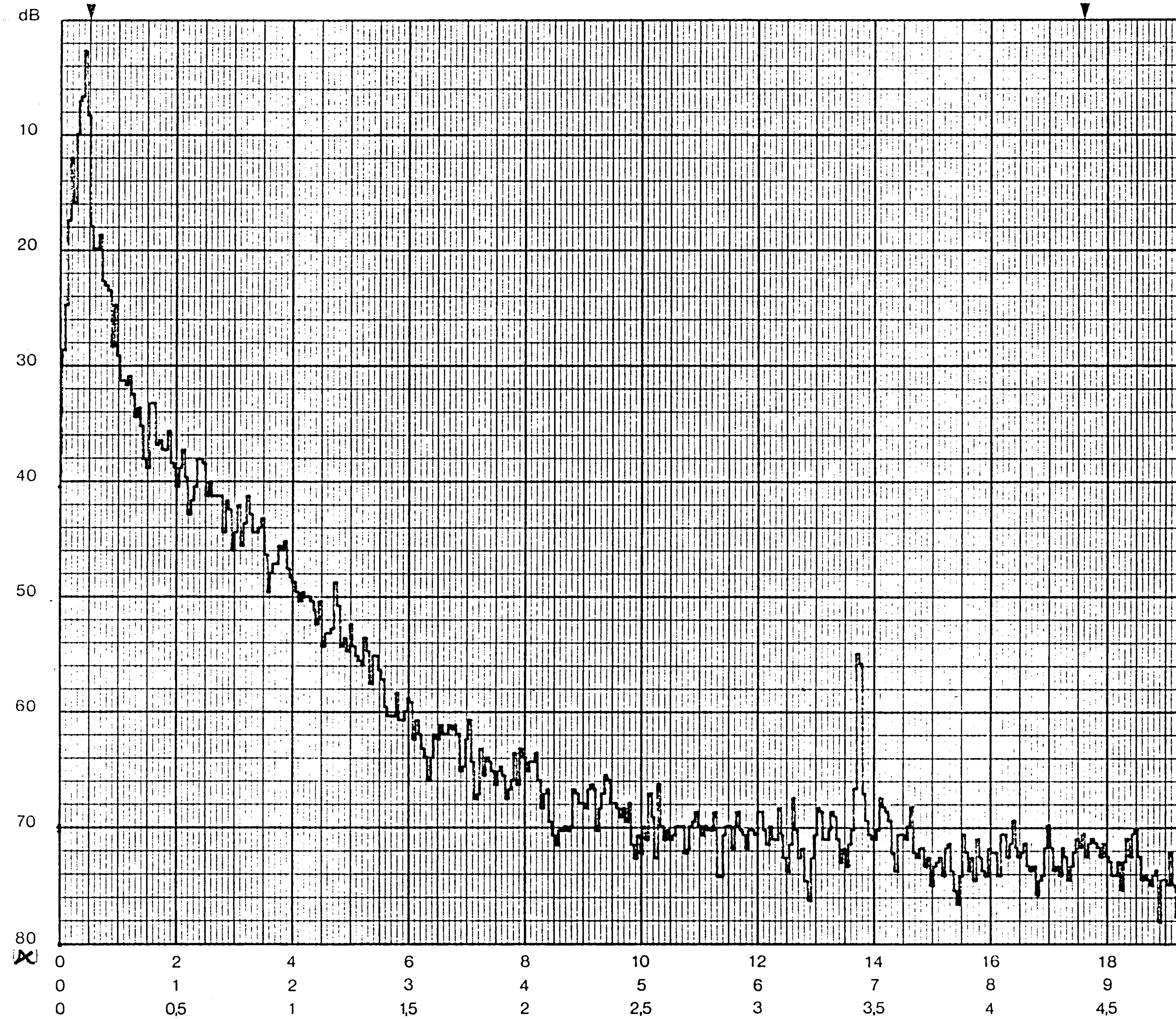
Random Kerb test
faster speed ≈ 8 mph.
JCB '3CX', not new.

SEAT ONLY: for
CAB & AXLE see
other sheet.

120 dB FSL = 100 m/s²

209

Record No.: RmK/F/22
Date: 15-10-82
Sign.: D Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As Below dB

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 7.

Comments: 'Z' axis

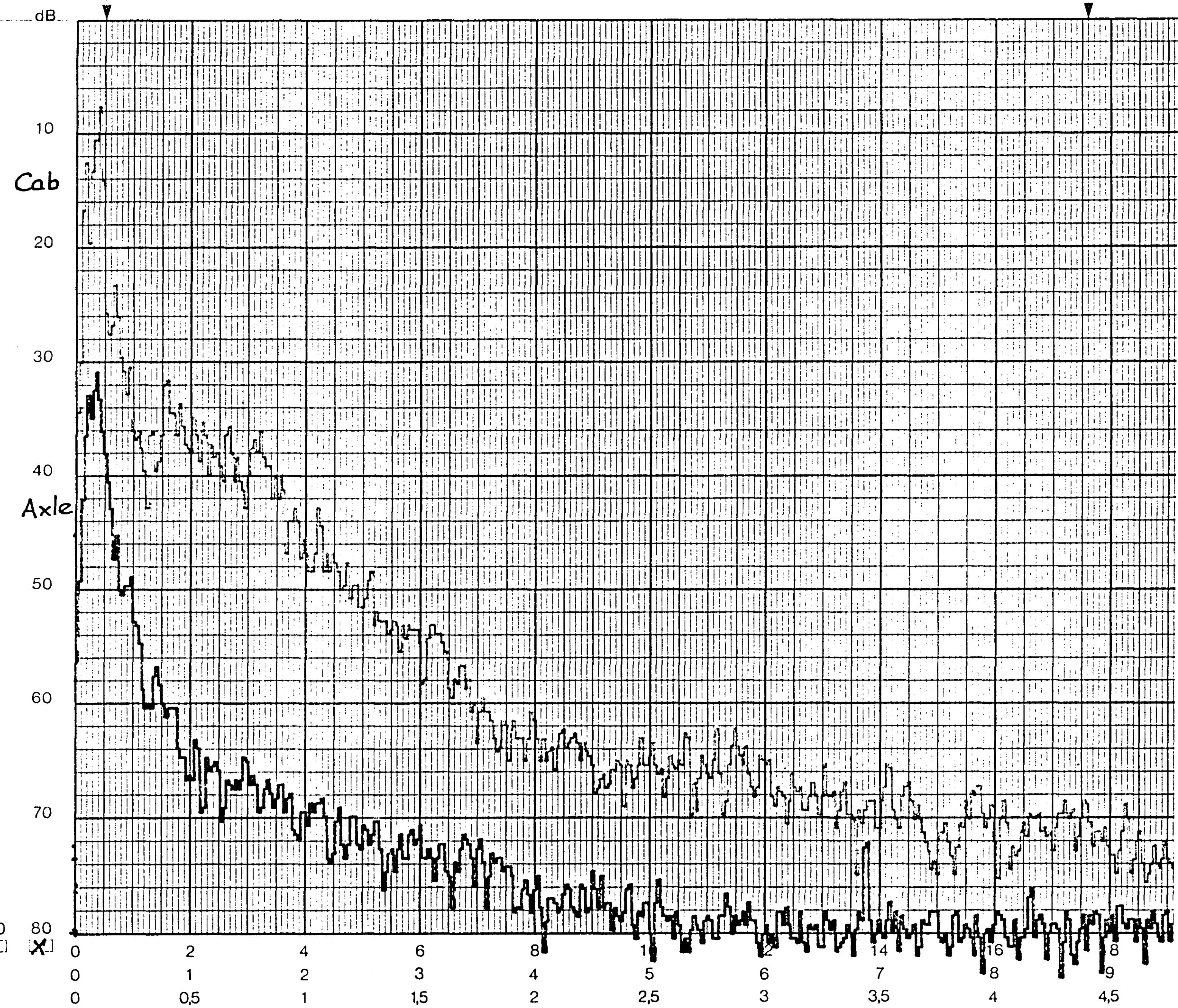
Random Kerb test
faster speed ≈ 8 mph.
JCB '3CX', not new.

SEAT: see other sheet.

210 CAB: 120dB FSL

AXLE: 140dB FSL

Each FSL = 100 m/s²



Record No.: RmK/F/2Z

Date: 15-10-82

Sign. D Douglas

Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: As BELOW.
F. S. Frequency: 100 Hz.
Weighting: Hanning.
Average Mode: Lin.
No. of Spectra: 13.

Comments: 'X' axis.
'Quarry' Floor test
slow speed ≃ 4mph.
JCB '3CX', (not new)

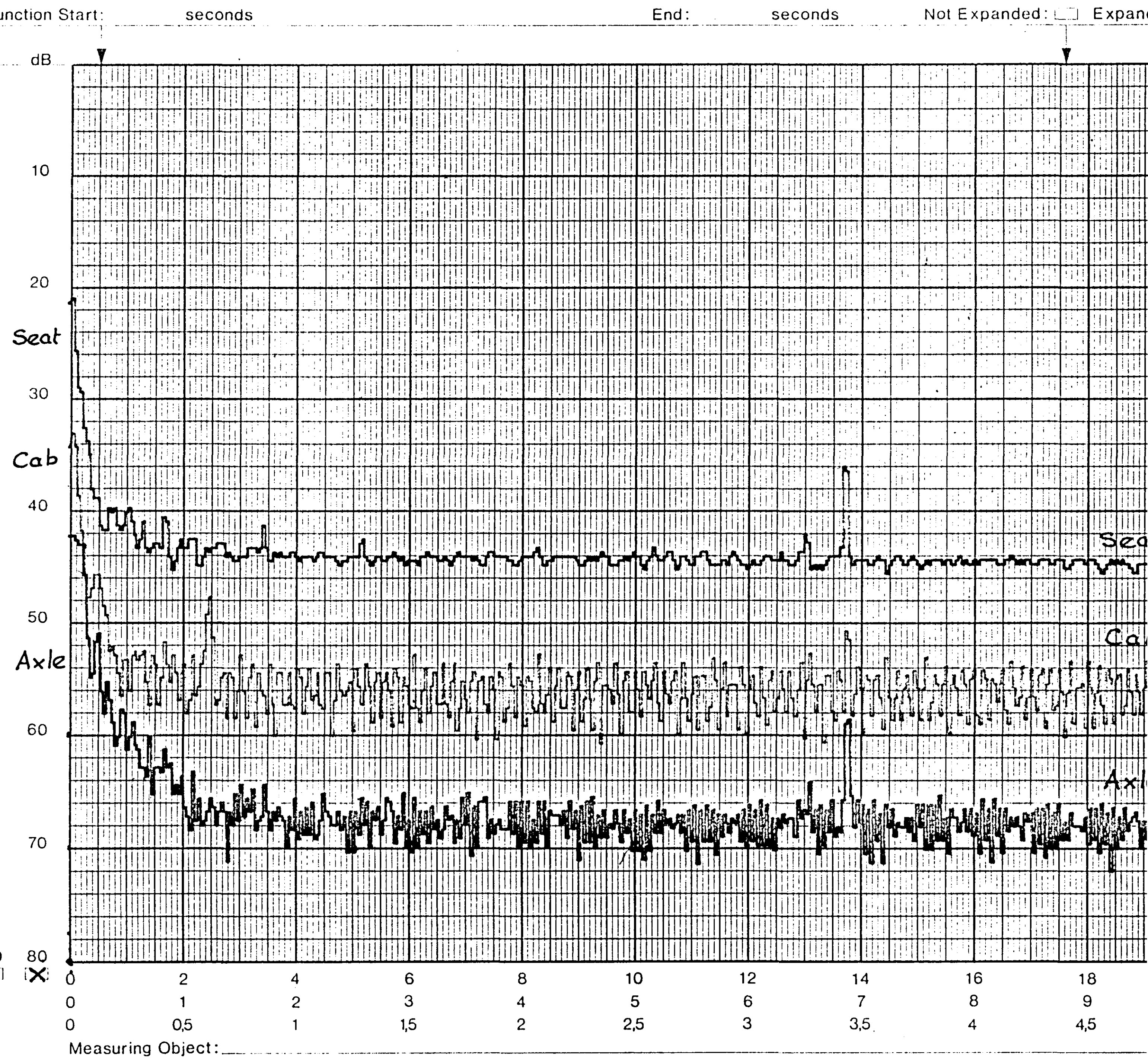
SEAT : 100 dB FSL

CAB : 110 dB FSL

AXLE : 130 dB FSL

Each FSL = $1.0\ m/s^2$

Record No.: QF/5/2X
Date: 15/10/82
Sign.: Douglas



QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

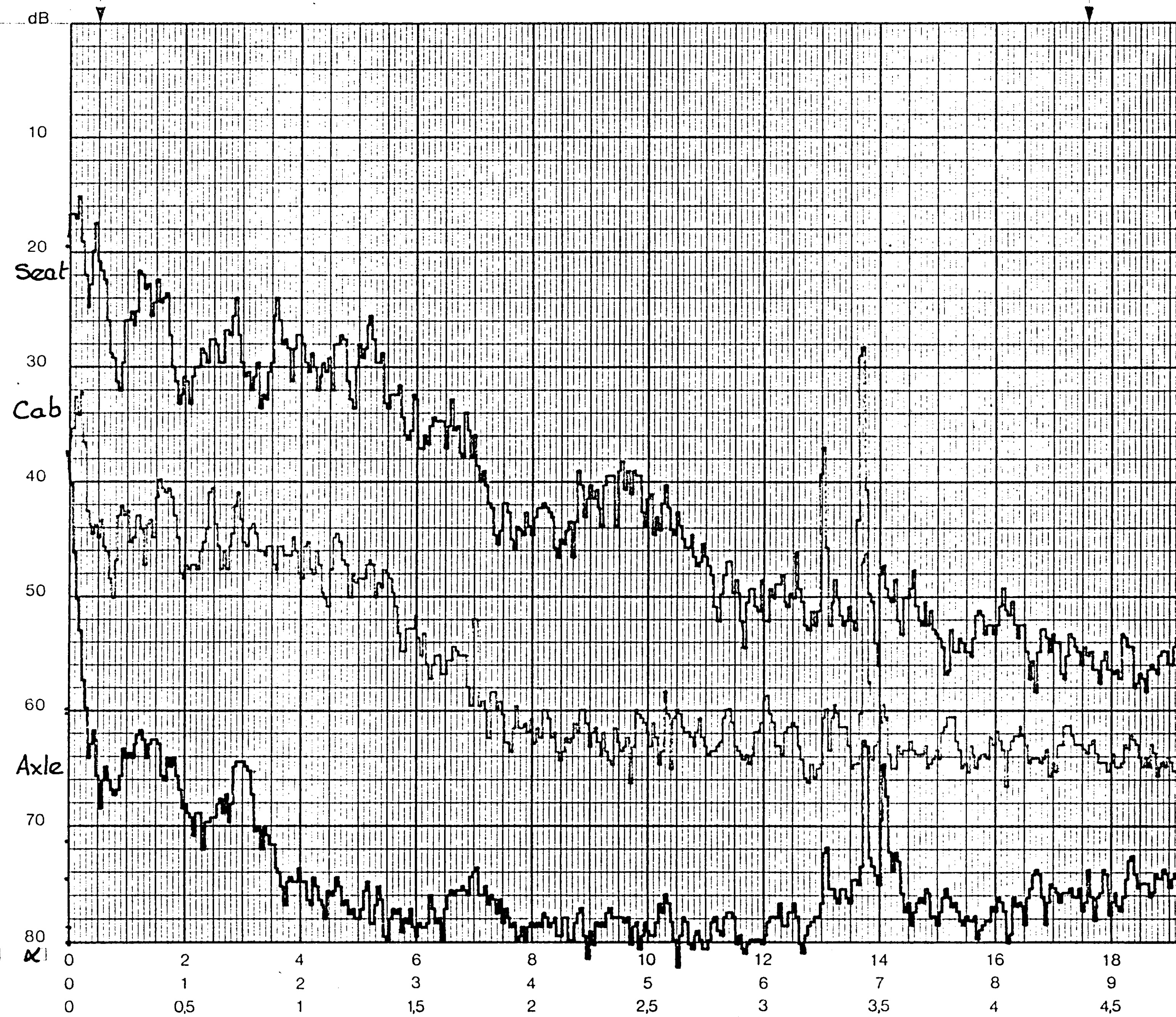
Full Scale Level: As Below.
F. S. Frequency: 100 Hz.
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 13
Comments: 'Y' axis
Quarry Floor test
slow speed ≃ 4mph.
JCB '3CX', not new.

SEAT : 90 dB FSL

CAB : 110 dB FSL

AXLE: 130 dB FSL

Each FSL = 1·0 m/s²



Measuring Object:

Record No.: QF/8/2Y
Date: 15/10/82
Sign.: Douglas

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expan

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 13

Comments: 'Z' axis

Quarry Floor test

slow speed ≃4mph.

JCB '3CX', not new.

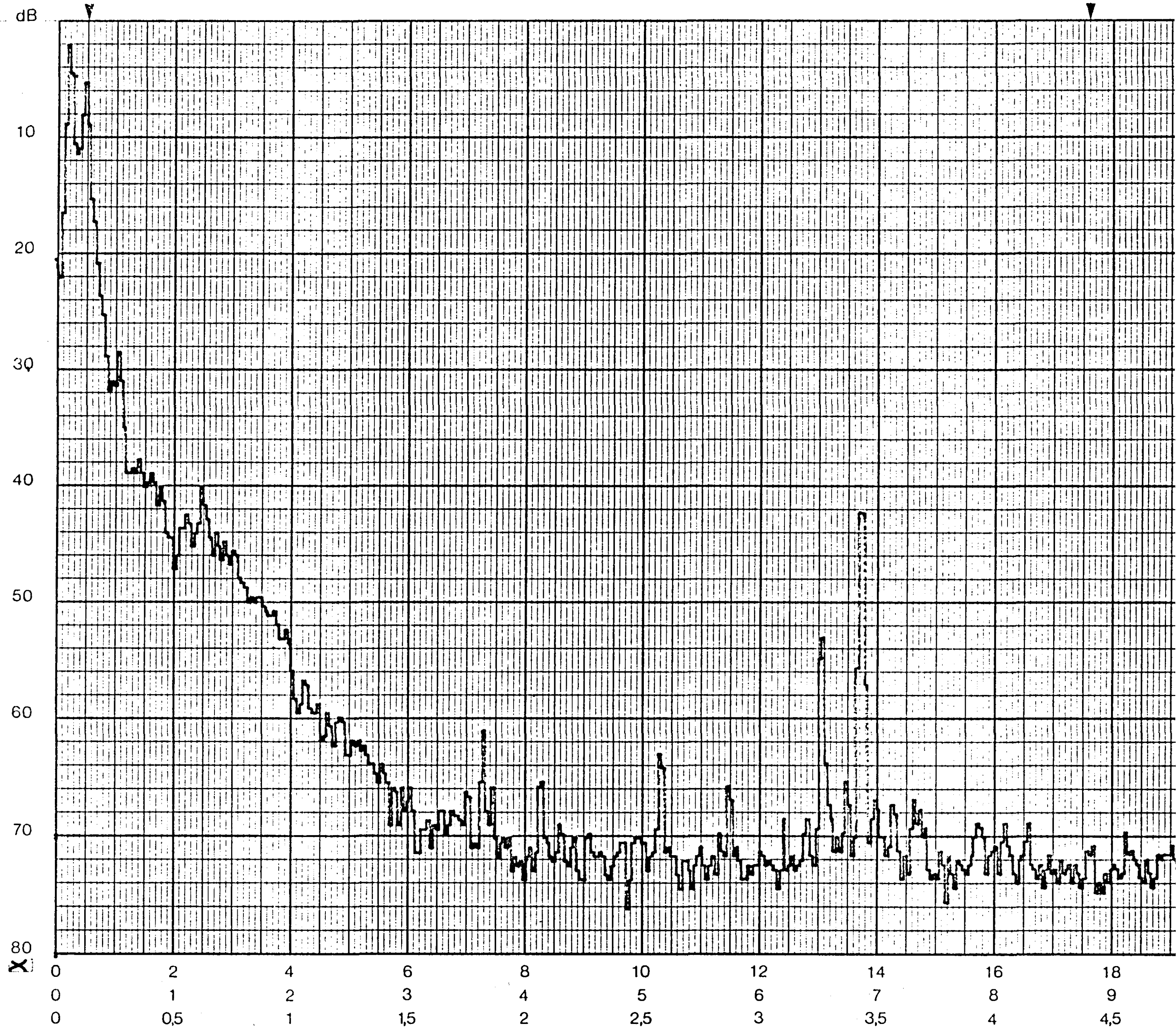
SEAT: 110 dB FSL

"See other sheet

for 'CAB' and

AXLE traces"

213



Record No.: QF/S/2Z

Date: 15/10/82

Sign.: D Douglas

Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 13

Comments: 'Z' axis

Quarry Floor test

slow speed ≃ 4 mph.

JCB '3CX', not new.

SEAT: 110dB FSL

CAB: 110dB FSL

AXLE: 130dB FSL

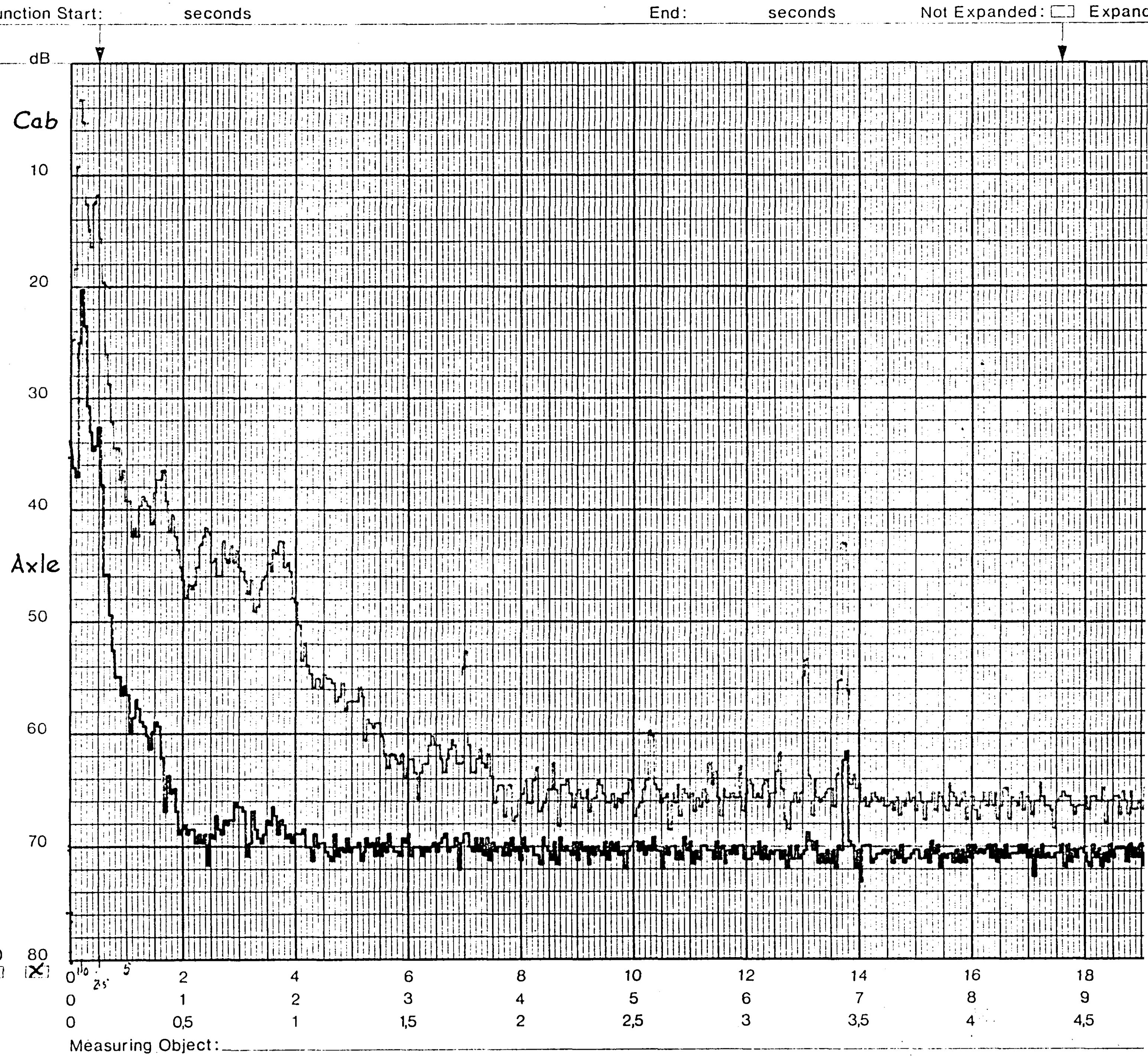
Each FSL = 100 m/s²

"See second sheet for SEAT trace"

Record No.: QF/S/2Z

Date: 15/10/82

Sign.: J Douglas



QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 13.

Comments: 'X' axis

Wave Motion test

slow speed ≈ 4mph.

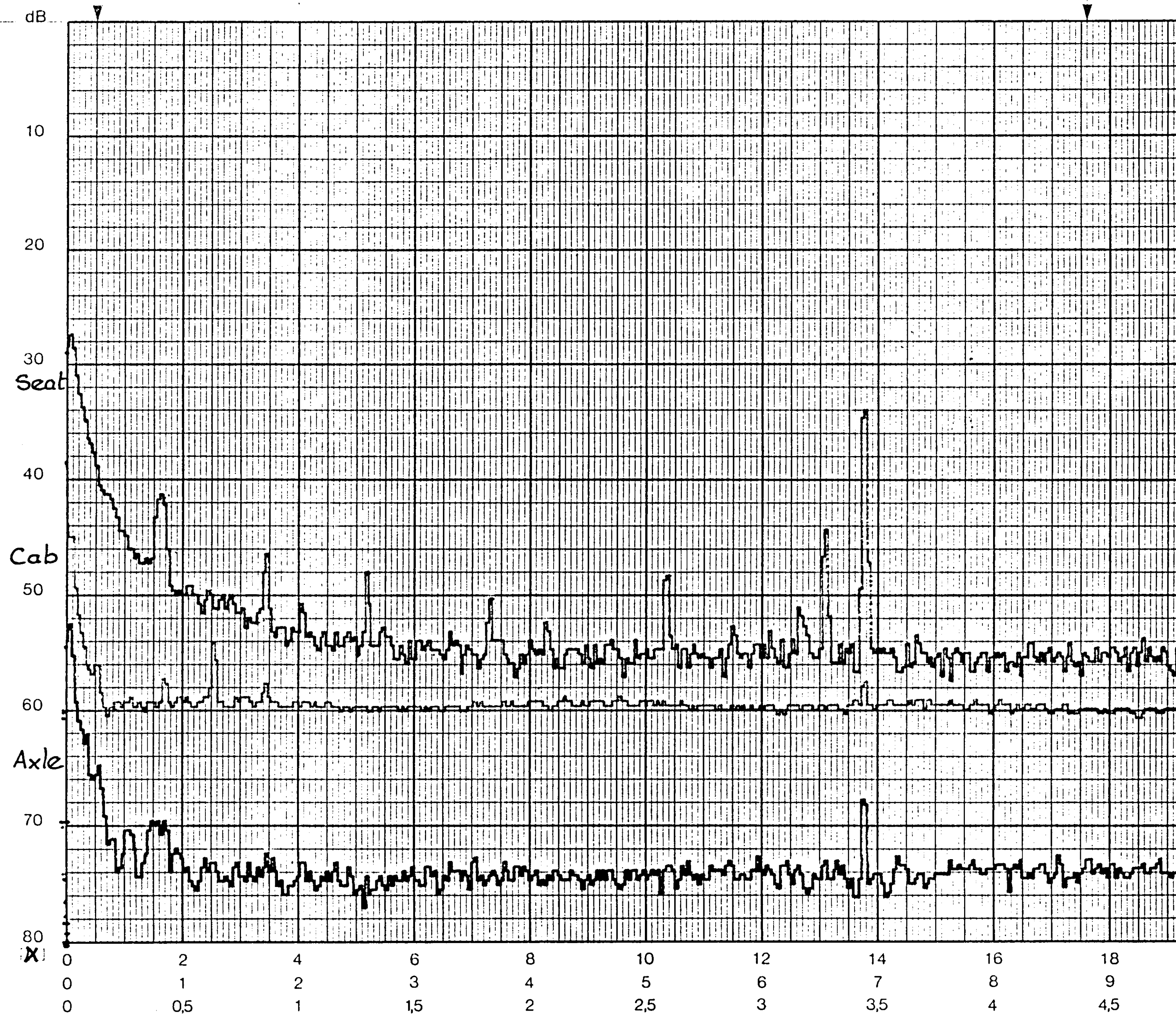
JCB '3CX', not new.

Seat: 100 dB FSL

Cab: 120dB FSL

Axle: 130dB FSL

Each FSL = 1·0 m/s²



Record No.: WM/S/2X

Date: 15/10/82

Sign.: D Douglas

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expanded

Full Scale Level: As Below.

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 13

Comments: 'Y' axis.
Wave Motion test
slow speed ≈ 4mph.
JCB '3CX', not new.

SEAT: 90 dB FSL

CAB: 100 dB FSL

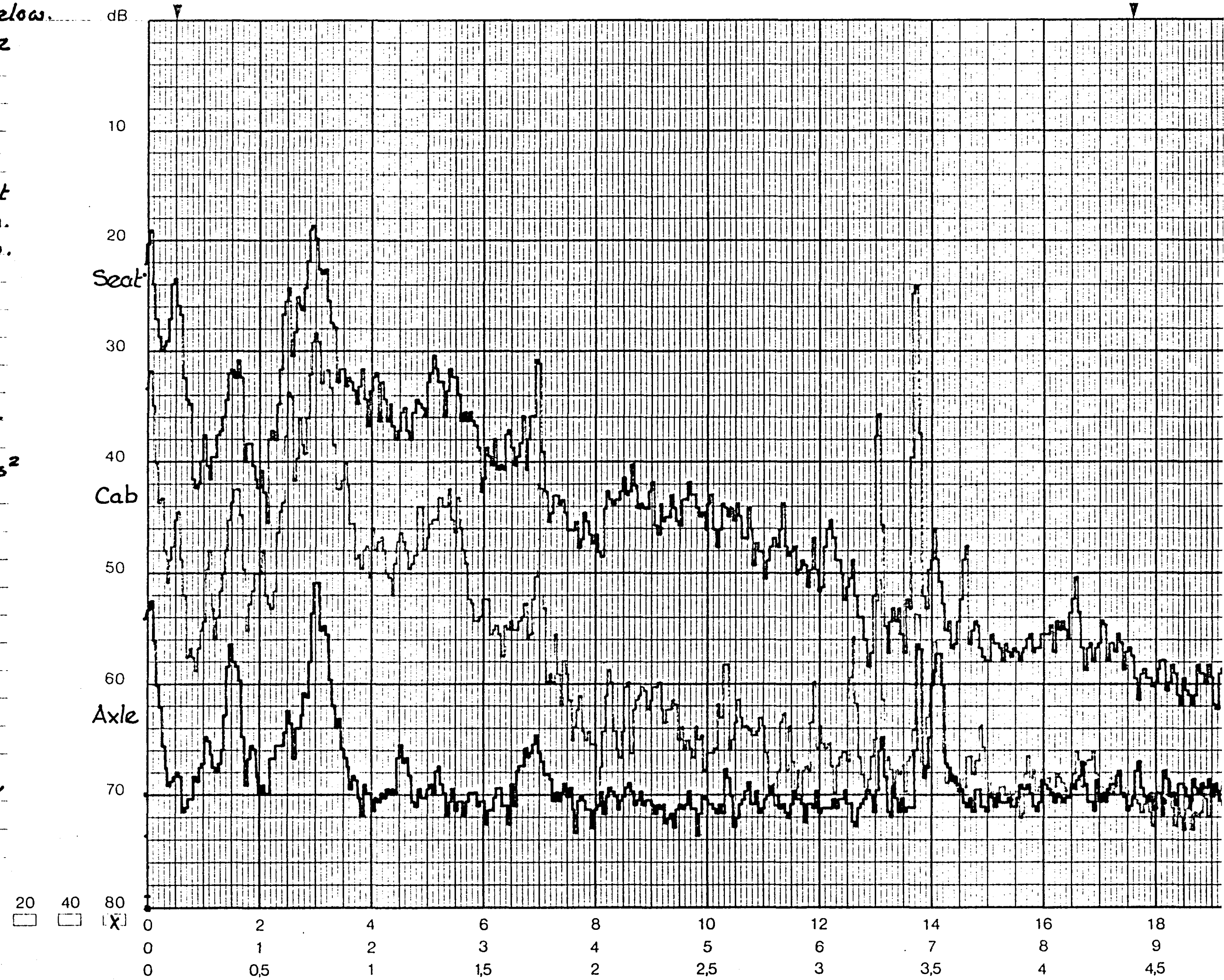
AXLE: 120 dB FSL

Each FSL = 1·0 m/s²

Record No.: WM/3/2Y

Date: 15/10/82

Sign.: D Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As Below.
F. S. Frequency: 100 Hz.
Weighting: Hanning.
Average Mode: Lin.
No. of Spectra: 13

Comments: 'Z' axis
Wave Motion test
slow speed ≃ 4mph.
JCB '3CX', not new.

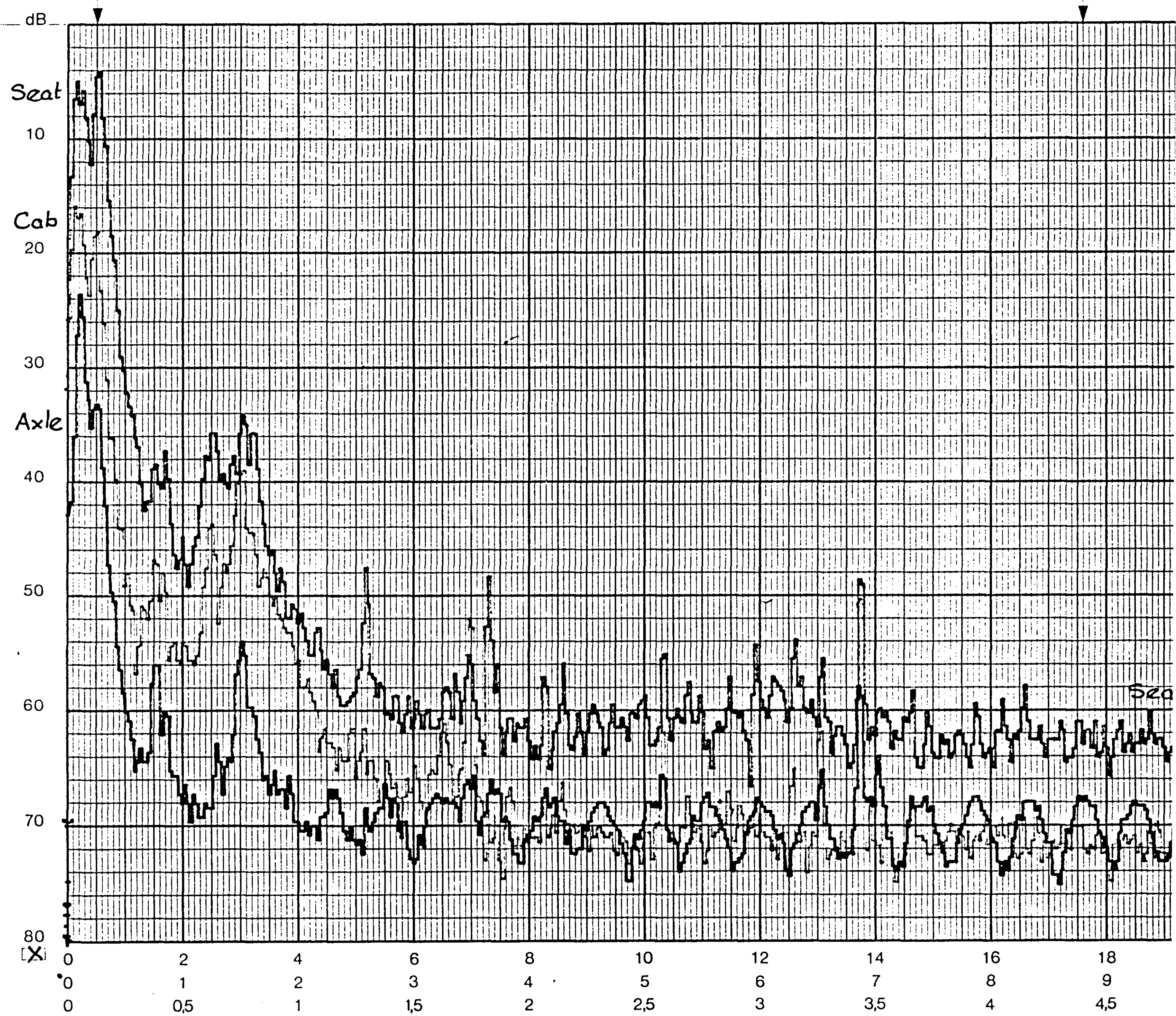
SEAT : 100dB FSL

CAB : 110dB FSL

AXLE : 120dB FSL

Each FSL = 100 m/s²

Record No.: WM/S/22
Date: 15/10/82
Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expand

Full Scale Level: As Below
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 13.
Comments: 'X' axis.

Regular Kerb test
slow speed ≃ 4mph

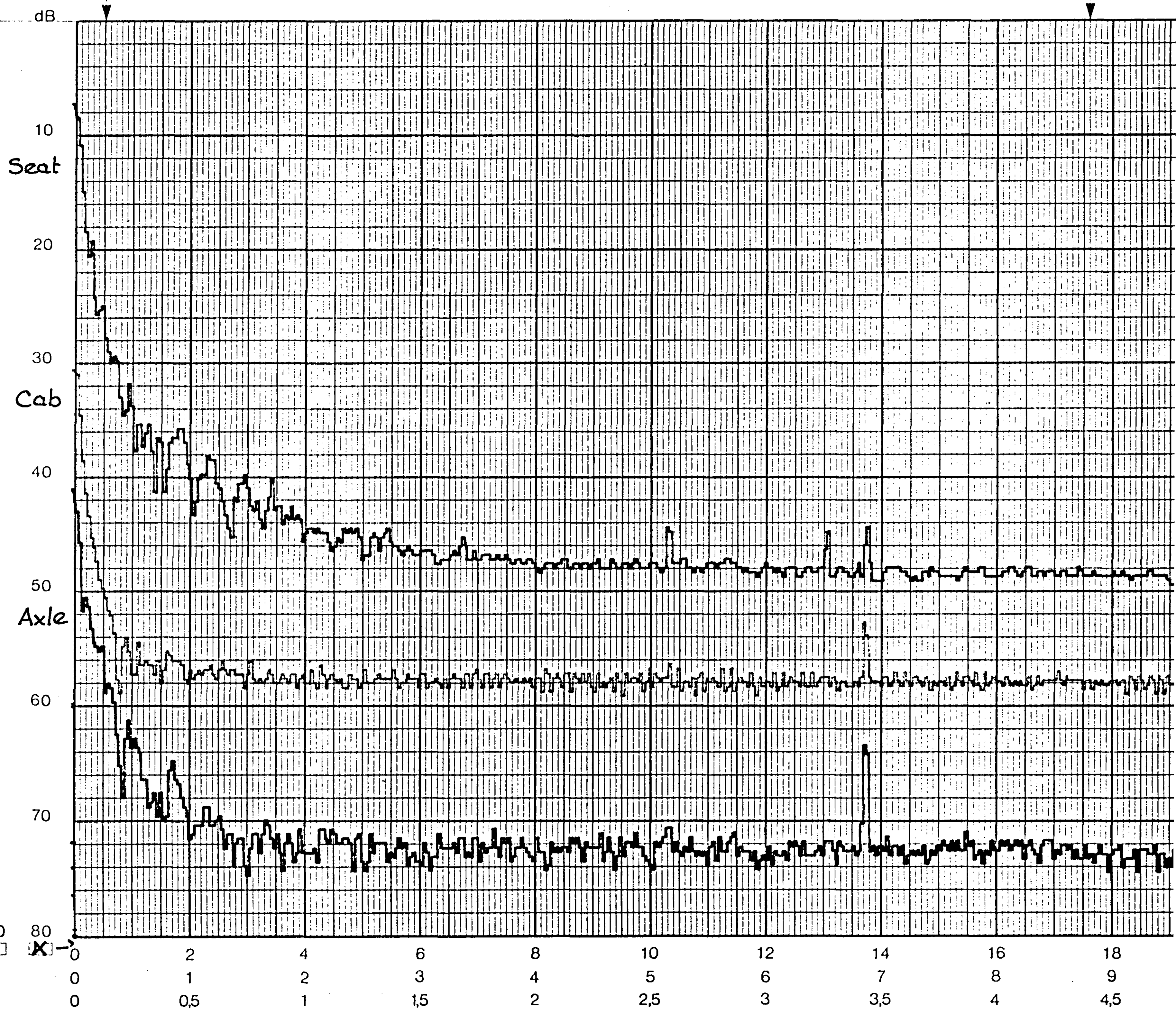
SEAT: 100 dB FSL

CAB: 120dB FSL

AXLE: 130dB FSL

Each FSL = 1·0 m/s²

J.CB. '3CX', not new.



Record No.: RgK/S/2X
Date: 15/10/82
Sign.: Douglas

QP 1002

Measuring Object:

Brüel & Kjær

Time Function Start: seconds   End: seconds   Not Expanded: [ ] Expand

Full Scale Level: As Below. dB
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 13.
Comments: 'Y' axis.

Regular Kerb test.
JCB '3CX', not new.
slow speed ≃ 4 mph

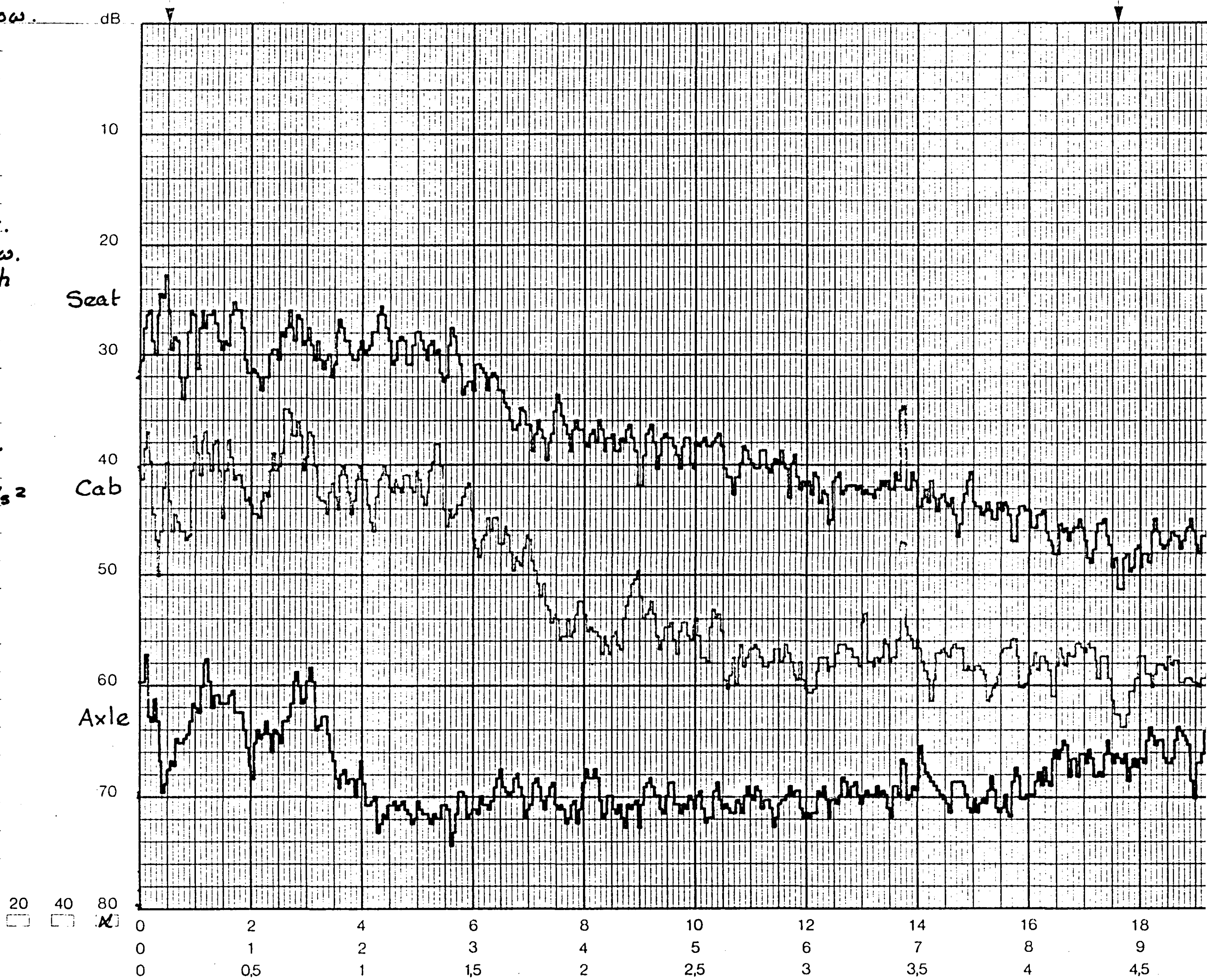
SEAT: 100dB FSL

CAB: 110dB FSL

AXLE: 130dB FSL

Each FSL = $1 \cdot 0 \, m/s^2$

Record No.: RgK/S/2Y
Date: 15/10/82
Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær Time Function Start: seconds End: seconds Not Expanded: [ ] Expan

Full Scale Level: 120dB.
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 13
Comments: Z axis

Regular Kerb test,
slow speed ≈4mph.
JCB '3CX', not new.

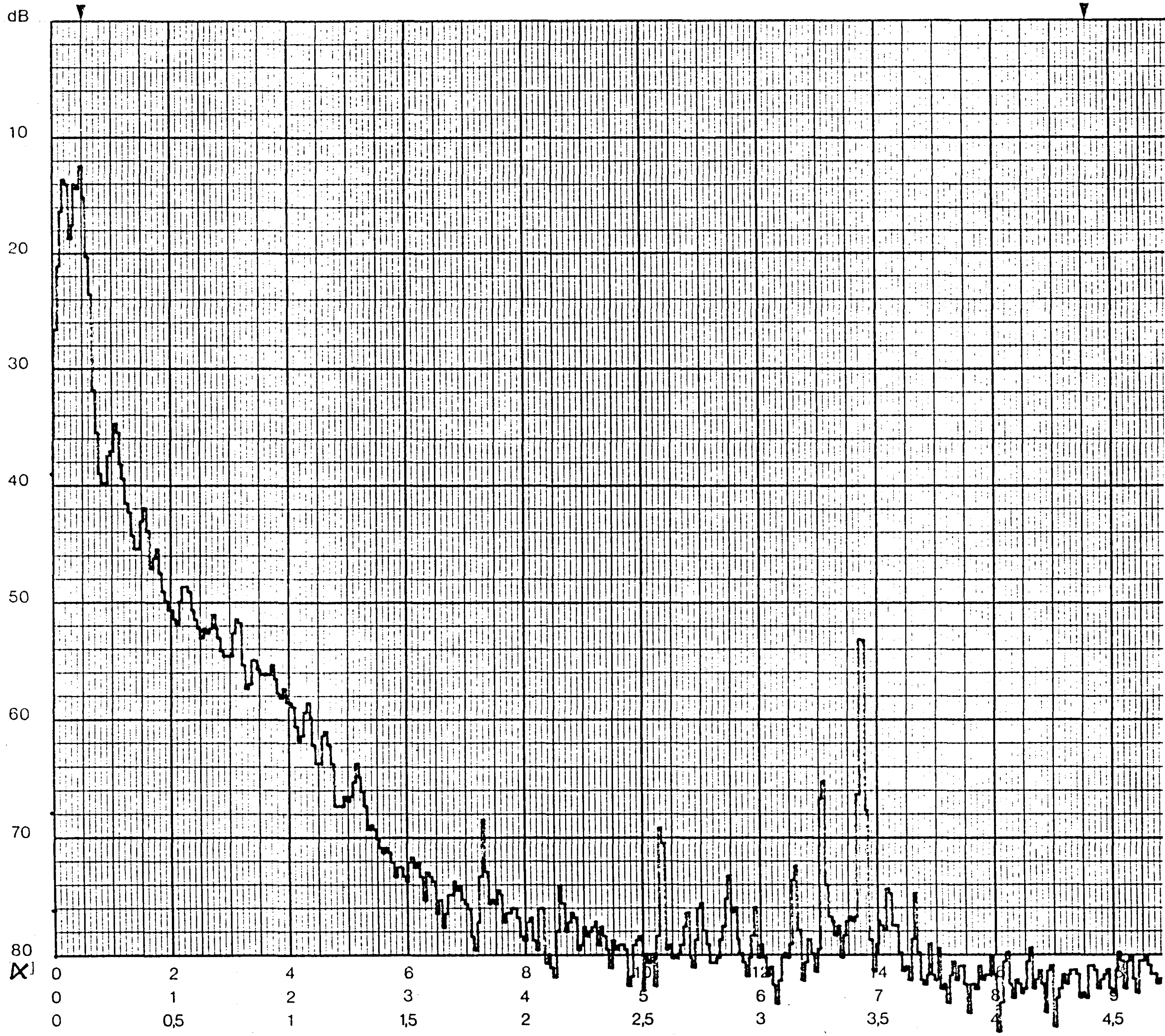
SEAT ONLY: 120dBFSL

For CAB & AXLE
see other sheet.

220

Record No.: RgK/3/2Z
Date: 15/10/82
Sign.: D Douglas

20 [ ] 40 [ ] 80 [X]



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 13

Comments: 'Z'axis

Regular Kerb test.
slow speed ≃ 4mph.
JCB '3CX', not new.

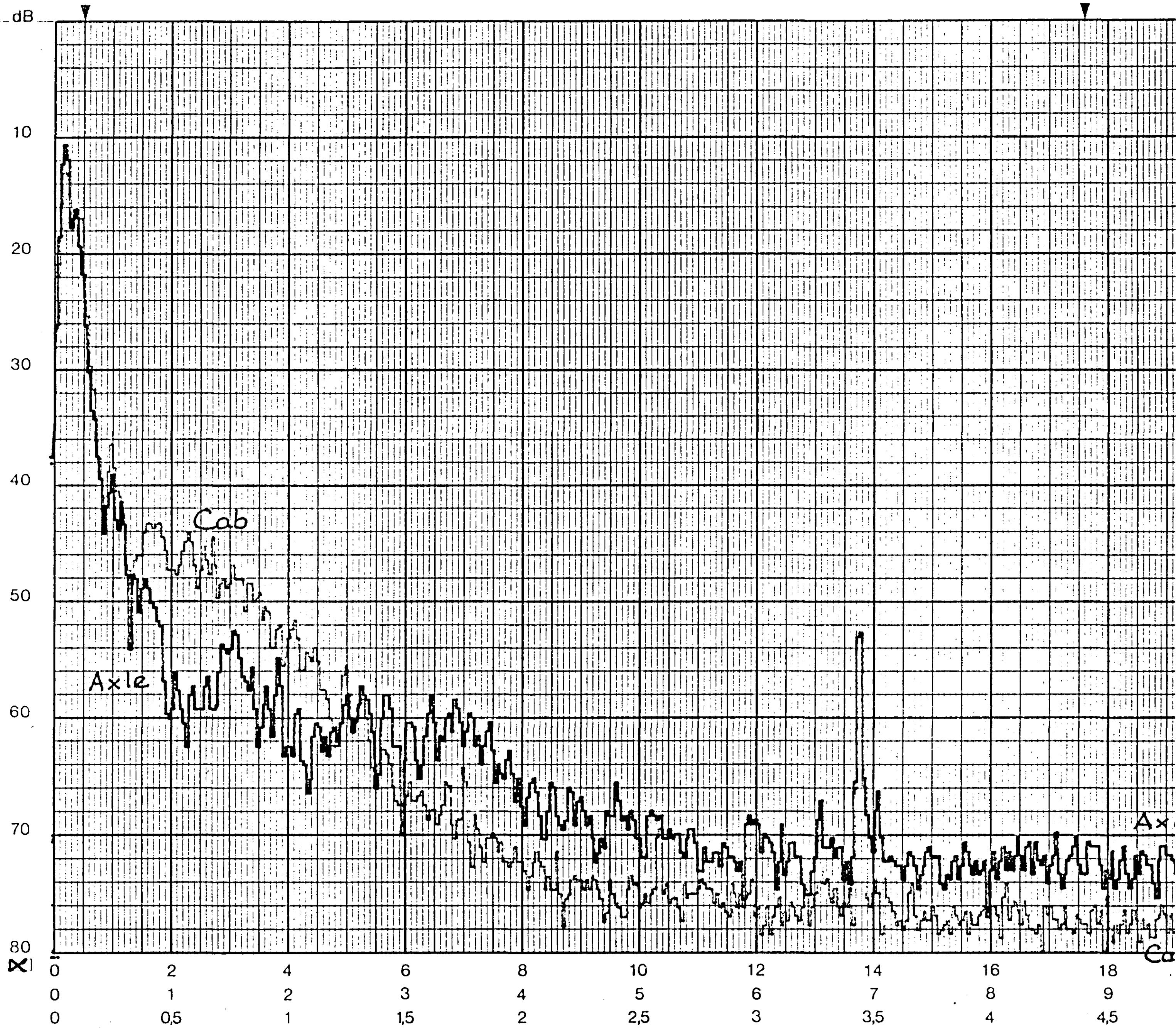
SEAT: see other sheet.

CAB: 120dB FSL

221

AXLE: 120dB FSL

Each FSL = $100 m/s^2$



Record No.: RgK/S/2Z

Date: 15/10/82

Sign.: Douglas

20 ☐ 40 ☐ 80 ☒

Measuring Object:

QP 1002

Bruel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expand

Full Scale Level: As BELOW. dB

F. S. Frequency: 100 Hz.

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 13.

Comments: 'X' axis

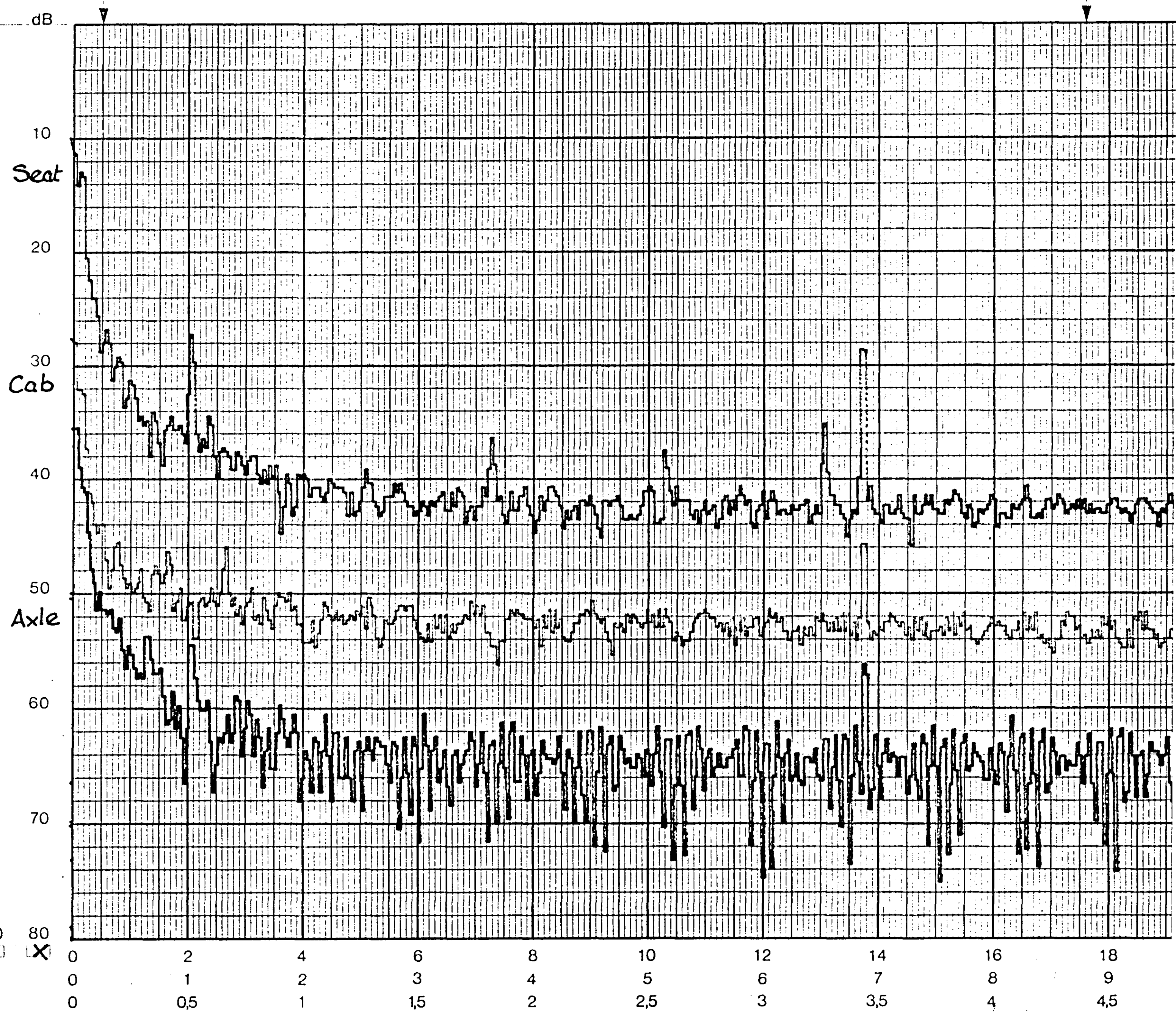
Random Kerb test slow speed ≃ 4mph. JCB '3CX', not new.

SEAT: 90 dB FSL

CAB: 110 dB FSL

AXLE: 120 dB FSL.

Each FSL = $1\cdot0\ m/s^2$



Record No.: RmK/S/2X.

Date: 15/10/82.

Sign.: D Douglas

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: As Below

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 13.

Comments: 'Y' axis.

Random Kerb test.
slow speed ≃ 4 mph.
JCB '3CX', not new.

SEAT : 110dB FSL

CAB : 120dB FSL

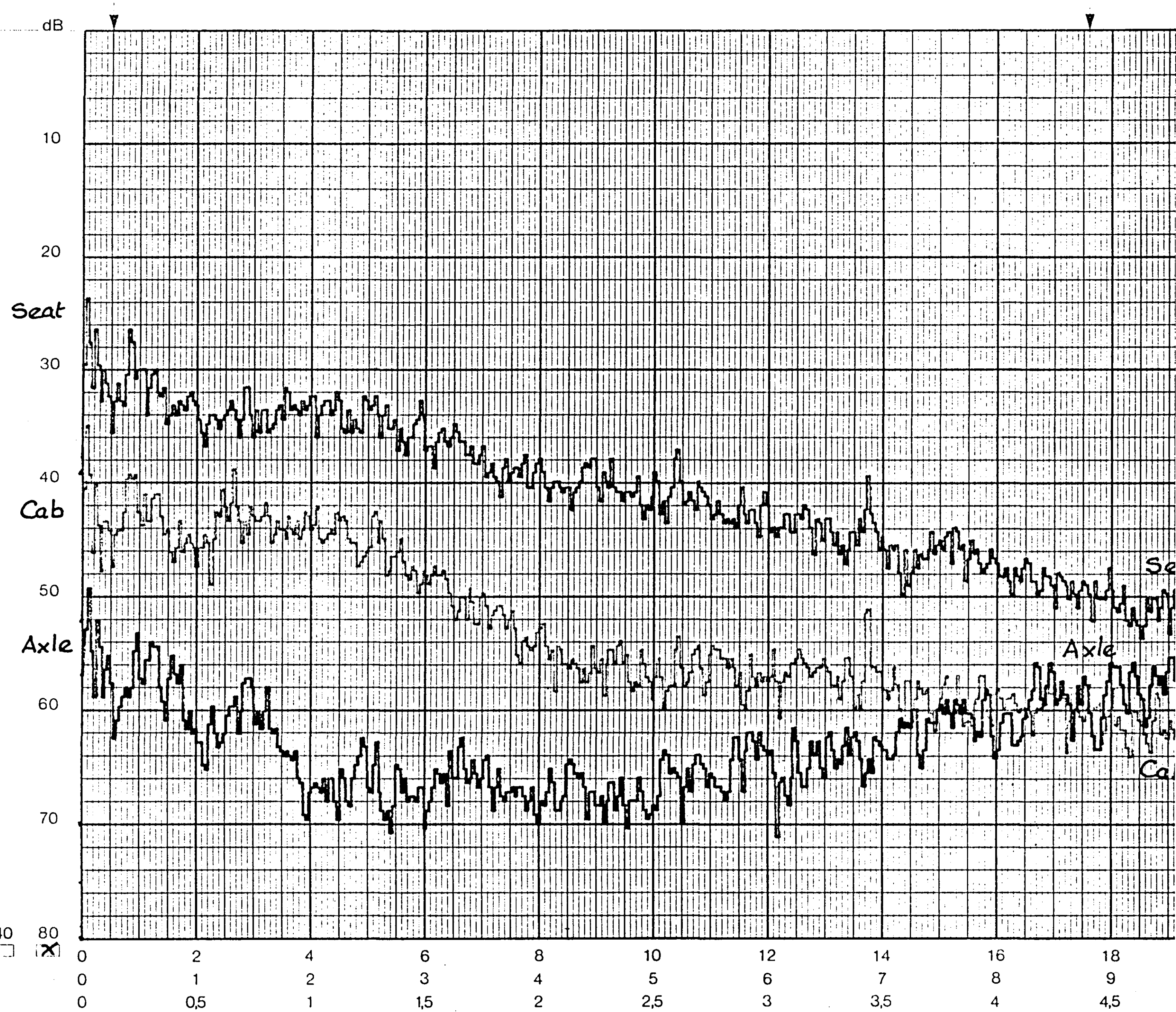
AXLE : 140dB FSL

Each FSL = 1·0 m/s²

Record No.: RmK/S/2Y

Date: 15/10/82

Sign.: [signature]



Measuring Object:

QP 1002

Bruel & Kjær   Time Function Start: ____ seconds   End: ____ seconds   Not Expanded: Expand

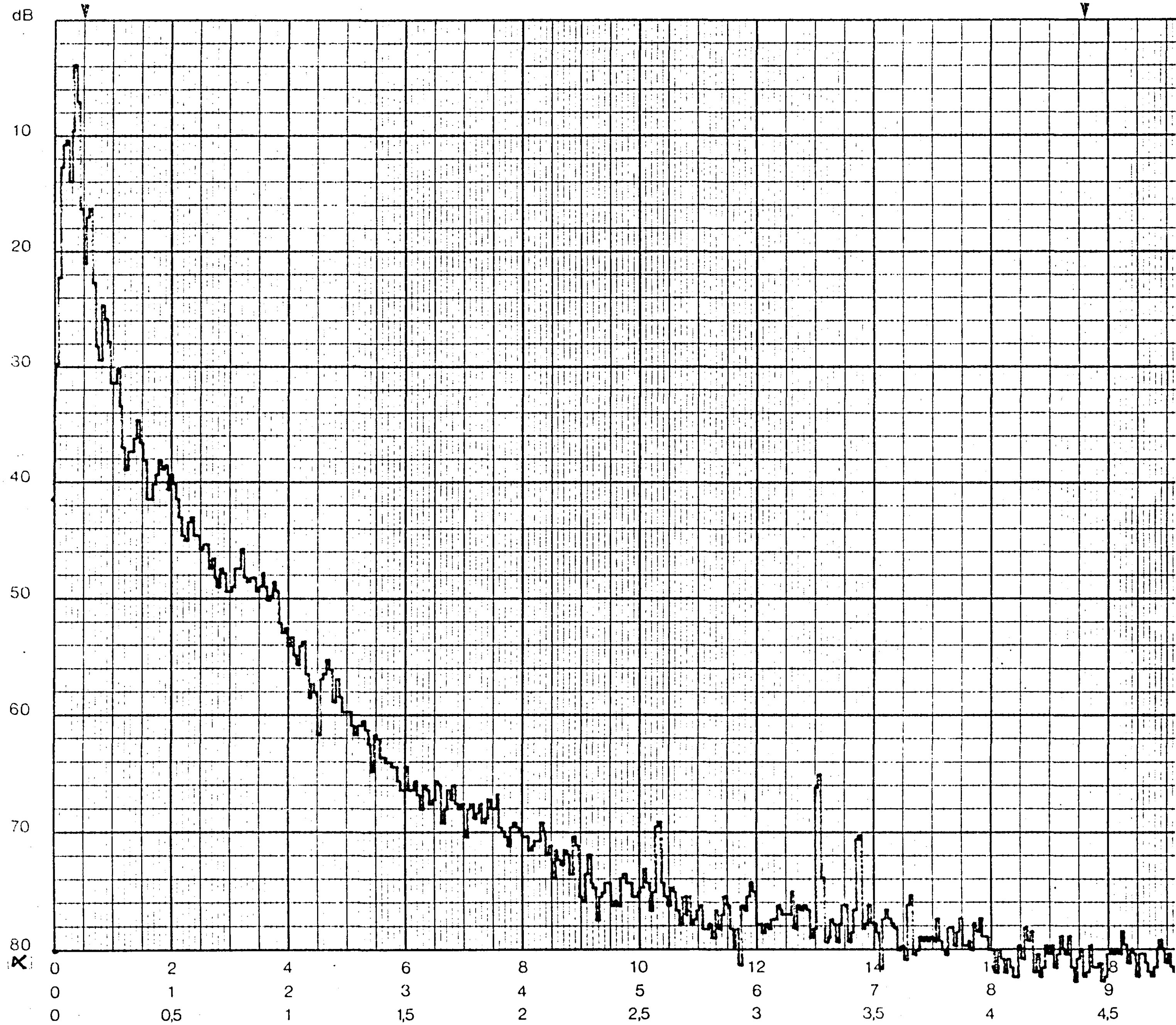
Full Scale Level: 120 dB.
F. S. Frequency: 100 Hz
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 13
Comments: Z axis

Random Kerb test
slow speed ≃4mph.
JCB '3CX', not new.

SEAT ONLY: see
other sheet for
CAB & AXLE

224

FSL = 100 m/s²



Measuring Object: ____

Record No.: RmK/3/2Z
Date: 15/10/82
Sign.: Douglas

QP 1002

Bruel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expan

Full Scale Level: As Below.

F. S. Frequency: 100 Hz

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 13

Comments: 'Z axis.

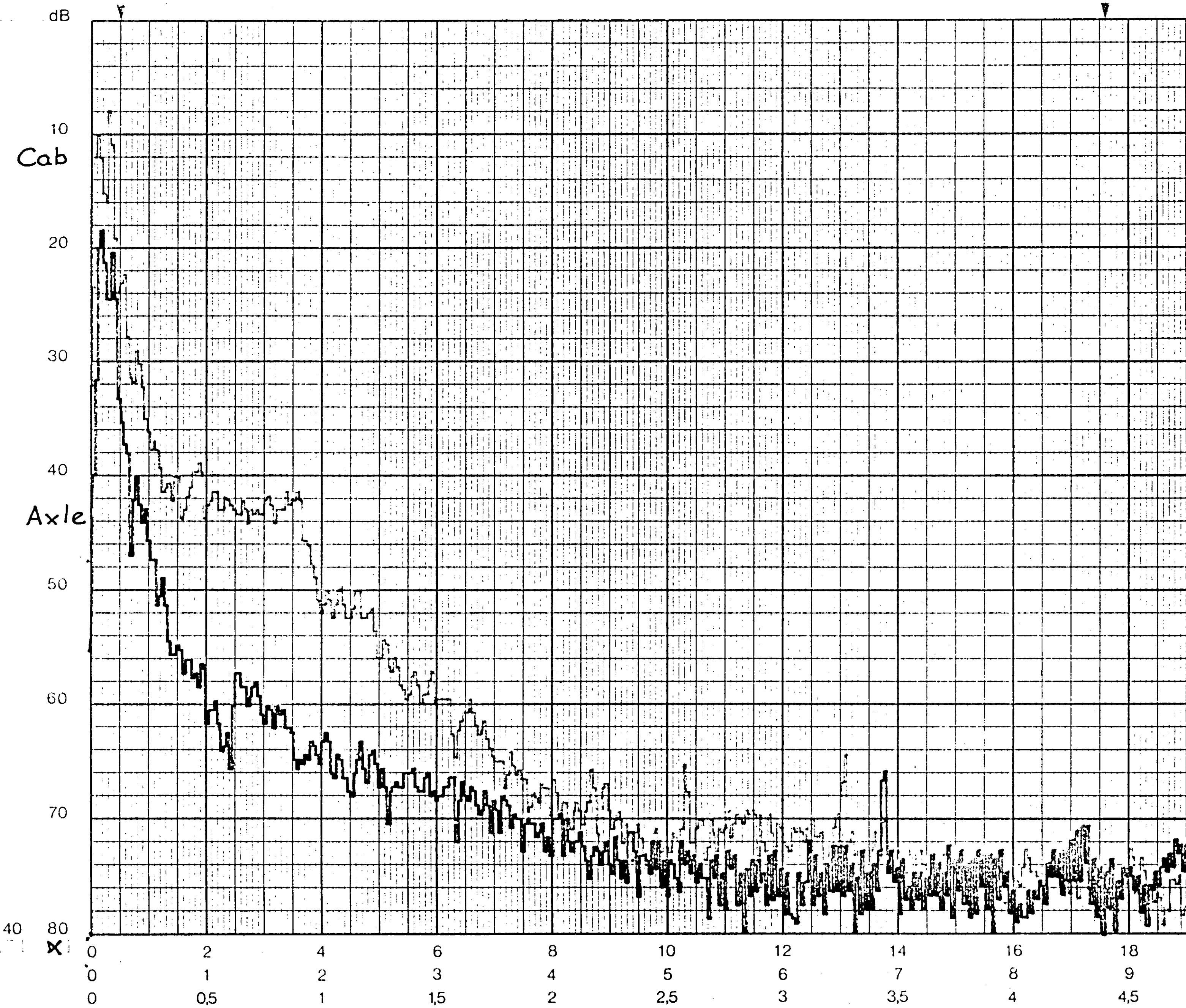
Random Kerb test.
slow speed ≃ 4 mph.
JCB. '3CX', not new.

SEAT : See other sheet.

CAB : 120 dB FSL

AXLE : 130 dB FSL

Each FSL = 100 m/s²



Record No.: RmK/S/2Z

Date: 15/10/82

Sign.: D Douglas

Measuring Object:

QP 1002

APPENDIX 'D'

Computer programmme for the analysis of results from Appendix 'C' to provide:

1 for each of 30 frequencies between 1Hz and 80Hz the following information:-

(a) conversion of acceleration from dB to m/s^2

(b) amplification - attenuation ratios for

$\frac{\text{Seat}}{\text{Axle}}$; $\frac{\text{Seat}}{\text{Cab}}$; $\frac{\text{Cab}}{\text{Axle}}$

2 At seat, cab and axle the following statistical data:- mean, variance, standard deviation.

3 Correlation coefficient for Axle : Seat ; Cab : Seat ; Axle : Cab.

APPENDIX D

COMPUTER PROGRAMME : 'VIBAN'

The programme, in 'MBASIC', operates on the 'dB' spectral density values in the frequency analyses from accelerometer locations at axle, cab and seat to produce:-

(i) acceleration values in m/s^2,

(ii) acceleration ratios for $\frac{\text{seat}}{\text{axle}}$; $\frac{\text{seat}}{\text{cab}}$; $\frac{\text{cab}}{\text{axle}}$

(iii) values of the mean, variation and standard deviation of acceleration at each location.

(iv) correlation coefficients with respect to:-
axle : seat; cab : seat; axle : cab

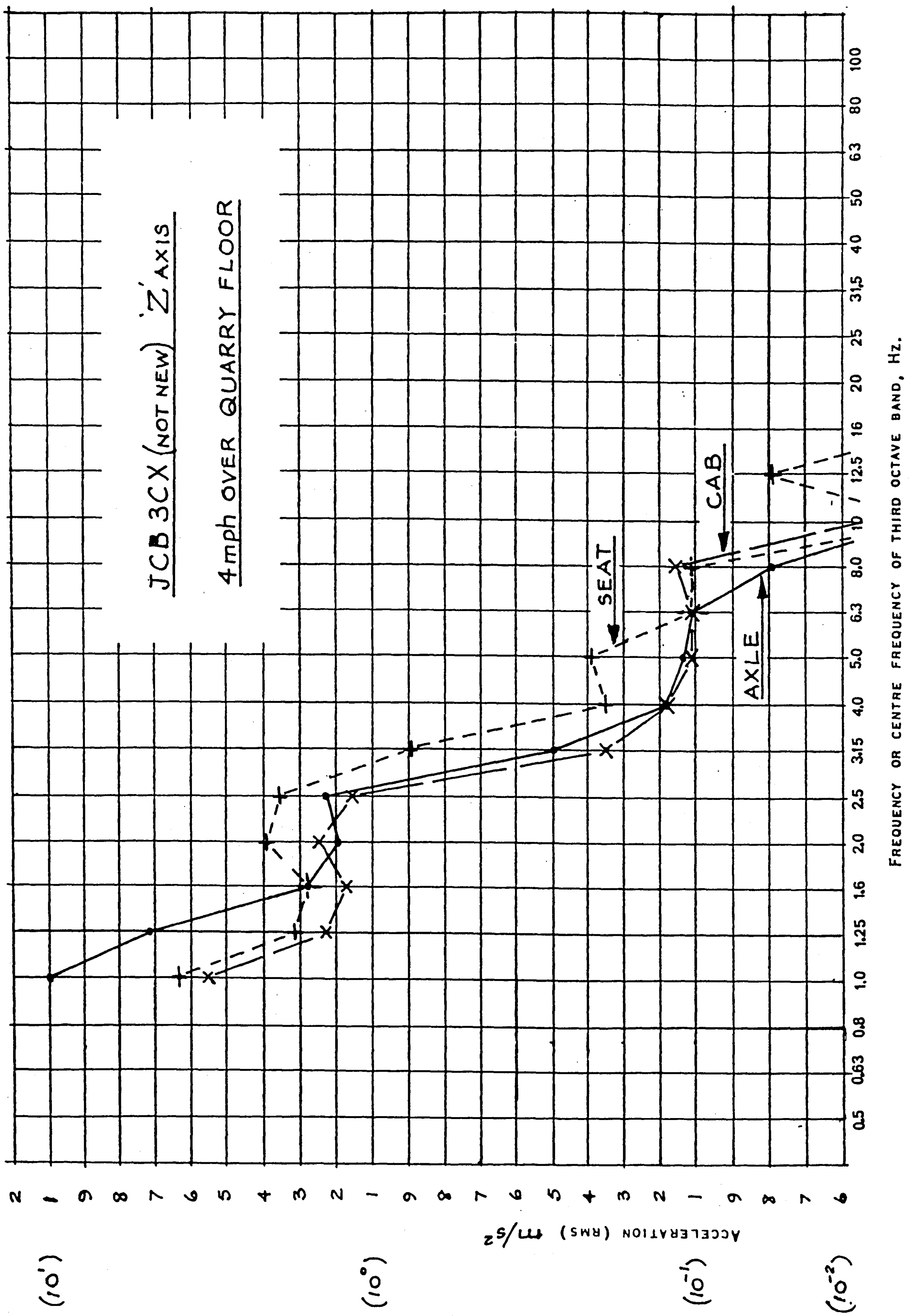
The principal frequencies for (i) and (ii) above were the twenty, one-third octave centre frequencies from 1Hz to 80Hz in IS02631:1978(E). To improve the validity of the statistical data from (iii) and (iv) ten further frequencies re-spectral density were included. These frequencies had the remaining highest accelerations recorded at the seat of the machine to which cab and axle values were related.

```
5 LPRINT CHR$(18)
10 PRINT TAB(28) "VIBRATION ANALYSIS PROGRAM"
20 PRINT
30 DIM SV(30),CV(30),AV(30),SA(30),CA(30),AA(30),HZ(30),RSA(30),RSC(30),
     RCA(30)
40 REM    DATA INPUT
50 INPUT  "ENTER FULL SCALE LEVEL FOR SEAT CAB AND AXLE IN
          m/s^2";SFS,CFS,AFS
60 PRINT
70 PRINT "ENTER THE dB LEVELS FOR SEAT CAB AND AXLE FOR THE FOLLOWING
          FREQUENCIES":PRINT
80   FOR I = 1 TO 30
90       READ HZ(I)
100      PRINT HZ(I); "Hz";
110      INPUT SV (I),CV(I),AV(I)
120      PRINT
130  NEXT I
140 DATA 1,1.25,1.6,2,2.5,3.15,4,5,6.3,8,10,12.5,16,20,25,31.5,40,50,63,80
150 DATA
160 LPRINT " NO.  FREQUENCY (Hz)  SEAT ACC (dB)  CAB ACC (dB)  AXLE ACC
           (dB)"
170 LPRINT
180  FOR I = 1 TO 30
190      LPRINT USING " ££       £££.££            £££.£            £££.£
                         £££.£";I,HZ(I),SV(I),CV(I),AV(I)
200  NEXT I
210 LPRINT:LPRINT "FULL SCALE LEVEL FOR SEAT = ";SFS;"M/S^2"
220 LPRINT "FULL SCALE LEVEL FOR CAB = ";CFS;"M/S^2"
230 LPRINT "FULL SCALE LEVEL FOR AXLE =";AFS;"M/S^2"
240 LPRINT
300 REM   CALCULATIONS
310  FOR I = 1 TO 30
320      SA(I) = SFS * (10^(SV(I)*.1/2))
330      SUMS = SUMS + SA(I)
340      SQS = SQS + (SA(I)^2)
350      CA(I) = CFS * (10^(CV(I)*.1/2))
360      SUMC =SUMC + CA(I)
370      SQC = SQC + (CA(I)^2)
380      AA(I) = AFS * (10^(AV(I)*.1/2))
390      SUMA = SUMA + AA(I)
400      SQA = SQA + (AA(I)^2)
410  NEXT I
420 SM = SUMS/30
430 CM = SUMC/30
440 AM = SUMA/30
450 SASS = SUMS^2
460 CASS = SUMC^2
470 AASS = SUMA^2
480  FOR I = 1 TO 30
490      VS = VS + (SA(I)-SM)^2
500      VC = VC + (CA(I)-CM)^2
510      VA = VA + (AA(I)-AM)^2
520      RSA(I) = SA(I)/AA(I)
530      RSC(I) = SA(I)/CA(I)
540      RCA(I) = CA(I)/AA(I)
```

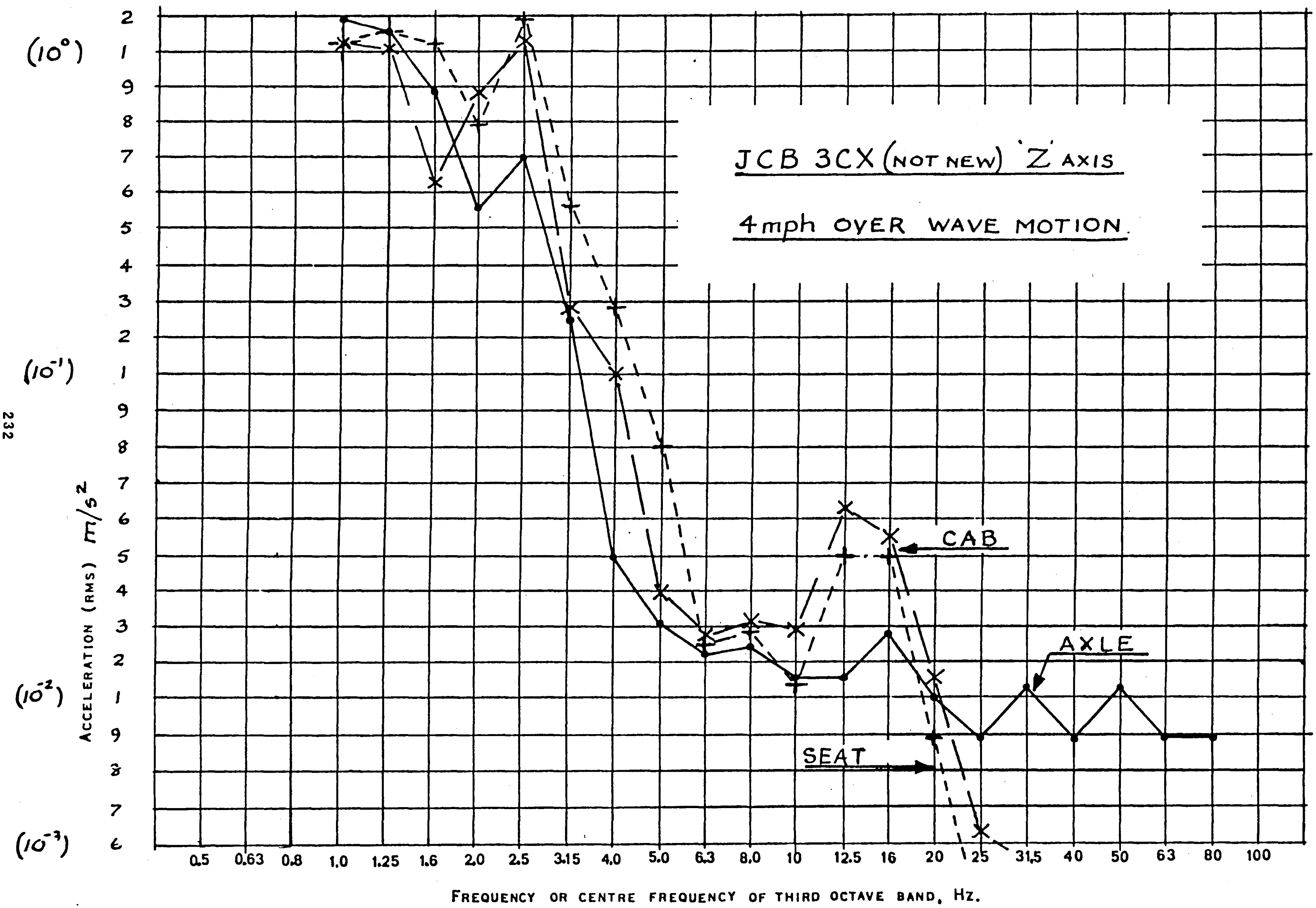
```
550       SAS = SAS + (AA(I)*SA(I))
560       SCS = SCS + (CA(I)*SA(I))
570       SAC = SAC + (AA(I)*CA(I))
580   NEXT I
590 VS = VS/29
600 VC = VC/29
610 VA = VA/29
620 SDS = VS^.5
630 SDC = VC^.5
640 SDA = VA^.5
650 TAC = SAC - (SUMA * SUMC/30)
660 BAC = ((SQA - AASS/30) * (SQC - CASS/30)) ^ .5
670 CCAC = TAC/BAC
680 TCS = SCS - (SUMC * SUMS/30)
690 BCS = ((SQC - CASS/30) * ( SQS - SASS/30)) ^ .5
700 CCCS = TCS/BCS
710 TAS = SAS - (SUMA * SUMS/30)
720 BAS = ((SQA - AASS/30) * (SQS - SASS/30)) ^ .5
730 CCAS = TAS/BAS
740 LPRINT "FREQUENCY      SEAT          CAB          AXLE          S/A
           S/C      C/A"
750 LPRINT  "  HZ          M/S^2          M/S^2          M/S^2"
760 LPRINT
770   FOR I = 1 TO 30
780        LPRINT USING "££.££       £££.£££^^^^   £££.£££^^^^   £££.£££^^^^
                         £££.££    ££.££    ££.££";HZ(I),SA(I),CA(I),AA(I),
                         RSA(I),RSC(I),RCA(I)
790   NEXT I
800 LPRINT
810 LPRINT USING "MEAN          £££.£££^^^^    £££.£££^^^^
                £££.£££^^^^";SM,CM,AM
820 LPRINT  USING "VAR          £££.£££^^^^    £££.££^^^^
                £££.££^^^^";VS,VC,VA
830 LPRINT USING "SD             ££.££^^^^       ££.££^^^^
                ££.££^^^^";SDS,SDC,SDA
840 LPRINT USING  "CORR          £.££  A/S       £.££  C/S       £.££
                A/C"; CCAS,CCCS,CCAC
```

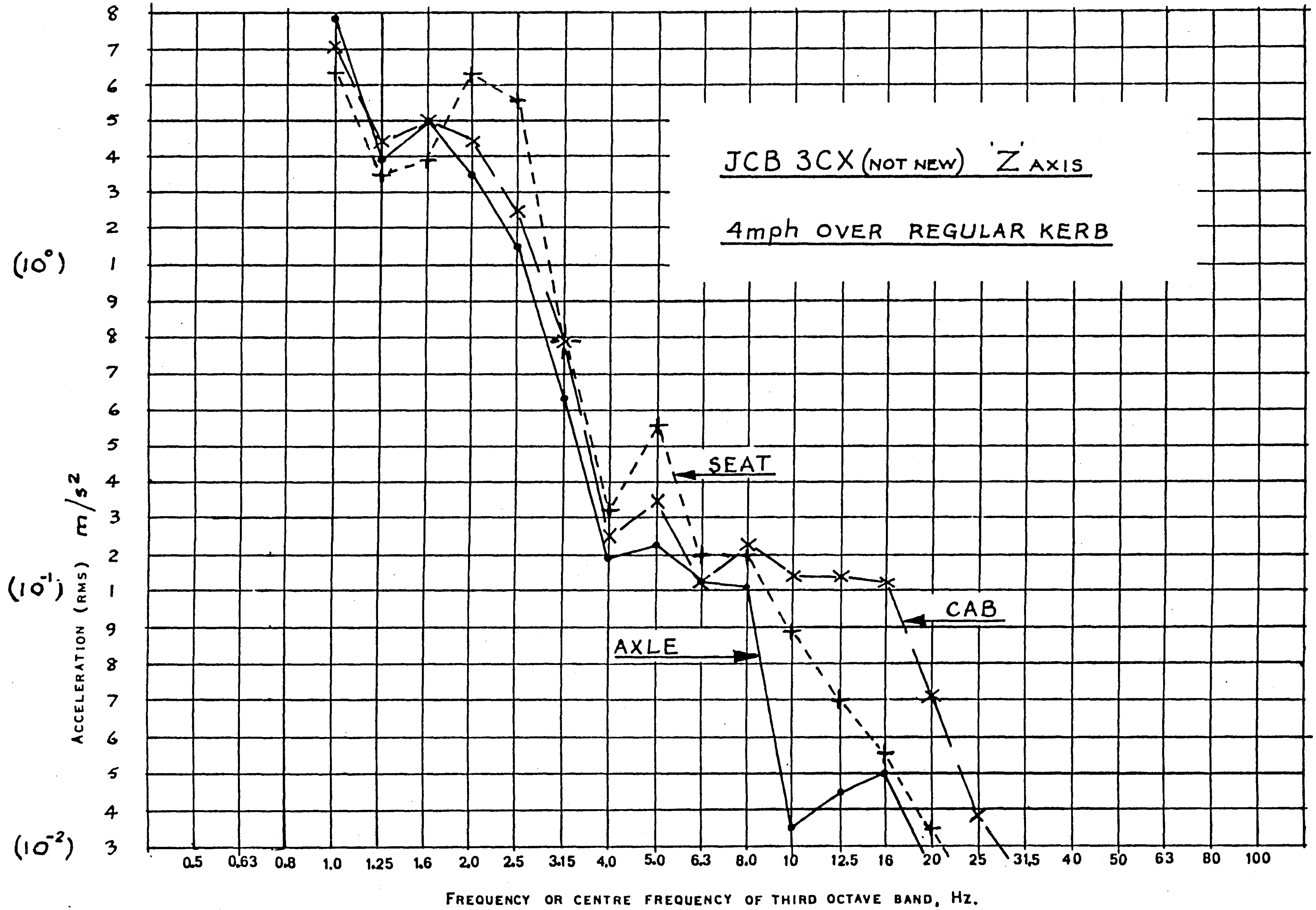
A P P E N D I X 'E'

Graphical presentation of acceleration levels (m/s^2) - v - frequency (Hz) at axle, cab and seat, over each test track for both 'new' and 'not new' JCB 3CX Excavator/Loader vehicles.

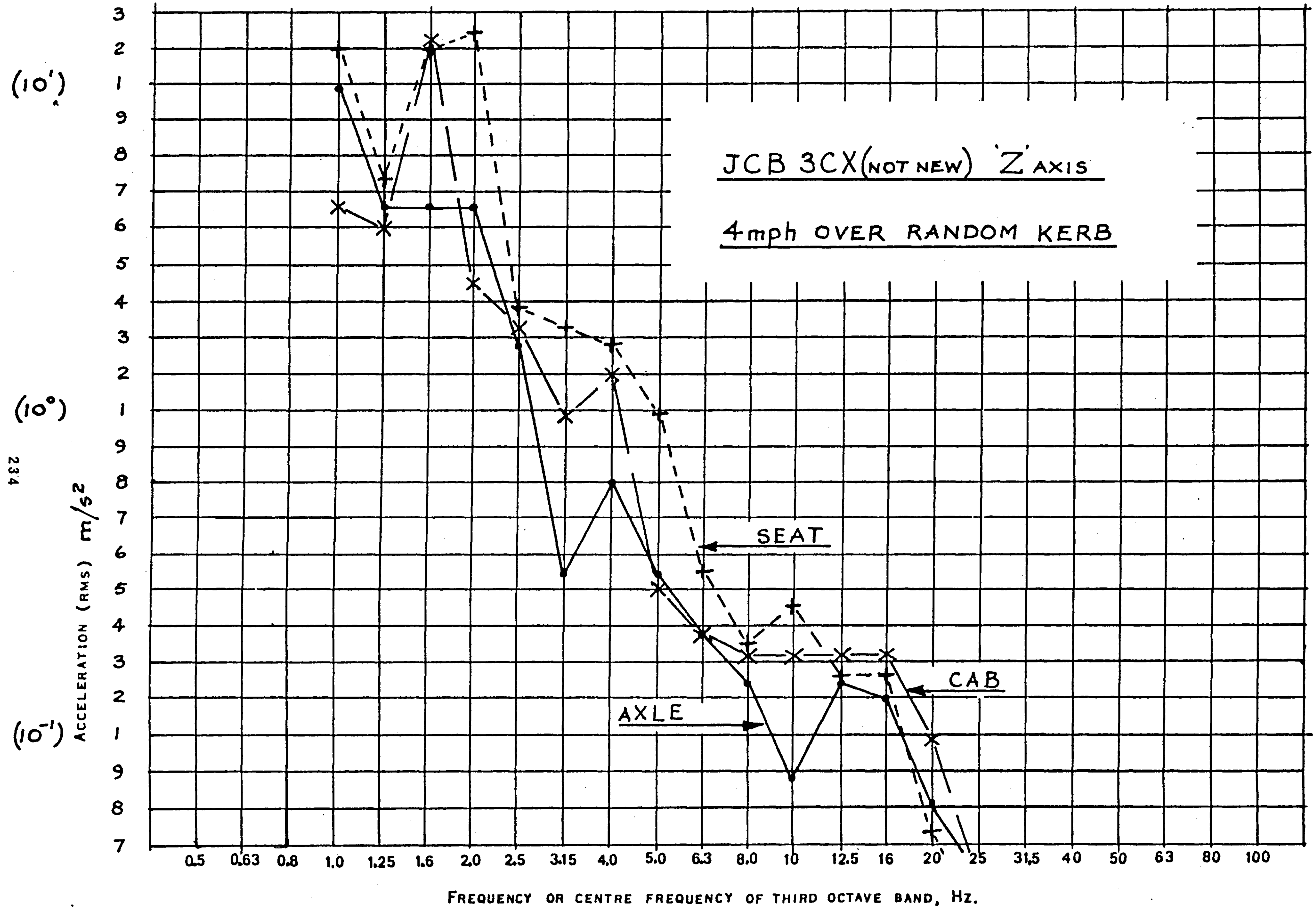


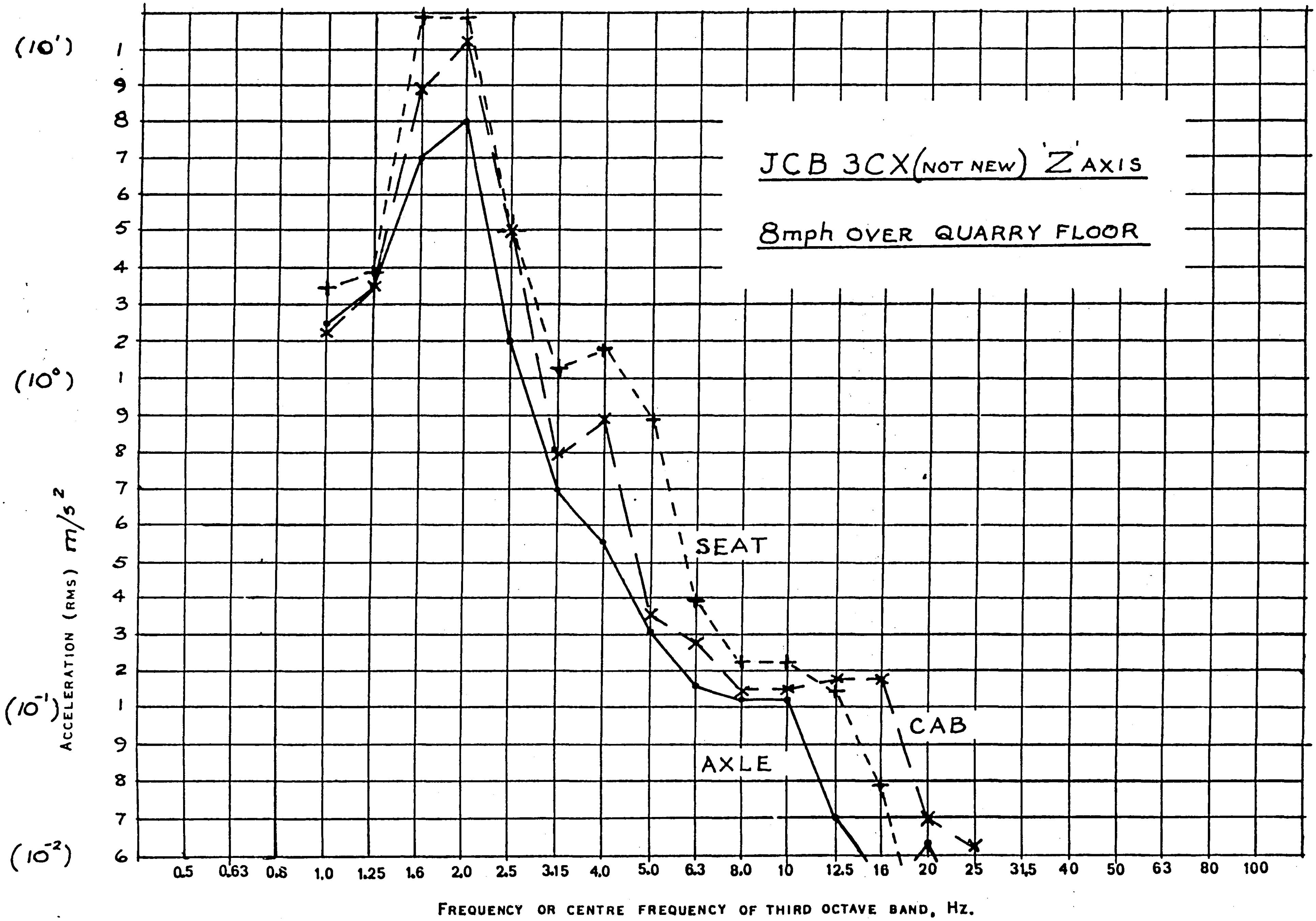
JCB 3CX (NOT NEW) 'Z' AXIS
4 mph OVER QUARRY FLOOR
SEAT
CAB
AXLE
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
ACCELERATION (RMS) m/s²
(10¹) (10⁰) (10⁻¹) (10⁻²)

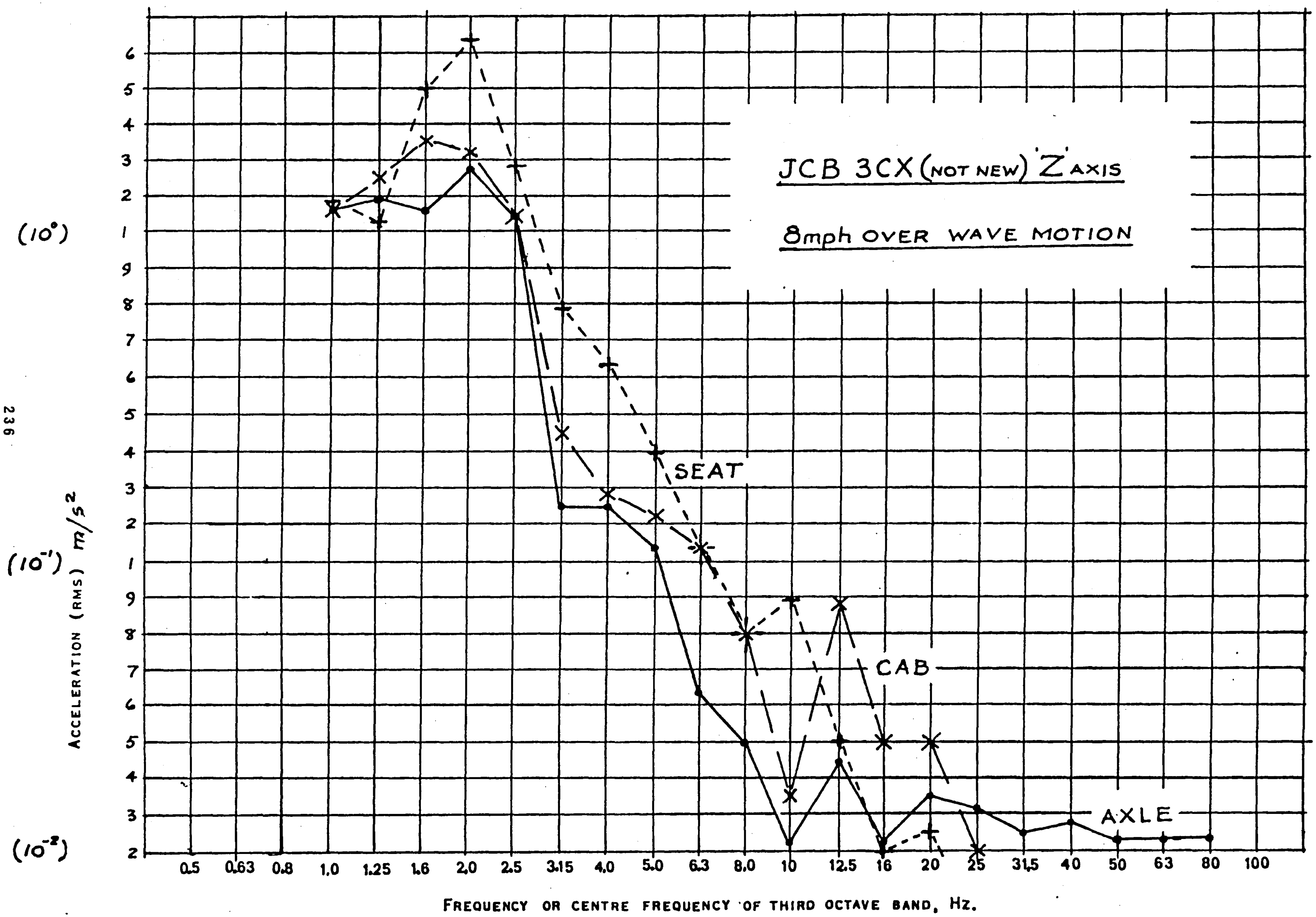

JCB 3CX (NOT NEW) 'Z' AXIS
4mph OVER WAVE MOTION.
CAB
AXLE
SEAT
ACCELERATION (RMS) m/s²
(10°)
(10⁻¹)
(10⁻²)
(10⁻³)
2
1
9
8
7
6
5
4
3
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.



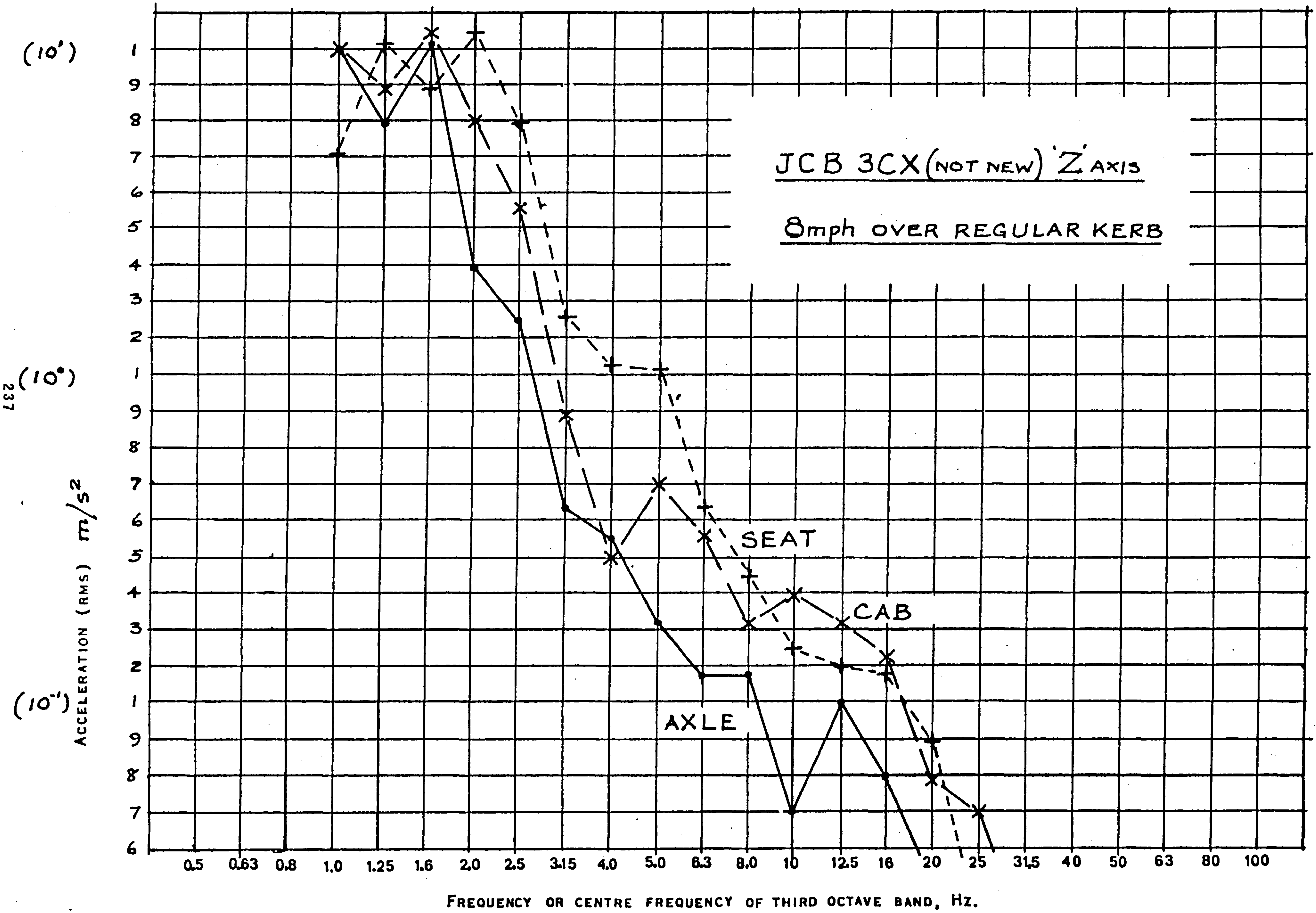
JCB 3CX (NOT NEW) 'Z' AXIS
4mph OVER REGULAR KERB
SEAT
CAB
AXLE
ACCELERATION (RMS) m/s²
(10°)
(10⁻¹)
(10⁻²)
8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.


JCB 3CX (NOT NEW) 'Z' AXIS
4mph OVER RANDOM KERB
SEAT
CAB
AXLE
ACCELERATION (RMS) m/s²
(10¹)
(10⁰)
(10⁻¹)
3
2
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
9
8
7
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

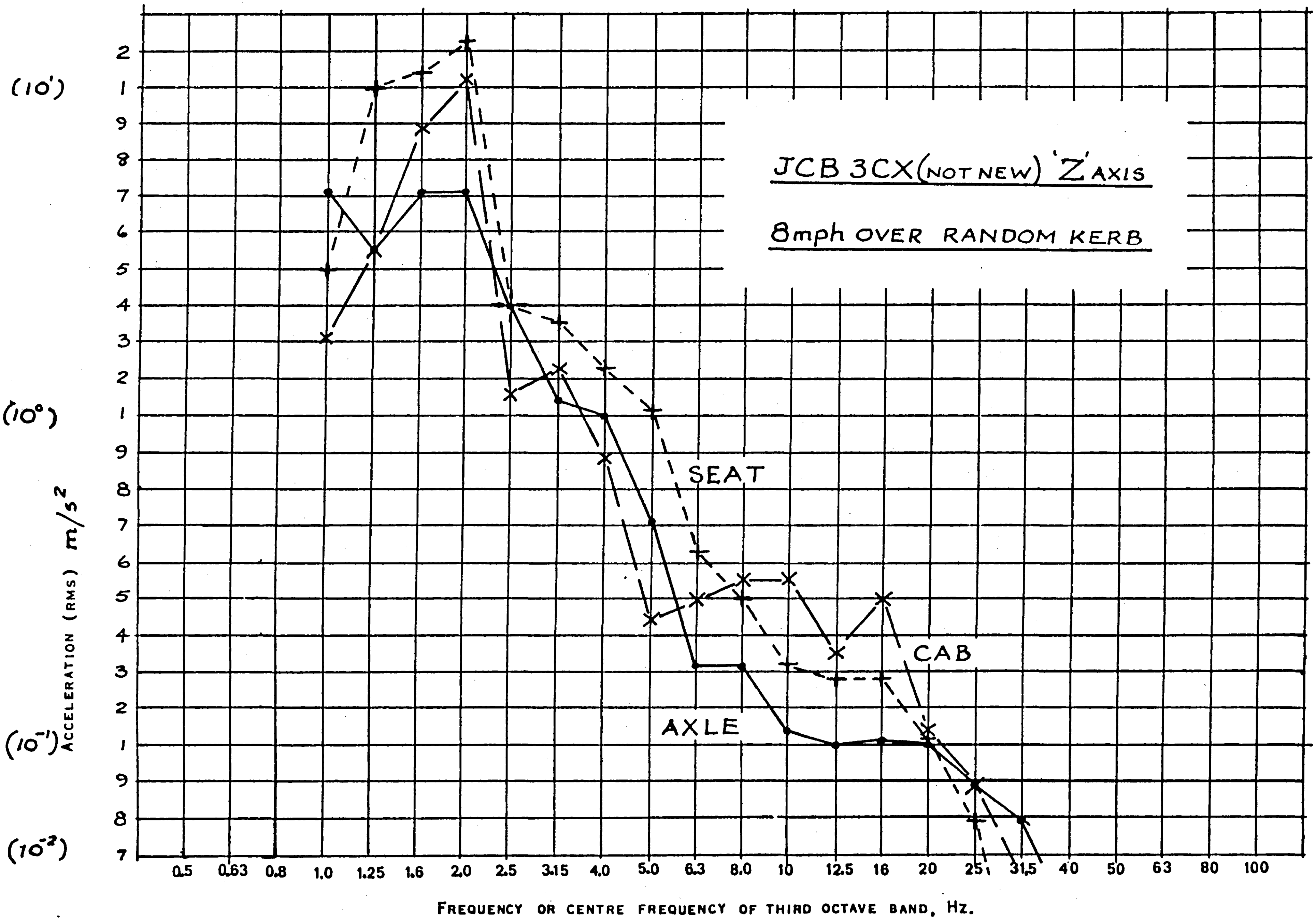

JCB 3CX (NOT NEW) 'Z' AXIS
8mph OVER QUARRY FLOOR
SEAT
CAB
AXLE
ACCELERATION (RMS) m/s²
(10¹)
(10⁰)
(10⁻¹)
(10⁻²)
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

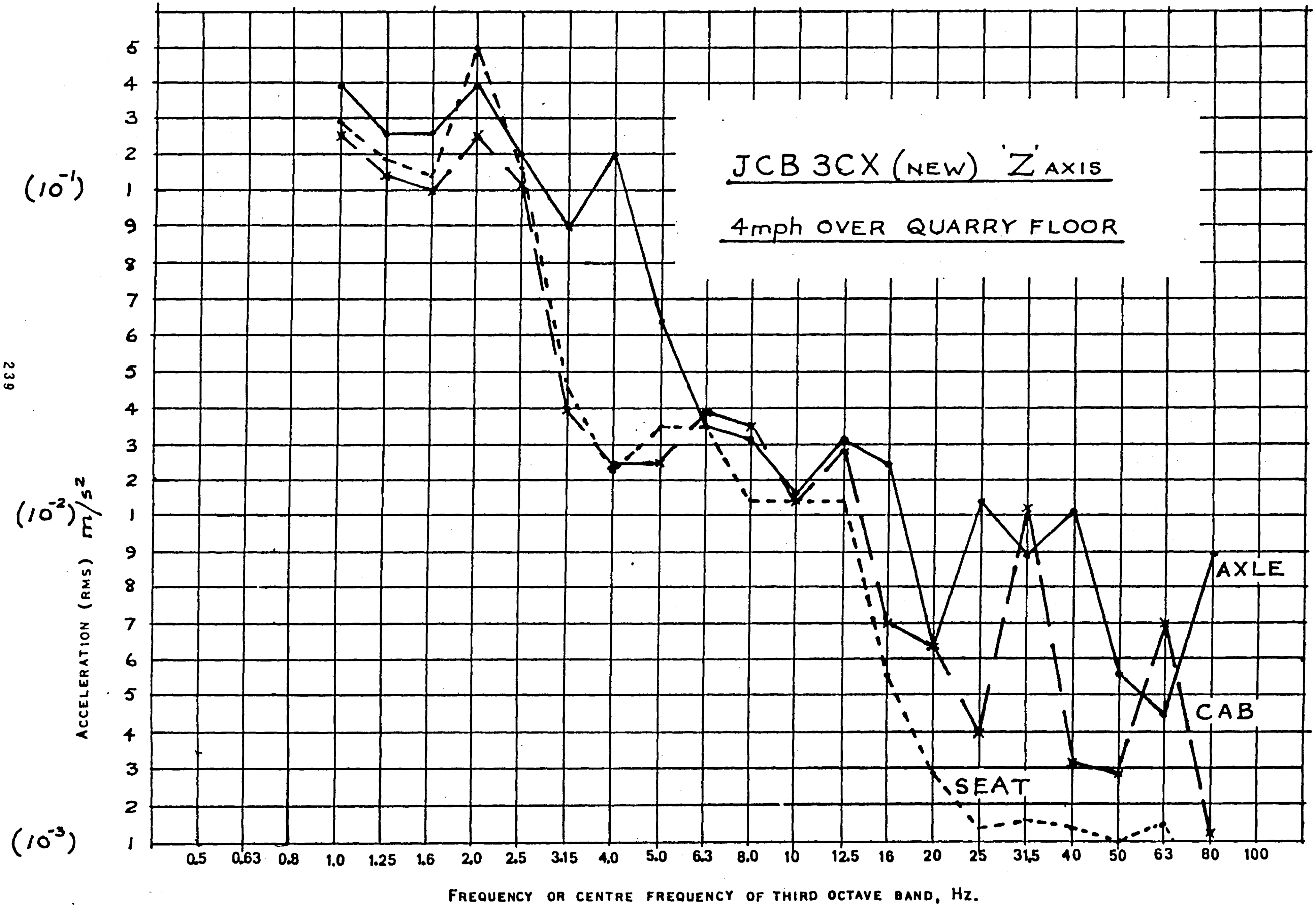


JCB 3CX (NOT NEW) 'Z' AXIS
8mph OVER WAVE MOTION
SEAT
CAB
AXLE
ACCELERATION (RMS) m/s²
(10°)
(10⁻¹)
(10⁻²)
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

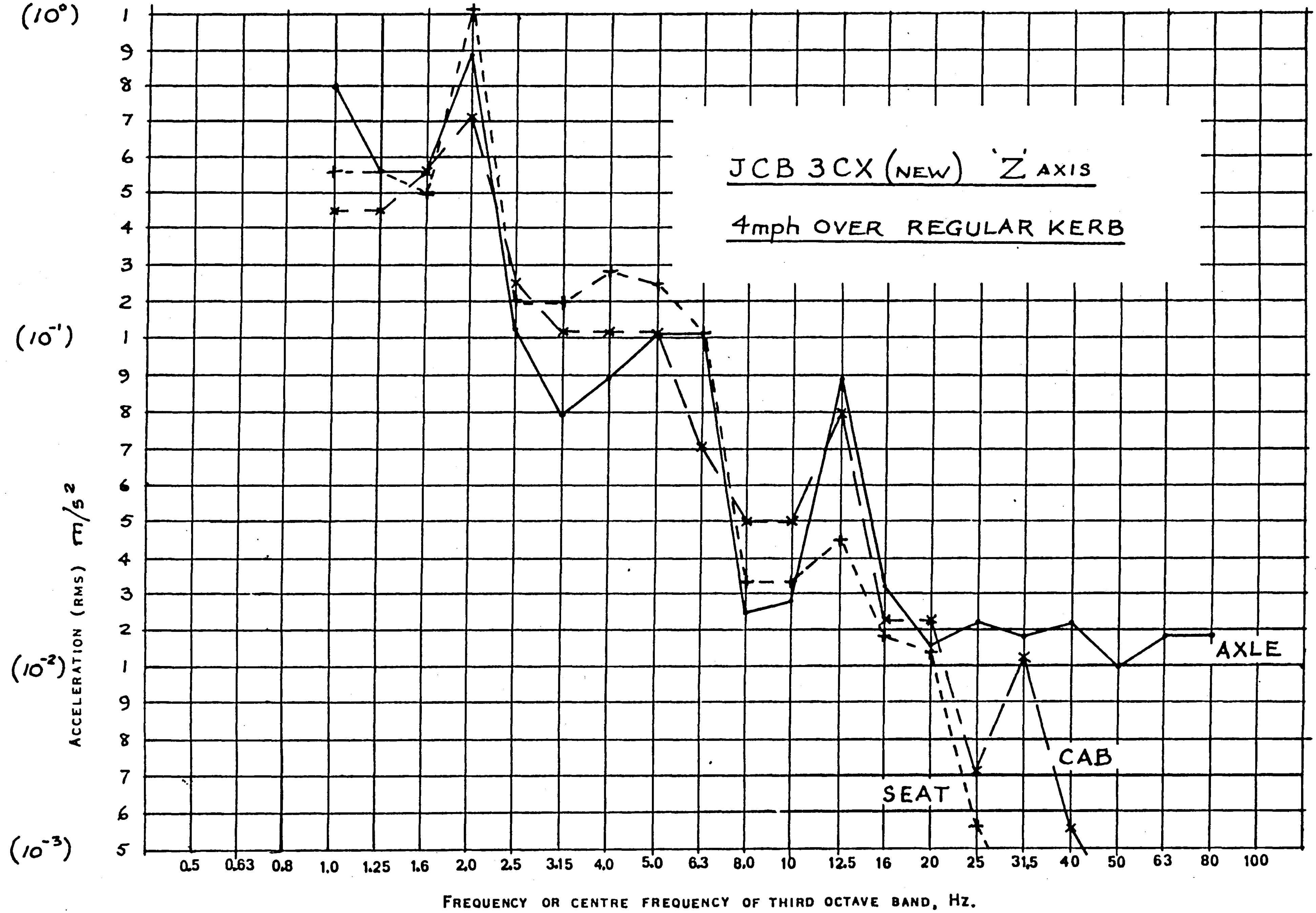


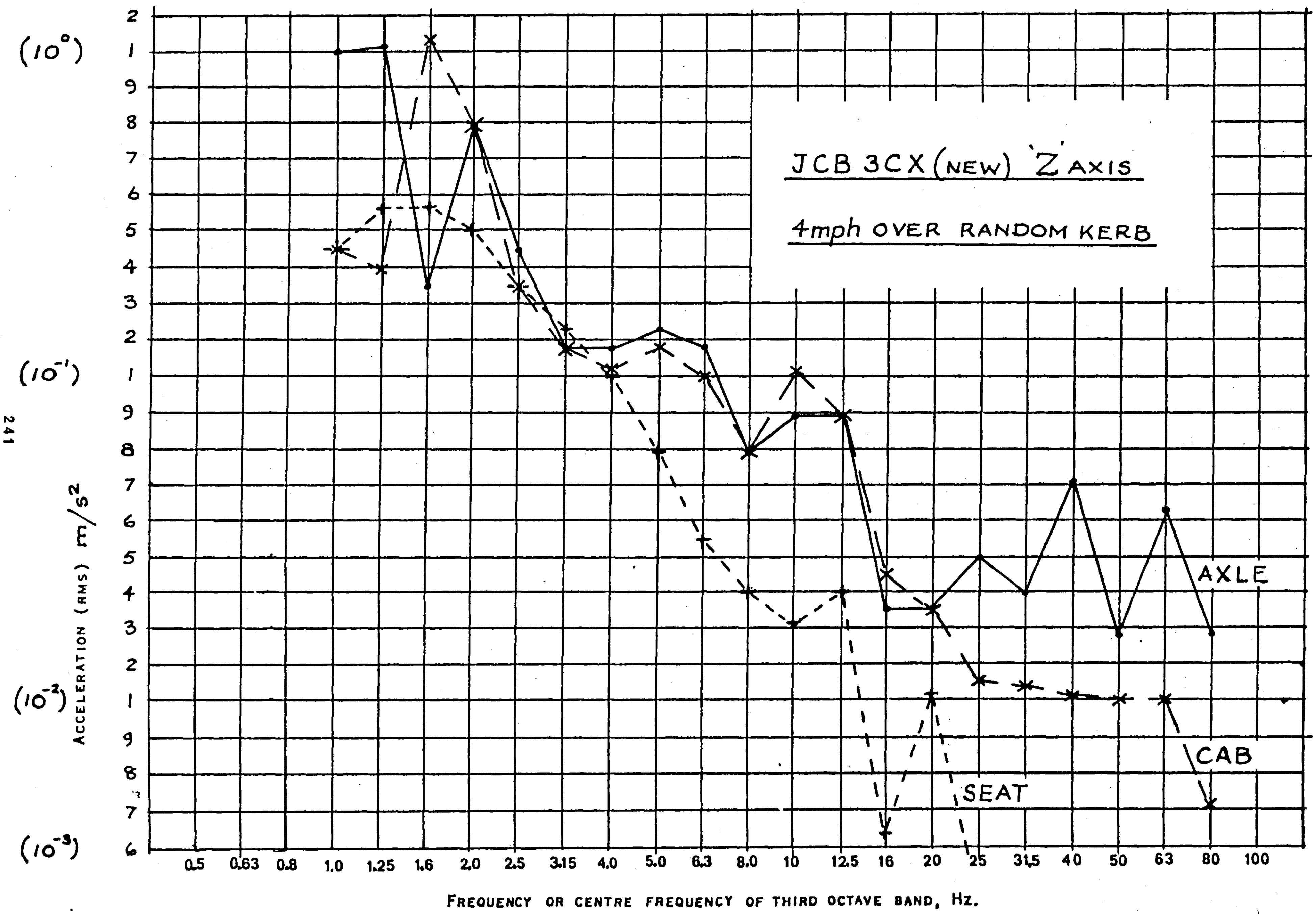
JCB 3CX (NOT NEW) 'Z' AXIS
8mph OVER REGULAR KERB
SEAT
CAB
AXLE
(10')
(10°)
(10⁻¹)
ACCELERATION (RMS) m/s²
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

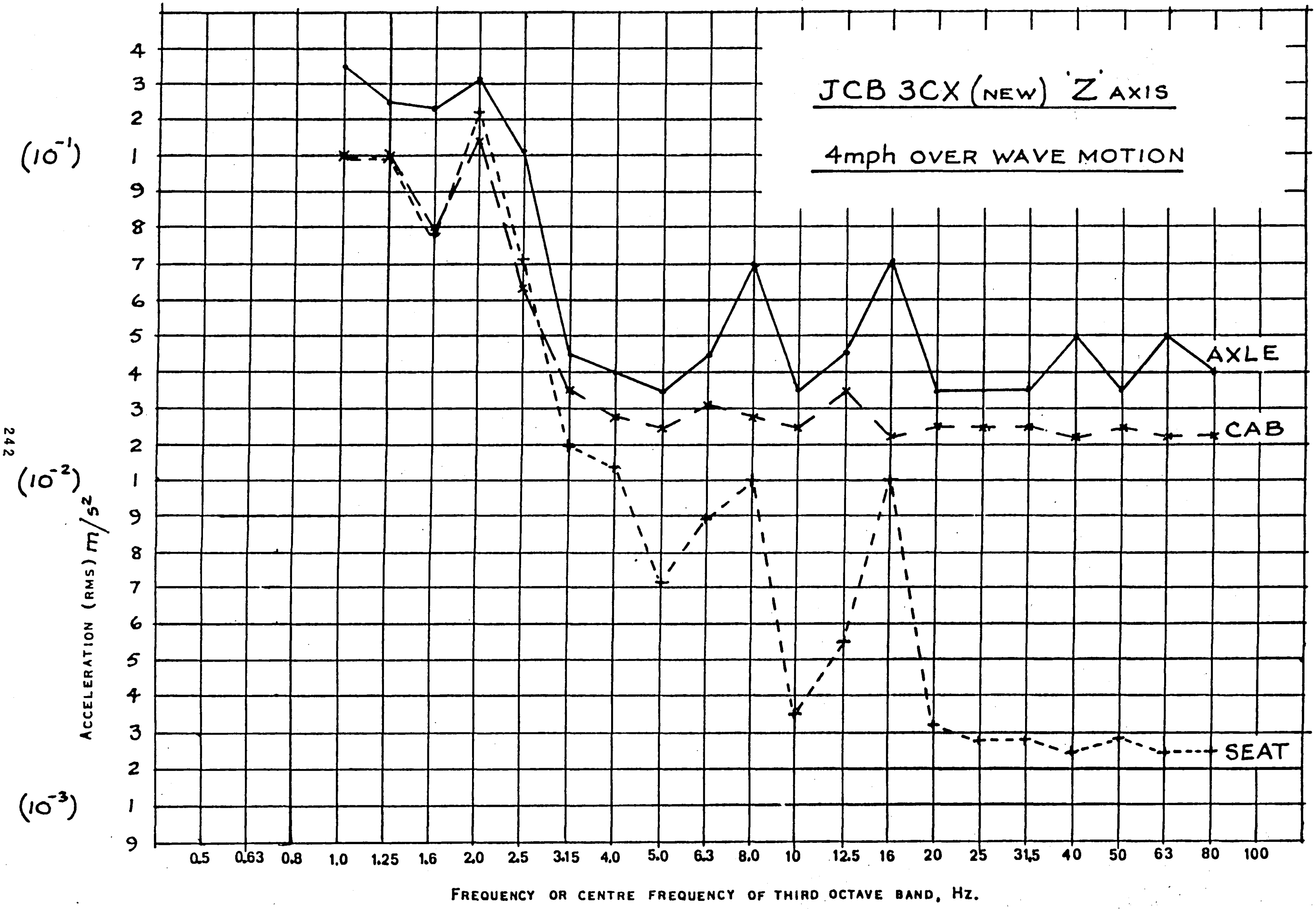

JCB 3CX (NOT NEW) 'Z' AXIS
8mph OVER RANDOM KERB
SEAT
CAB
AXLE
(10¹)
(10⁰)
(10⁻¹)
(10⁻²)
2
1
9
8
7
6
5
4
3
ACCELERATION (RMS) m/s²
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

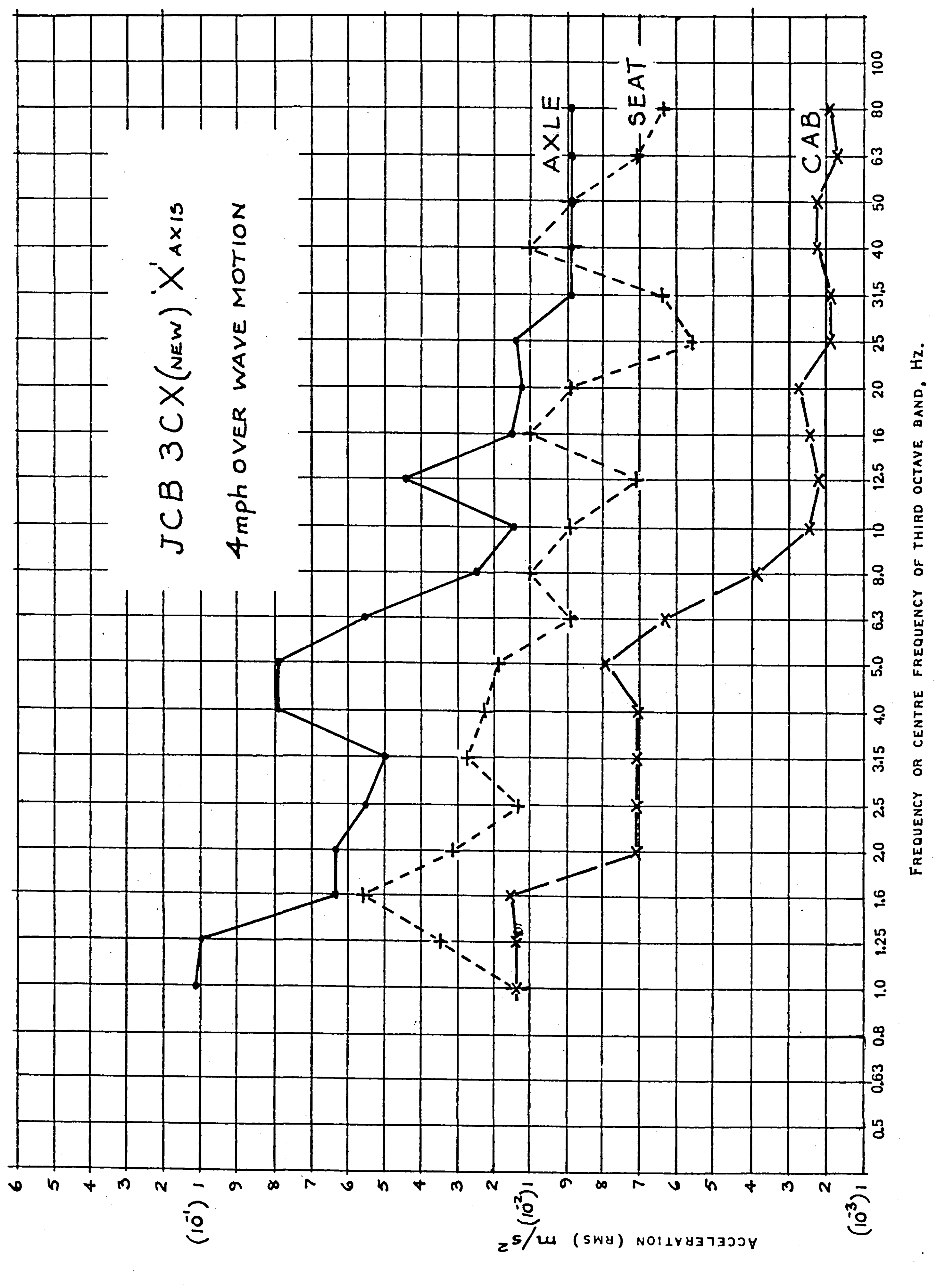


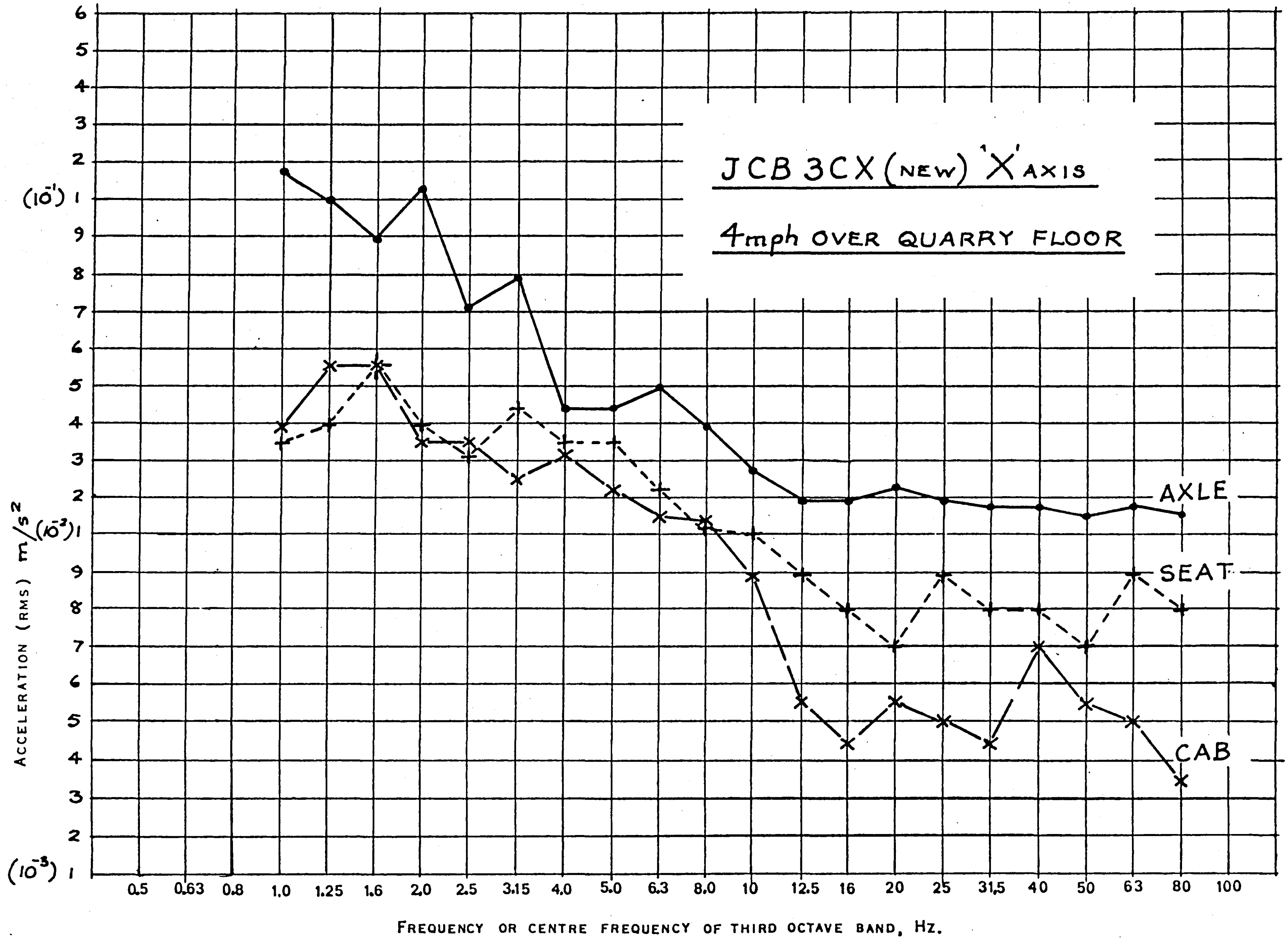
JCB 3CX (NEW) 'Z' AXIS
4mph OVER QUARRY FLOOR
AXLE
CAB
SEAT
ACCELERATION (RMS) m/s²
(10⁻¹)
(10⁻²)
(10⁻³)
5 4 3 2 1 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2 1
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.


JCB 3CX (NEW) 'Z' AXIS
4mph OVER REGULAR KERB
AXLE
CAB
SEAT
(10°)
(10⁻¹)
(10⁻²)
(10⁻³)
1 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2 1 9 8 7 6 5
ACCELERATION (RMS) m/s²
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

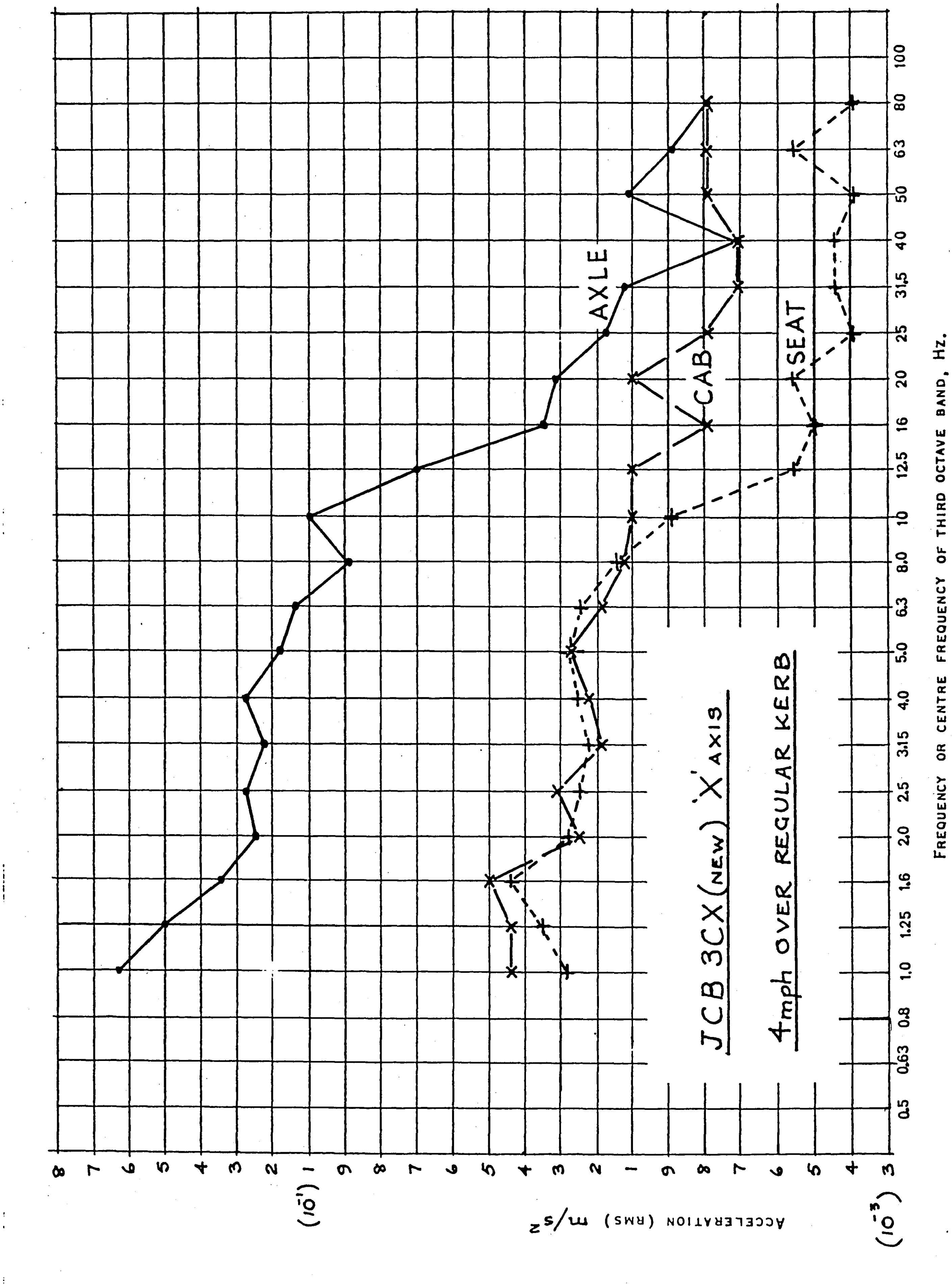

JCB 3CX (NEW) 'Z' AXIS
4mph OVER RANDOM KERB
AXLE
CAB
SEAT
(10°)
(10⁻¹)
(10⁻²)
(10⁻³)
2
1
9
8
7
6
5
4
3
ACCELERATION (RMS) m/s²
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

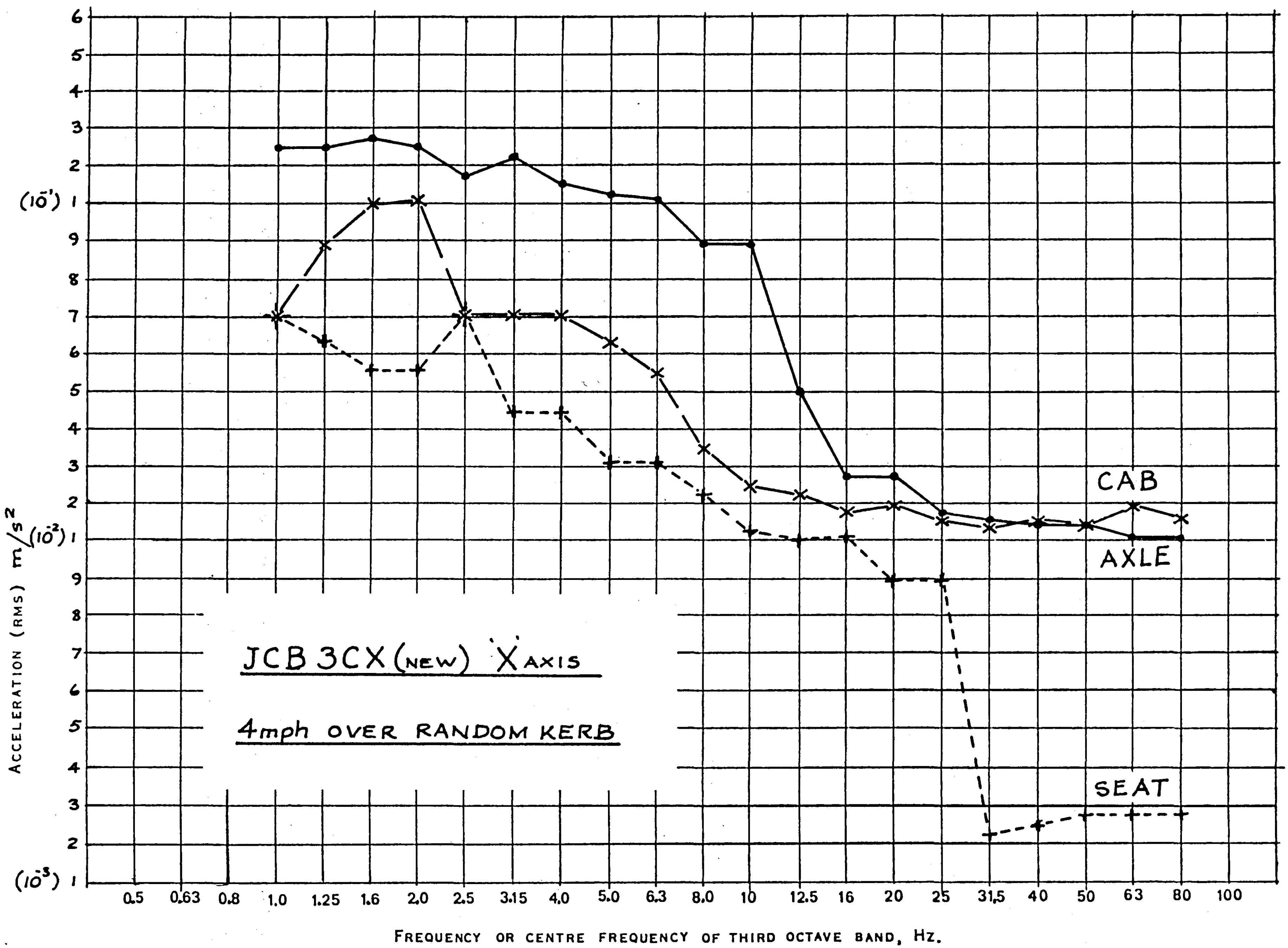

JCB 3CX (NEW) 'Z' AXIS
4mph OVER WAVE MOTION
AXLE
CAB
SEAT
(10^-1)
(10^-2)
(10^-3)
ACCELERATION (RMS) m/s²
4 3 2 1 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2 1 9
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.


JCB 3CX (NEW) X' AXIS
4mph OVER WAVE MOTION
AXLE
SEAT
CAB
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
ACCELERATION (RMS) m/s²

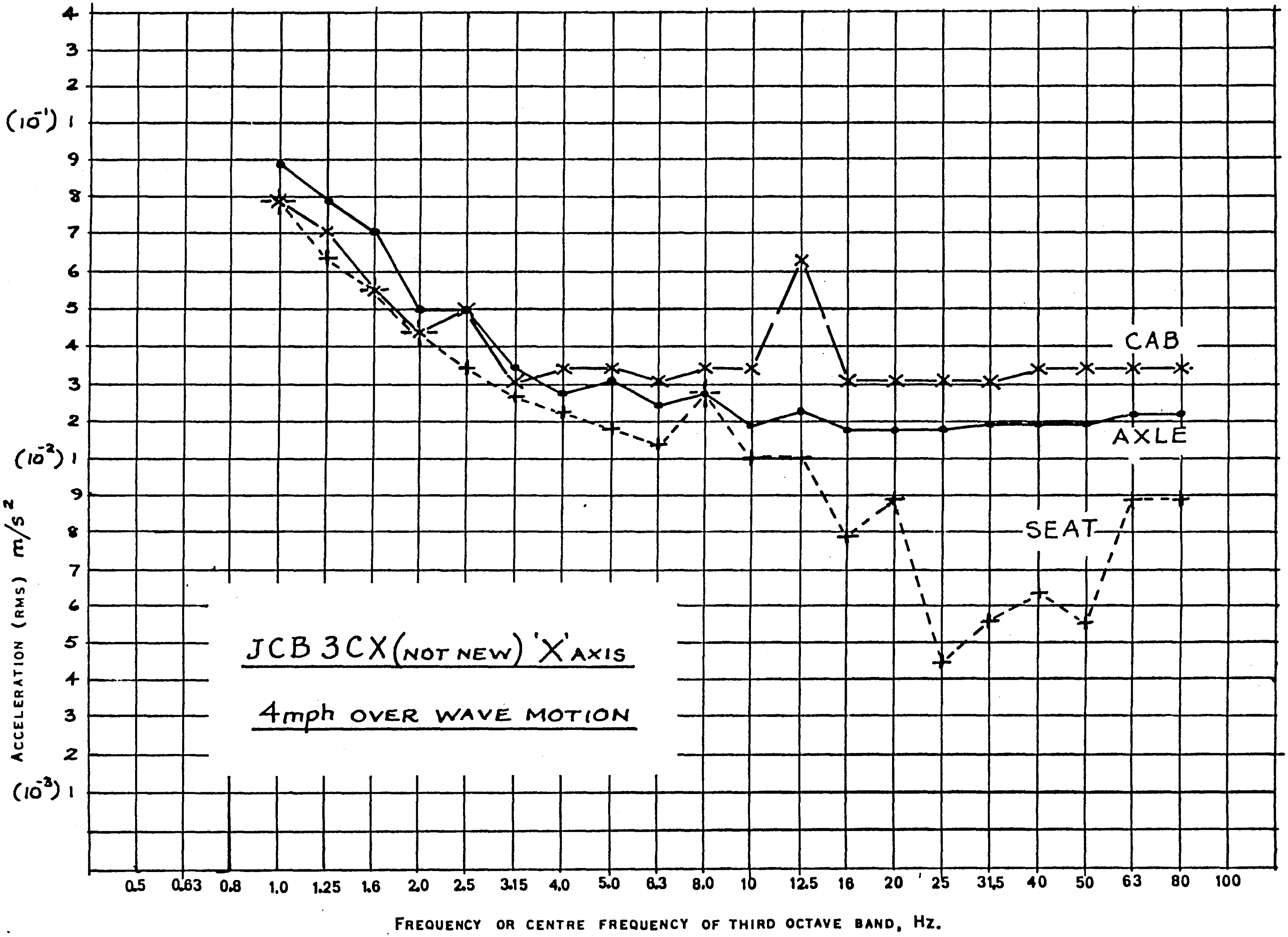


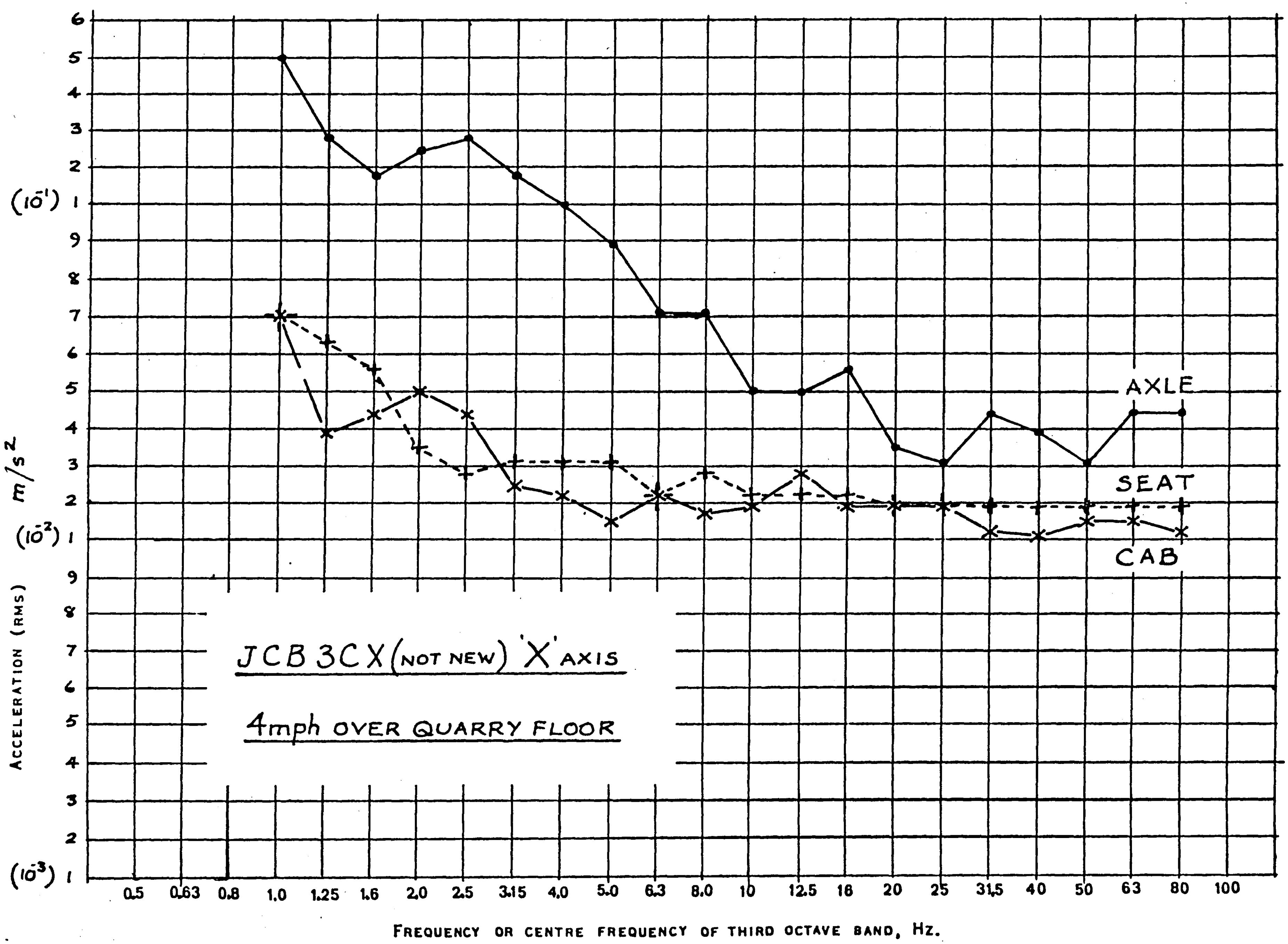
JCB 3CX (NEW) 'X' AXIS
4mph OVER QUARRY FLOOR
AXLE
SEAT
CAB
ACCELERATION (RMS) m/s²
(10⁻¹) 1
(10⁻²) 1
(10⁻³) 1
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

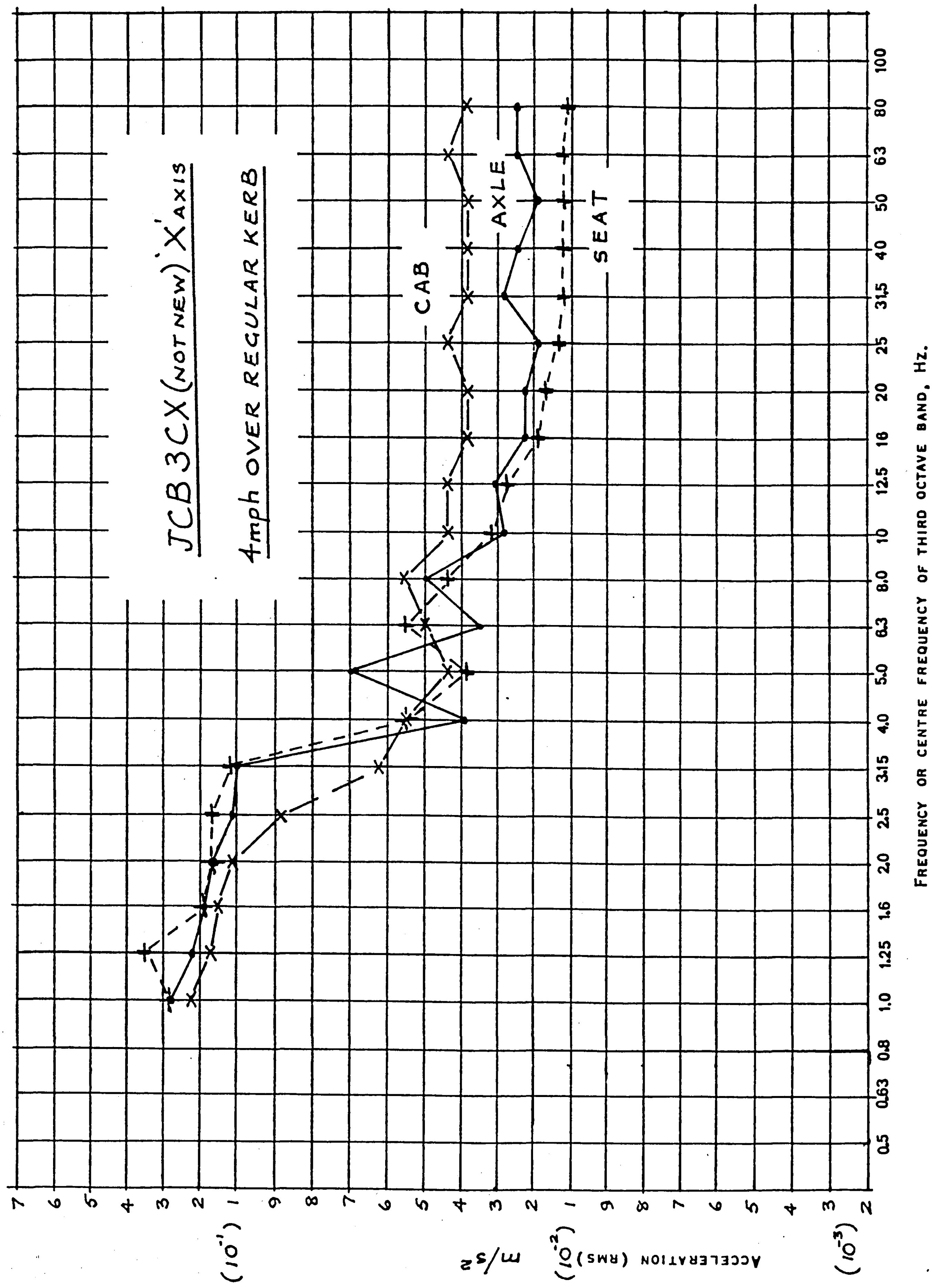

JCB 3CX (NEW) 'X' AXIS
4mph OVER REGULAR KERB
AXLE
CAB
SEAT
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
ACCELERATION (RMS) m/s²
(10⁻¹)
(10⁻³)
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100

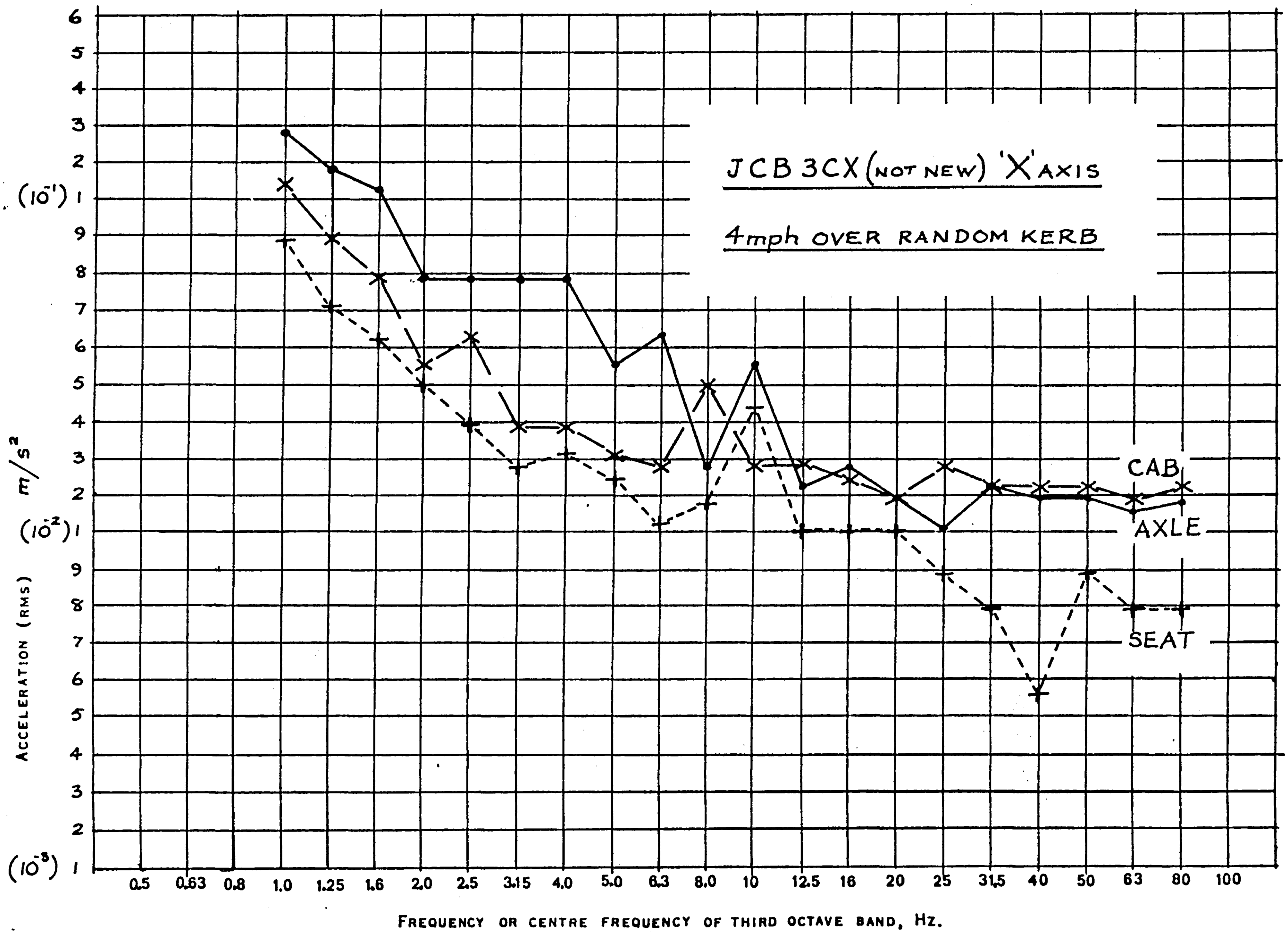


JCB 3CX (NEW) X AXIS
4mph OVER RANDOM KERB
CAB
AXLE
SEAT
ACCELERATION (RMS) m/s²
(10⁻¹)
(10⁻²)
(10⁻³)
6
5
4
3
2
1
9
8
7
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

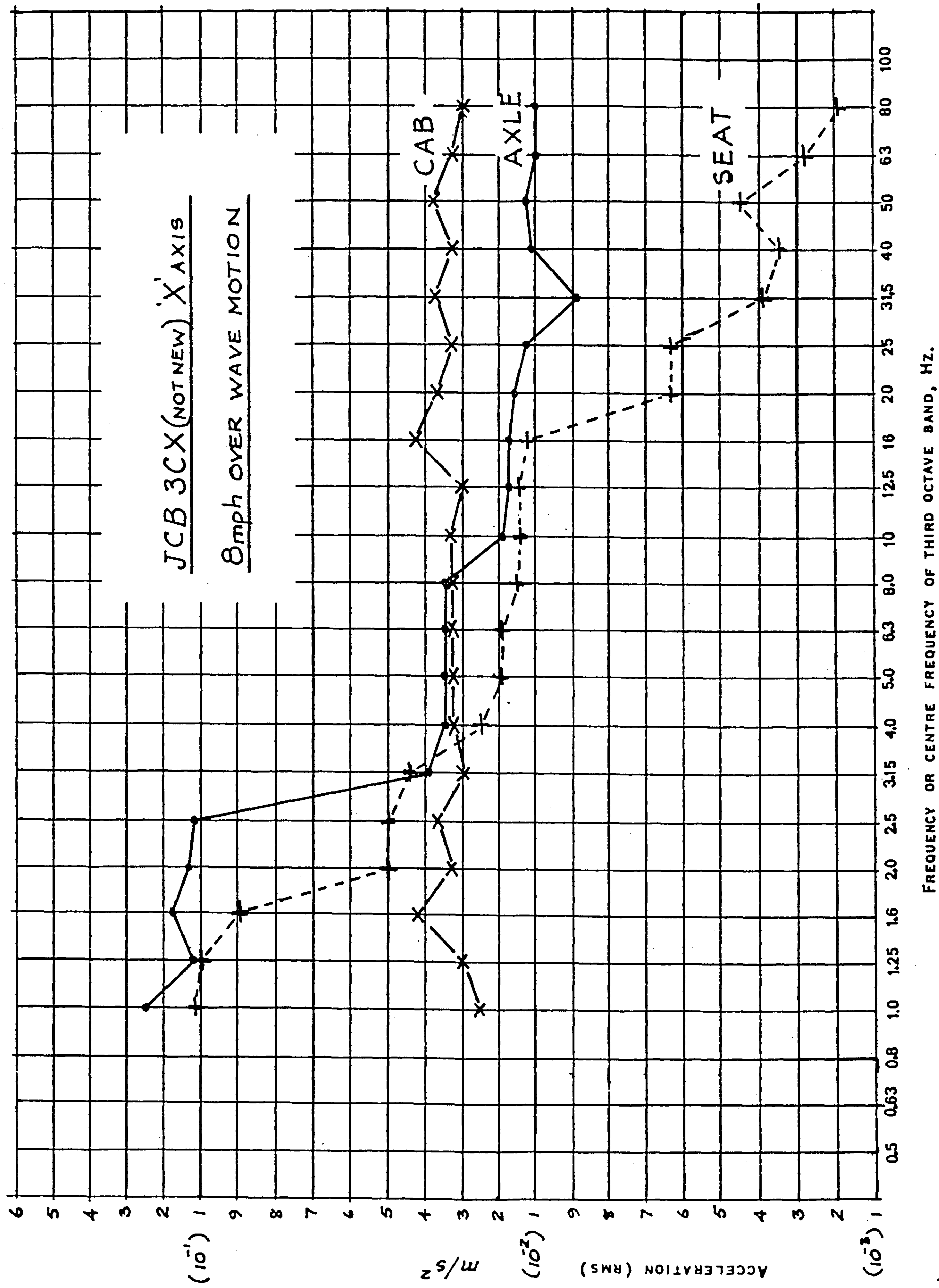

JCB 3CX (NOT NEW) 'X' AXIS
4mph OVER WAVE MOTION
CAB
AXLE
SEAT
ACCELERATION (RMS) m/s²
(10⁻¹) (10⁻²) (10⁻³)
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

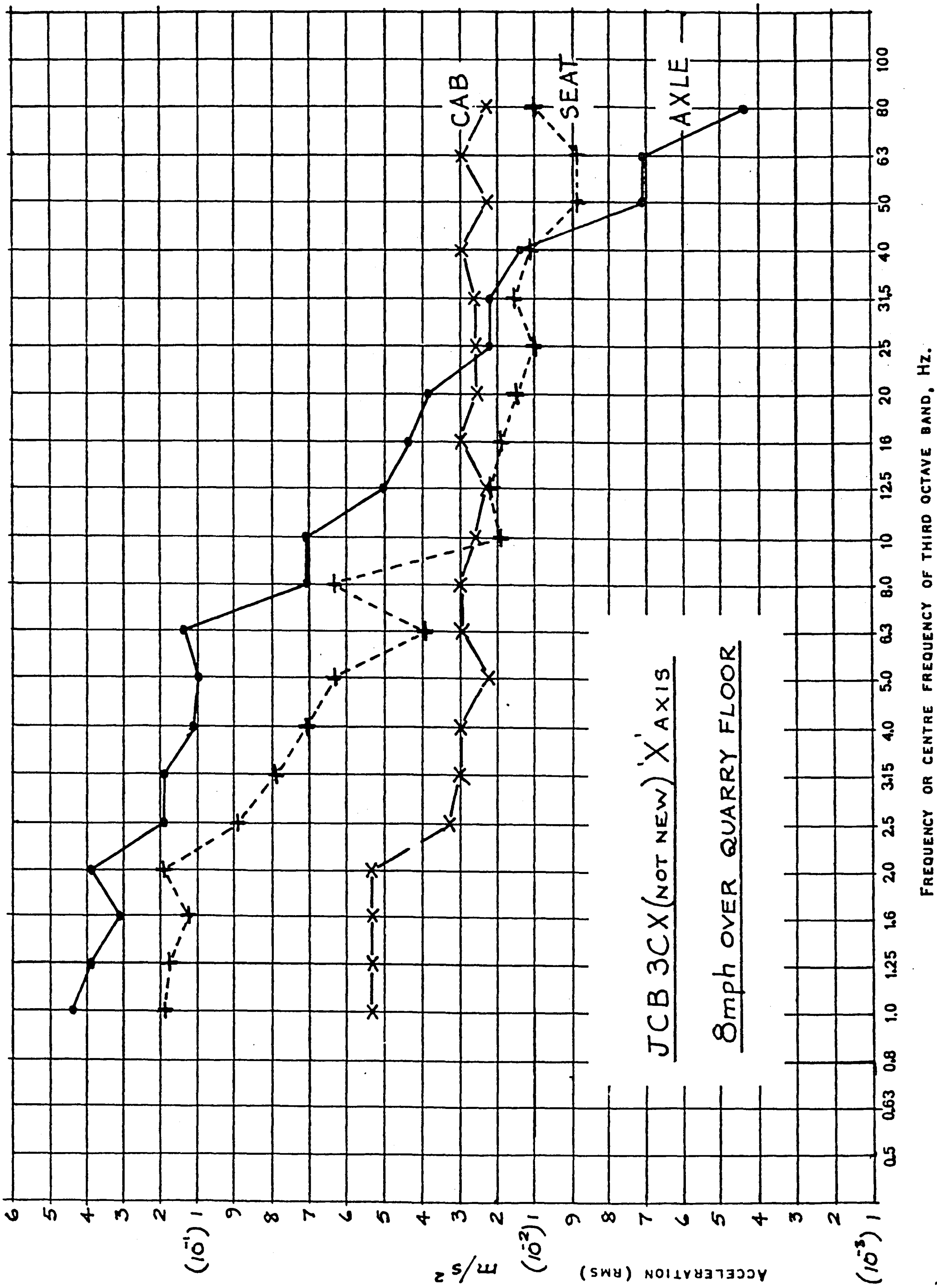

AXLE
SEAT
CAB
JCB 3CX (NOT NEW) 'X' AXIS
4mph OVER QUARRY FLOOR
ACCELERATION (RMS) m/s²
(10⁻¹)
(10⁻²)
(10⁻³)
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.


JCB 3CX (NOT NEW) 'X' AXIS
4mph OVER REGULAR KERB
CAB
AXLE
SEAT
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
ACCELERATION (RMS)
m/s²
(10⁻¹)
(10⁻²)
(10⁻³)

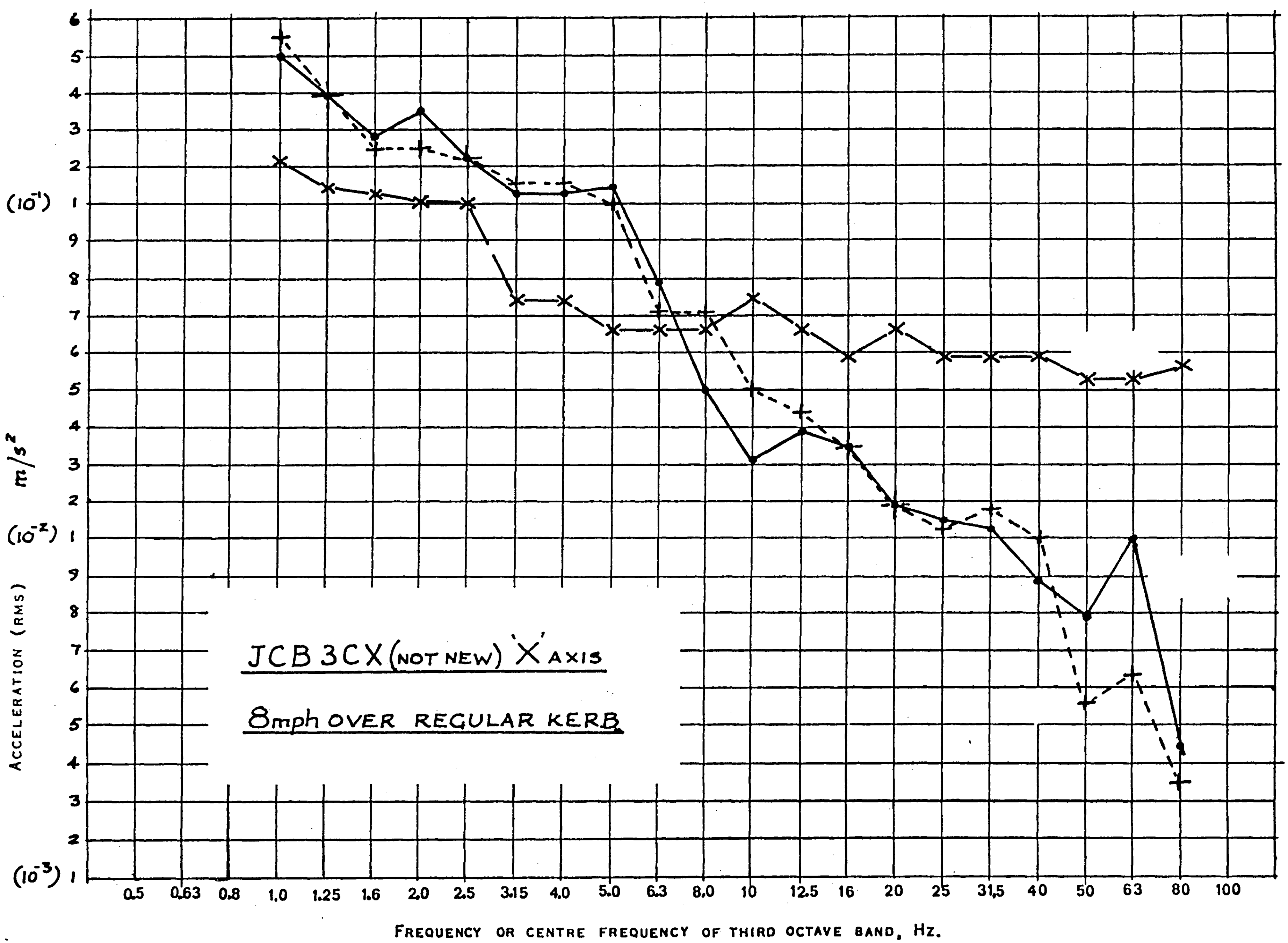


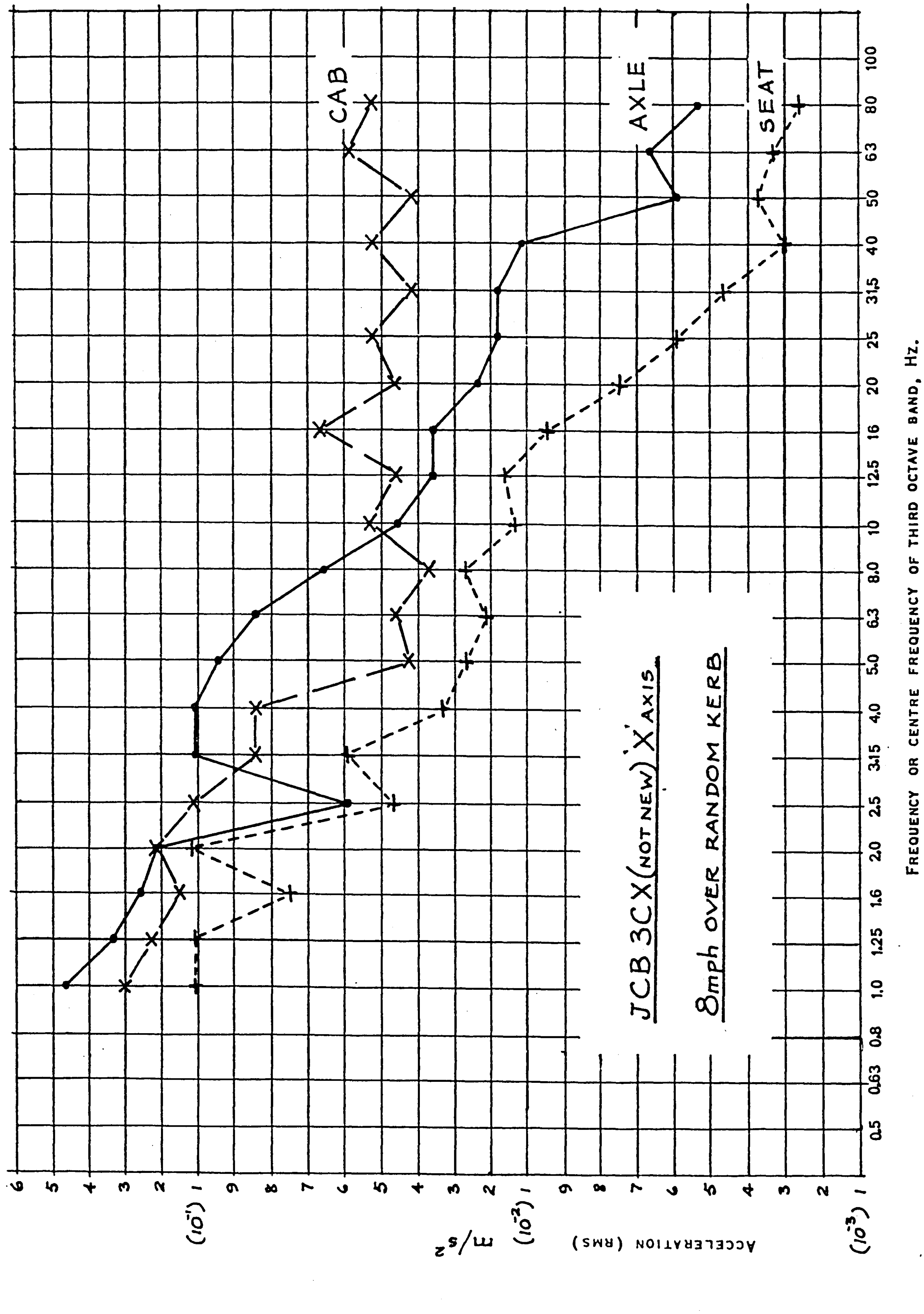
JCB 3CX (NOT NEW) 'X' AXIS
4mph OVER RANDOM KERB
CAB
AXLE
SEAT
ACCELERATION (RMS) m/s²
(10⁻¹)
(10⁻²)
(10⁻³)
6
5
4
3
2
1
9
8
7
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

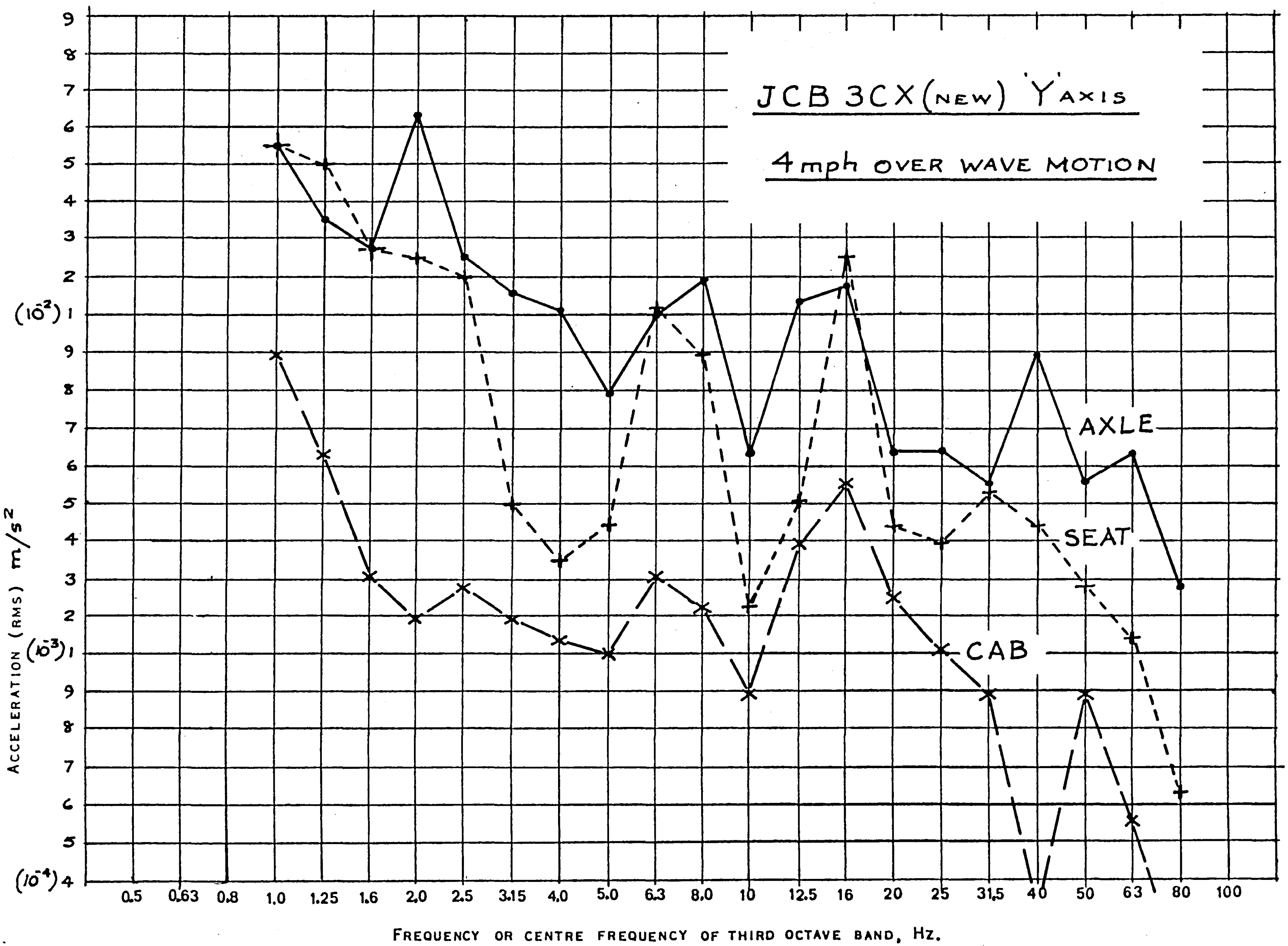

JCB 3CX (NOT NEW) 'X' AXIS
8mph OVER WAVE MOTION
CAB
AXLE
SEAT
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
ACCELERATION (RMS)
m/s²
(10^{-1})
(10^{-2})
(10^{-3})



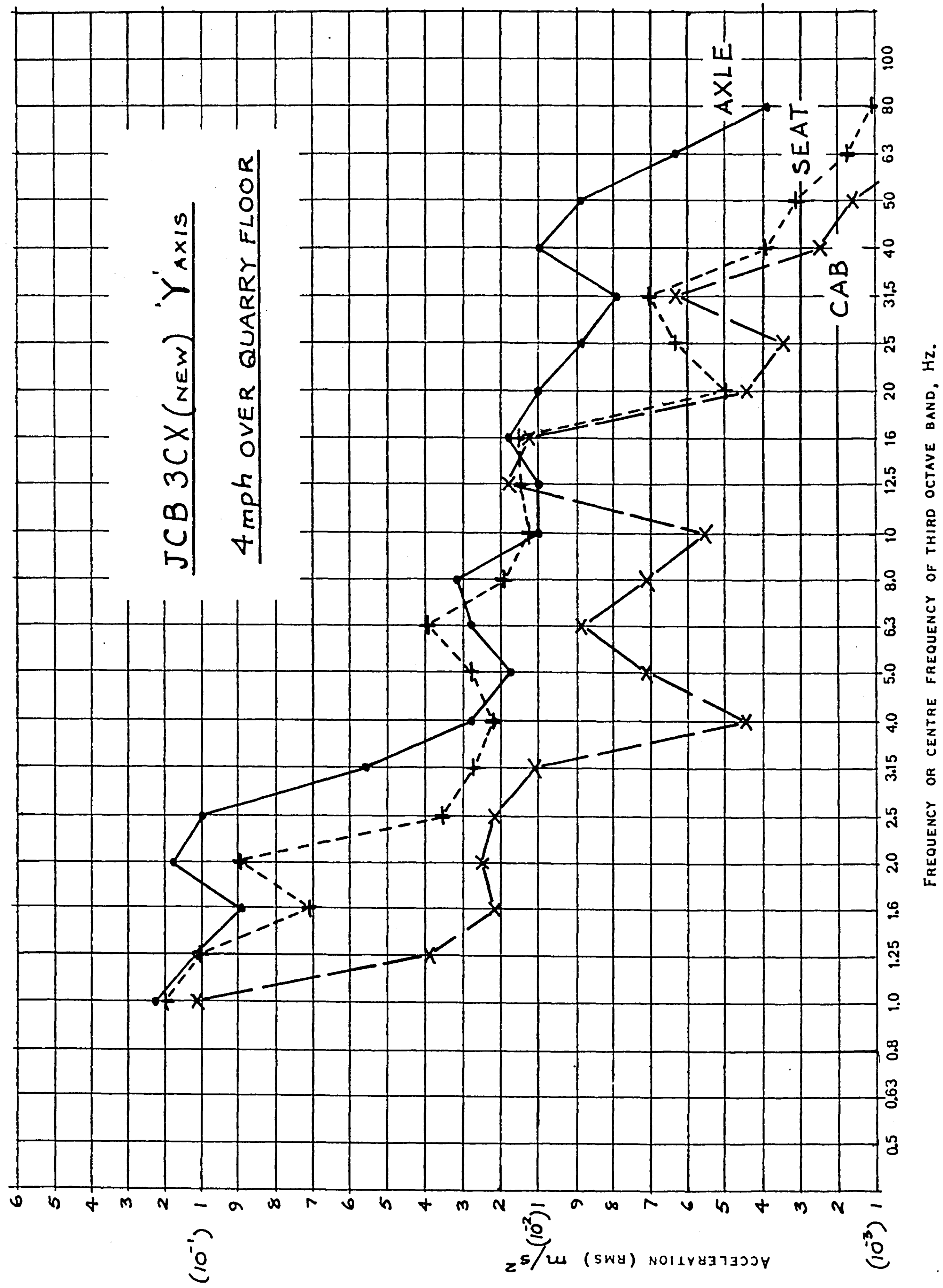
JCB 3CX (NOT NEW) 'X' AXIS
8mph OVER QUARRY FLOOR
CAB
SEAT
AXLE
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
ACCELERATION (RMS)
m/s²
(10⁻¹)
(10⁻²)
(10⁻³)
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100

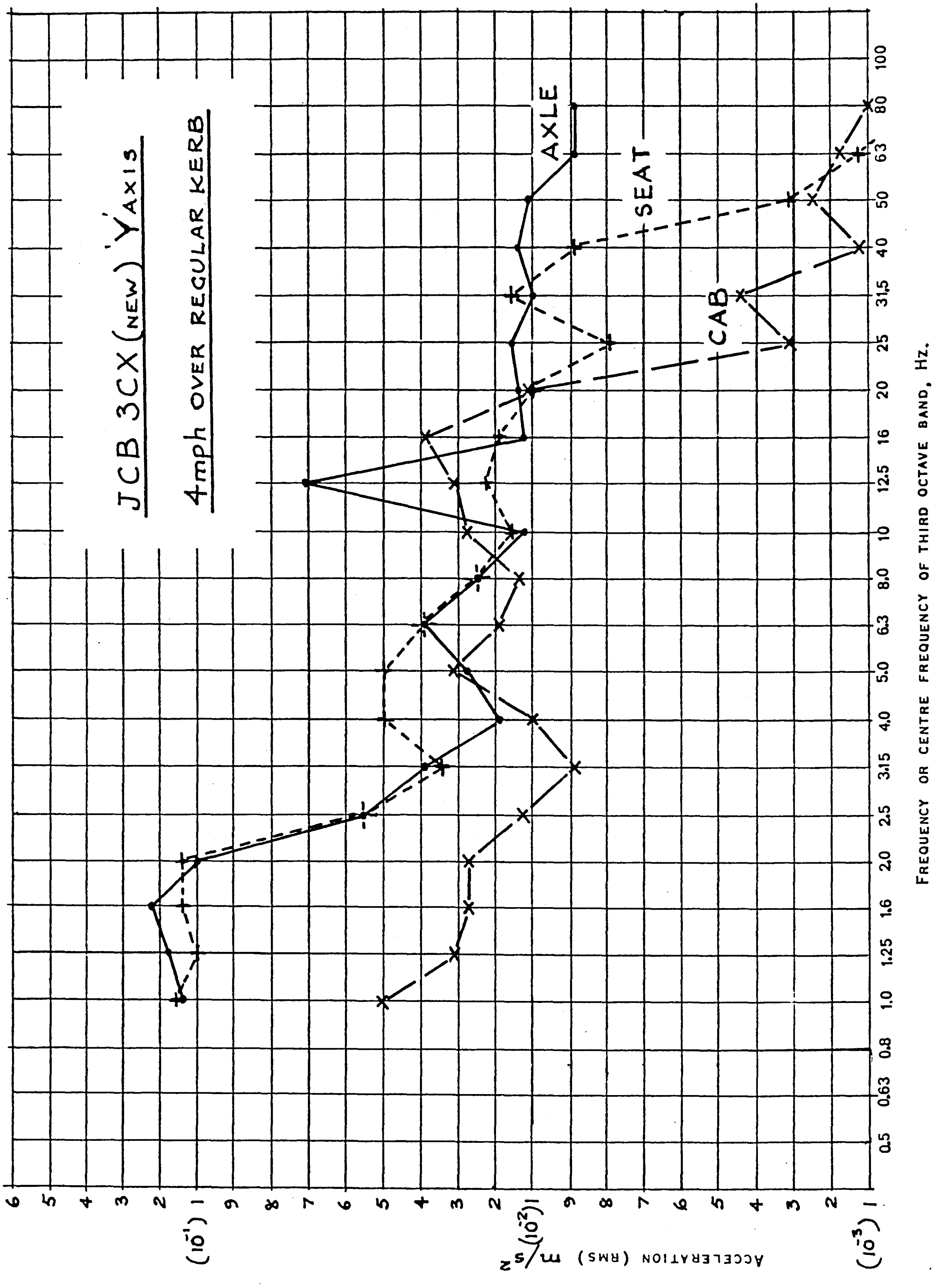

JCB 3CX (NOT NEW) 'X' AXIS
8mph OVER REGULAR KERB
ACCELERATION (RMS)
m/s²
(10⁻¹)
(10⁻²)
(10⁻³)
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

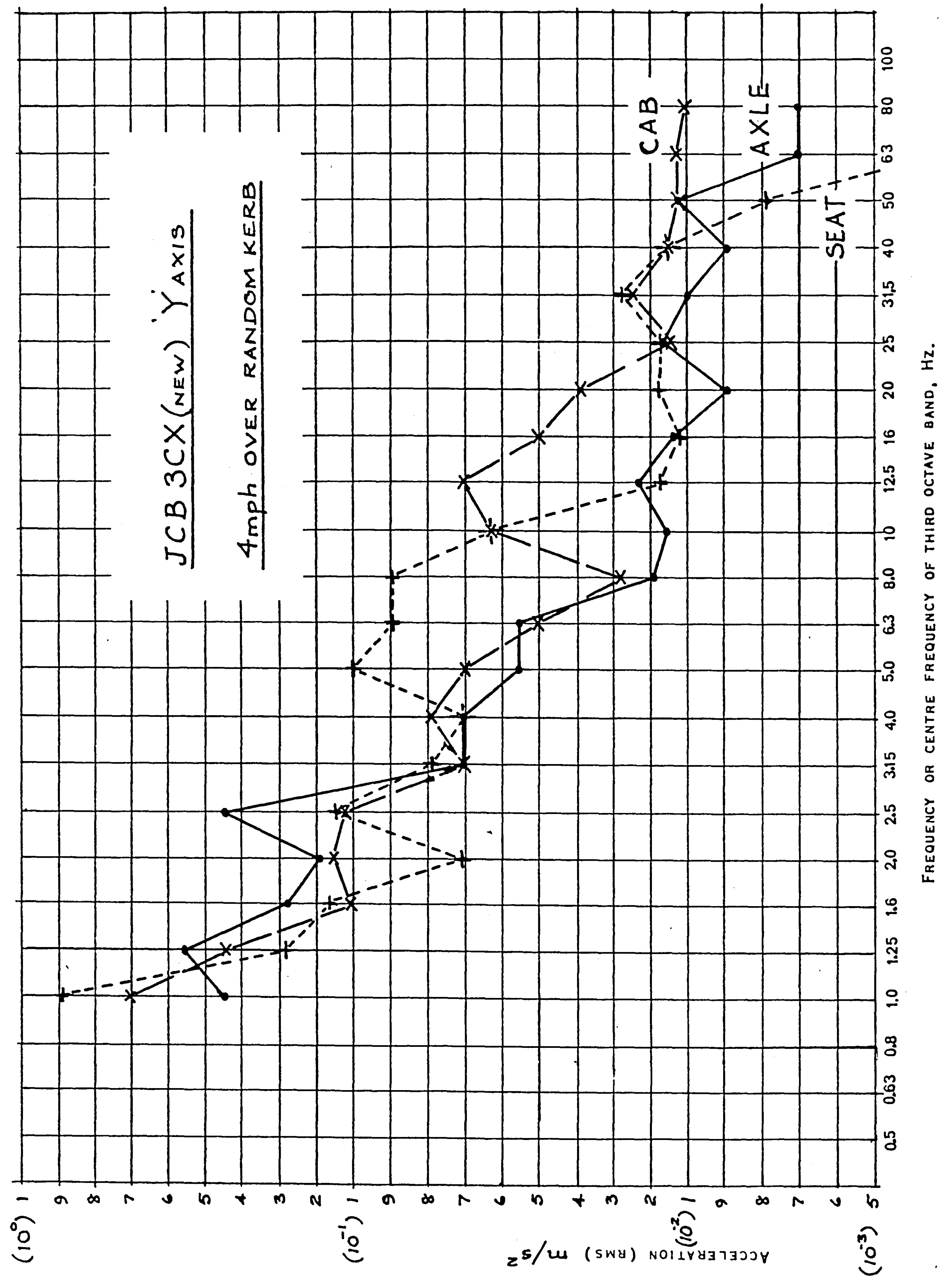

JCB 3CX (NOT NEW) 'X' AXIS
8mph OVER RANDOM KERB
CAB
AXLE
SEAT
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
ACCELERATION (RMS)
m/s²
(10⁻¹)
(10⁻²)
(10⁻³)

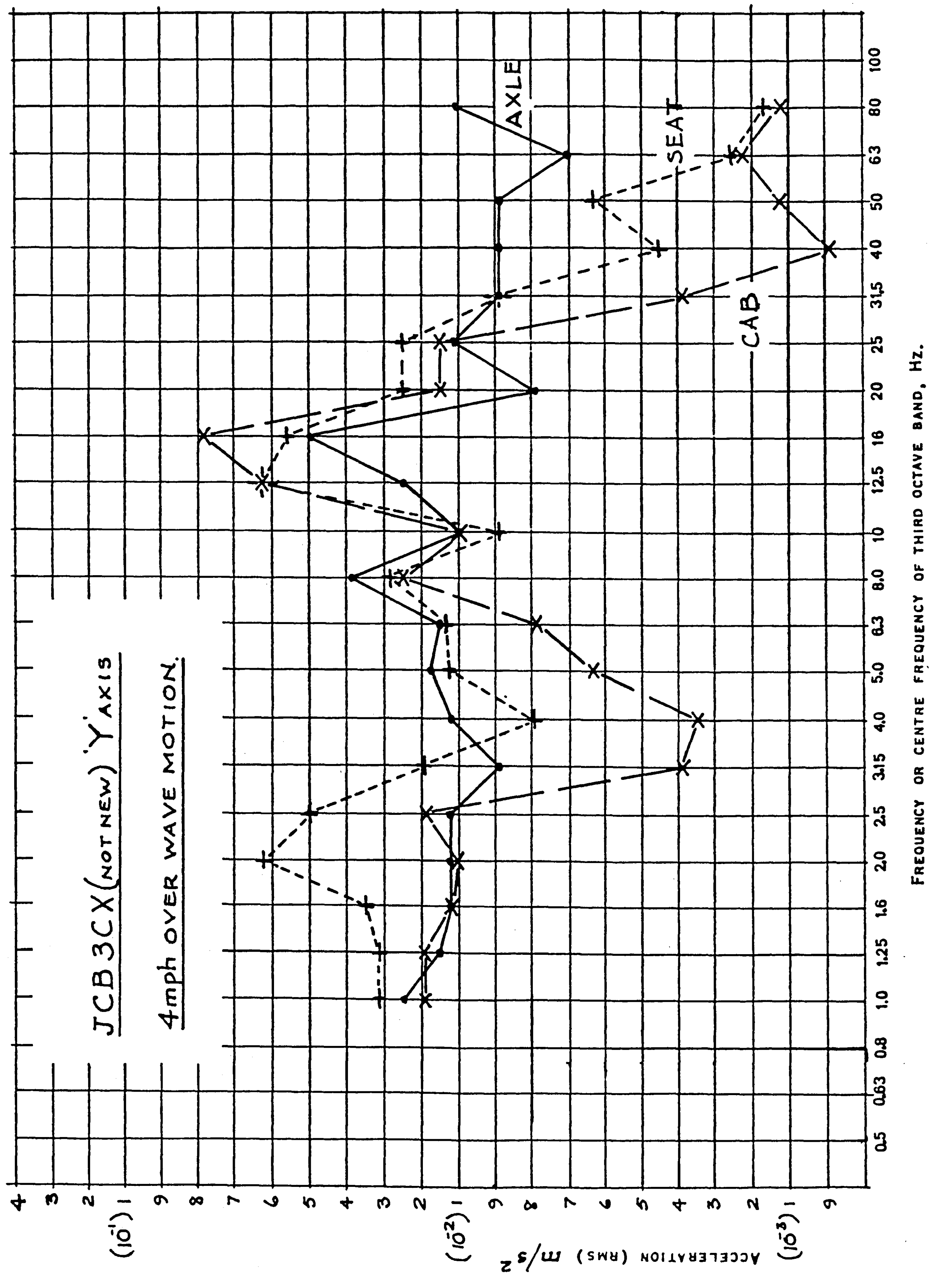


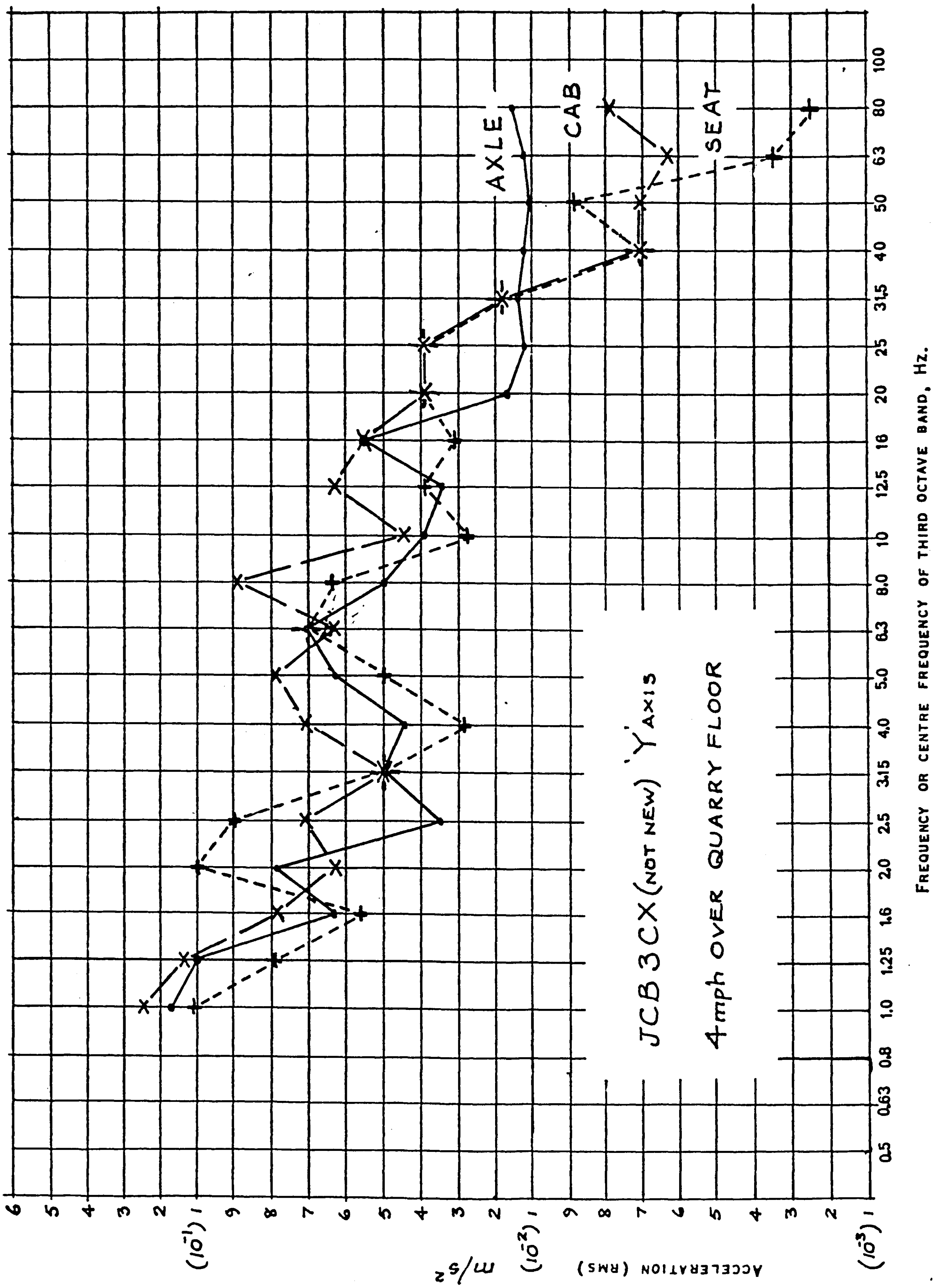
JCB 3CX (NEW) 'Y' AXIS
4 mph OVER WAVE MOTION
AXLE
SEAT
CAB
ACCELERATION (RMS) m/s²
(10⁻²) 1
(10⁻³) 1
(10⁻⁴) 4
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.

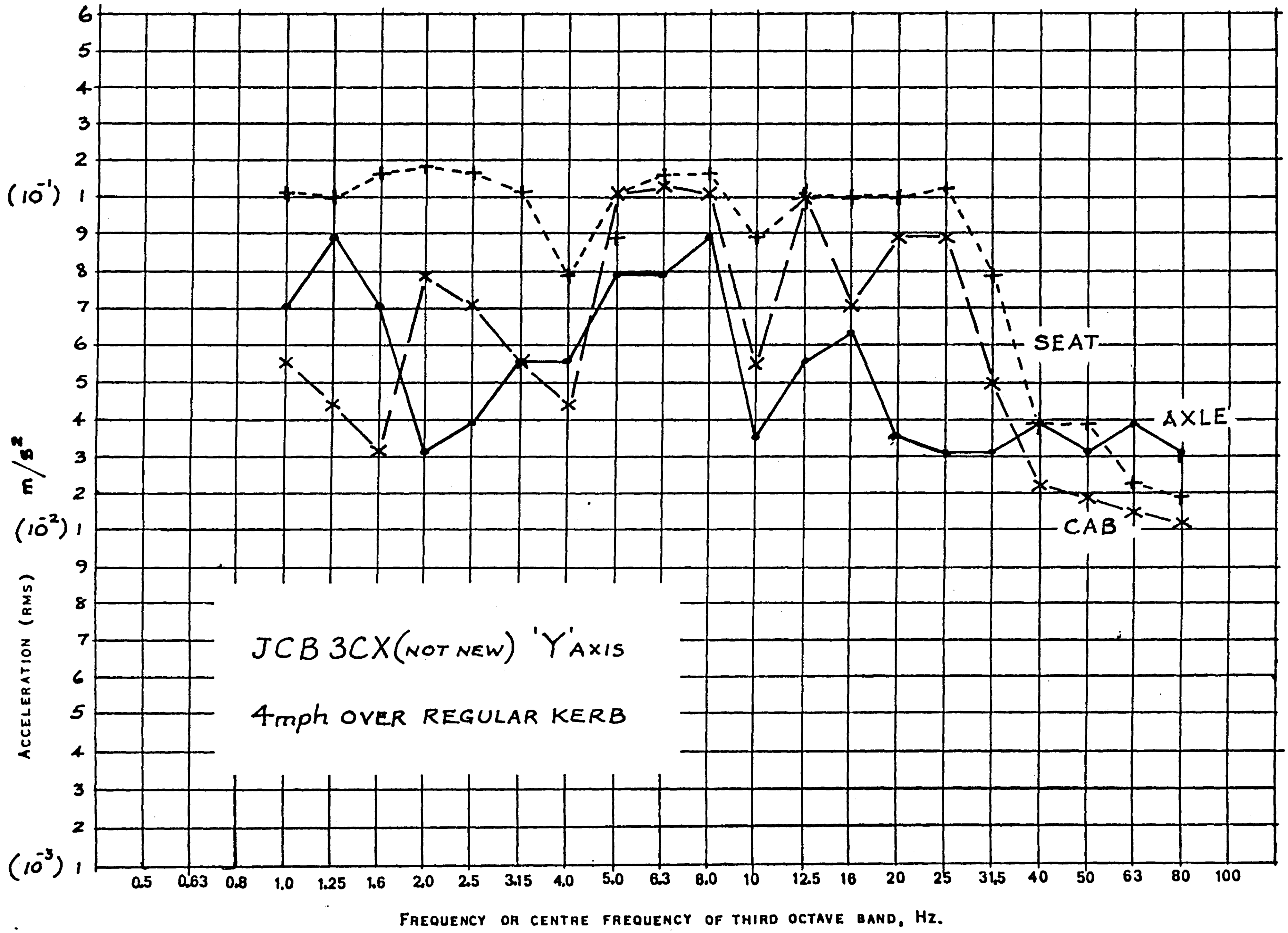

JCB 3CX (NEW) Y' AXIS
4 mph OVER QUARRY FLOOR
AXLE
SEAT
CAB
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
ACCELERATION (RMS) m/s²
(10⁻¹)
(10⁻²)
(10⁻³)

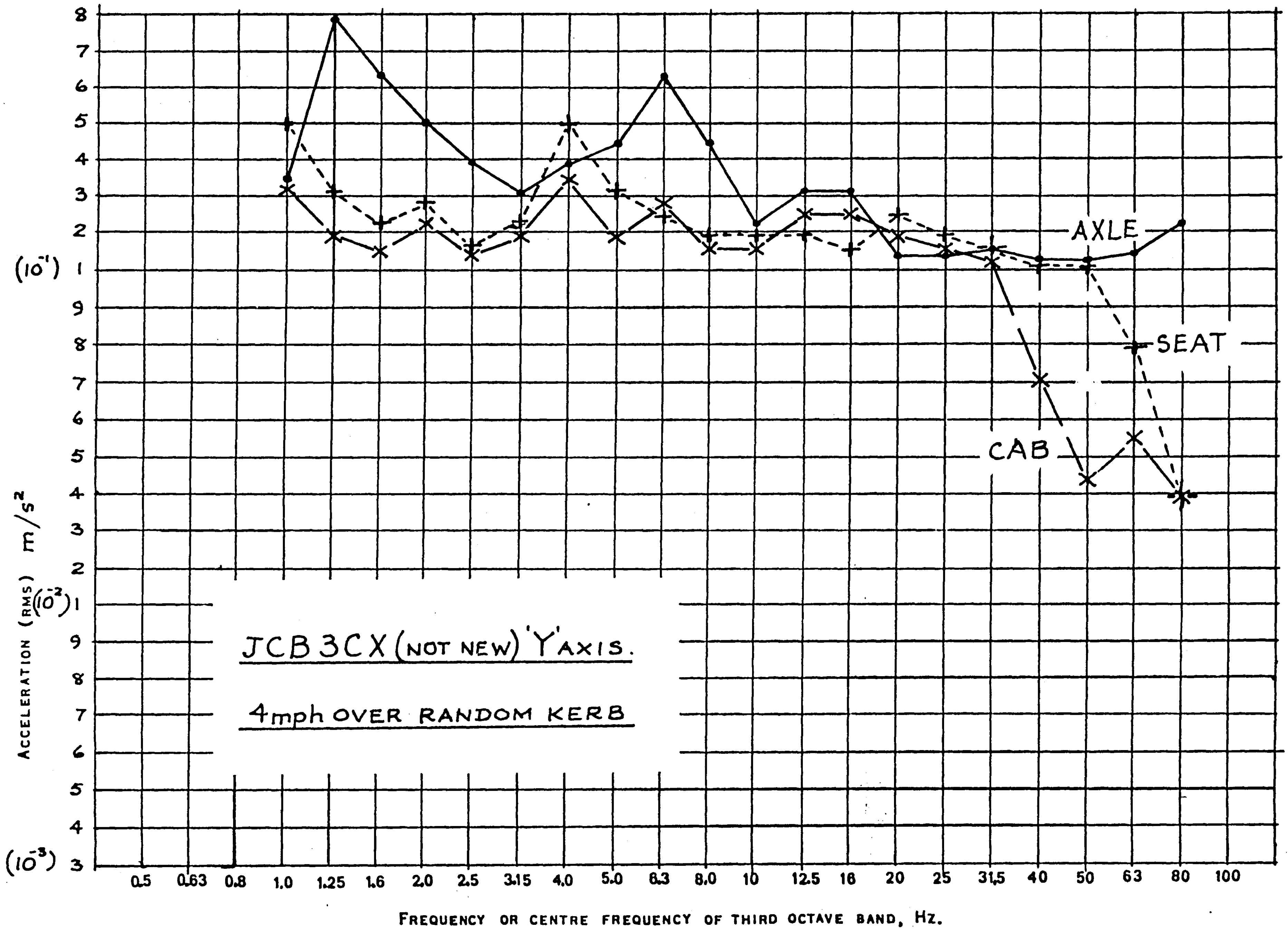

JCB 3CX (NEW) Y' AXIS
4mph OVER REGULAR KERB
AXLE
SEAT
CAB
ACCELERATION (RMS) m/s²
(10^{-1})
(10^{-2})
(10^{-3})
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100

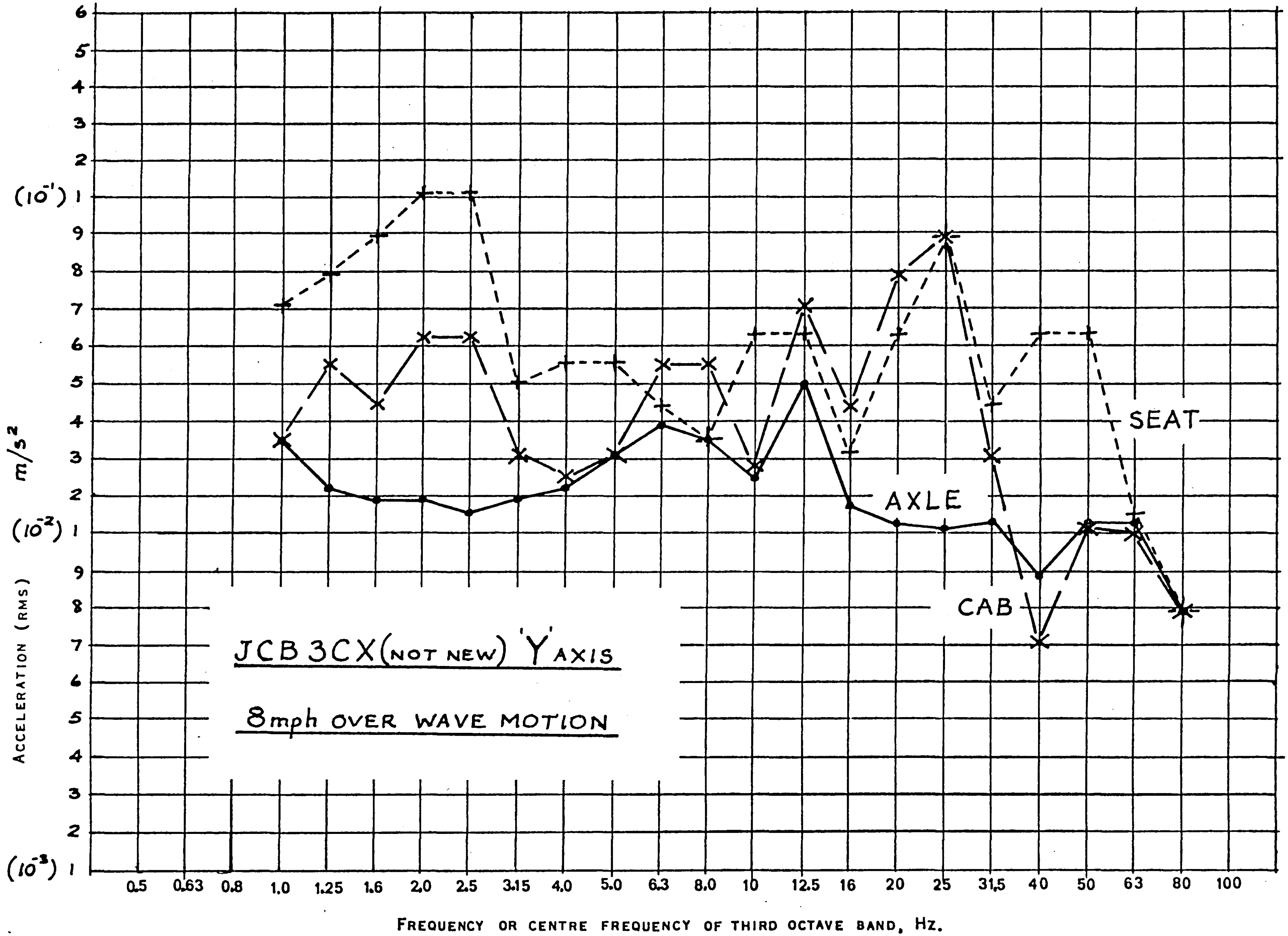

JCB 3CX (NEW) Y AXIS
4mph OVER RANDOM KERB
CAB
AXLE
SEAT
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
ACCELERATION (RMS) m/s²
(10⁰) 1 9 8 7 6 5 4 3 2
(10⁻¹) 1 9 8 7 6 5 4 3 2
(10⁻²) 1 9 8 7 6 5
(10⁻³)

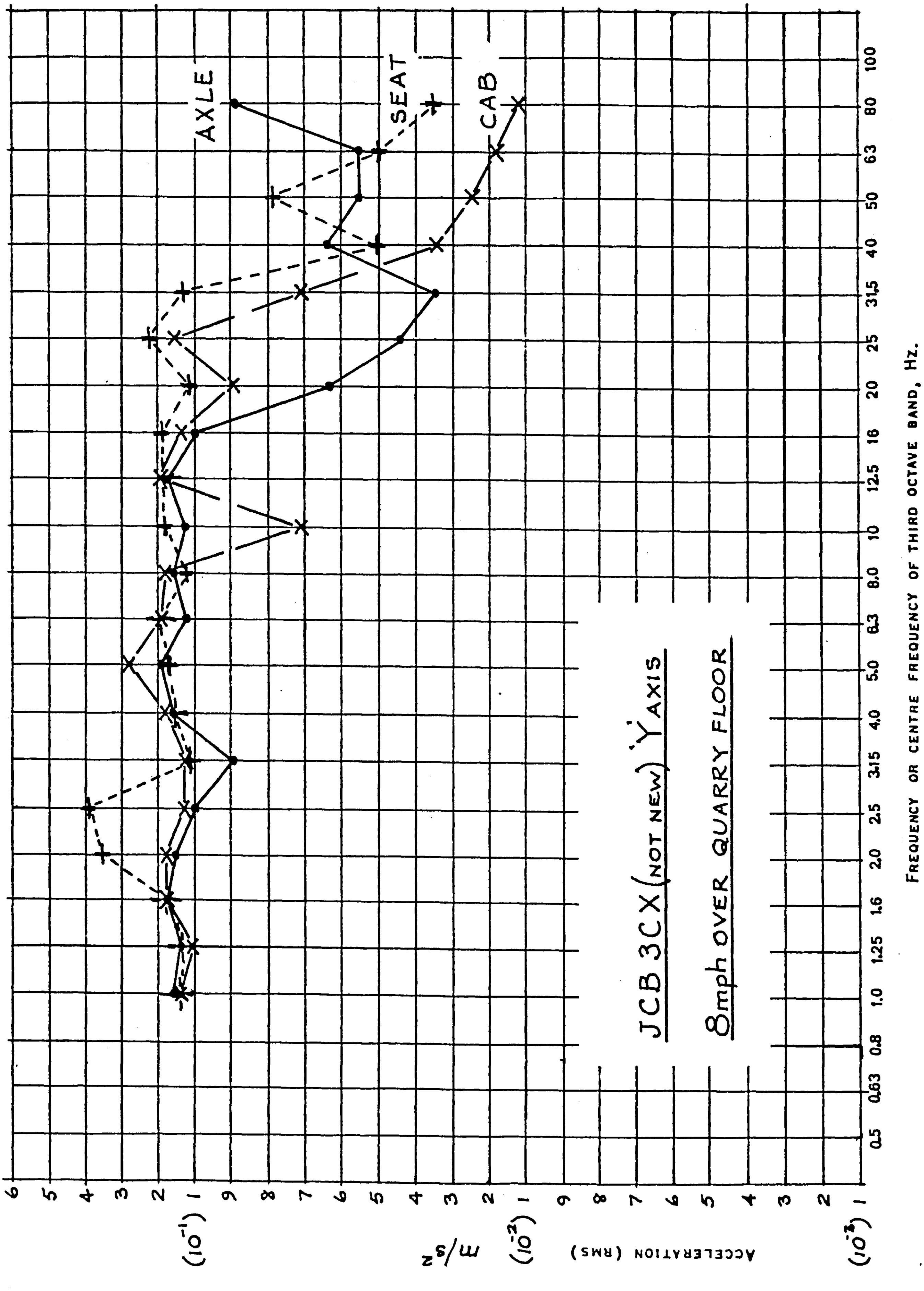

JCB 3CX (NOT NEW) 'Y' AXIS
4mph OVER WAVE MOTION.
AXLE
SEAT
CAB
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
ACCELERATION (RMS) m/s²


JCB 3CX (NOT NEW) 'Y' AXIS
4mph OVER QUARRY FLOOR
AXLE
CAB
SEAT
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
ACCELERATION (RMS)
m/s²
(10⁻¹)
(10⁻²)
(10⁻³)

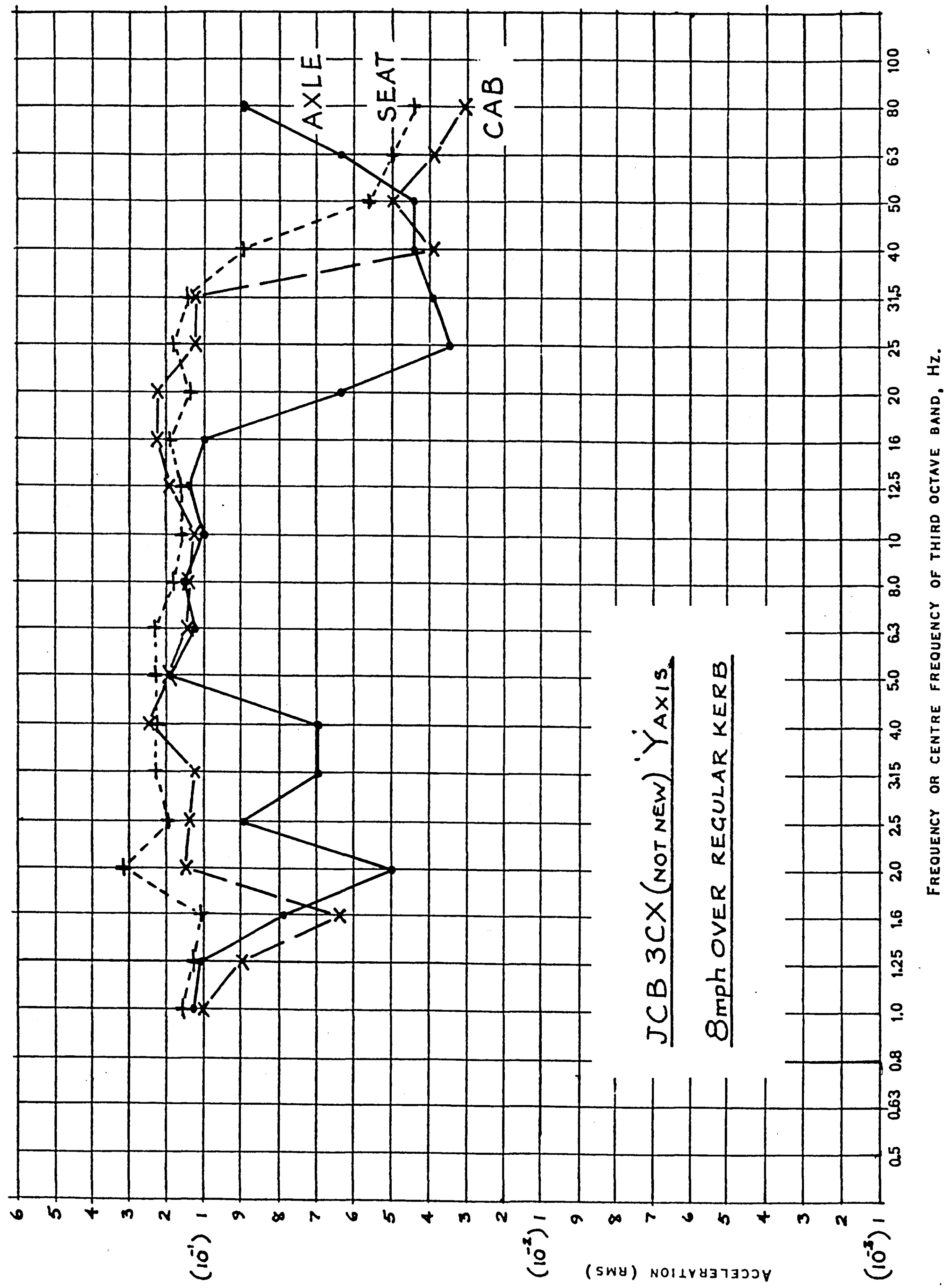

JCB 3CX(NOT NEW) 'Y' AXIS
4mph OVER REGULAR KERB
SEAT
AXLE
CAB
ACCELERATION (RMS) m/s²
(10⁻¹)
(10⁻²)
(10⁻³)
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100

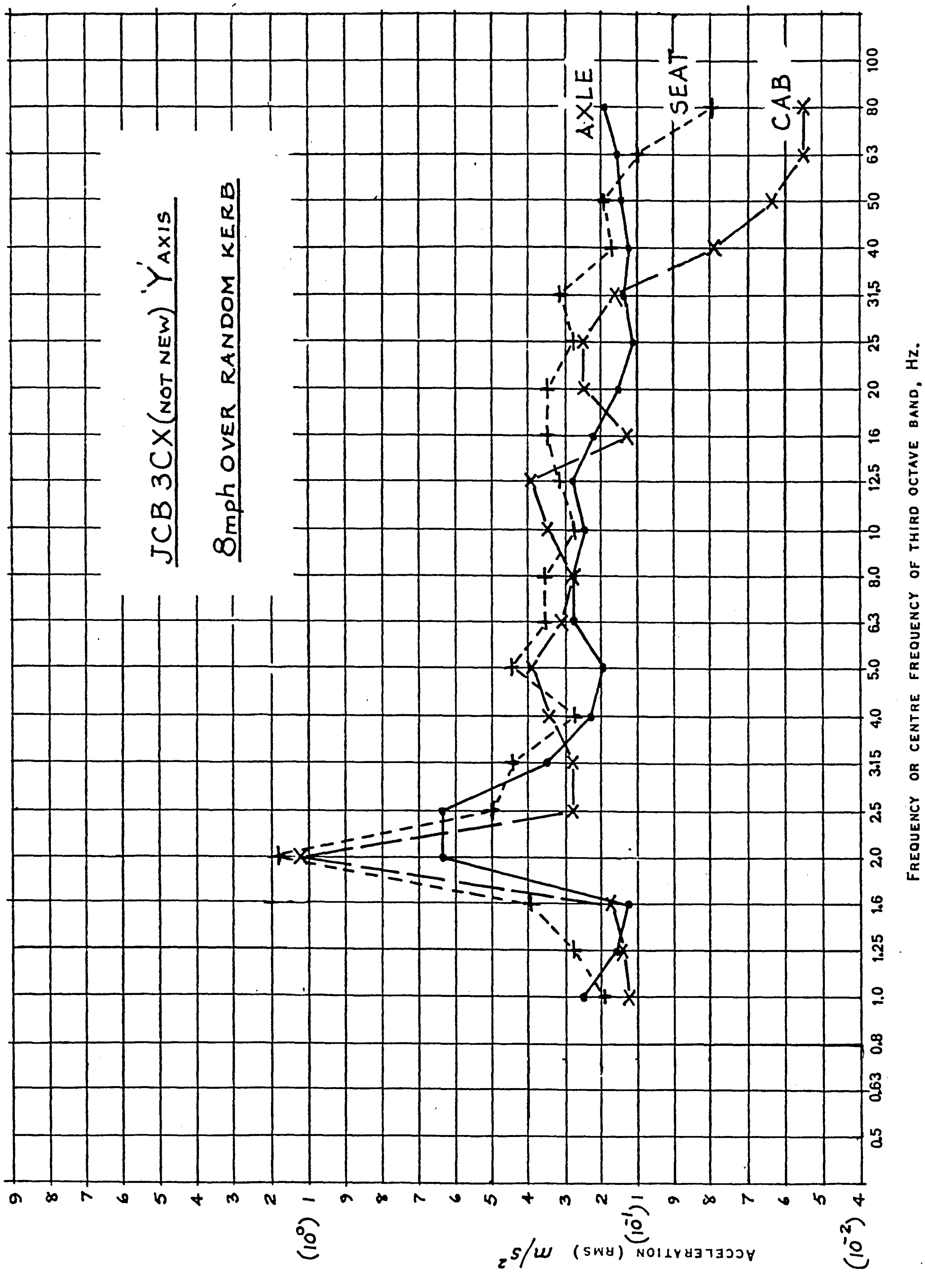

JCB 3CX (NOT NEW) 'Y' AXIS.
4mph OVER RANDOM KERB
AXLE
SEAT
CAB
ACCELERATION (RMS) m/s²
(10^{-1})
(10^{-2})
(10^{-3})
8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.


JCB 3CX (NOT NEW) 'Y' AXIS
8mph OVER WAVE MOTION
SEAT
AXLE
CAB
ACCELERATION (RMS)
m/s²
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.



JCB 3CX (NOT NEW) 'Y' AXIS
8mph OVER QUARRY FLOOR
AXLE
SEAT
CAB
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
ACCELERATION (RMS)
m/s²


AXLE
SEAT
CAB
JCB 3CX (NOT NEW) 'Y' AXIS
8mph OVER REGULAR KERB
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
0.5 0.63 0.8 1.0 1.25 1.6 2.0 2.5 3.15 4.0 5.0 6.3 8.0 10 12.5 16 20 25 31.5 40 50 63 80 100
ACCELERATION (RMS)
(10^{-1})
(10^{-2})
(10^{-3})
1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6

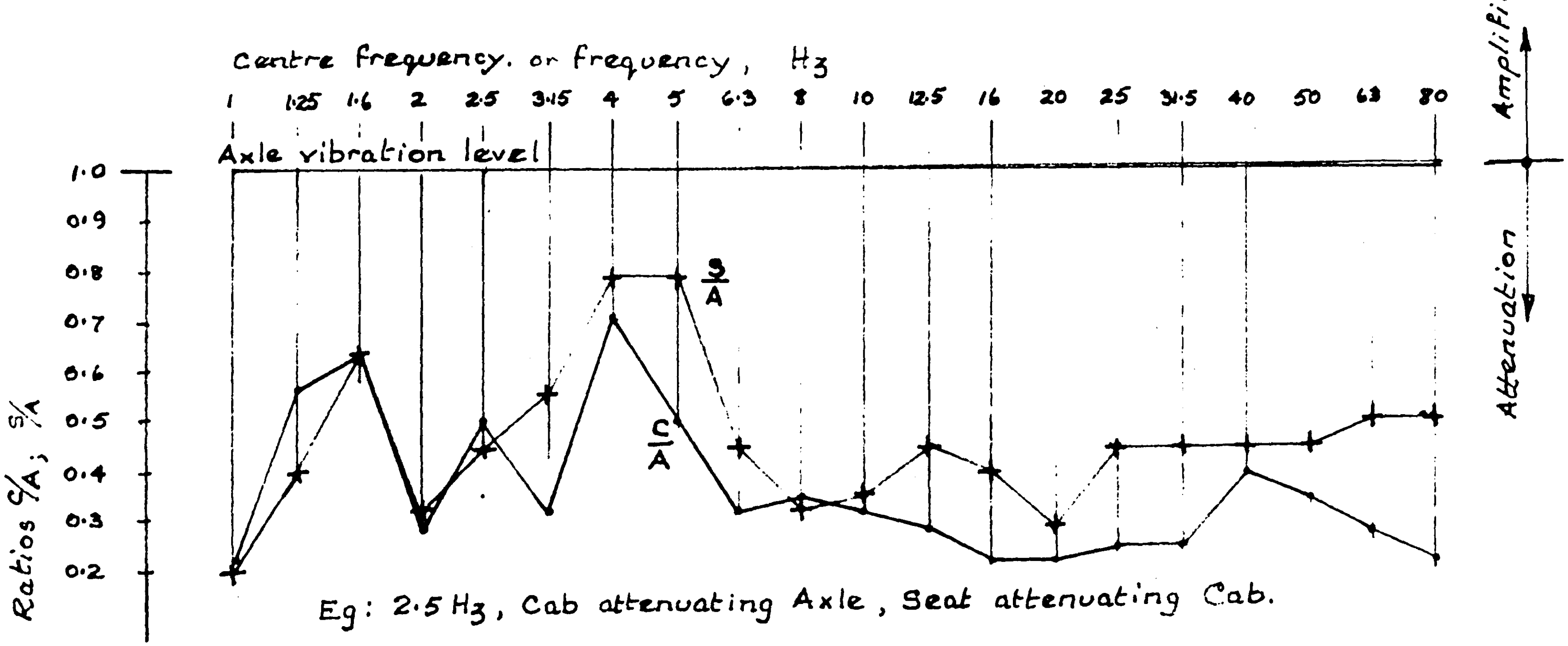

JCB 3CX (NOT NEW) 'Y' AXIS
8mph OVER RANDOM KERB
AXLE
SEAT
CAB
0.5
0.63
0.8
1.0
1.25
1.6
2.0
2.5
3.15
4.0
5.0
6.3
8.0
10
12.5
16
20
25
31.5
40
50
63
80
100
FREQUENCY OR CENTRE FREQUENCY OF THIRD OCTAVE BAND, Hz.
ACCELERATION (RMS) m/s²
(10⁰)
(10⁻¹)
(10⁻²)

APPENDIX 'F'

Graphical presentation of amplification - attenuation ratio's for $\frac{\text{Seat}}{\text{Axle}}$ and $\frac{\text{Cab}}{\text{Axle}}$ over each test track for both 'new' and 'not new' JCB 3CX Excavator/Loader vehicles.

JCB '3CX' (new) x 4mph over Quarry Floor test track 'X' axis

Correlations : $\frac{A}{S} = 0{\cdot}57$; $\frac{C}{S} = 0{\cdot}67$; $\frac{A}{C} = 0{\cdot}82$.

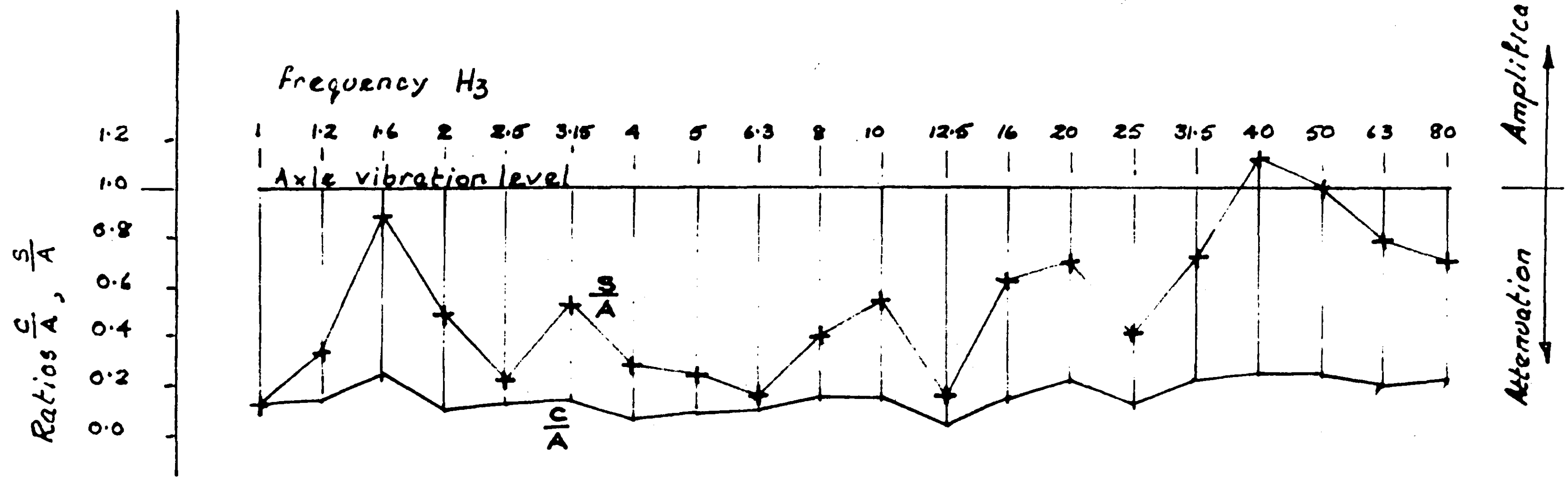


Eg: 2.5 Hz, Cab attenuating Axle, Seat attenuating Cab.

: 5 Hz, Cab attenuating Axle, Seat amplifying Cab.

JCB '3CX' (new) ≃ 4 mph travel over Wave Motion test track : 'X' axis.

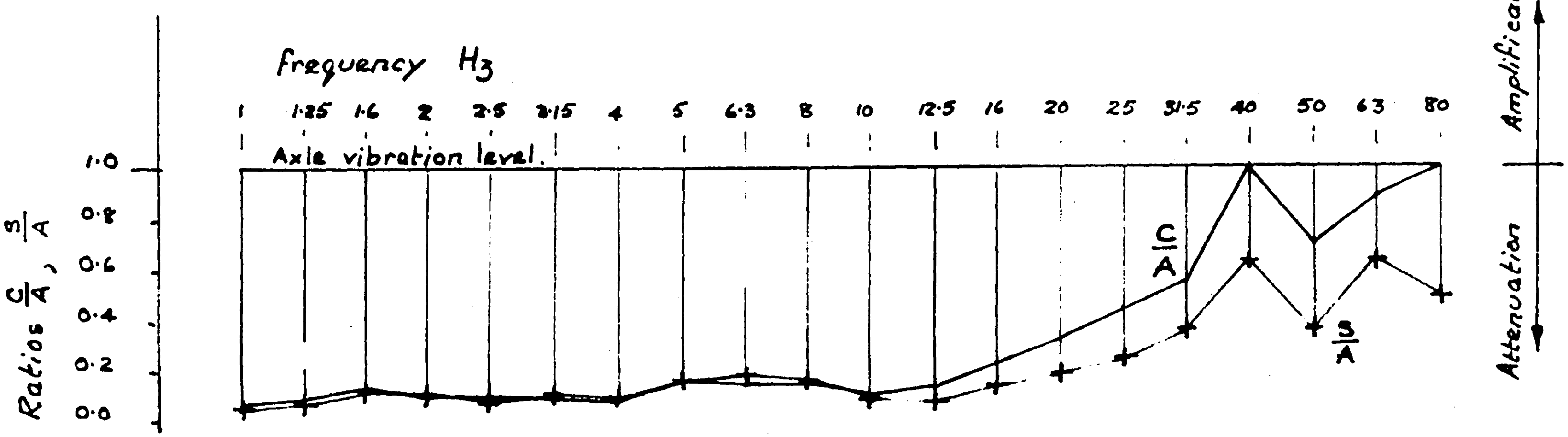
Correlations : $\frac{A}{S} = 0.25$; $\frac{C}{S}$ 0.43 ; $\frac{A}{C} = 0.80$



Eg: 1.6 Hz, Cab attenuating Axle, Seat amplifying Cab

JCB '3CX' (new) ≃ 4mph travel over Regular Kerb test track : 'X' axis.

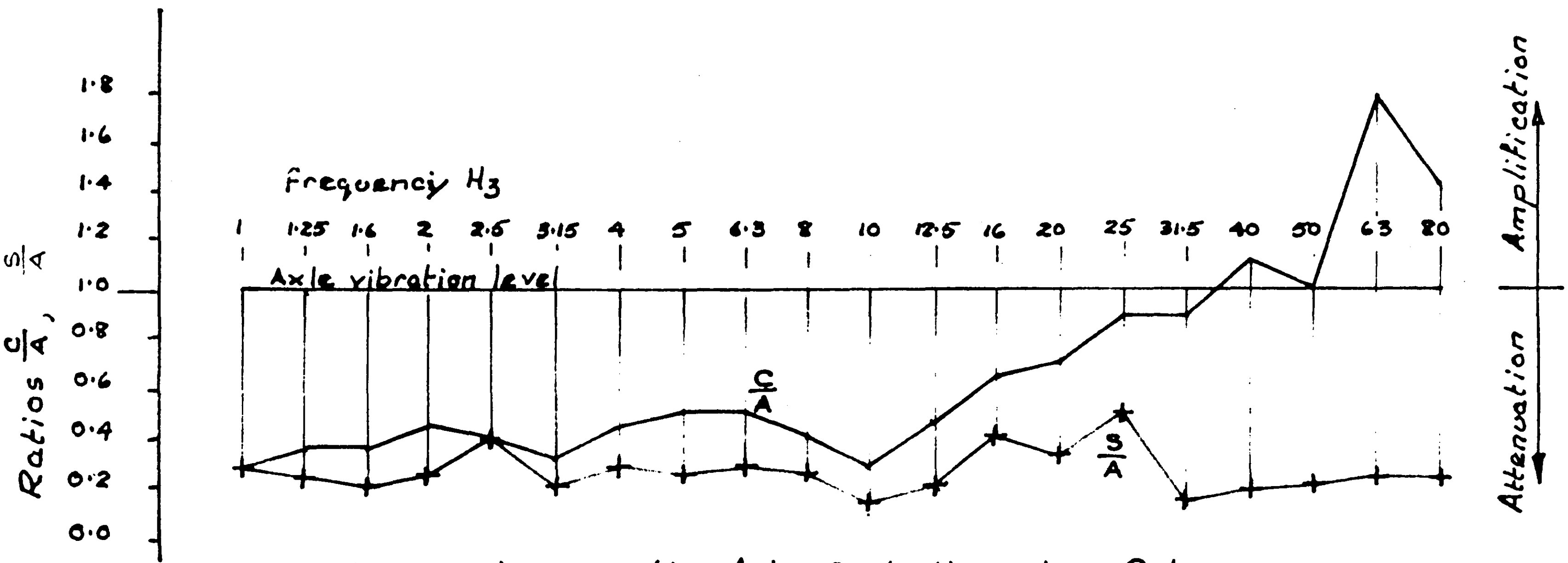
Correlations : $\frac{A}{S} = 0.56$, $\frac{C}{S} = 0.49$, $\frac{A}{C} = 0.86$.



Eg : 6·3 Hz , Cab attenuating Axle ; Seat amplifying Cab.
: 12·5 Hz , Cab attenuating Axle, Seat attenuating Cab.

JCB '3CX' (new) ≃ 4 mph travel over Random Kerb test track : 'X' axis

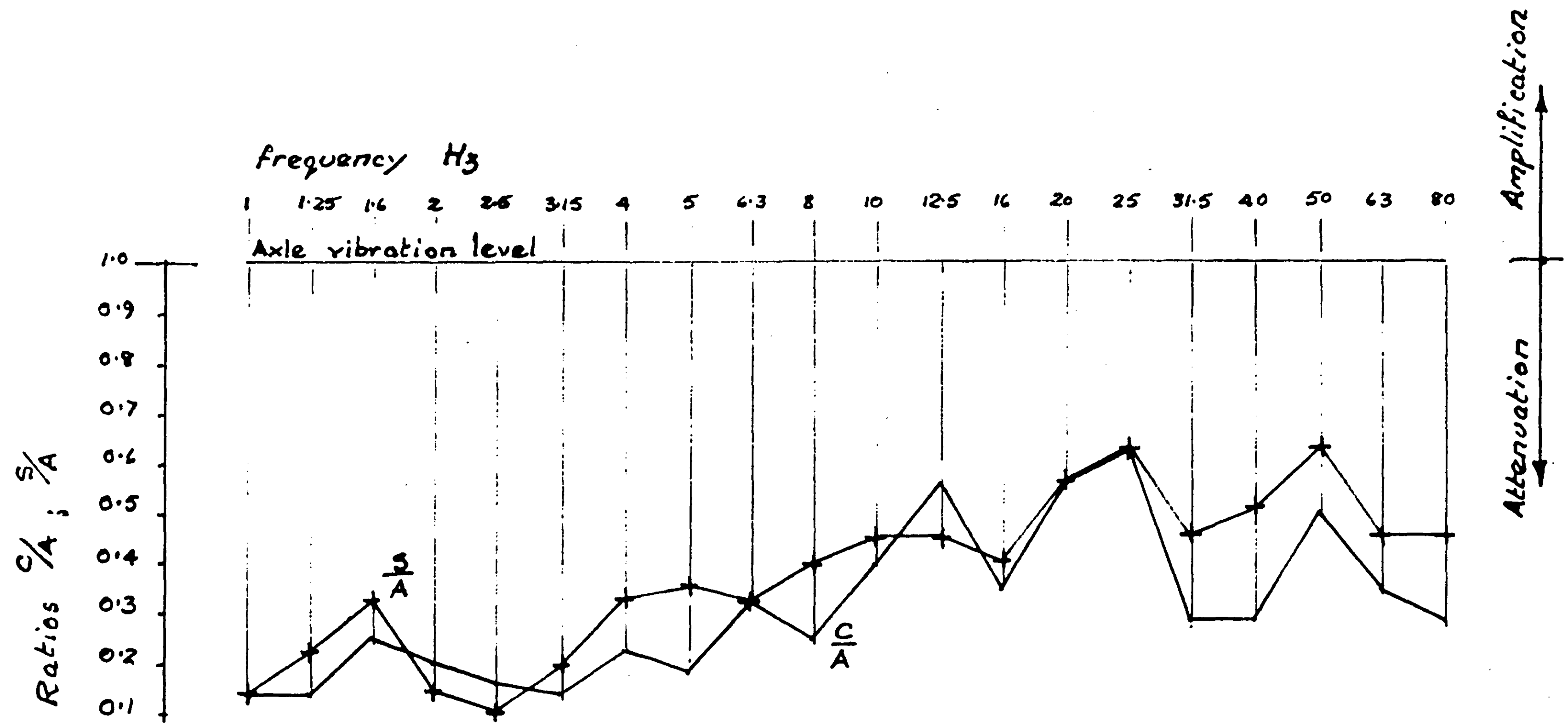
Correlations : $\frac{A}{S} = 0.80$, $\frac{C}{S} = 0.82$, $\frac{A}{C} = 0.95$



Eg: 2 Hz, Cab attenuating Axle, Seat attenuating Cab.
: 40 Hz, Cab amplifying Axle, Seat attenuating Cab.

JCB '3CX' (not new) ≃ 4mph over Quarry Floor test track : '**X**' axis

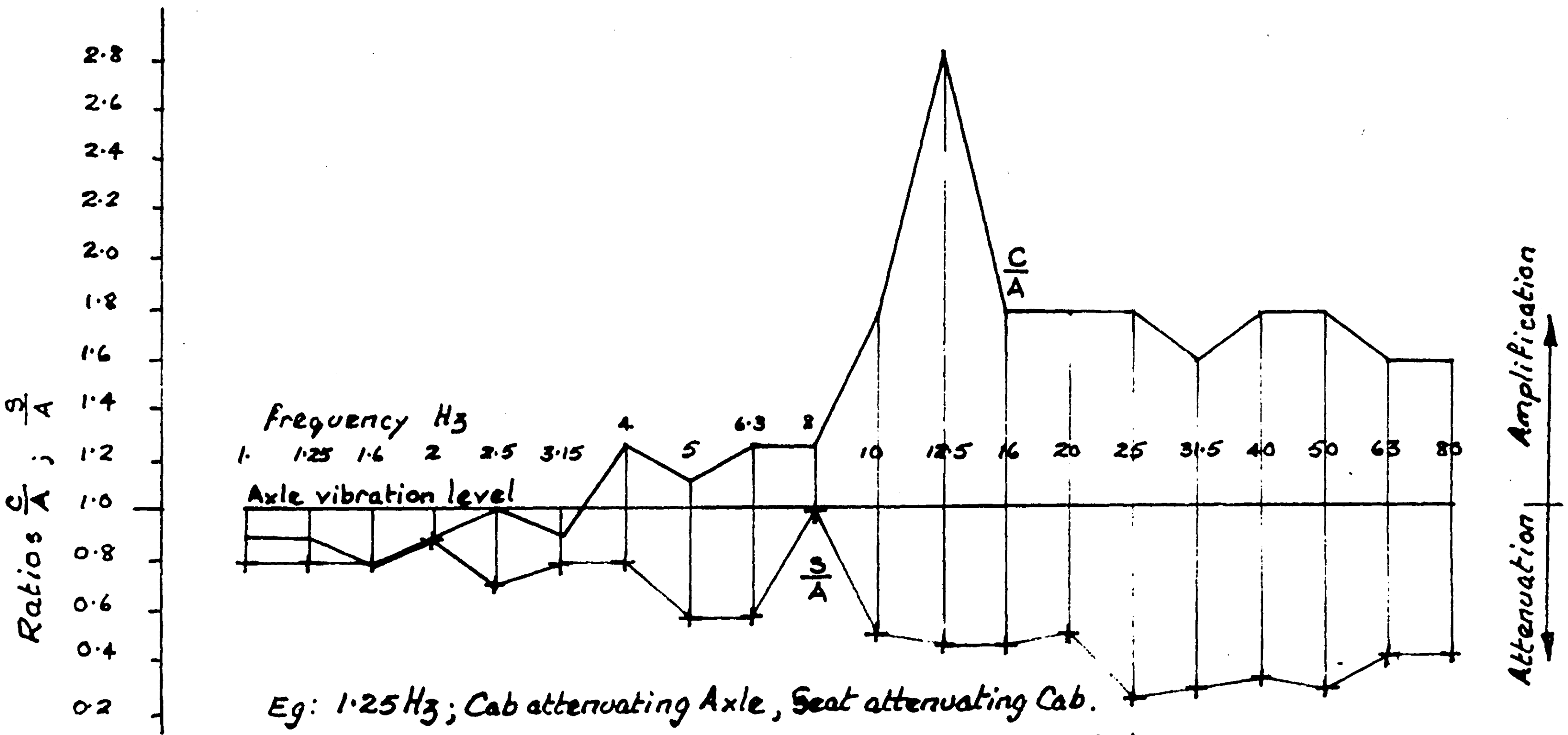
Correlations : $\frac{A}{S} = 0.81$; $\frac{C}{S} = 0.79$; $\frac{A}{C} = 0.94$.



E.g : 2.5 Hz - Cab attenuating Axle, Seat attenuating Cab.
: 5 Hz - Cab attenuating Axle, Seat amplifying Cab.

JCB '3CX' (not new) ≃ 4 mph travel over Wave Motion test track : 'X' axis.

Correlations : $\frac{A}{S} = 0{\cdot}97$, $\frac{C}{S} = 0{\cdot}78$, $\frac{A}{C} = 0{\cdot}84$

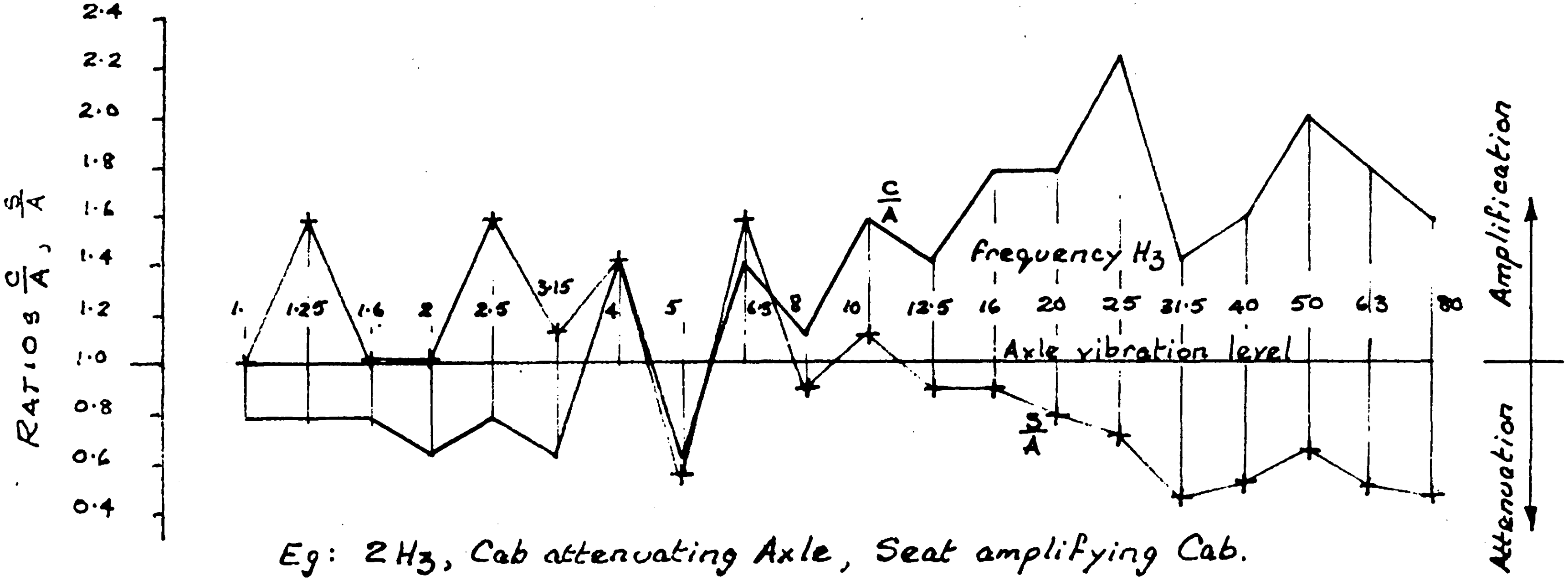


Eg: 1·25 Hz ; Cab attenuating Axle, Seat attenuating Cab.

: 5 Hz ; Cab amplifying Axle, Seat attenuating Cab.

JCB '3CX' (not new) ≃ 4 mph travel over Regular Kerb test track : 'X' axis.

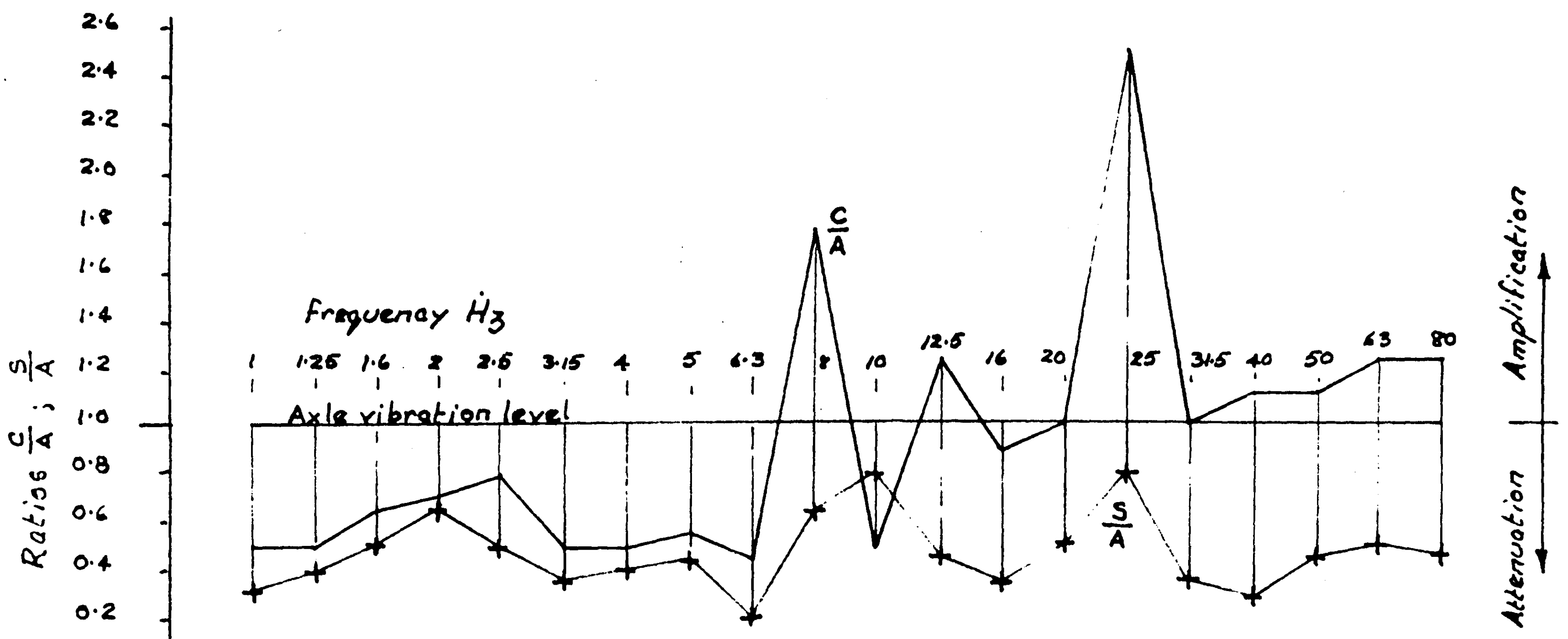
Correlations: A/S = 0·95, C/S = 0·93, A/C = 0·95.



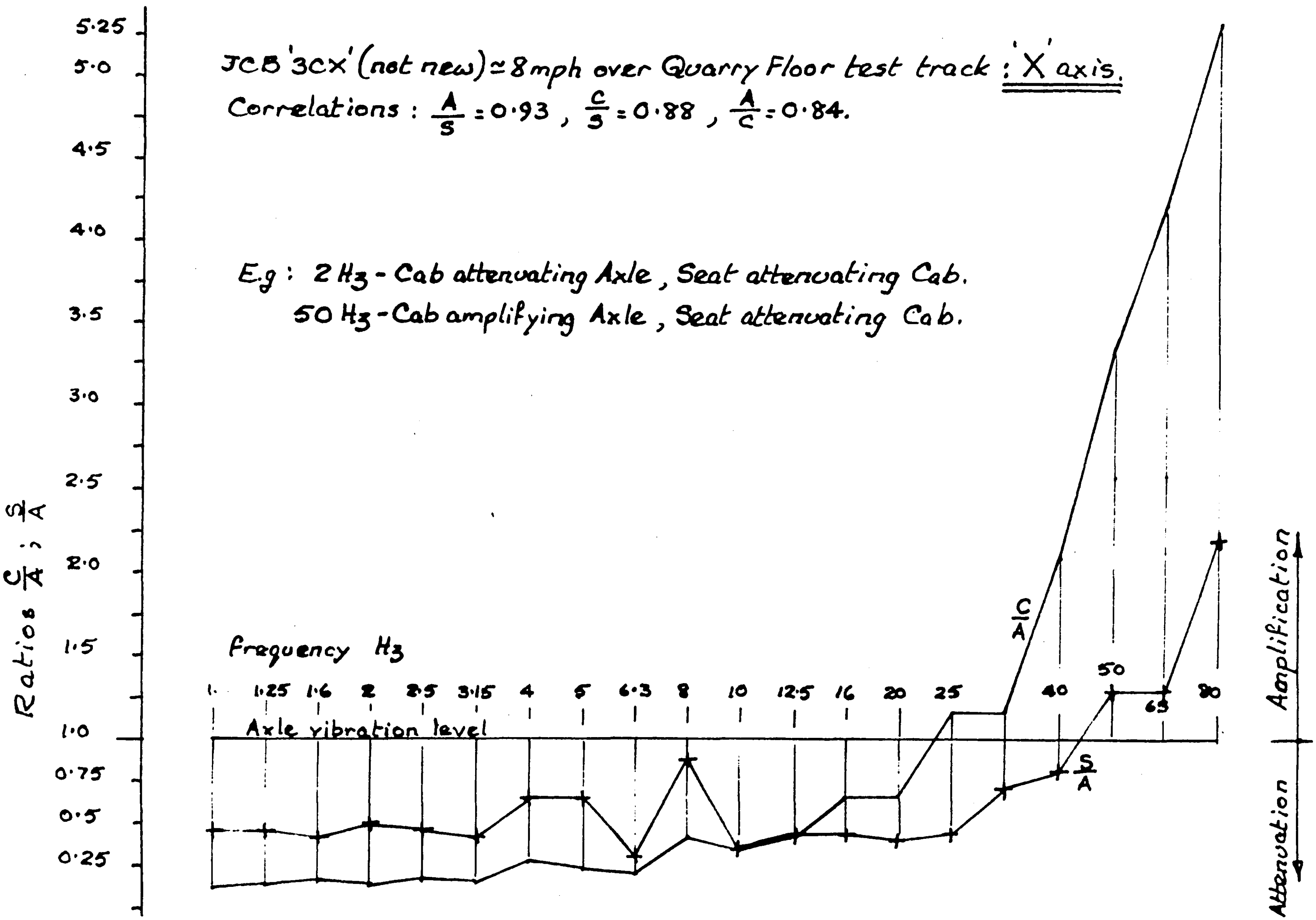
Eg: 2 Hz, Cab attenuating Axle, Seat amplifying Cab.
: 5 Hz, Cab attenuating Axle, Seat attenuating Cab.

JCB '3CX' (not new) ≃ 4mph travel over Random Kerb test track : '$\dot{X}$' axis.

Correlations : A/S = 0·92 ; C/S = 0·88 ; A/C = 0·94.

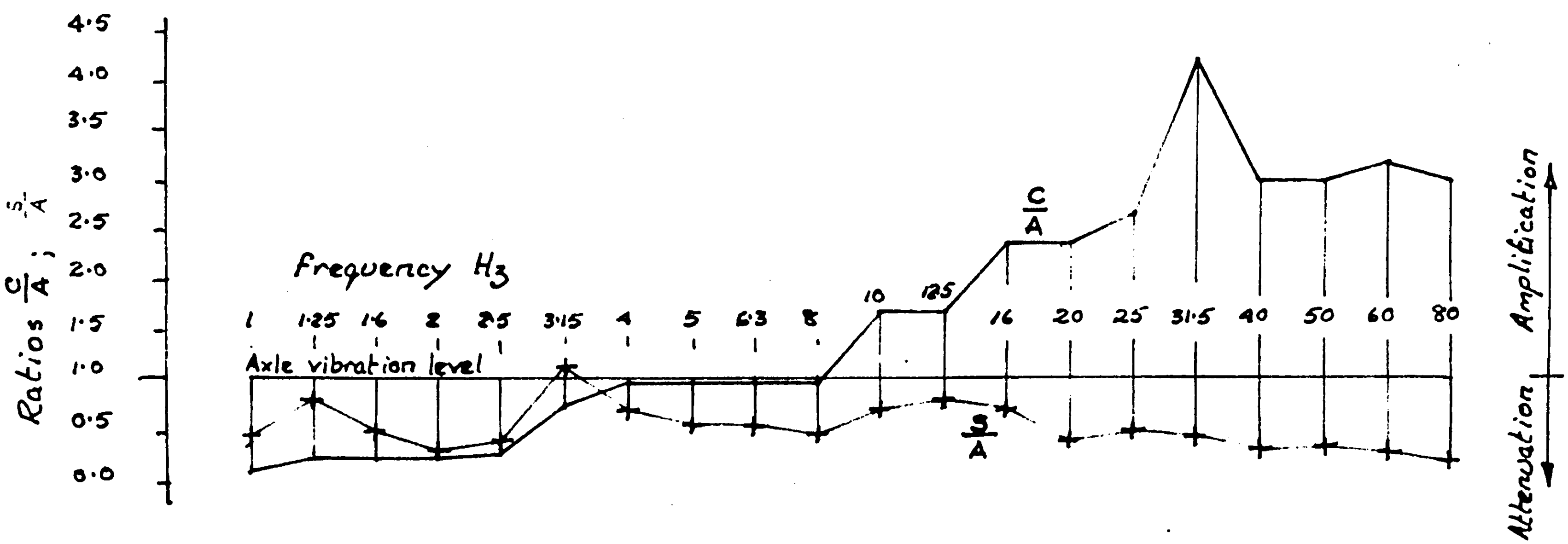


Eg : 8 Hz, Cab amplifying Axle, Seat attenuating Cab.
: 10 Hz, Cab attenuating Axle, Seat amplifying Cab.


JCB '3CX' (not new) ≃ 8mph over Quarry Floor test track : 'X' axis.
Correlations : A/S = 0·93 , C/S = 0·88 , A/C = 0·84.
E.g : 2 Hz - Cab attenuating Axle , Seat attenuating Cab.
50 Hz - Cab amplifying Axle , Seat attenuating Cab.
Ratios C/A ; S/A
5·25
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·75
0·5
0·25
Frequency Hz
1 1·25 1·6 2 2·5 3·15 4 5 6·3 8 10 12·5 16 20 25 40 50 65 80
Axle vibration level
C/A
S/A
Amplification
Attenuation

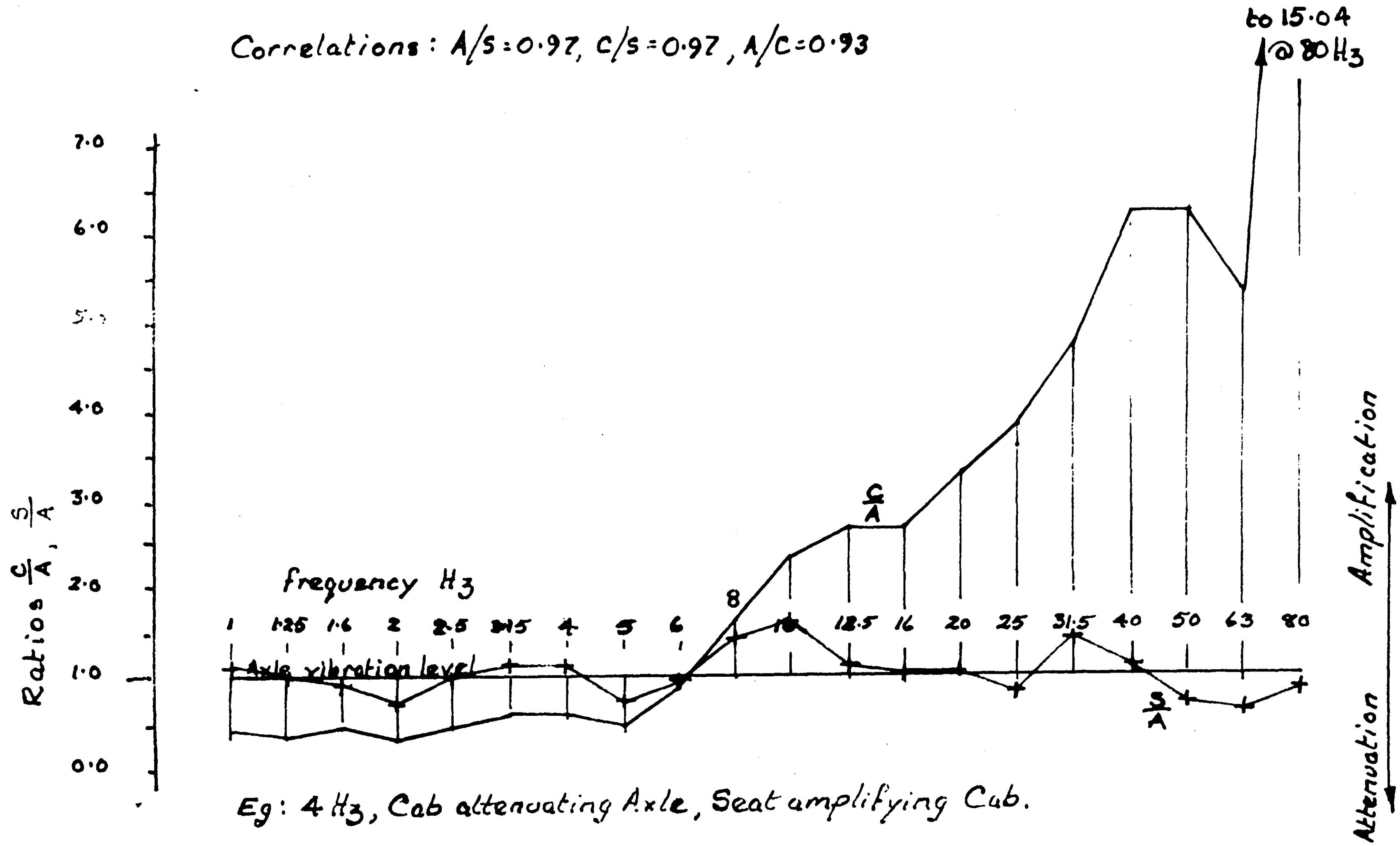
JCB '3CX' (not new) ≃ 8mph travel over Wave Motion test track : 'X' axis.

Correlations: A/S = 0·85 ; C/S = 0·11 ; A/C = −0·1

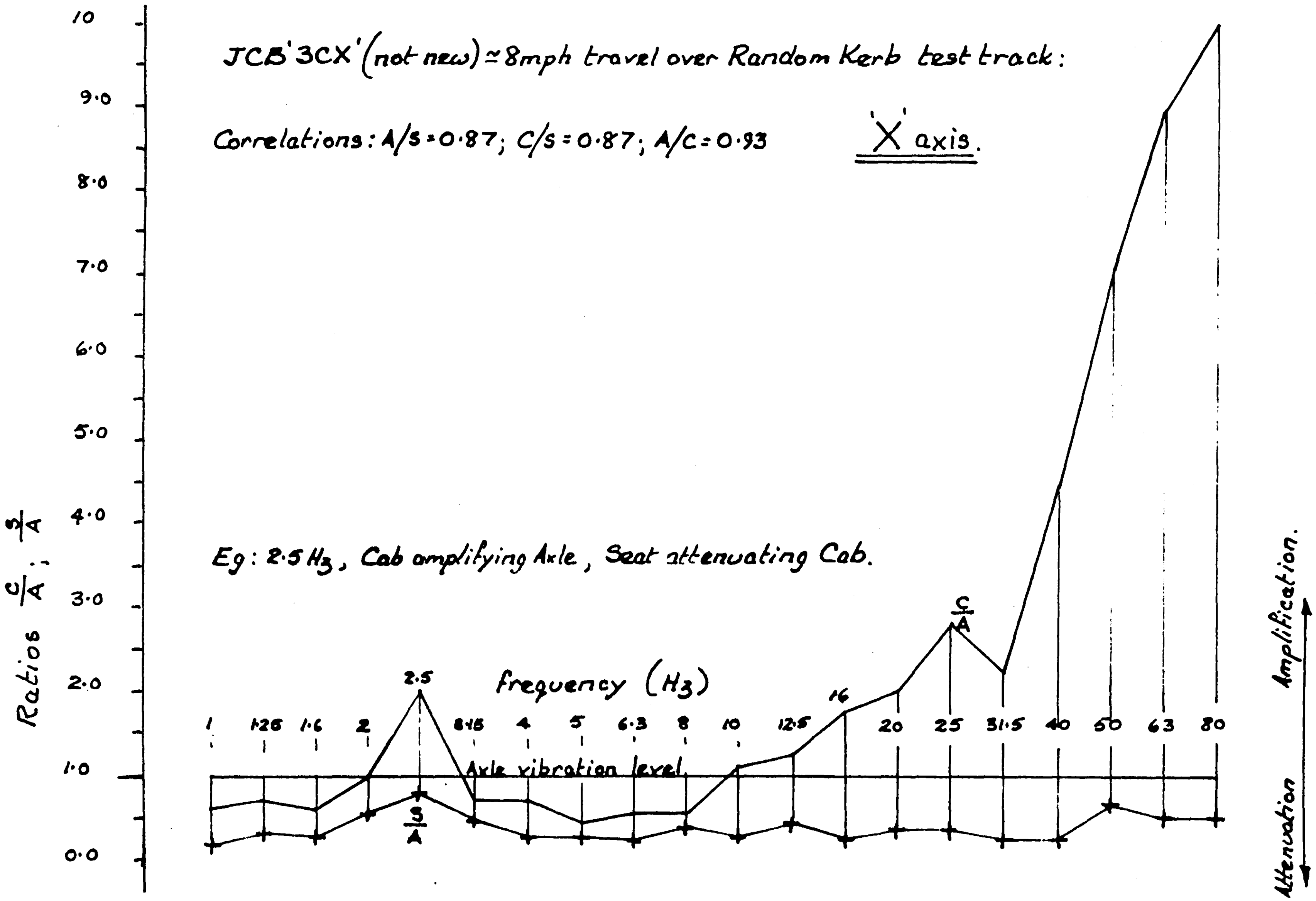


JCB '3CX' (not new) ≃ 8 mph travel over Regular Kerb test track : 'X' axis.

Correlations : A/S = 0·97, C/S = 0·97, A/C = 0·93



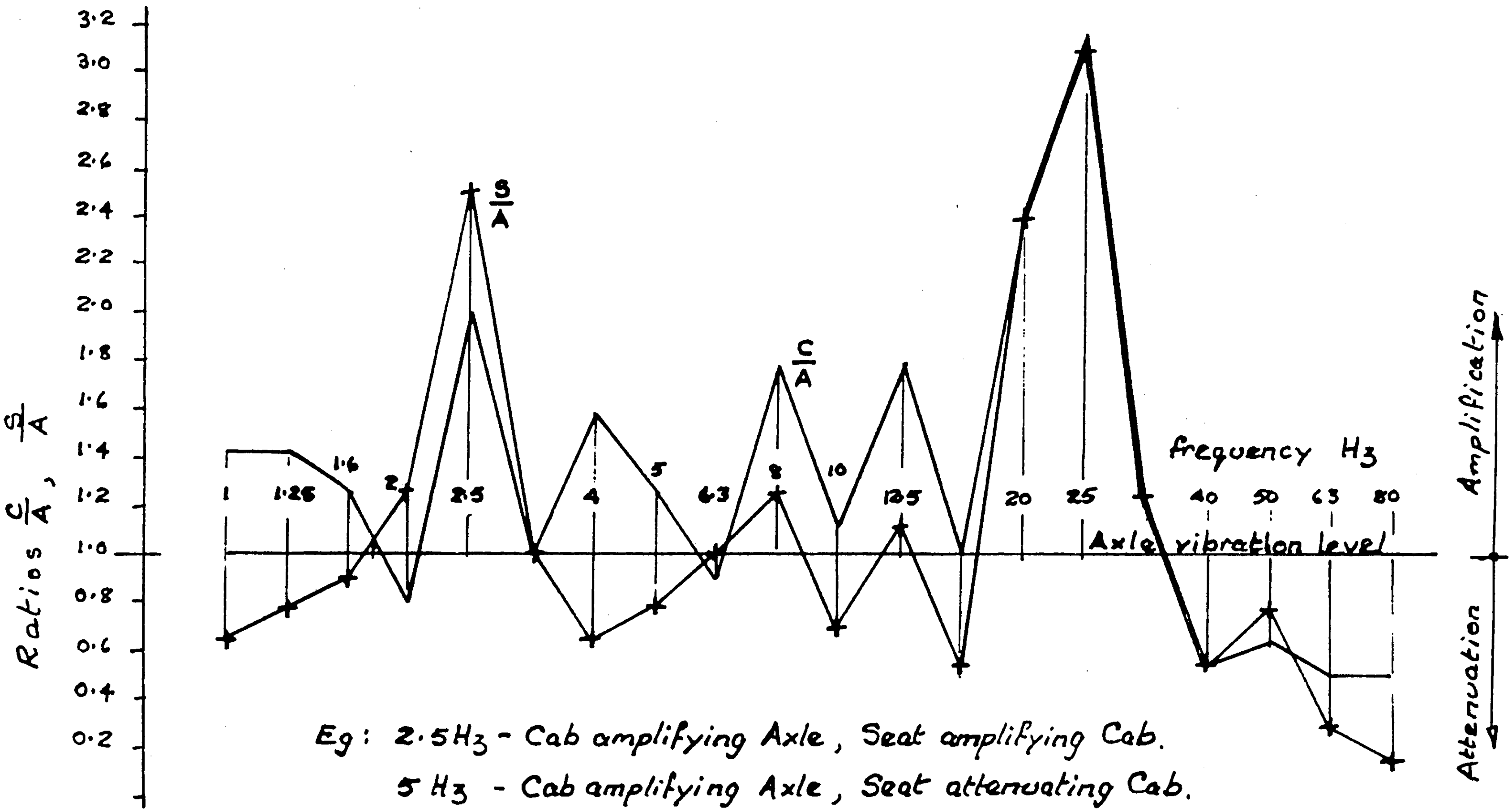
Eg: 4 Hz, Cab attenuating Axle, Seat amplifying Cab.

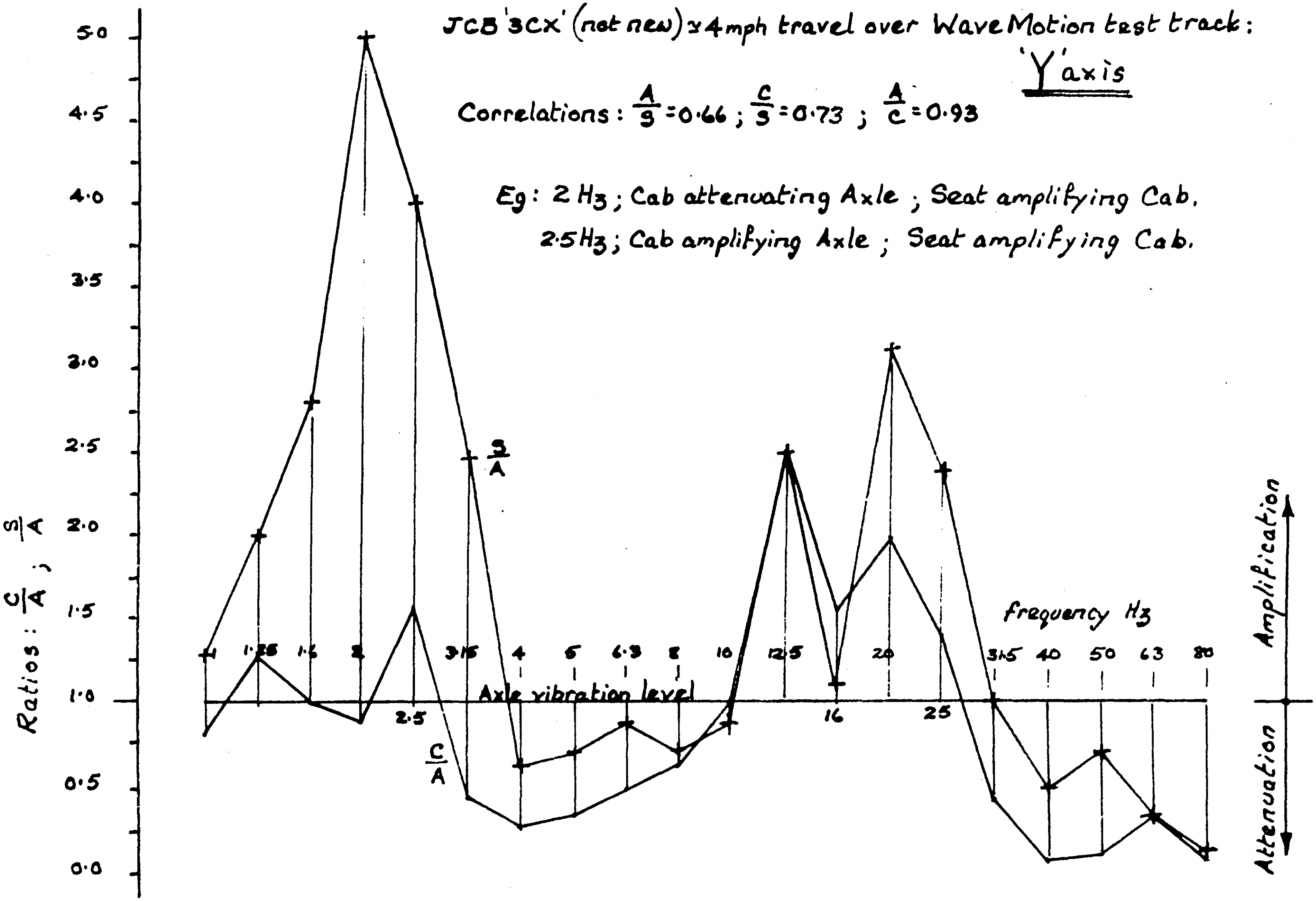


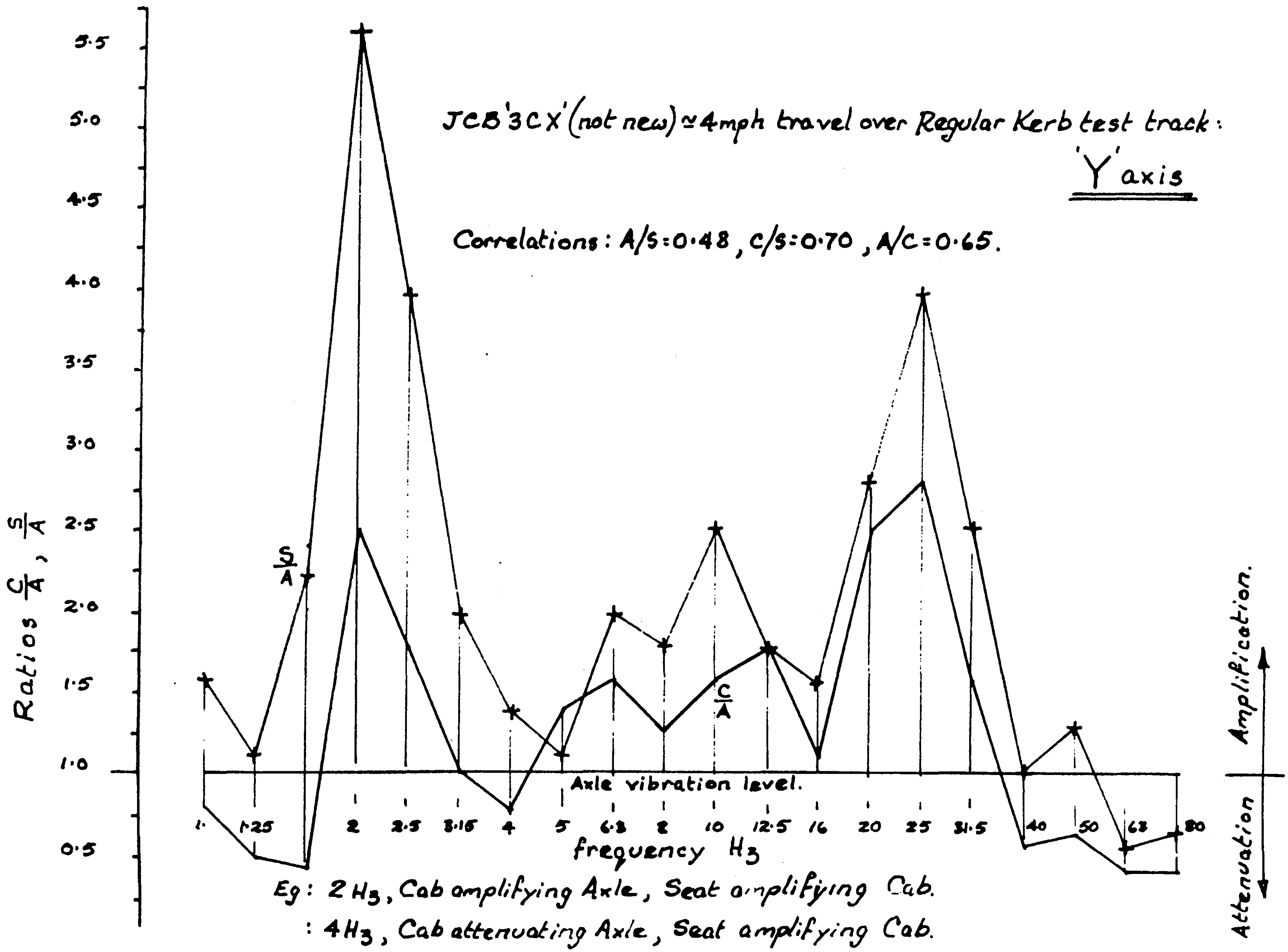
JCB '3CX' (not new) ≃ 8mph travel over Random Kerb test track:
Correlations: A/S = 0·87; C/S = 0·87; A/C = 0·93
'X' axis.
Eg: 2·5 Hz, Cab amplifying Axle, Seat attenuating Cab.
Ratios C/A ; S/A
10
9·0
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0·0
frequency (Hz)
1
1·25
1·6
2
2·5
3·15
4
5
6·3
8
10
12·5
16
20
25
31·5
40
50
63
80
Axle vibration level
C/A
S/A
Amplification
Attenuation

JCB '3CX' (not new) ≃ 4mph over Quarry Floor test track : 'Y' axis

Correlations: $\frac{A}{S} = 0{\cdot}72$, $\frac{C}{S} = 0{\cdot}65$, $\frac{A}{C} = 0{\cdot}85$

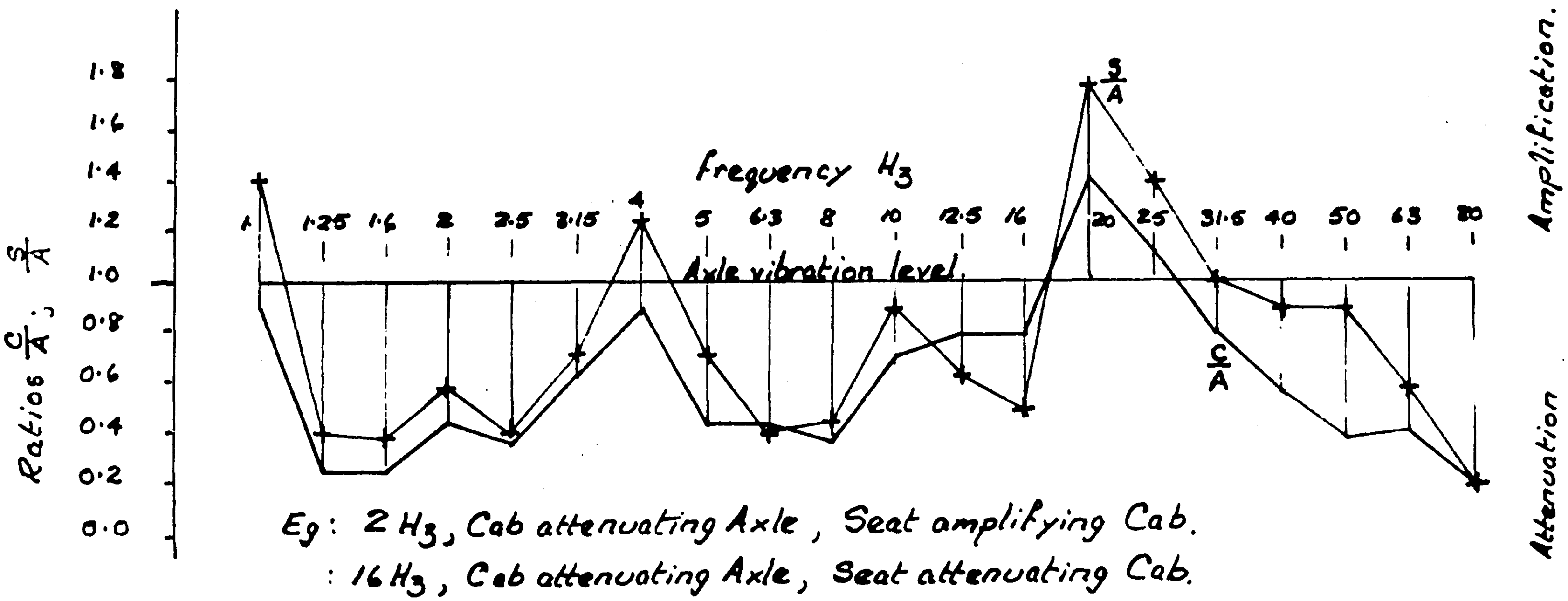


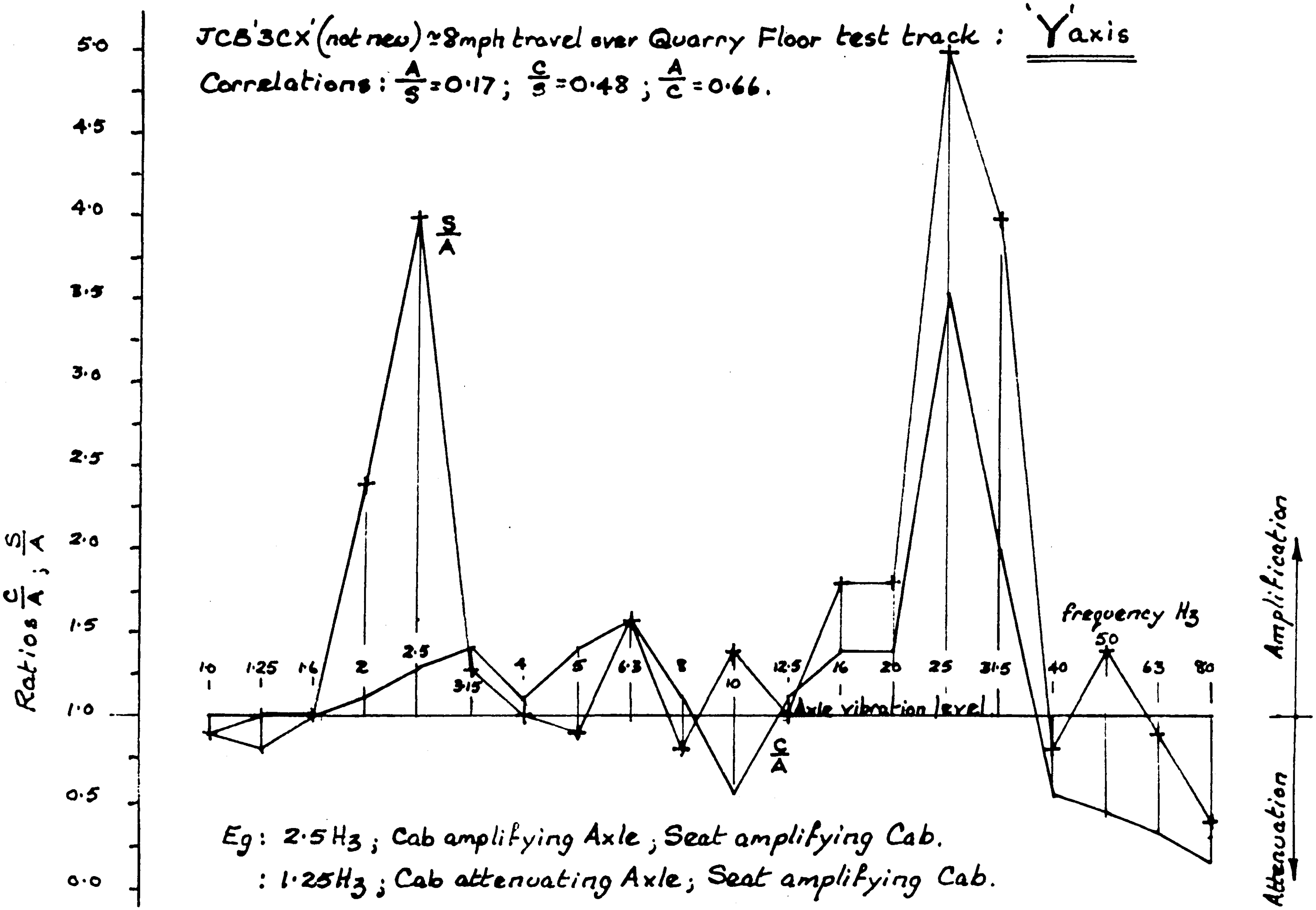

JCB '3CX' (not new) ≃ 4 mph travel over Wave Motion test track:
'Y' axis
Correlations: $\frac{A}{S}$ = 0·66 ; $\frac{C}{S}$ = 0·73 ; $\frac{A}{C}$ = 0·93
Eg: 2 Hz ; Cab attenuating Axle ; Seat amplifying Cab.
2·5 Hz ; Cab amplifying Axle ; Seat amplifying Cab.
Ratios : $\frac{C}{A}$; $\frac{S}{A}$
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0·0
$\frac{S}{A}$
$\frac{C}{A}$
frequency Hz
1
1·25
1·6
2
2·5
3·15
4
5
6·3
8
10
12·5
16
20
25
31·5
40
50
63
80
Axle vibration level
Amplification
Attenuation


JCB '3CX' (not new) ≃ 4mph travel over Regular Kerb test track:
'Y' axis
Correlations: A/S=0·48, C/S=0·70, A/C=0·65.
Ratios C/A, S/A
5·5
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
S/A
C/A
Axle vibration level.
1· 1·25 2 2·5 3·15 4 5 6·3 8 10 12·5 16 20 25 31·5 40 50 63 80
frequency Hz
Amplification.
Attenuation
Eg: 2 Hz, Cab amplifying Axle, Seat amplifying Cab.
: 4 Hz, Cab attenuating Axle, Seat amplifying Cab.

JCB '3CX' (not new) 24mph travel over Random Kerb test track : 'Y' axis

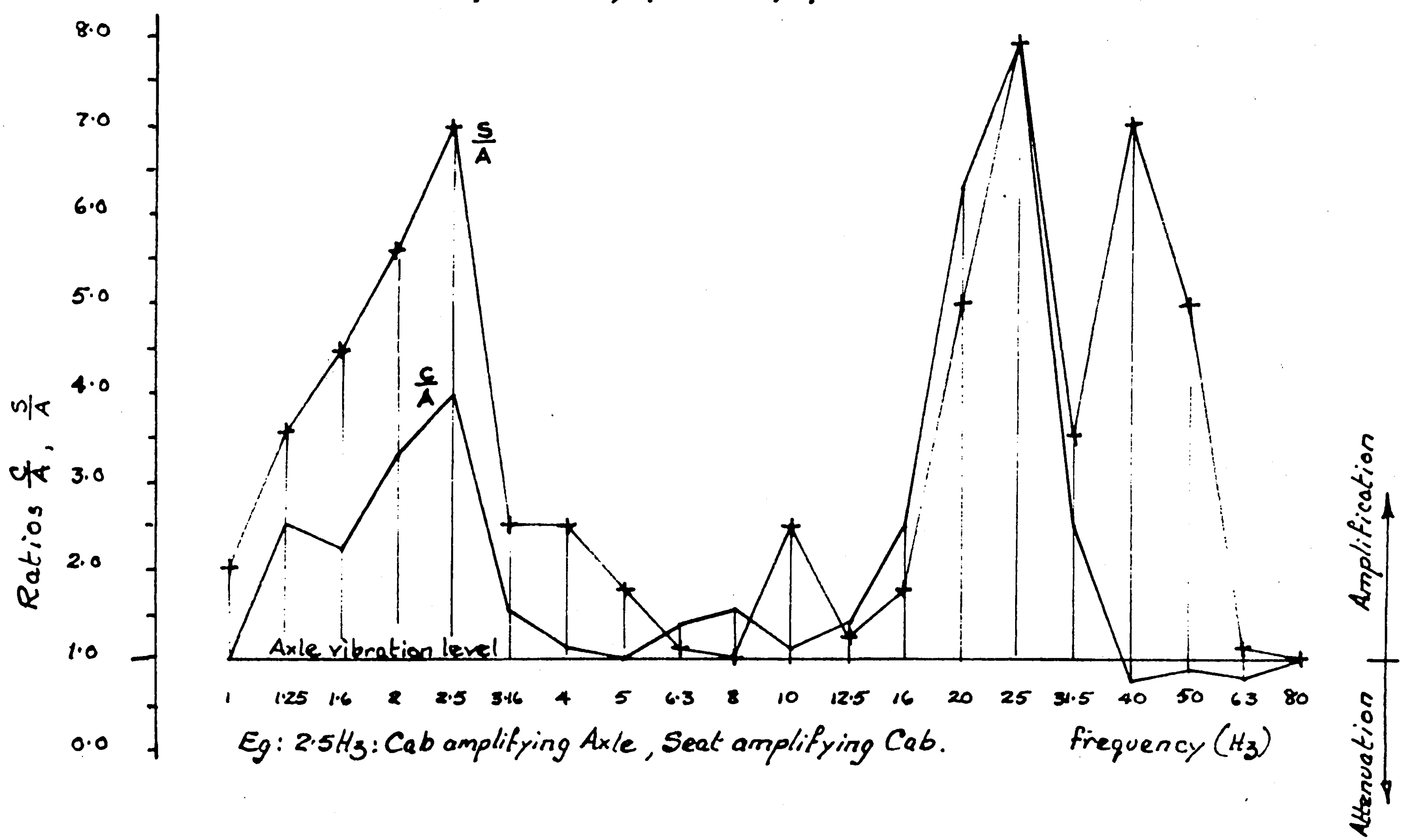
Correlations : A/S = 0·46 ; C/S = 0·39 , A/C = 0·20.




JCB '3CX' (not new) ≈ 8mph travel over Quarry Floor test track : 'Y' axis
Correlations : A/S = 0·17 ; C/S = 0·48 ; A/C = 0·66.
S/A
C/A
Axle vibration level.
frequency Hz
1·0 1·25 1·6 2 2·5 3·15 4 5 6·3 8 10 12·5 16 20 25 31·5 40 50 63 80
Ratios C/A ; S/A
5·0 4·5 4·0 3·5 3·0 2·5 2·0 1·5 1·0 0·5 0·0
Amplification
Attenuation
Eg: 2·5 Hz ; Cab amplifying Axle ; Seat amplifying Cab.
: 1·25 Hz ; Cab attenuating Axle ; Seat amplifying Cab.

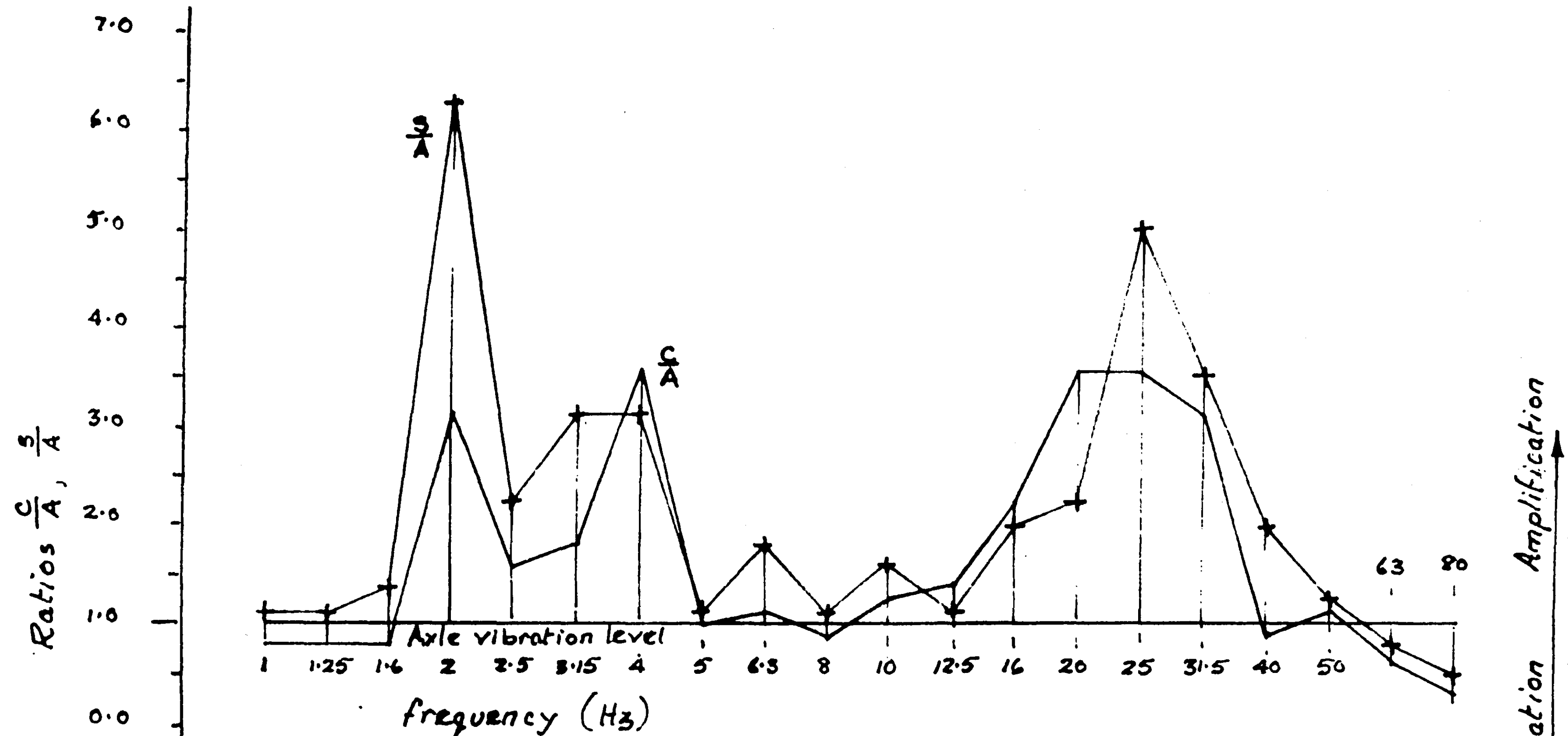
JCB '3CX' (not new) ≈ 8mph travel over Wave Motion test track : 'Y' axis.

Correlations : A/S = -0·08 ; C/S = 0·59 ; A/C = 0·34



JCB '3CX' (not new) ≃ 8mph travel over Regular Kerb test track : 'Y' axis.

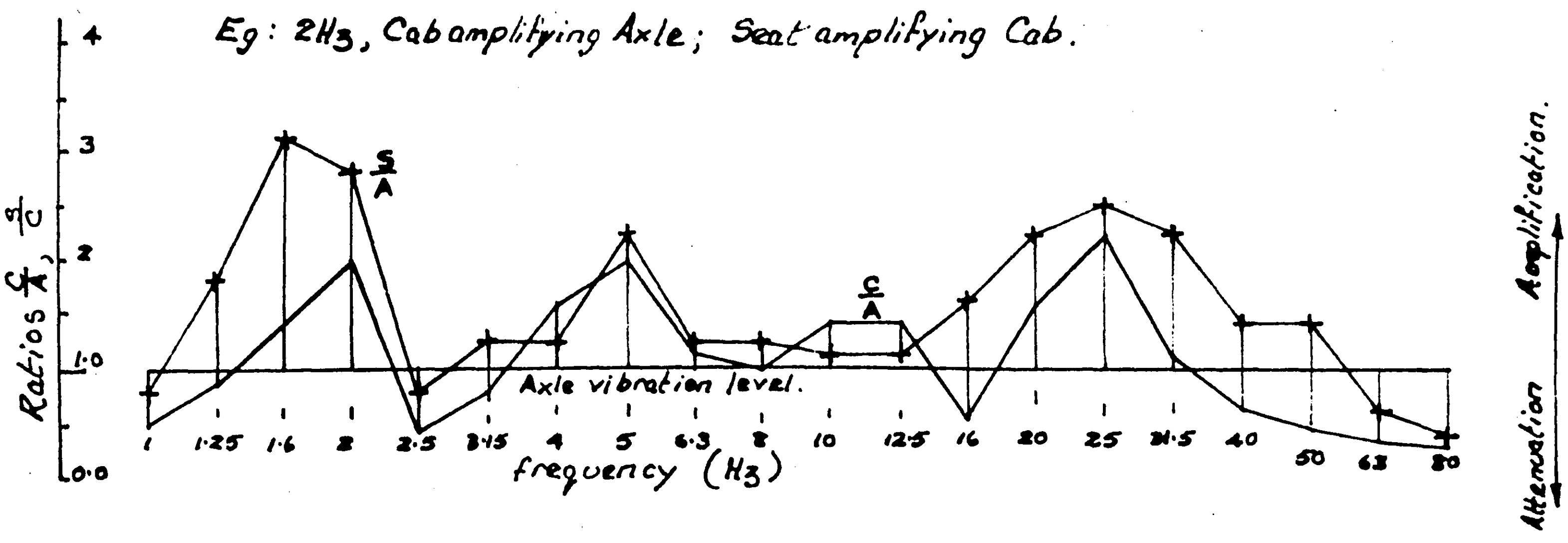
Correlations : A/S = 0·16 , C/S = 0·62 , A/C = 0·29 .



Eg: 2Hz, Cab amplifying Axle, Seat amplifying Cab.

JCB '3CX' (not new) ≃ 8mph travel over Random Kerb test track : 'Y' axis.

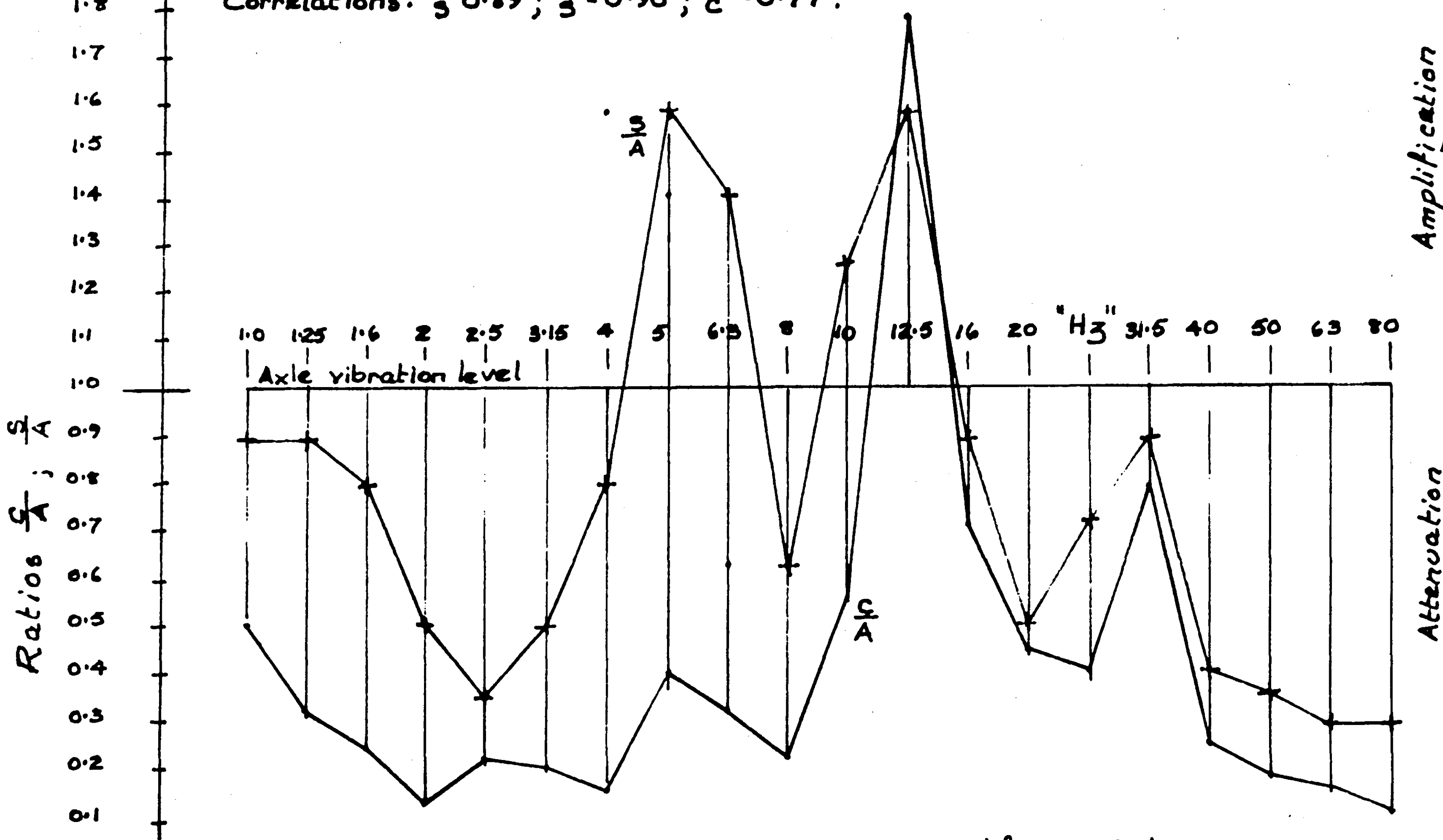
Correlations : A/S = 0·64, C/S = 0·91, A/C = 0·53



JCB '3CX' (new) ≃ 4mph over Quarry Floor test track

'Y' axis

Correlations: $\frac{A}{S}$ 0·89 ; $\frac{C}{S}$ = 0·90 ; $\frac{A}{C}$ = 0·77 .

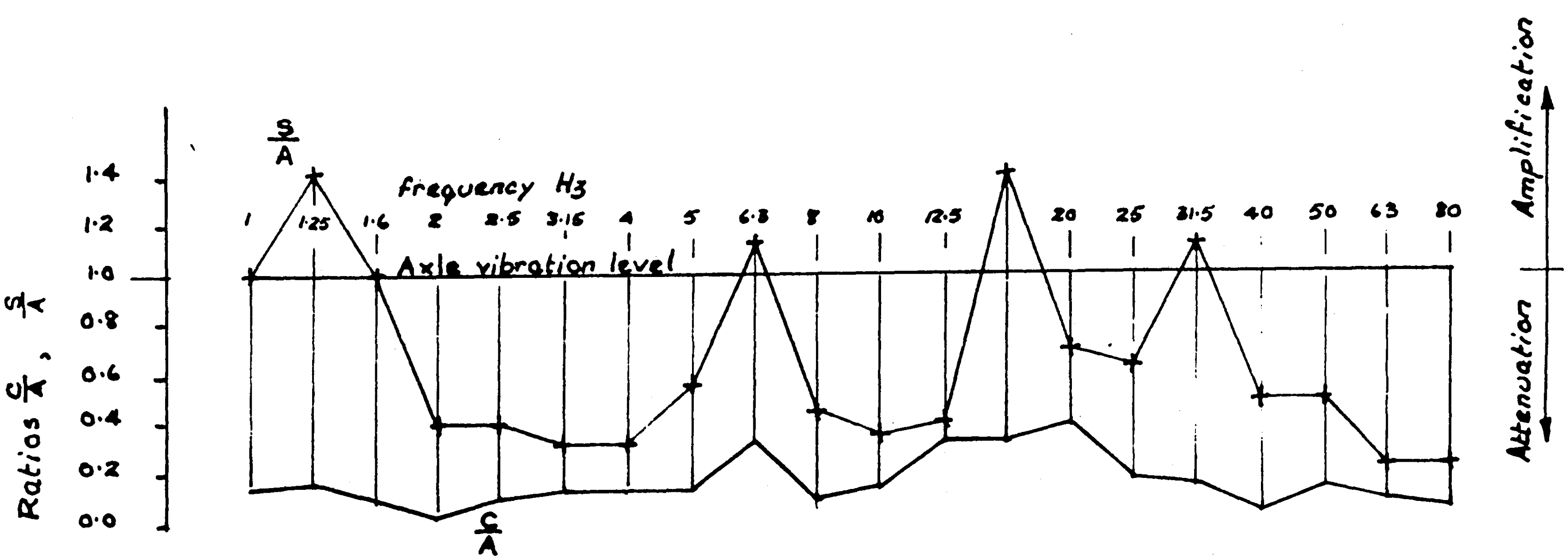


Eg : 2·5 Hz, Cab attenuating Axle, Seat amplifying Cab.

: 12·5 Hz, Cab amplifying Axle, Seat attenuating Cab.

JCB '3CX' (new) ≃ 4mph travel over Wave Motion test track : 'Y' axis

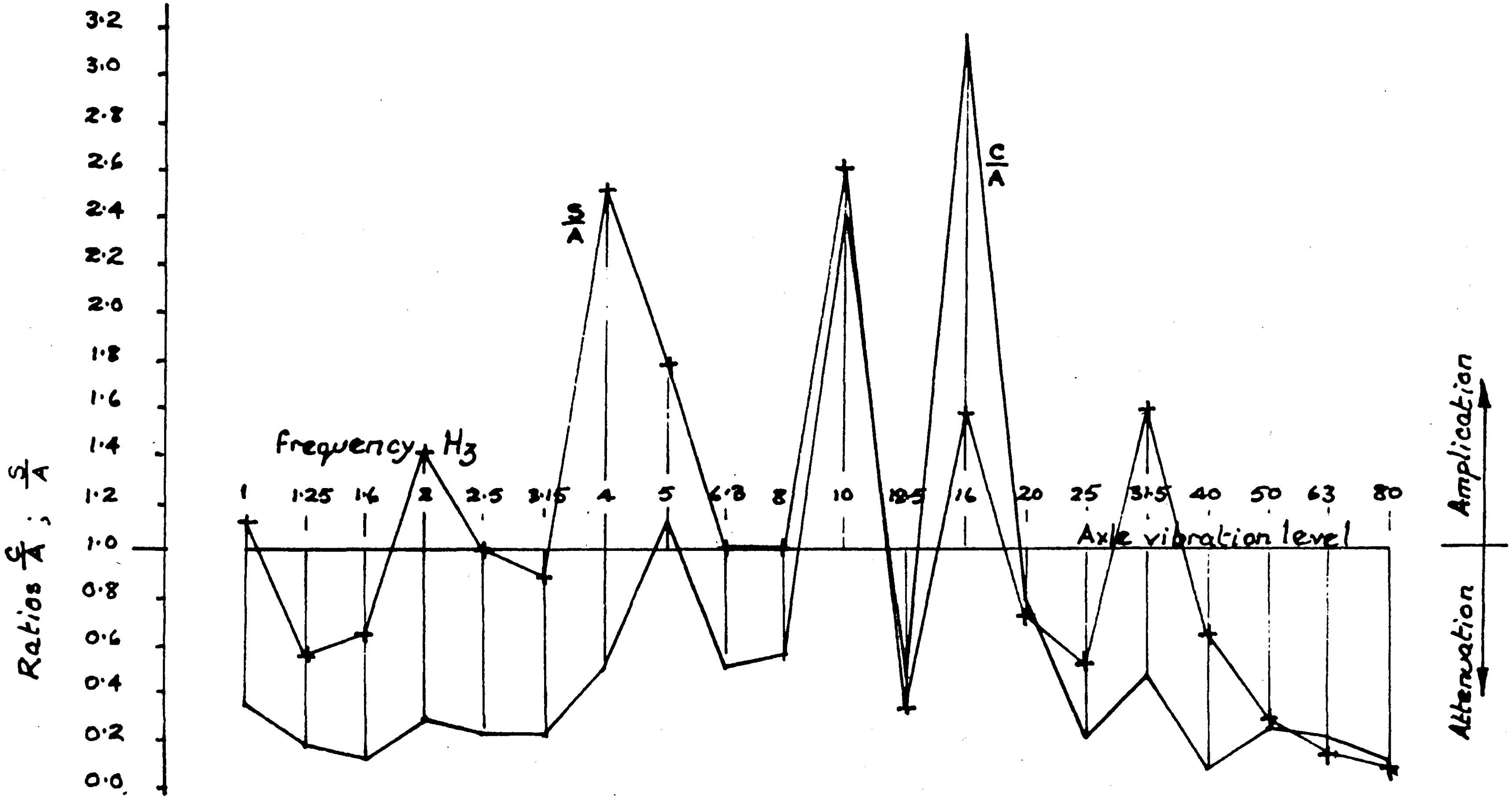
Correlations : $\frac{A}{S} = 0{\cdot}67$; $\frac{C}{S} = 0{\cdot}67$; $\frac{A}{C} = 0{\cdot}12$.



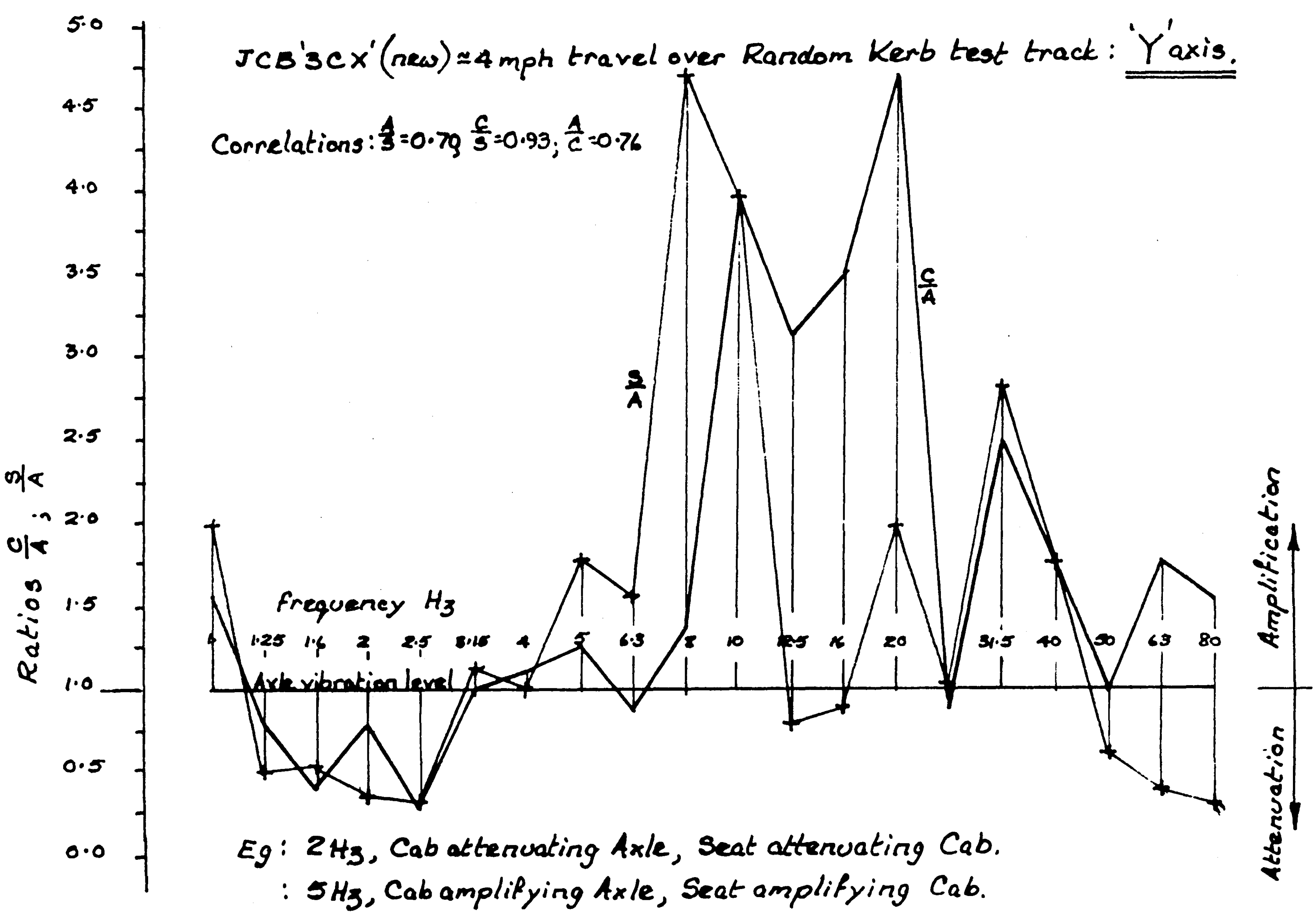
Eg: 2 Hz , Cab attenuating Axle , Seat amplifying Cab.

JCB '3CX' (new) ≃ 4mph travel over Regular Kerb test track : 'Y' axis

Correlations : $\frac{A}{S}$ = 0·87 ; $\frac{C}{S}$ = 0·36 ; $\frac{A}{C}$ = 0·16.

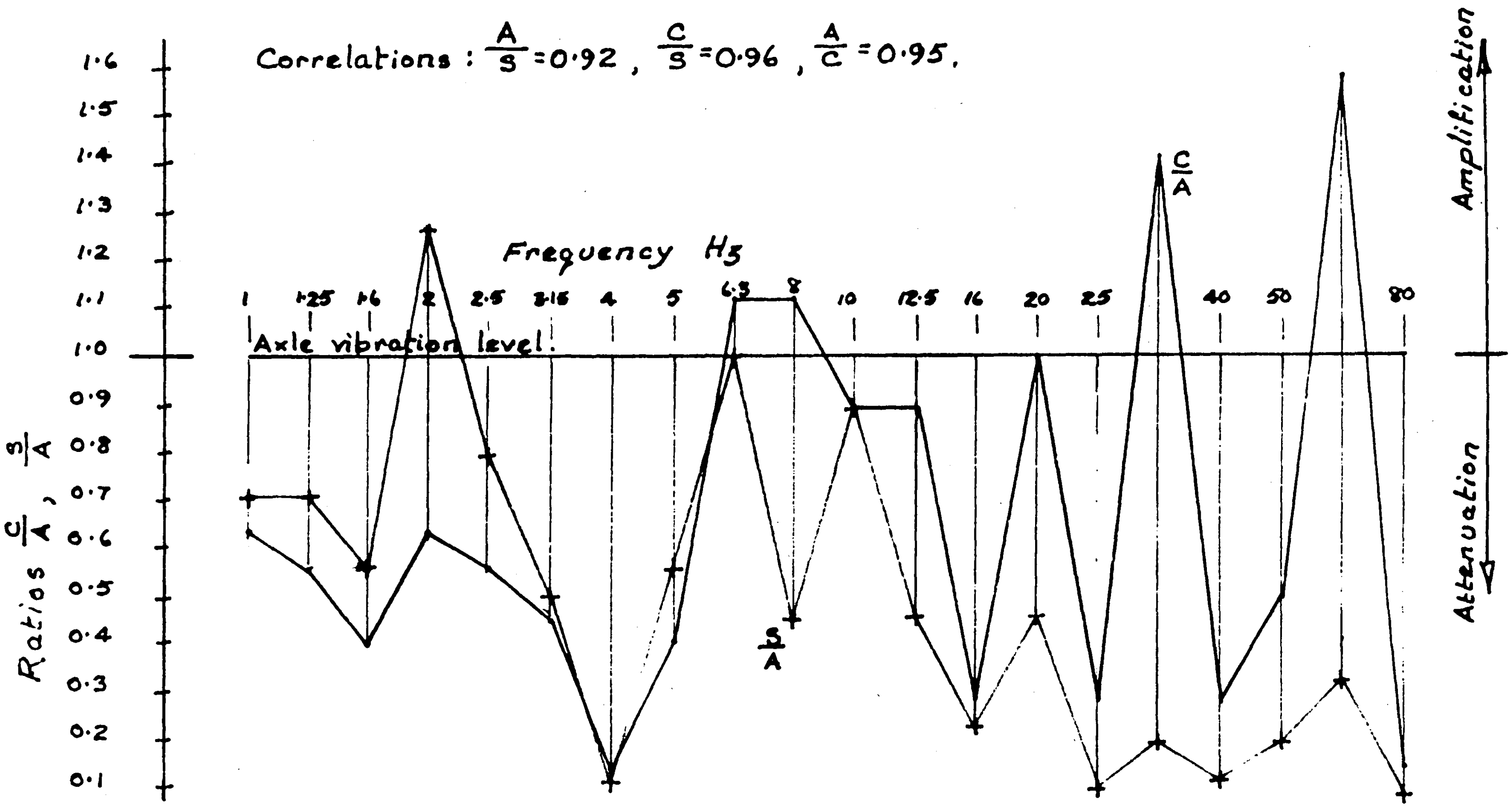


Eg : 2 Hz , Cab attenuating Axle , Seat amplifying Cab.
: 20 Hz , Cab attenuating Axle , Seat attenuating Cab .


JCB '3CX' (new) ≈ 4 mph travel over Random Kerb test track: 'Y' axis.
Correlations: A/S = 0·79 C/S = 0·93; A/C = 0·76
Ratios C/A ; S/A
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0·0
frequency Hz
1·25
1·6
2
2·5
3·15
4
5
6·3
8
10
12·5
16
20
31·5
40
50
63
80
Axle vibration level
S/A
C/A
Amplification
Attenuation
Eg: 2 Hz, Cab attenuating Axle, Seat attenuating Cab.
: 5 Hz, Cab amplifying Axle, Seat amplifying Cab.

JCB "3CX" (new) ≃ 4 mph over Quarry Floor test track. **'Z' axis.**

Correlations : $\frac{A}{S} = 0{\cdot}92$, $\frac{C}{S} = 0{\cdot}96$, $\frac{A}{C} = 0{\cdot}95$.

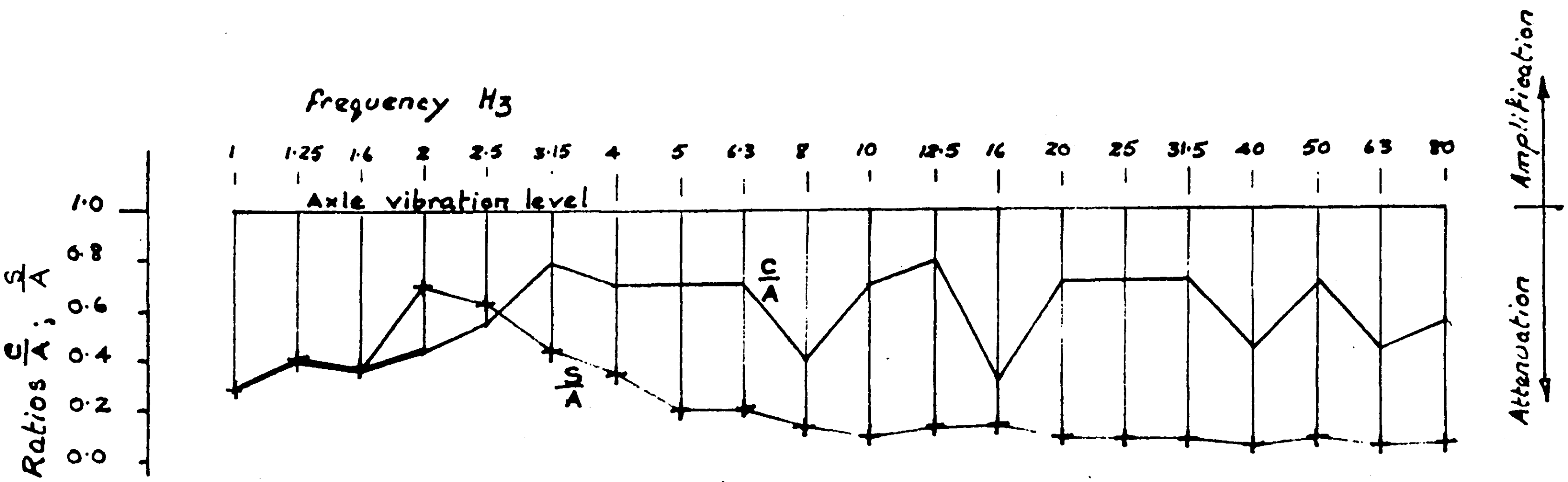


Eg : 2 Hz, Cab attenuating Axle, Seat amplifying Cab.

: 8 Hz, Cab amplifying Axle, Seat attenuating Cab.

JCB '3CX' (new) ≃ 4 mph travel over Wave Motion test track : 'Z' axis

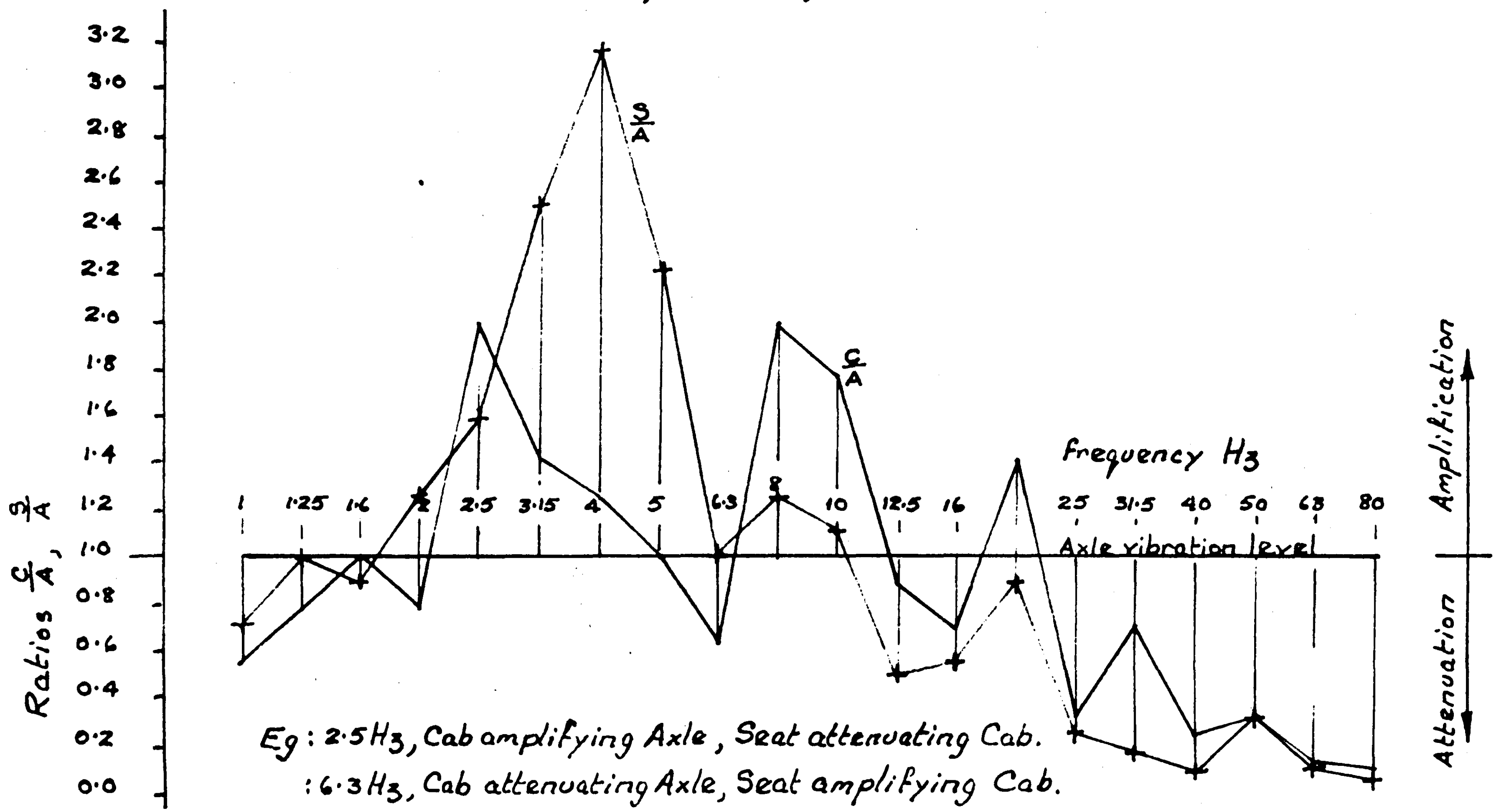
Correlations : $\frac{A}{S} = 0.88$; $\frac{C}{S} = 0.97$; $\frac{A}{C} = 0.91$.



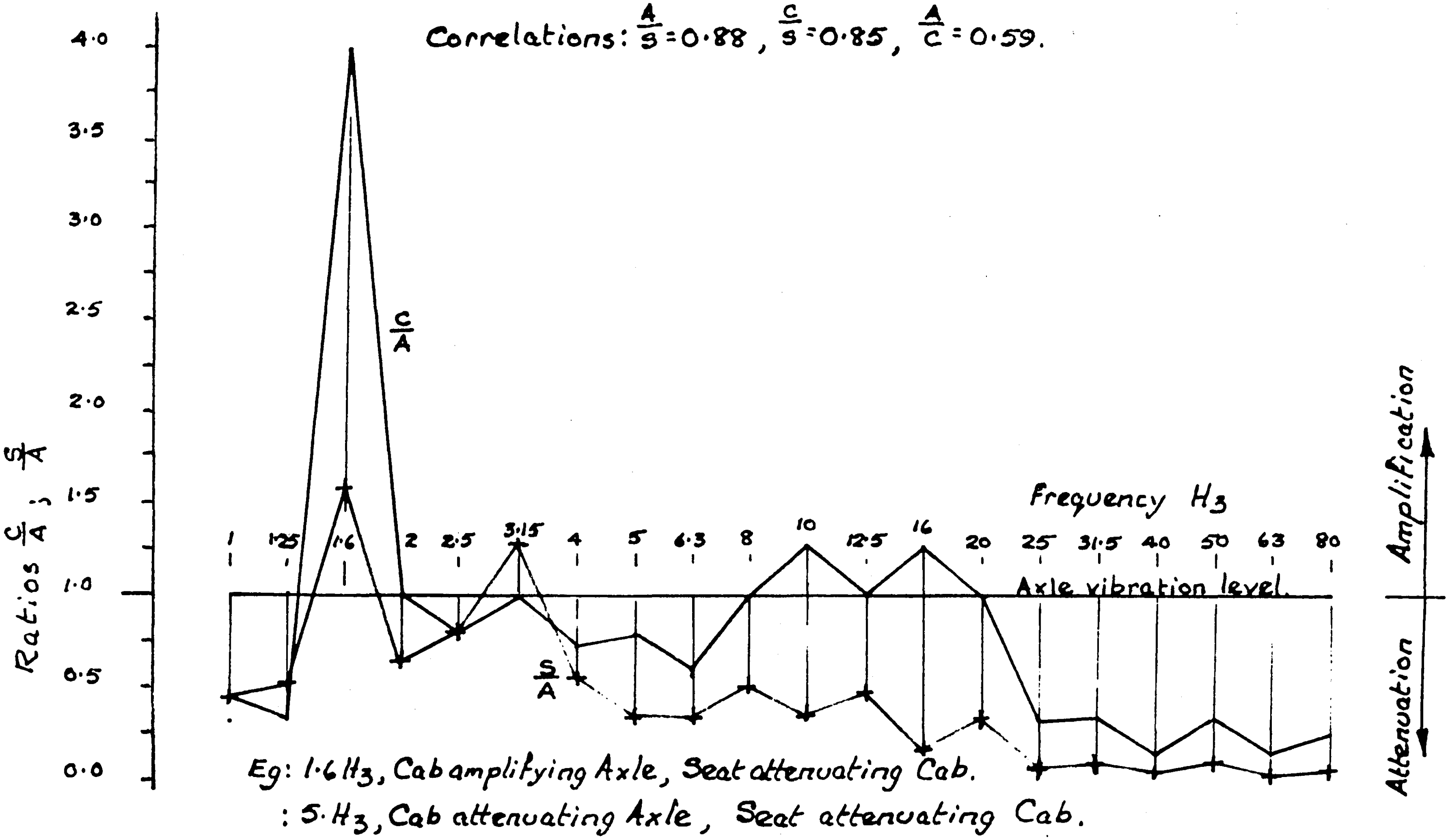
Eg : 2 Hz , Cab attenuating Axle , Seat amplifying Cab.
: 4 Hz , Cab attenuating Axle , Seat attenuating Cab.

JCB '3CX' (new) ≃ 4mph travel over Regular Kerb test track : 'Z' axis

Correlations : $\frac{A}{S} = 0{\cdot}90$, $\frac{C}{S} = 0{\cdot}94$; $\frac{A}{C} = 0{\cdot}93$

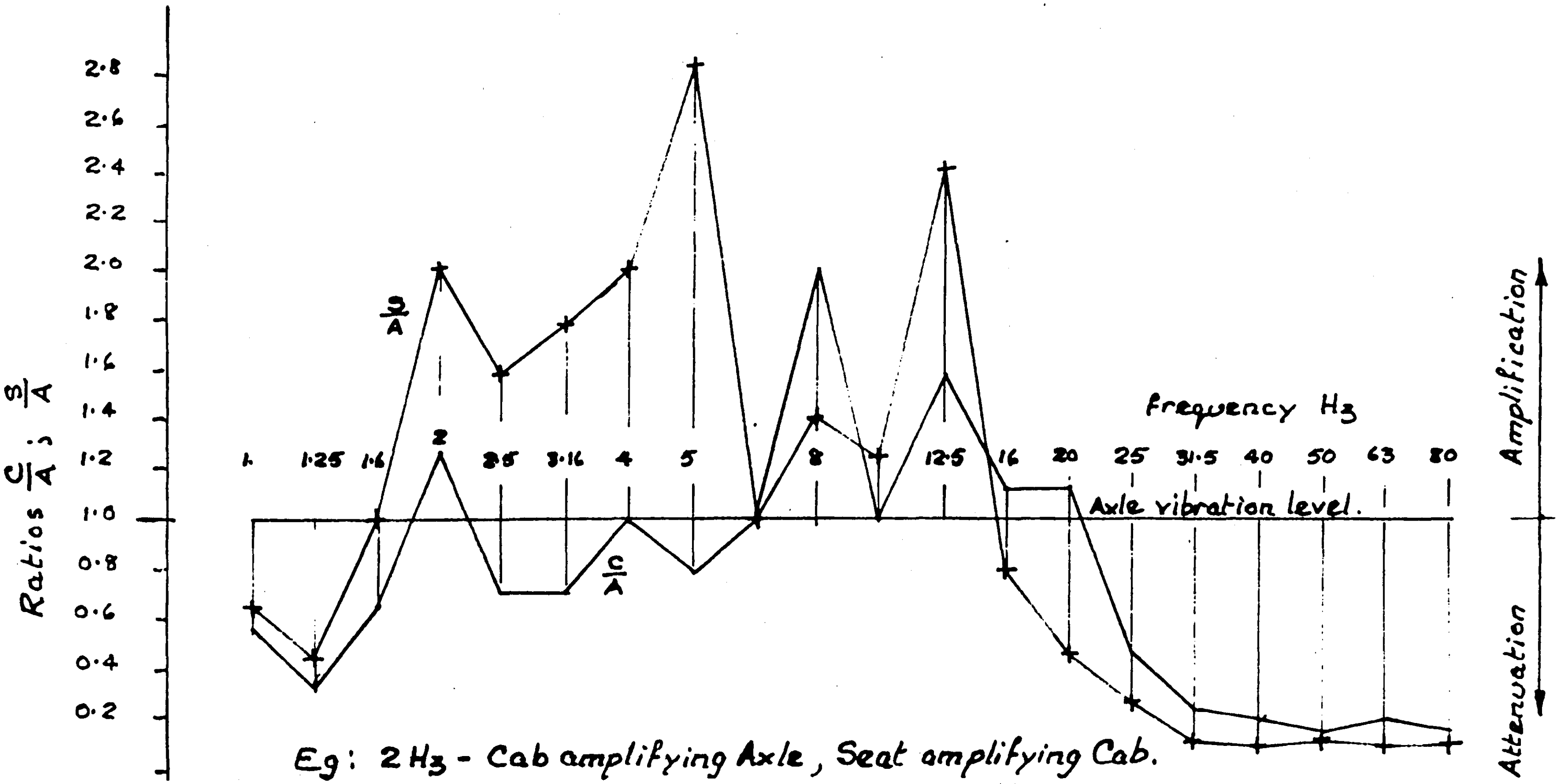


JCB '3CX' (new) ≈ 4mph travel over Random Kerb test track : 'Z' axis.

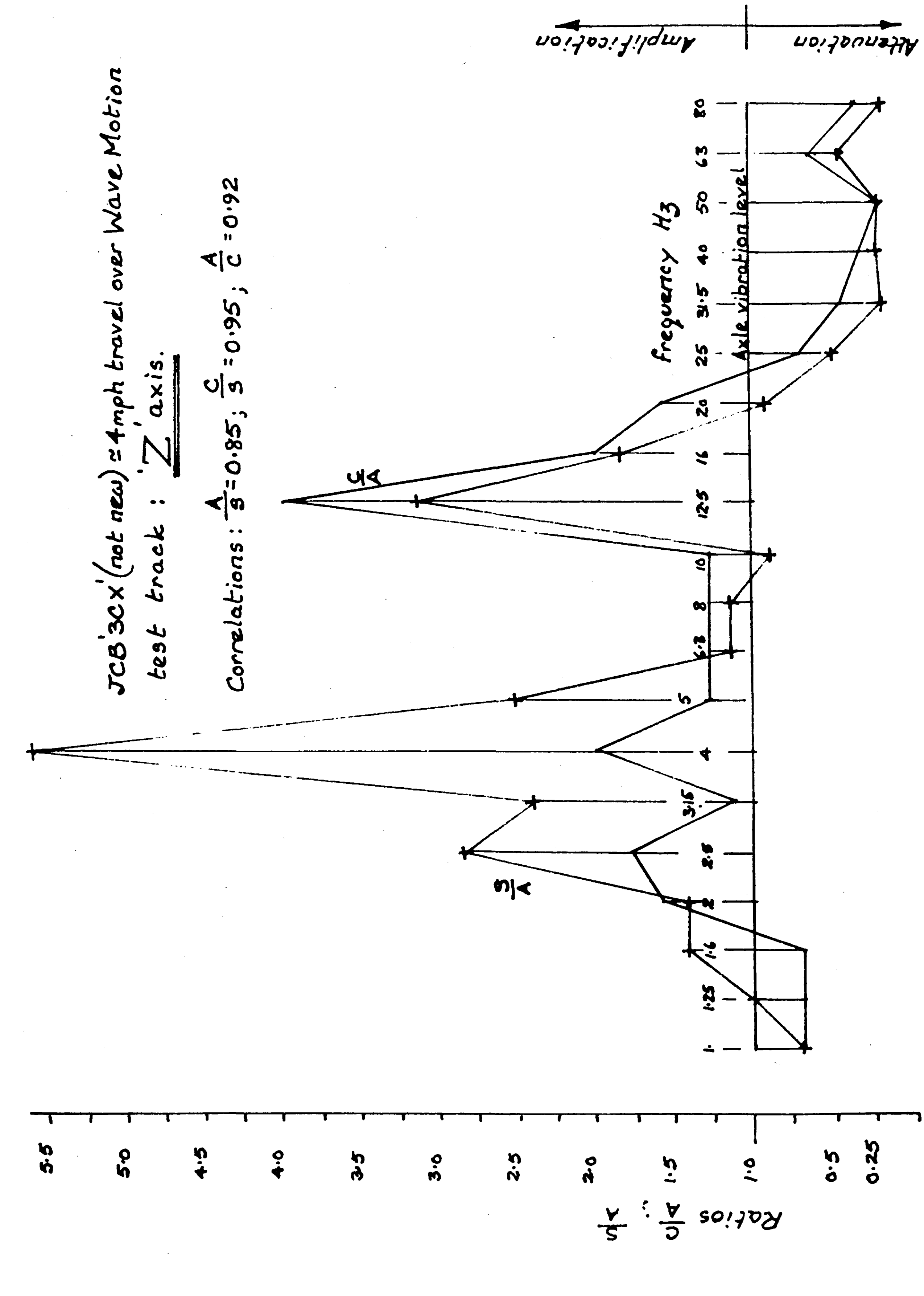


JCB '3CX' (not new) ≃ 4 mph over Quarry Floor test track : 'Z' axis

Correlations : $\frac{A}{S} = 0{\cdot}81$, $\frac{C}{S} = 0{\cdot}95$, $\frac{A}{C} = 0{\cdot}92$



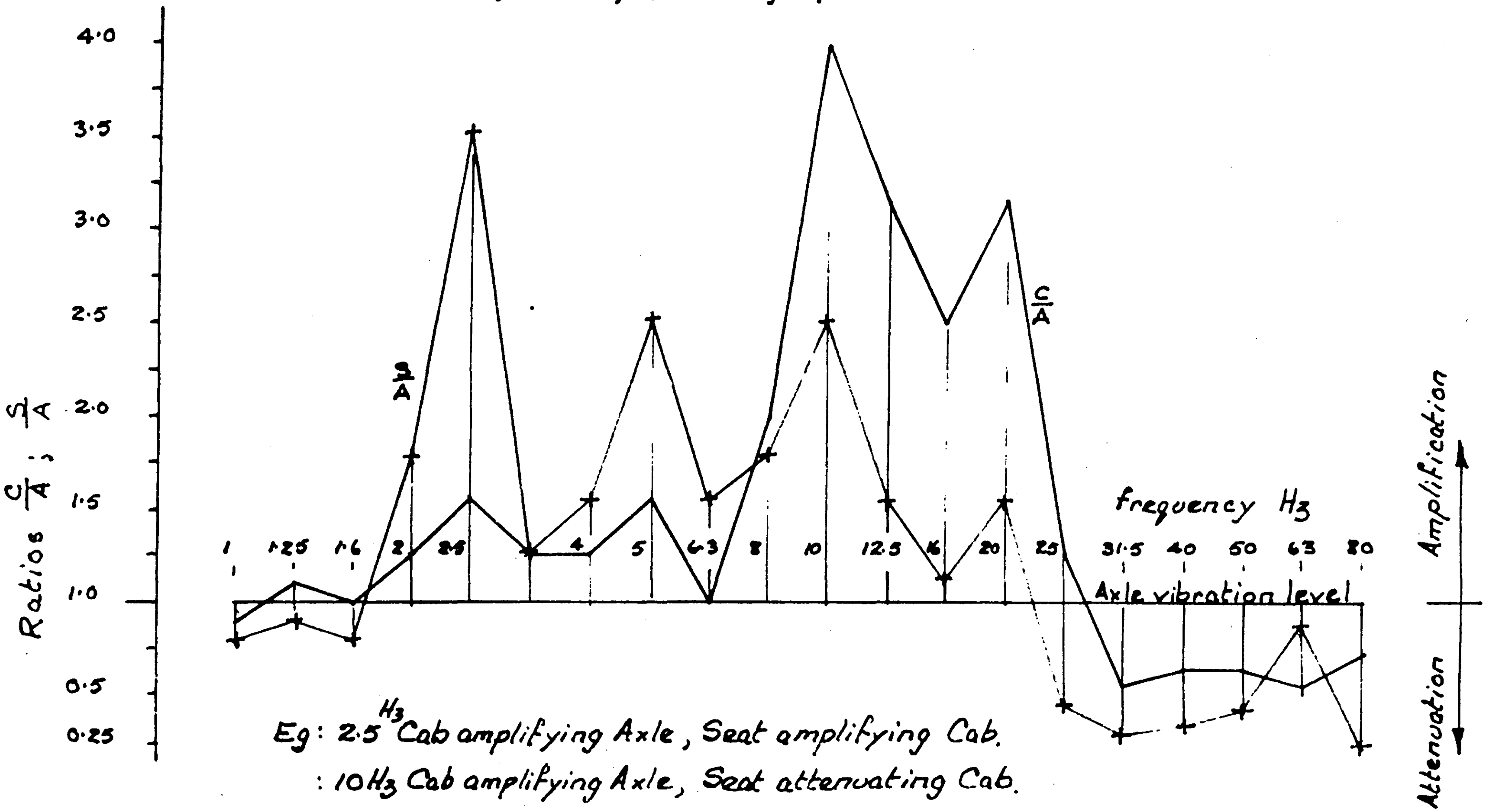
Eg: 2 Hz - Cab amplifying Axle, Seat amplifying Cab.
5 Hz - Cab attenuating Axle, Seat amplifying Cab.



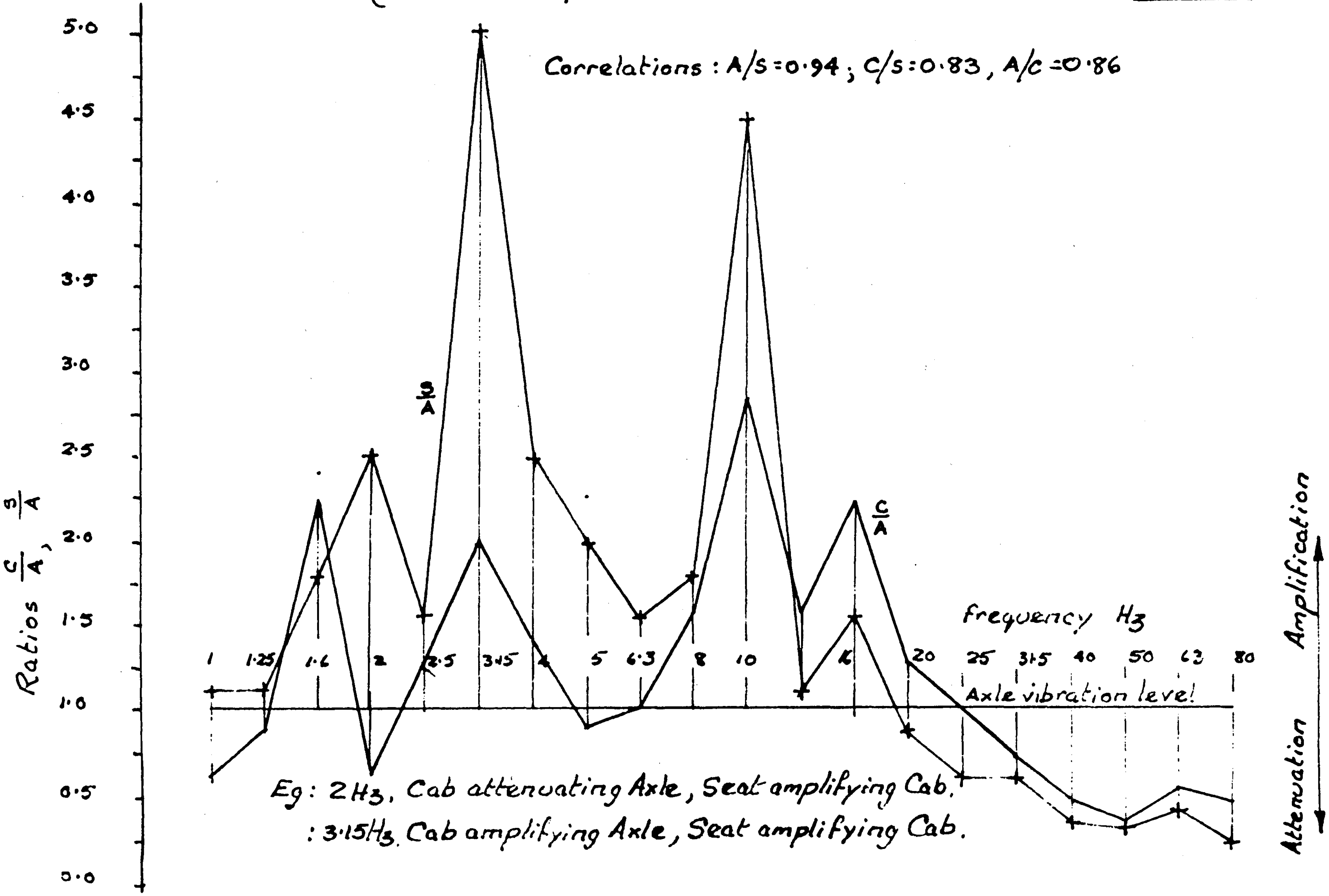
JCB '3CX' (not new) ≃ 4 mph travel over Wave Motion
test track : 'Z' axis.
Correlations : A/B = 0·85 ; C/B = 0·95 ; A/C = 0·92
Amplification
Attenuation
Frequency Hz
Axle vibration level
B/A
C/A
Ratios C/A ; B/A
5·5
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
1·0
0·5
0·25
1
1·25
1·6
2
2·5
3·15
4
5
6·3
8
10
12·5
16
20
25
31·5
40
50
63
80

JCB '3CX' (not new) ≃ 4 mph travel over Regular Kerb test track : 'Z' axis

Correlations : A/S = 0·89 ; C/S = 0·91 ; A/C = 0·96

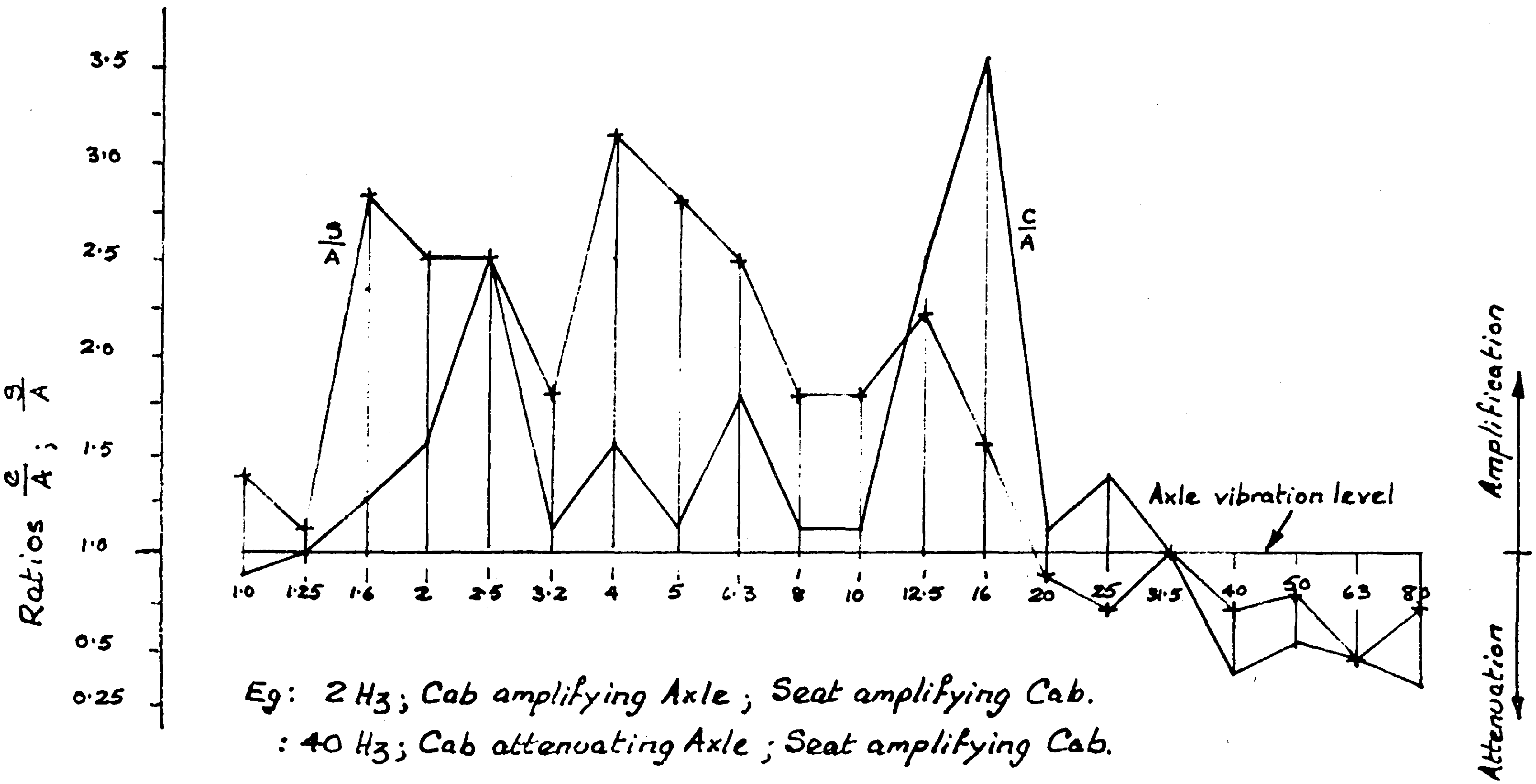


JCB '3CX' (not new) ≃ 4mph travel over Random Kerb test track : 'Z' axis



JCB '3CX' (not new) ≃ 8 mph travel over Quarry Floor test track : 'Z' axis

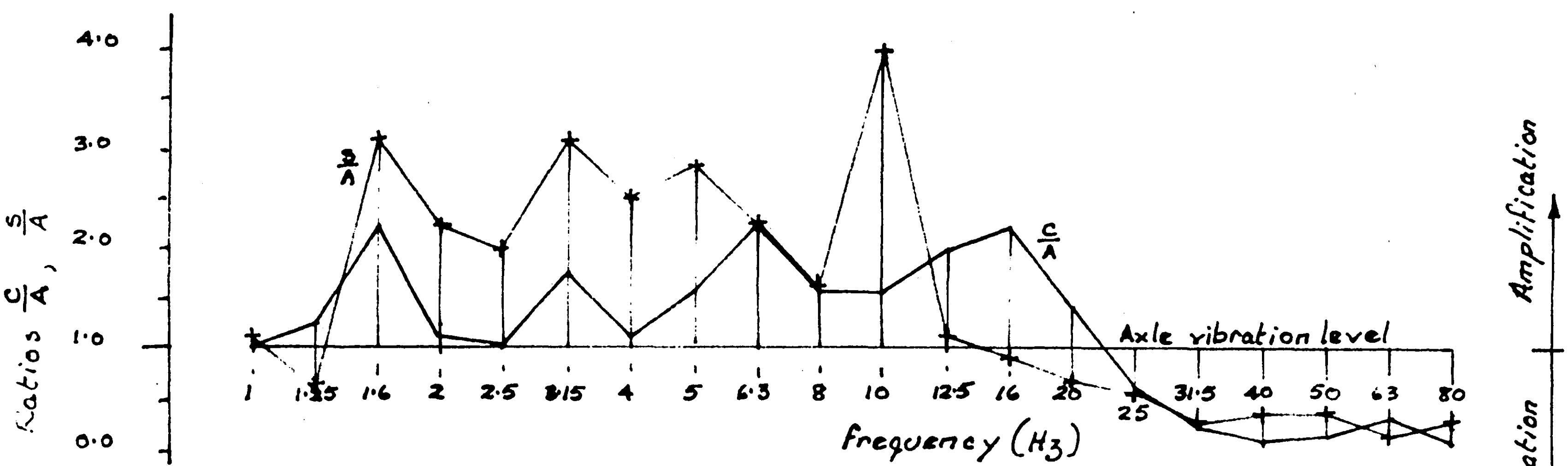
Correlations : $\frac{A}{S} = 0{\cdot}98$; $\frac{C}{S} = 0{\cdot}97$; $\frac{A}{C} = 0{\cdot}98$.



Eg: 2 Hz ; Cab amplifying Axle ; Seat amplifying Cab.
: 40 Hz ; Cab attenuating Axle ; Seat amplifying Cab.

JCB '3CX' (not new) ≃ 8mph travel over Wave Motion test track : 'Z' axis

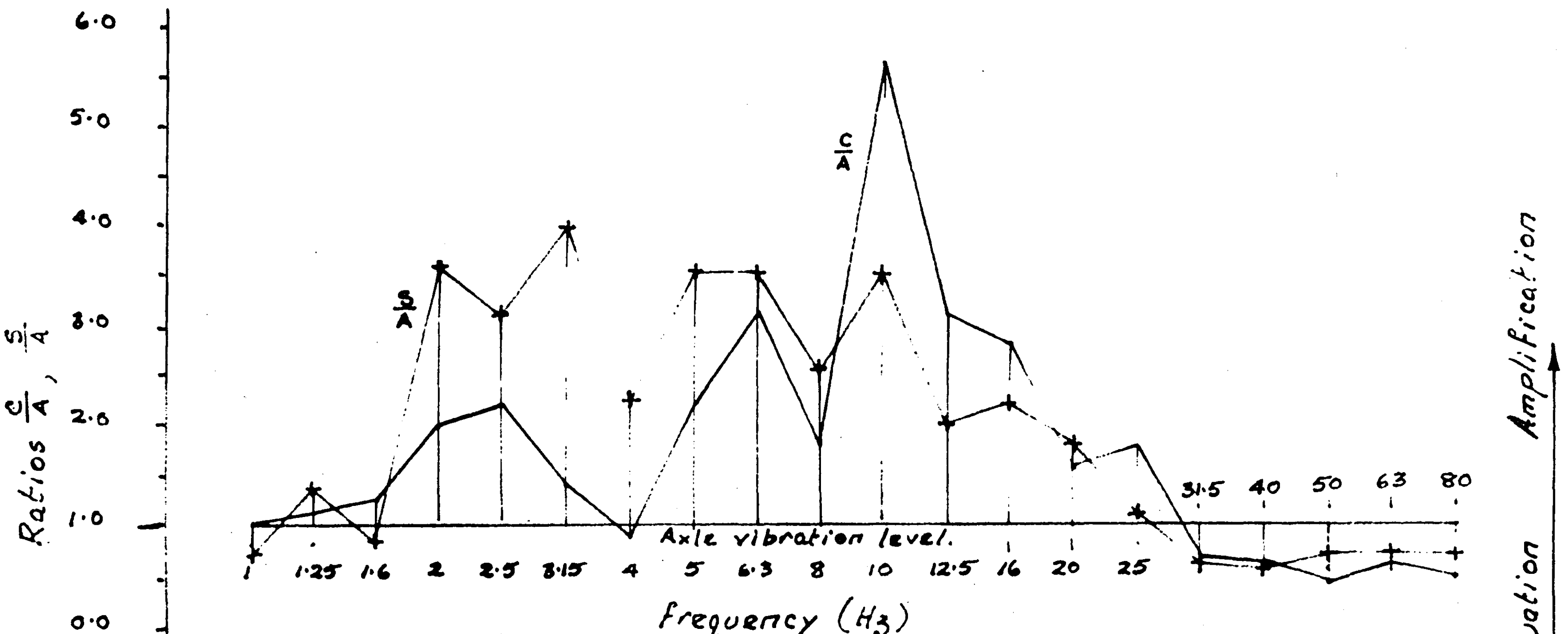
Correlations: A/S = 0·79 ; C/S = 0·93 ; A/C = 0·85



Eg: 2 Hz, Cab amplifying Axle, Seat amplifying Cab.

JCB '3CX' (not new) ≃ 8mph travel over Regular Kerb test track : $\dot{Z}$ axis

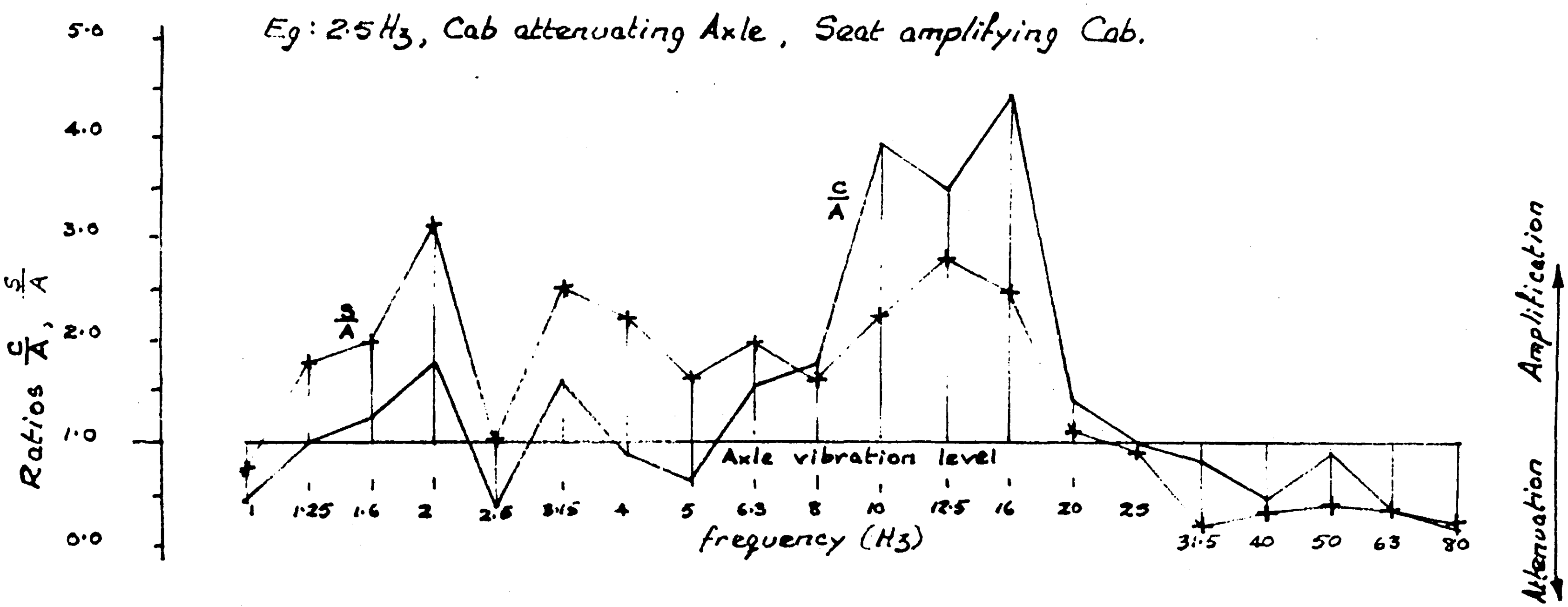
Correlations : A/S = 0·82, C/S = 0·91, A/C = 0·97.



Eg : 2 Hz, Cab amplifying Axle, Seat amplifying Cab.

JCB '3CX' (not new) ≈ 8mph travel over Random Kerb test track : '**Z**' axis

Correlations : A/S = 0·89 , C/S = 0·99 , A/C = 0·90.



APPENDIX 'G'

Graphical presentation of tyre responses to sinusoidal excitation at one-third octave centre frequencies from 1Hz to 10Hz.

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 110 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration.
(Vib meter = $1 m/s^2$ FSD

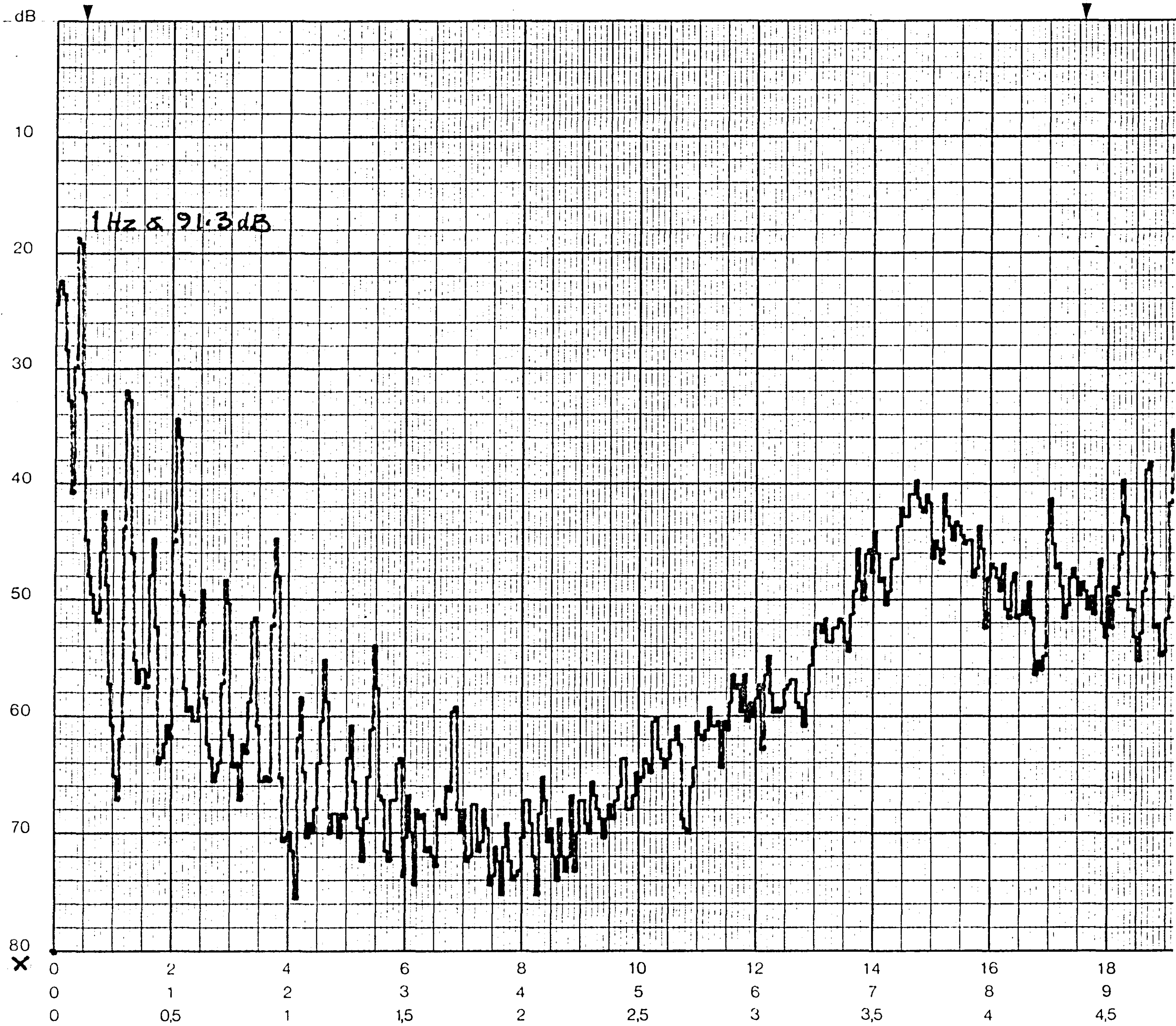
Schenk ram disp ±0.5mm

Frequency 1 Hz.

1 Hz value = 91.3dB

Free axle.

Record No.: Test 1
Date: 11/6/84
Sign.: [signature]



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expanded

Full Scale Level: 110 dB

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter = $1 m/s^2$ FSD)

Schenk ram disp ± 0.5mm.

Frequency ≈ 1.25Hz

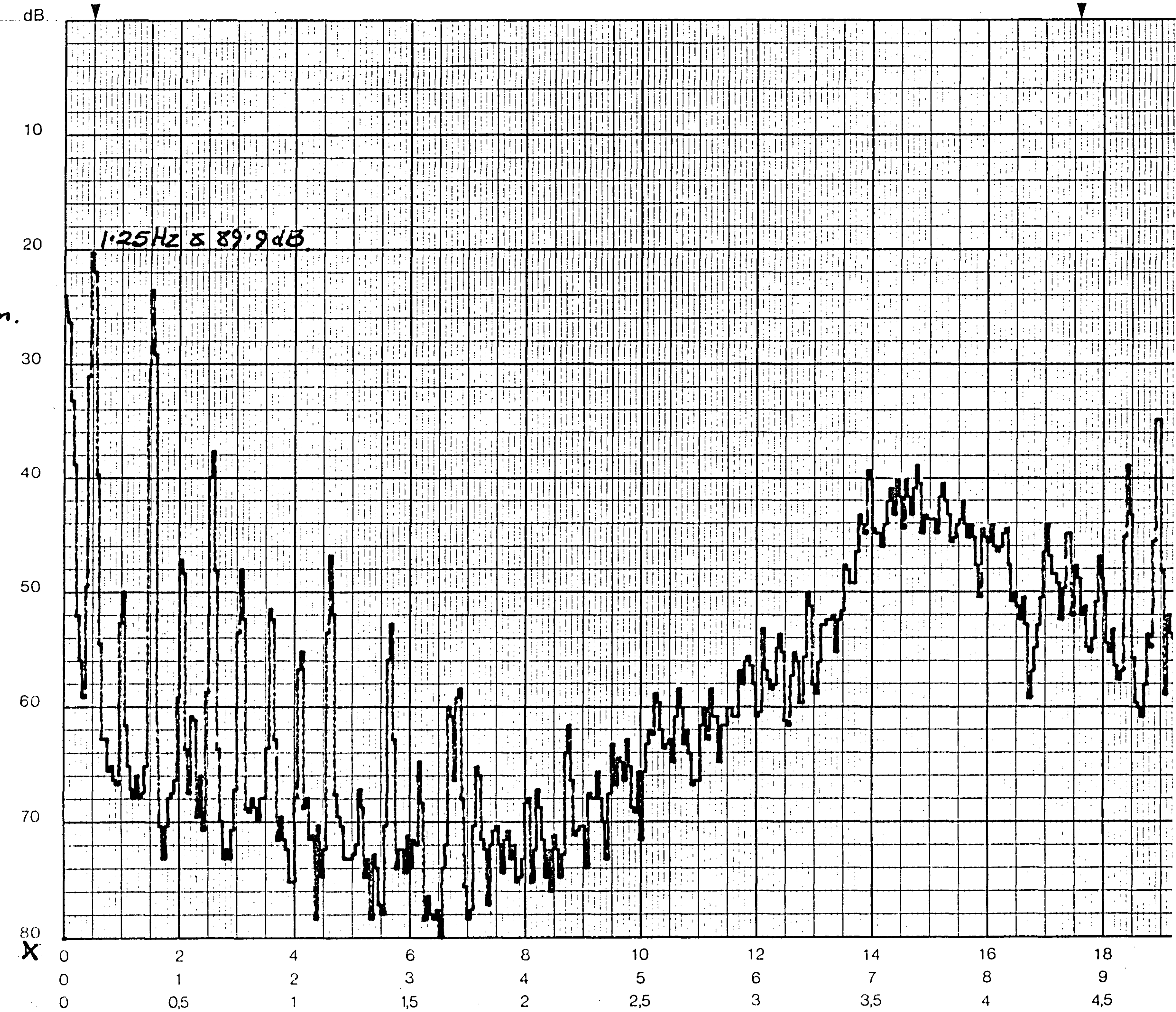
1.25 Hz = 89.9 dB

Free axle

Record No.: Test 1

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 100 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments: JCB Wheel

Tyre acceleration
(V. Meter = $1 m/s^2$ FSD)

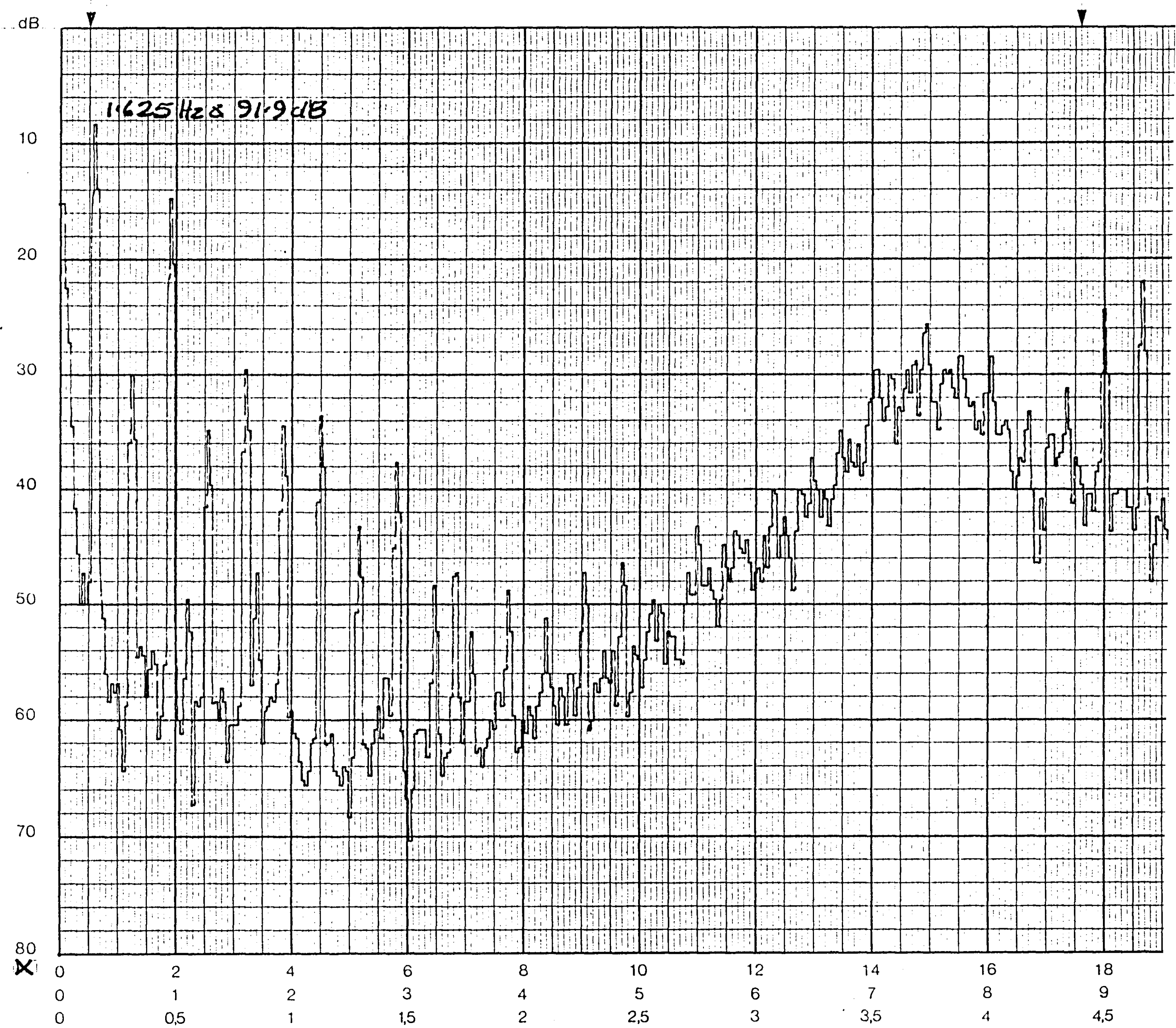
Schenk ram disp ±0·5mm.

Frequency ≃ 1·6 Hz

1·625 Hz = 91·9 dB

Free axle

Record No.: Test 1
Date: 11/6/84
Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 110

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

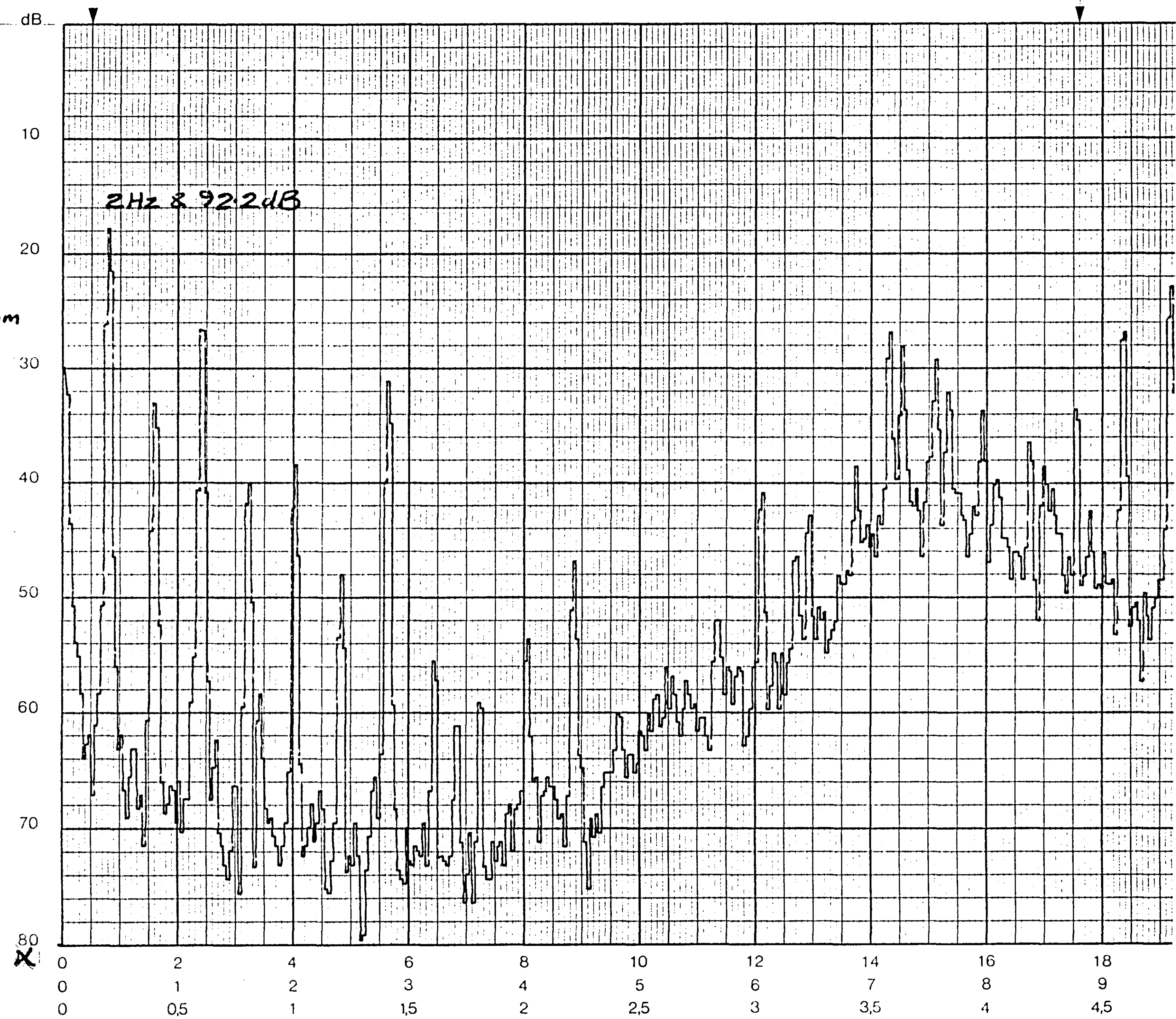
Comments: JCB Wheel.

Tyre acceleration.
(V. Meter = 1m/s² FSD)

Schenk ram disp = ±0.5 mm

Frequ. ≃ 2Hz

2Hz = 92·2dB



Free axle

Record No.: Test 1

Date: 11/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 110 dB

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter = 1m/s² FSD)

Schenk ram disp ±0.5mm

Frequ ≃ 2.5 Hz

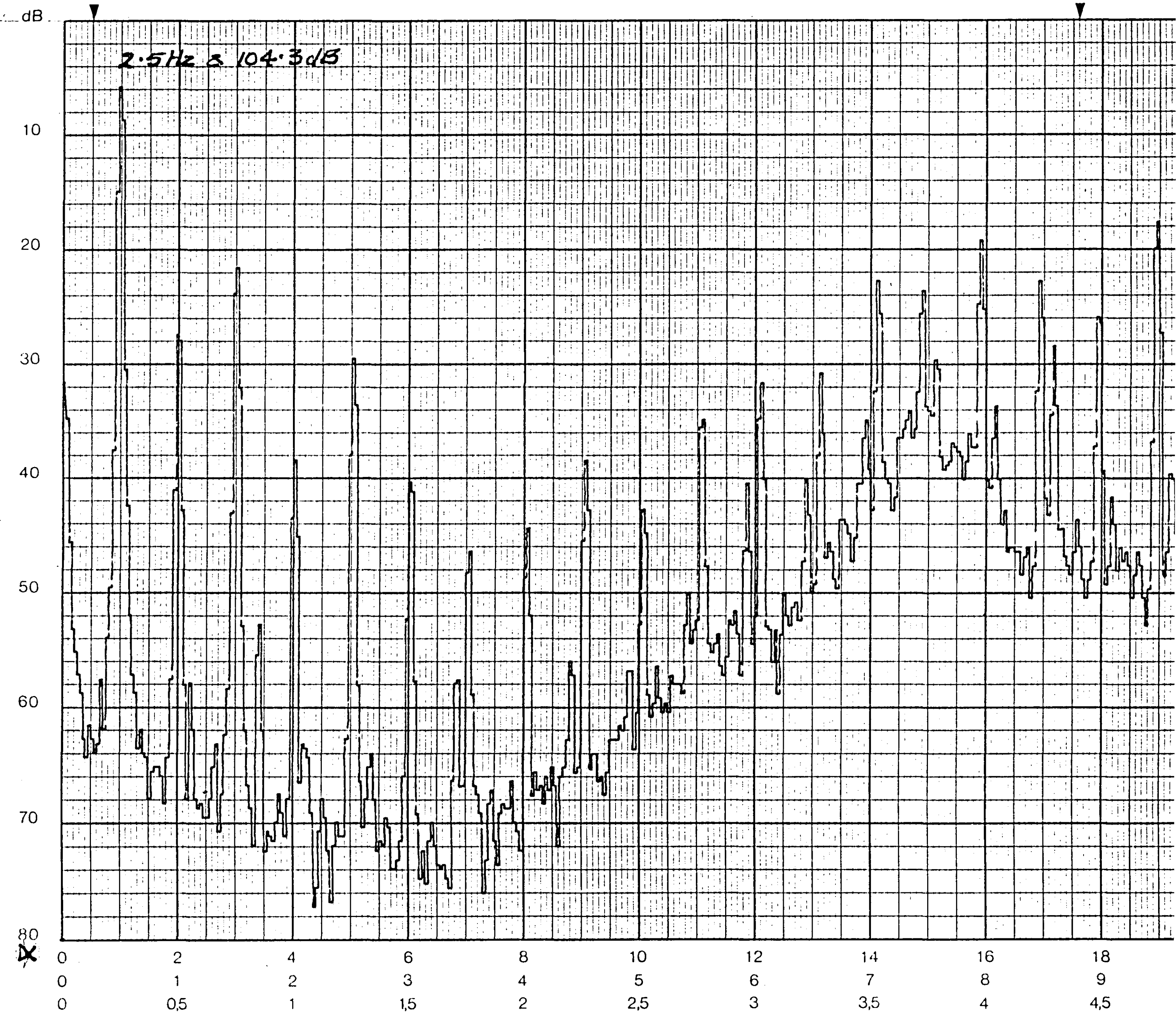
2.5Hz = 104.3dB

Free axle

Record No.: Test 1

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V.Meter 1m/s² FSD)

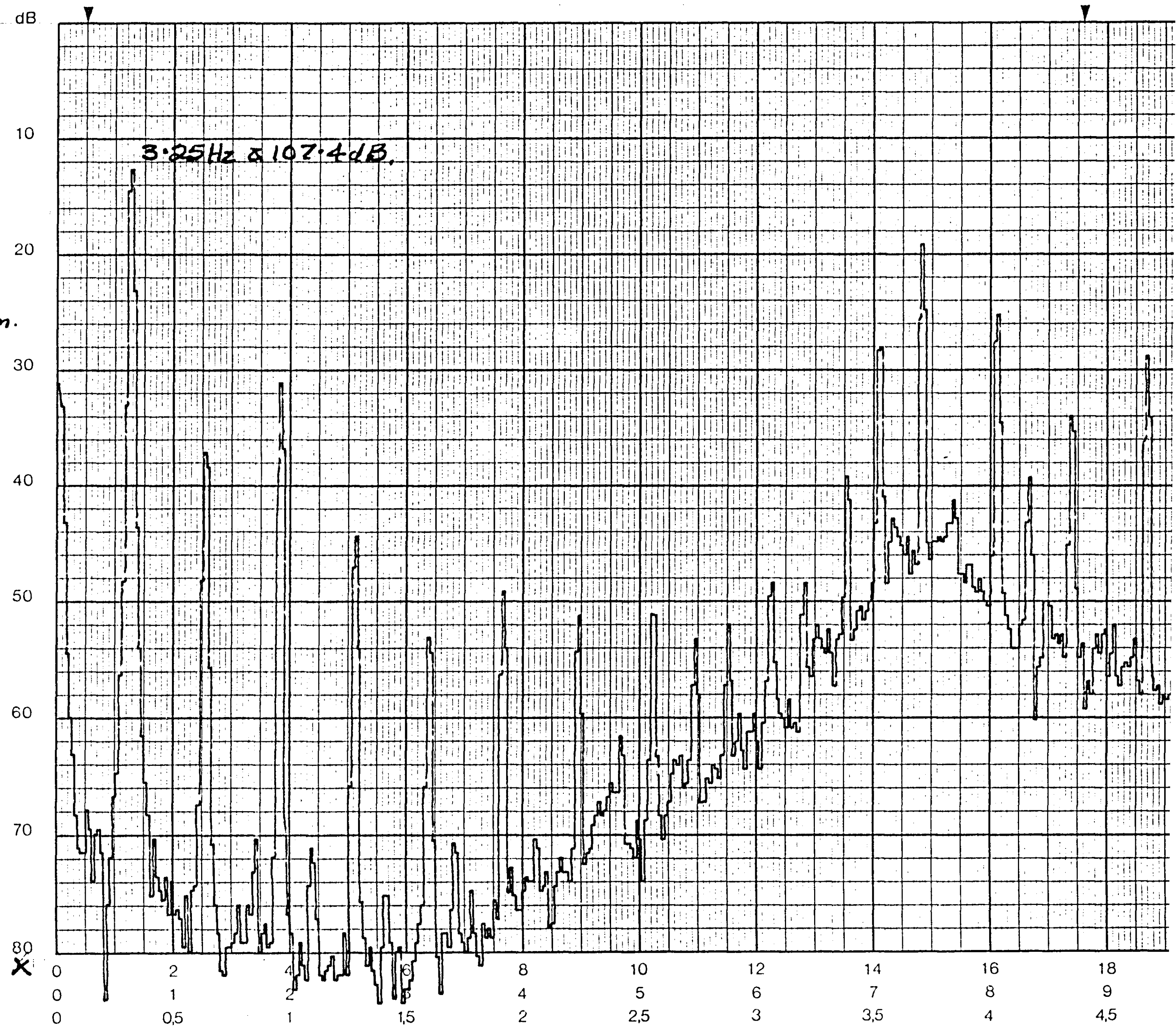
Schenk ram disp ±0·5mm.

Frequency ≃ 3·16 Hz

3·25 Hz = 107·4 dB

Free axle

Record No.: Test 1
Date: 11/6/84
Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5.

Comments: JCB Wheel.

Tyre acceleration
(V.Meter 1m/s² FSD)

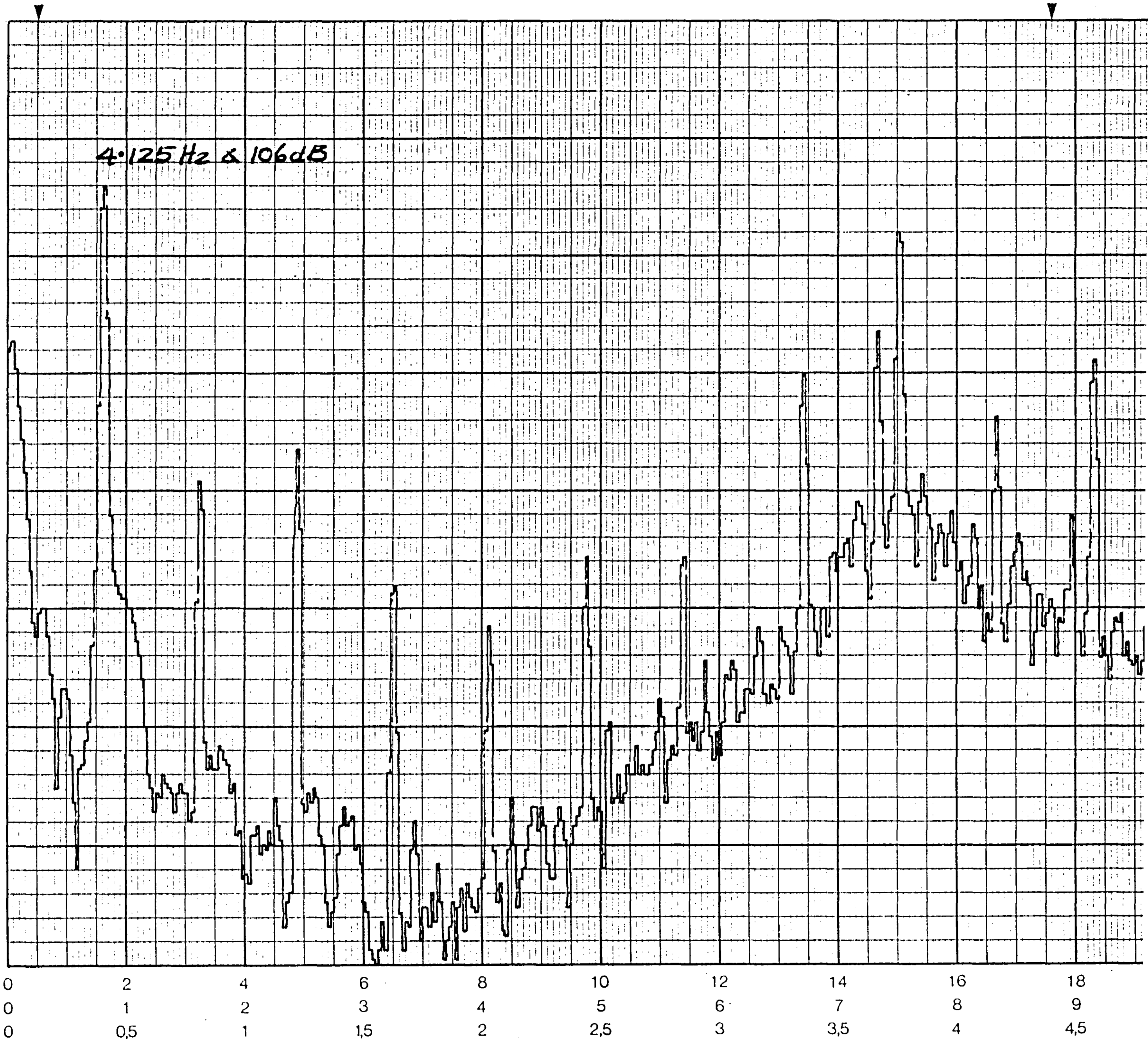
Schenk ram disp ±0·5mm

Frequency ≃ 4Hz.

4·125 Hz = 106 dB

Free axle

Record No.: Test 1.
Date: 11/6/84.
Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration.
(V.Meter $1 m/s^2$ FSD)

Schenk ram disp $\pm 0{\cdot}5 m/s^2$

Frequency $\simeq$ 5 Hz.

5·625 Hz = 105·5 dB

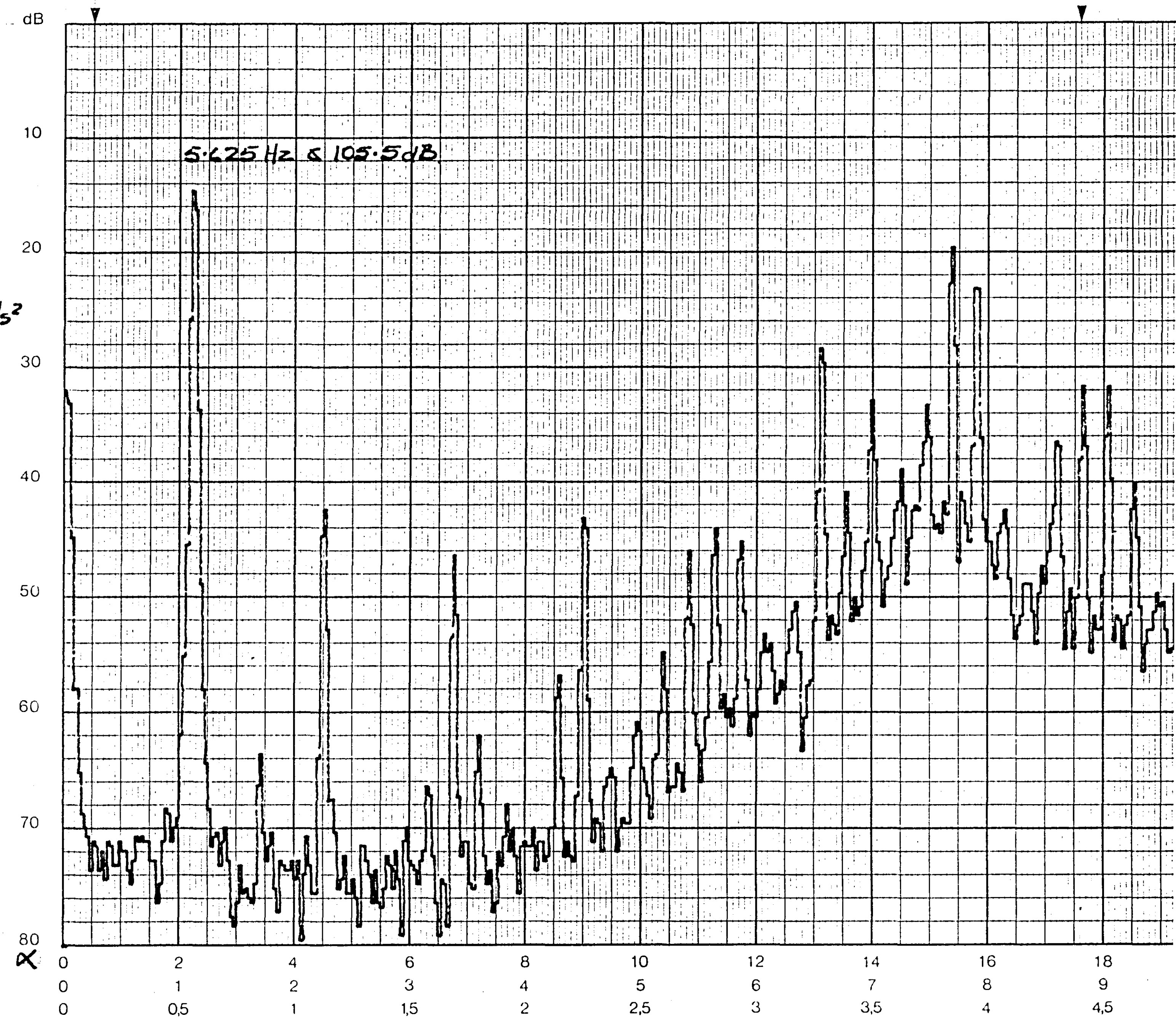
312

Free axle

Record No.: Test 1

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning.

Average Mode: Lin.

No. of Spectra: 5

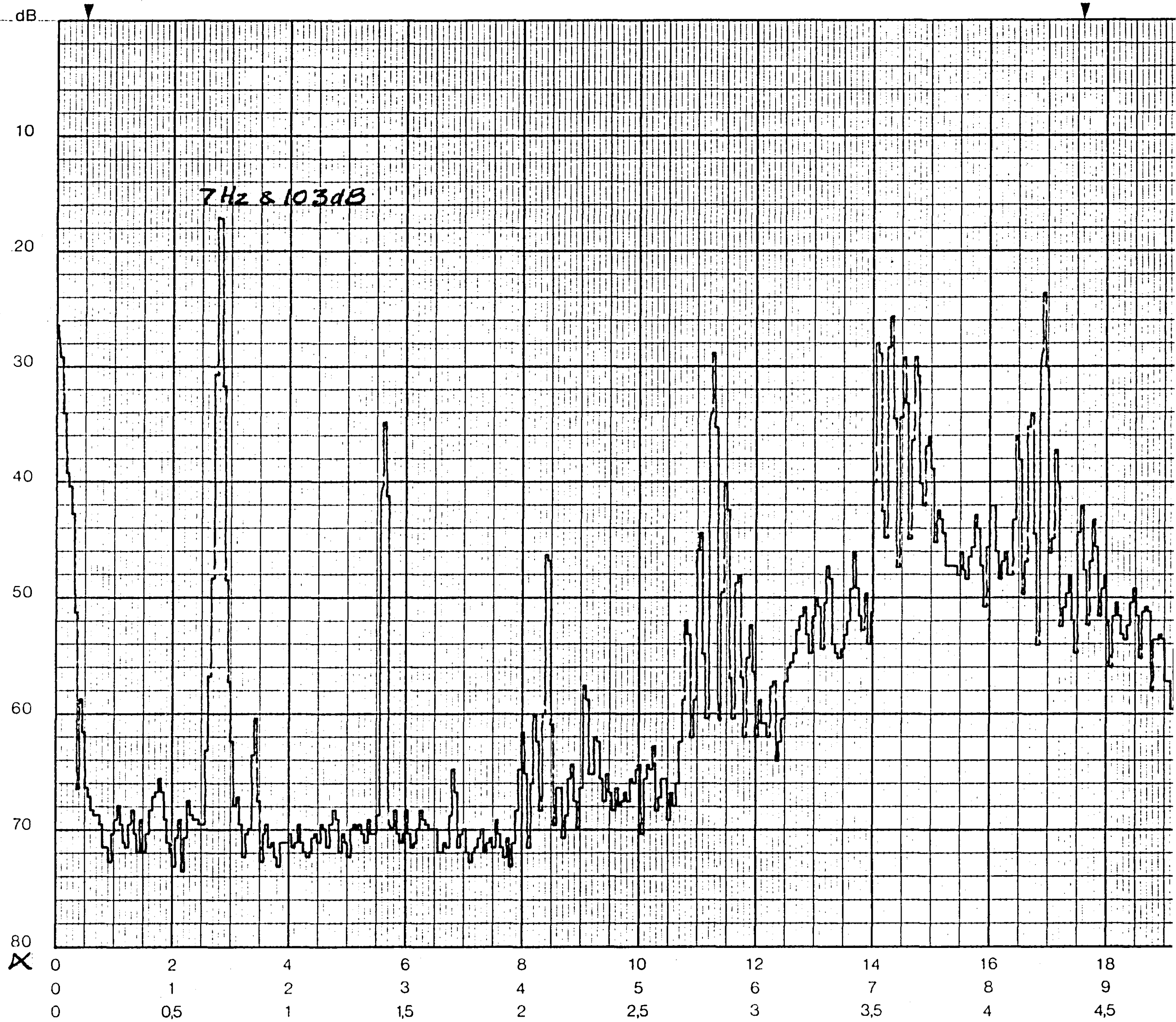
Comments: JCB Wheel.

Tyre acceleration
(V.Meter 1m/s² FSD)

Schenk ram disp = ±0·5mm

Frequency ≃ 6·3Hz

7 Hz = 103 dB



Free axle

Record No.: Test 1

Date: 11/6/84

Sign.:

QP 1002

Measuring Object:

Brüel & Kjær

Full Scale Level: 110

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter 1m/s²)

Schenk ram disp ±0.5mm

Frequency ≃ 8 Hz.

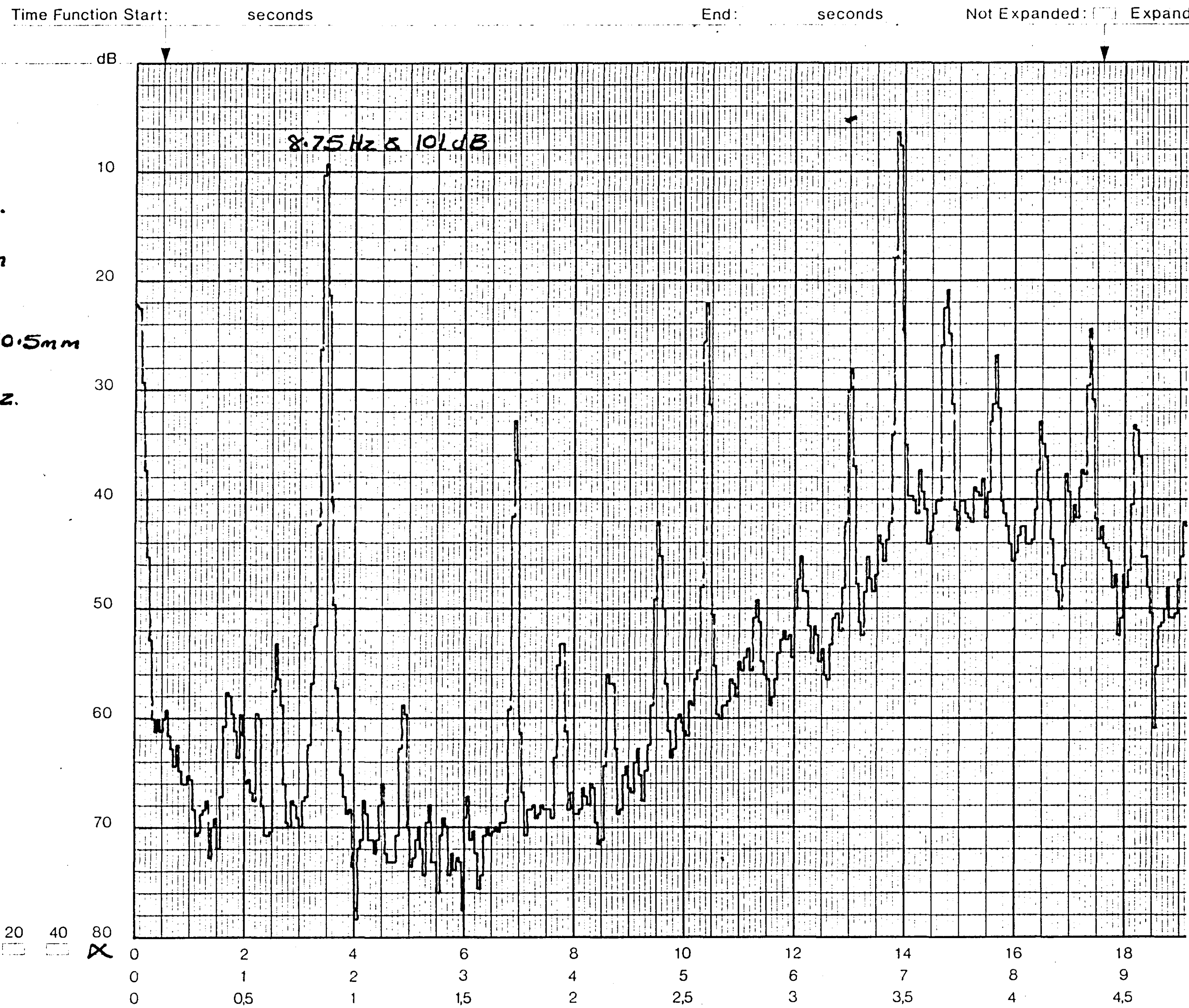
8.75 Hz = 101 dB

Free axle

Record No.: Test 1

Date: 11/6/84

Sign.:



Measuring Object:

314

QP 1002

Brüel & Kjær

Full Scale Level: 110

F. S. Frequency: 50

Weighting: Hamming

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V.Meter 1m/s² FSD)

Schenk ram disp ±0·5mm.

Frequency ≃ 10Hz

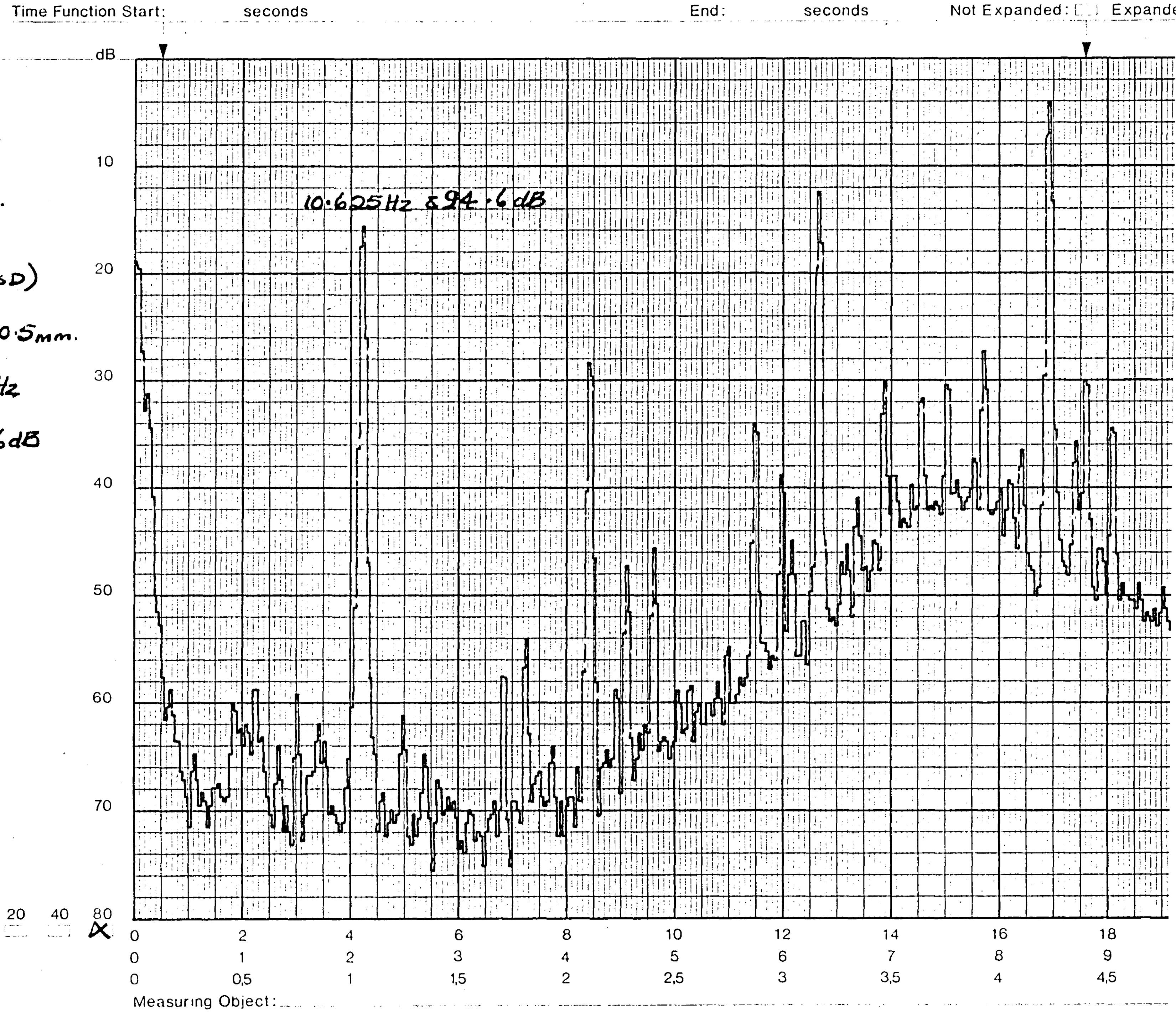
10·625 Hz = 94·6dB

Free axle

Record No.: Test 1

Date: 11/6/84.

Sign.:



QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 120

F. S. Frequency: 50.

Weighting: Hamming

Average Mode: Lin.

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V.Meter $1 m/s^2$ FSD)

Schenk ram disp ±1mm.

Frequency ≃ 1Hz.

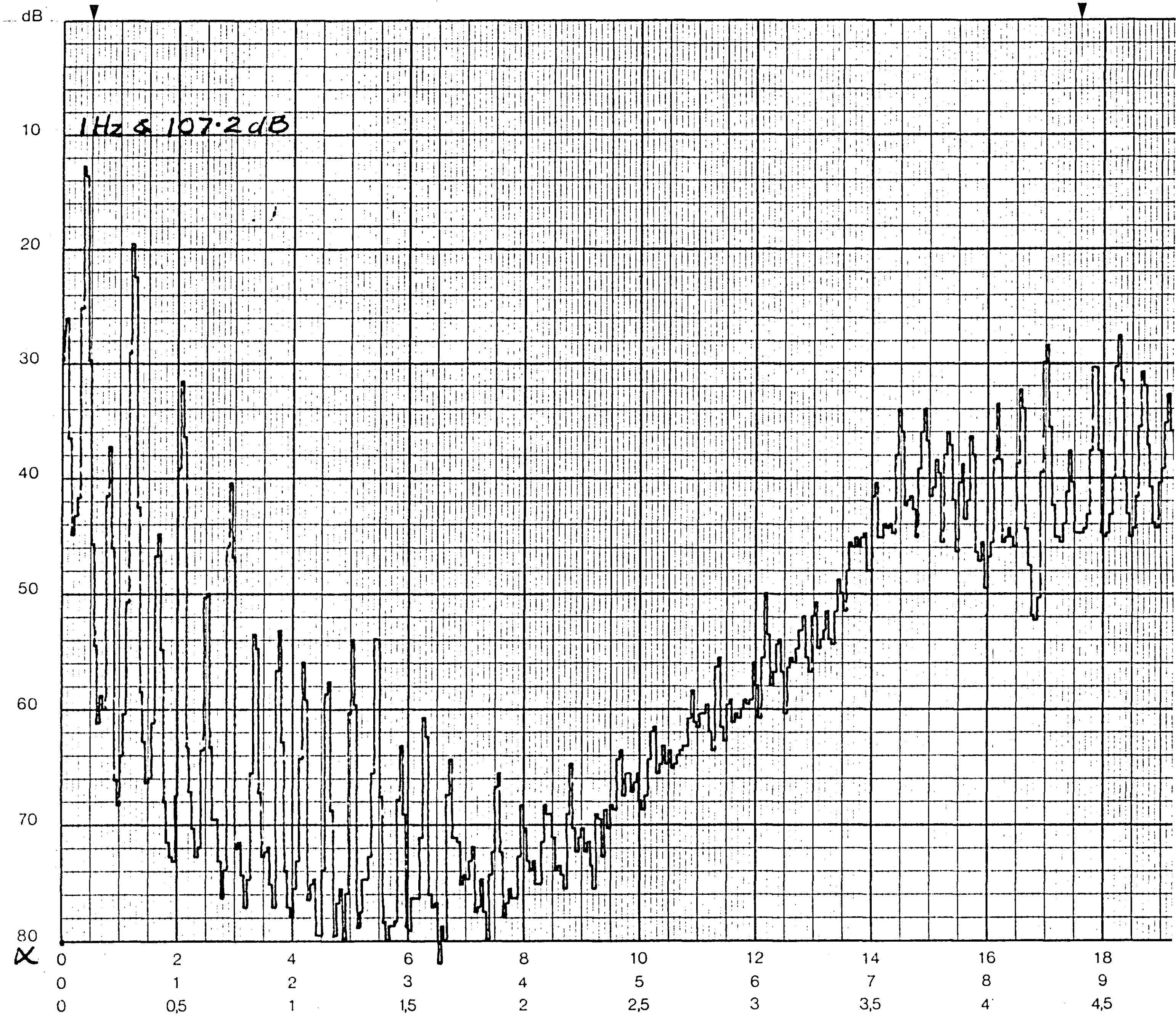
1Hz = 107·2dB

Free axle

Record No.: Test 2.

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

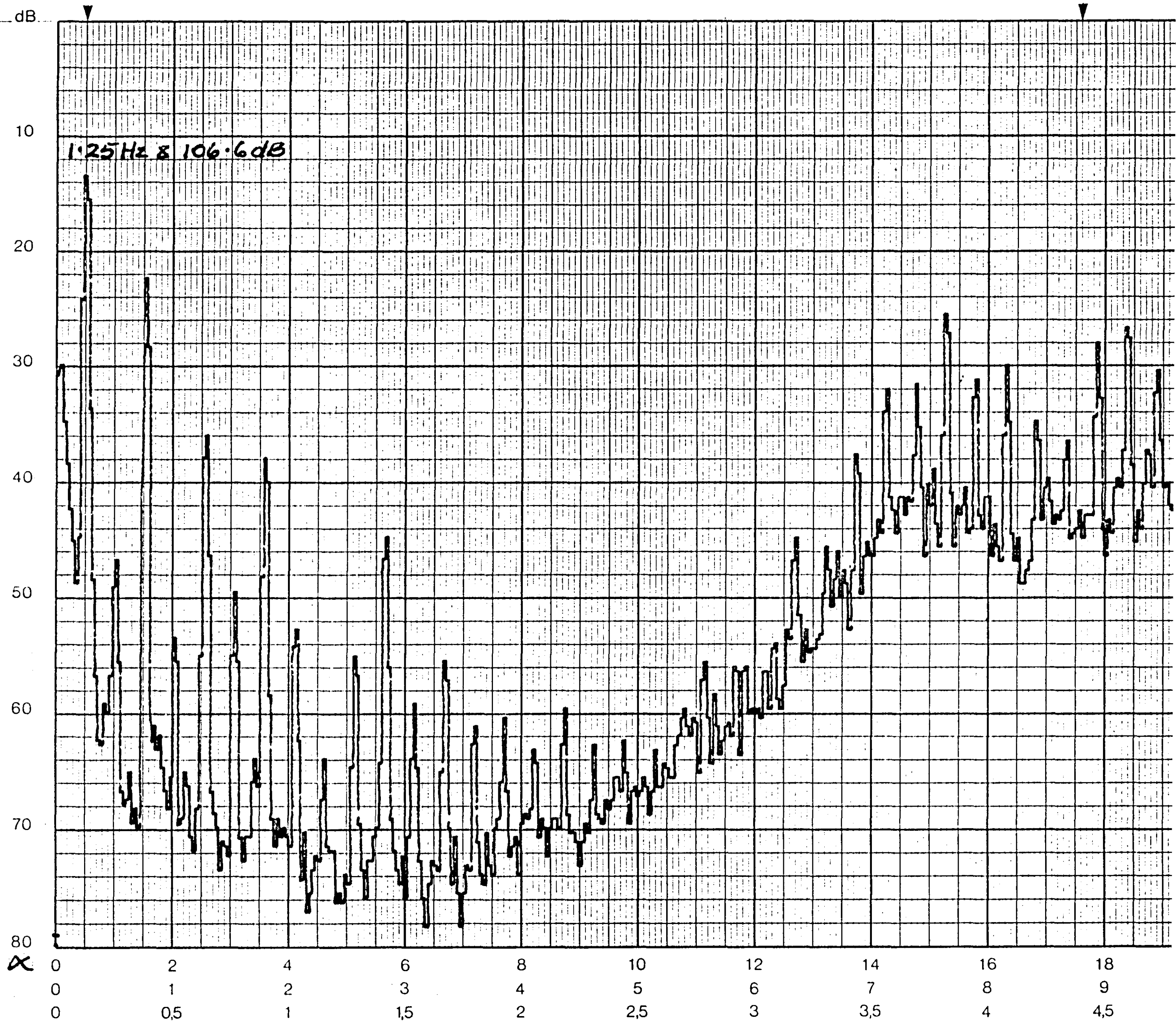
Comments: JCB Wheel.

Tyre acceleration
(V.Meter $1 m/s^2$ FSD)

Schenk ram disp ±1mm

Frequency ≃ 1·25Hz

1·25Hz = 106·6 dB



Free axle

Record No.: Test 2.

Date: 11/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration (V.Meter 1m/s² FSD)

Schenk ram disp ± 1mm.

Frequency ≃ 1·6 Hz.

1·625 Hz = 107·8 dB.

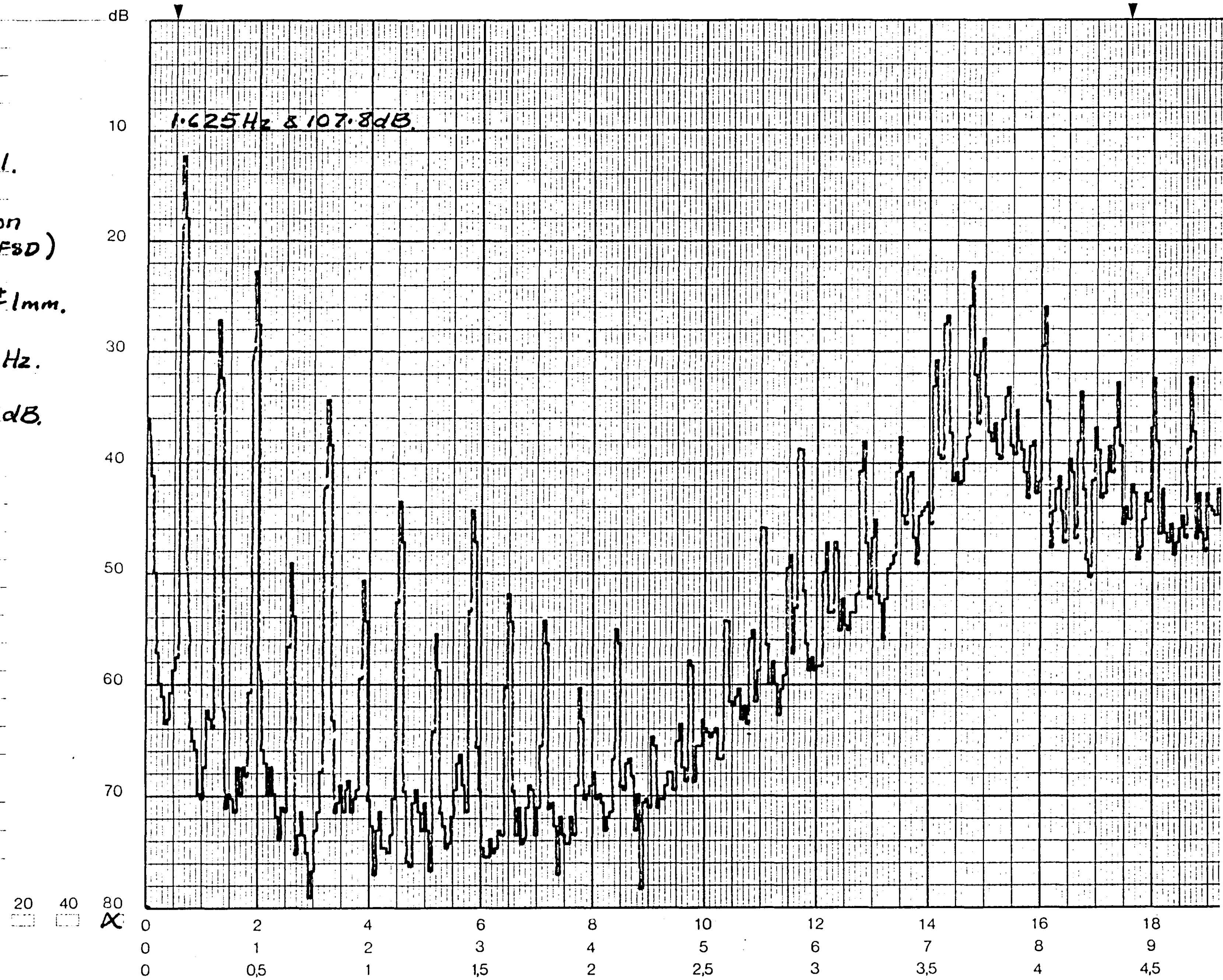
318

Free axle

Record No.: Test 2

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

axle acceleration.
(V. Meter = 1m/s² FSD)

Schenk ram disp ± 1mm.

Frequency ≃ 2 Hz.

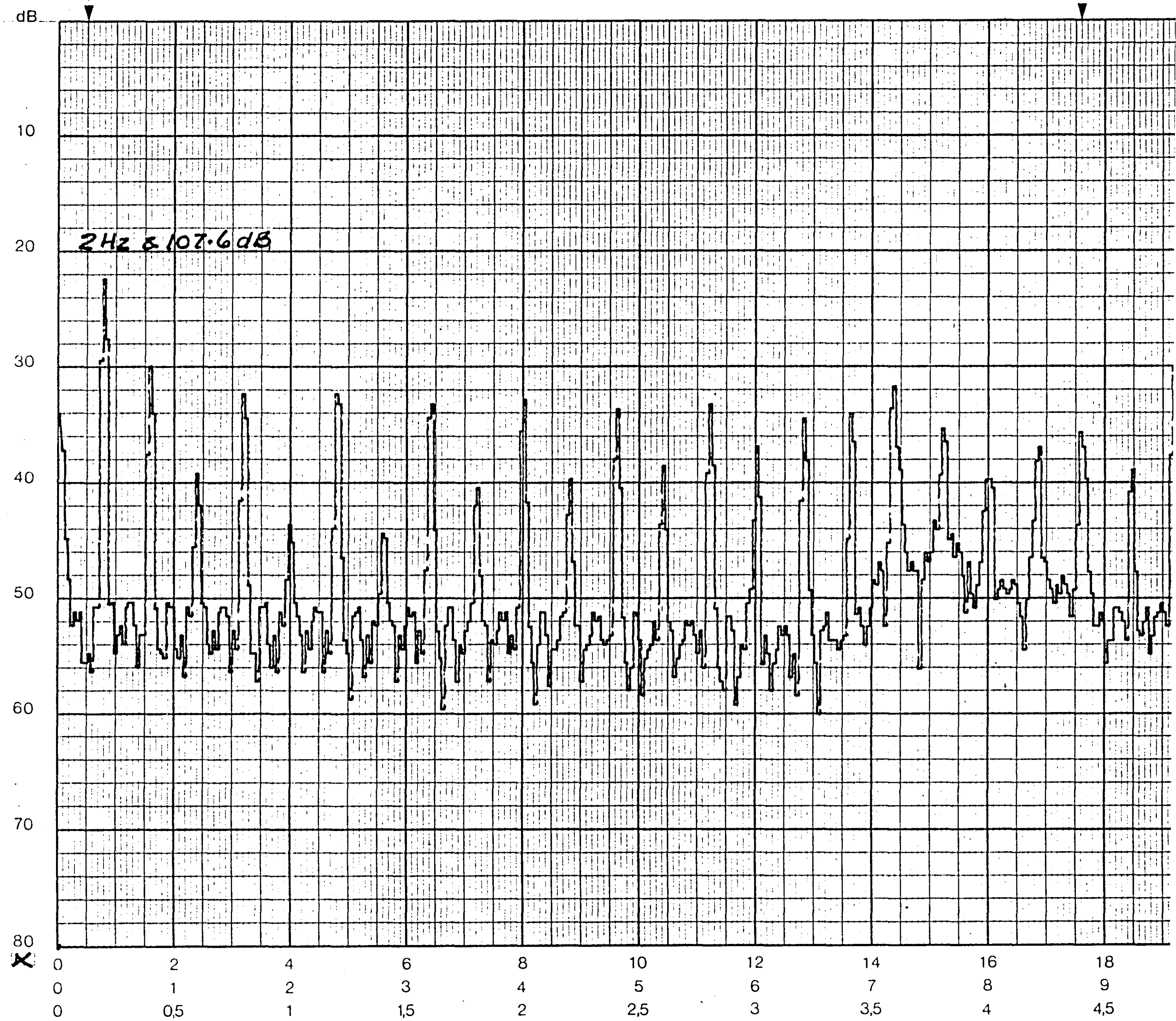
2 Hz = 107·6 dB

Free axle

Record No.: Test 2.

Date: 11/6/84.

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

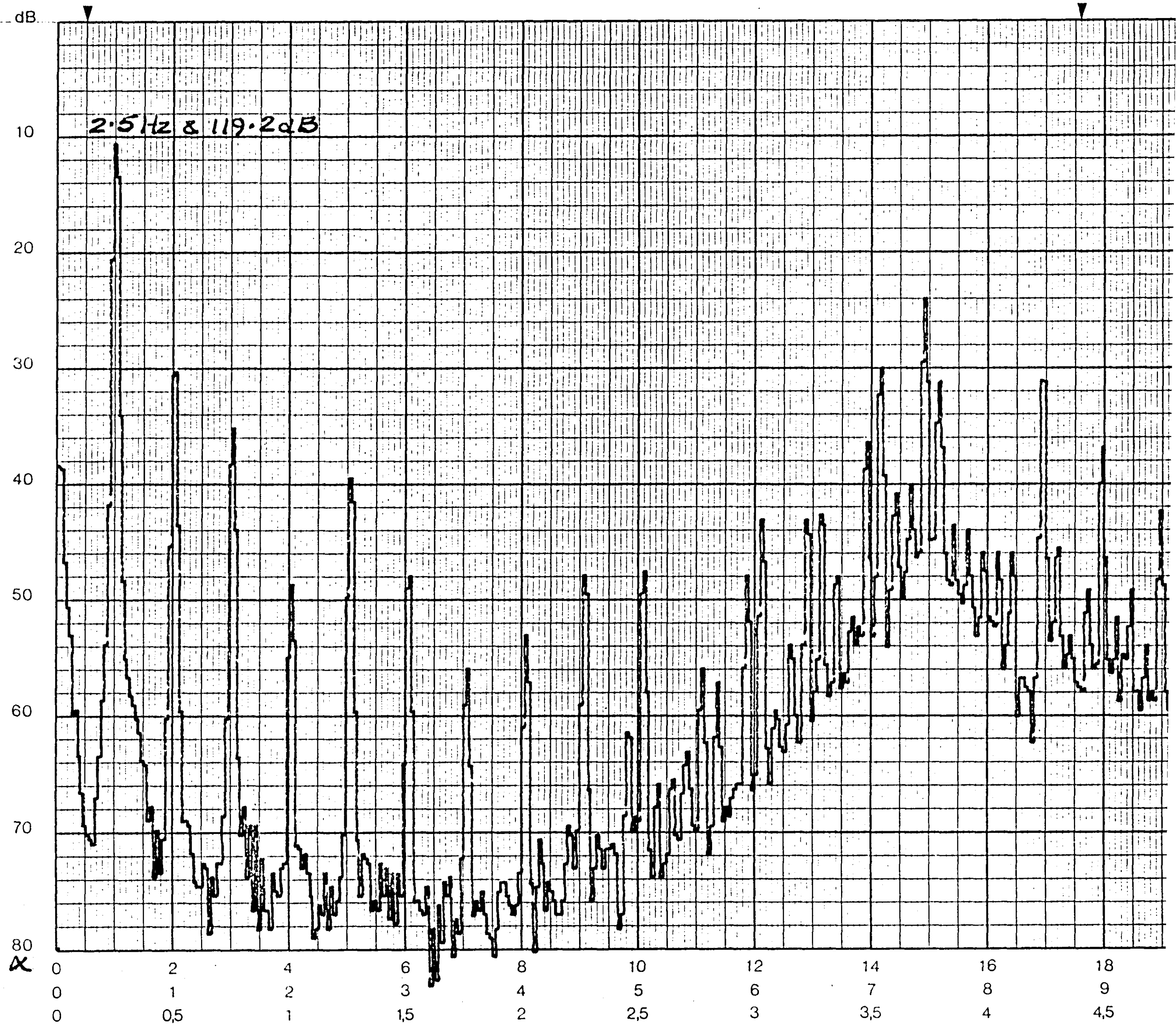
Full Scale Level: 130. dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5.

Comments: JCB Wheel.

Tyre acceleration
(V.Meter 1m/s² FSD)

Frequency ≃ 2.5Hz

2.5Hz = 119.2dB.



Measuring Object:

Free axle

Record No.: Test 2
Date: 11/6/84
Sign.:

QP 1002

Brüel & Kjær   Time Function Start: seconds   End: seconds   Not Expanded: ☐ Expand

Full Scale Level: 130 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5
Comments: JCB Wheel.

Tyre acceleration.
(V. Meter 1m/s^2 FSD)

Schenk ram disp ±1mm

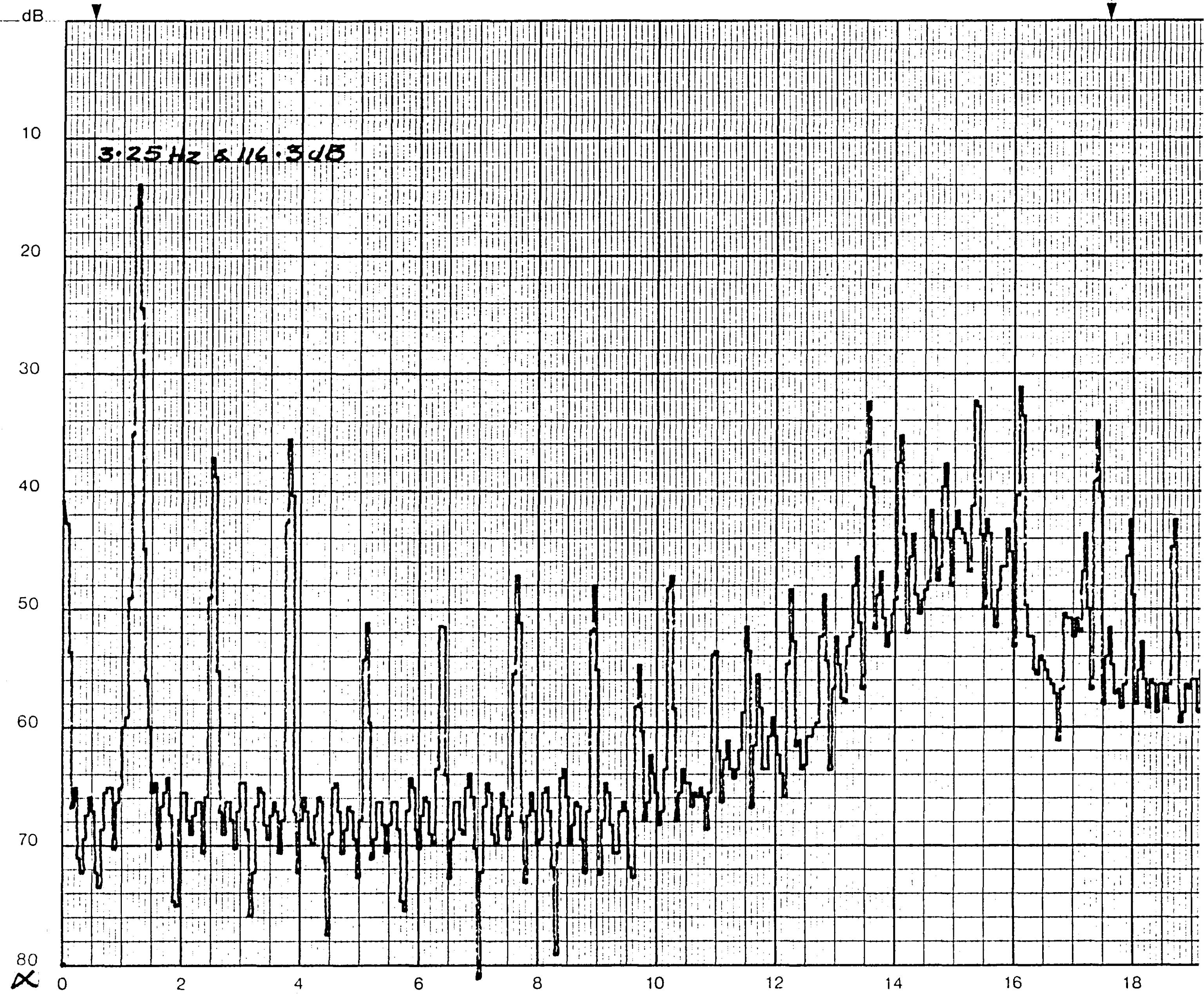
Frequency ≃ 3·16 Hz

3·25 Hz = 116·3 dB

321

Free axle

Record No.: Test 2.
Date: 11/6/84
Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter 1m/s²FSD)

Schenk ram disp ±1mm.

Frequency ≃ 4 Hz.

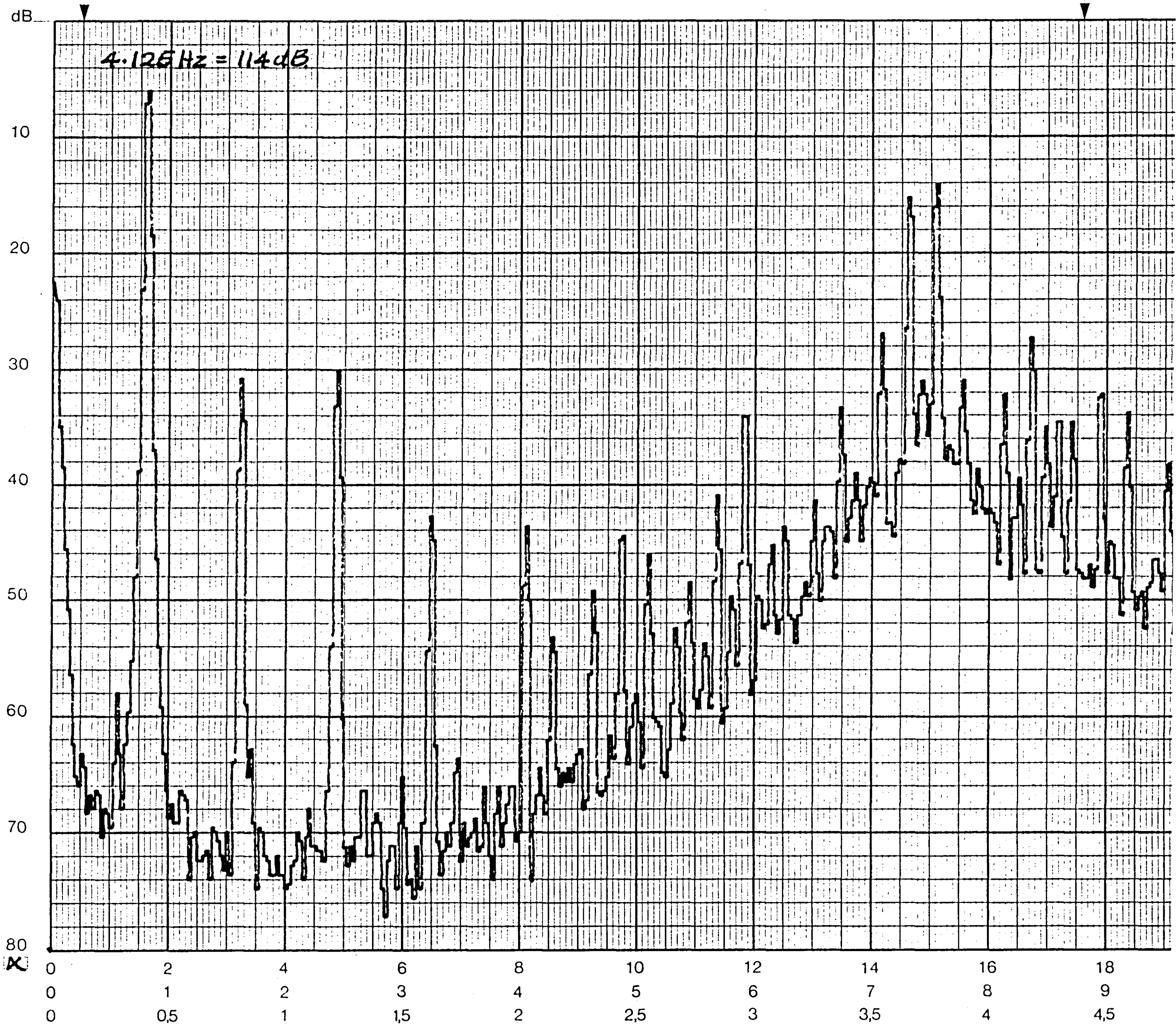
4·125 Hz = 114 dB.

Free axle

Record No.: Test 2

Date: 11/6/84.

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds   End: seconds   Not Expanded: ☐ Expand

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter = 1m/s² FSD.)

Schenk ram disp ± 1mm.

Frequency ≃ 5Hz

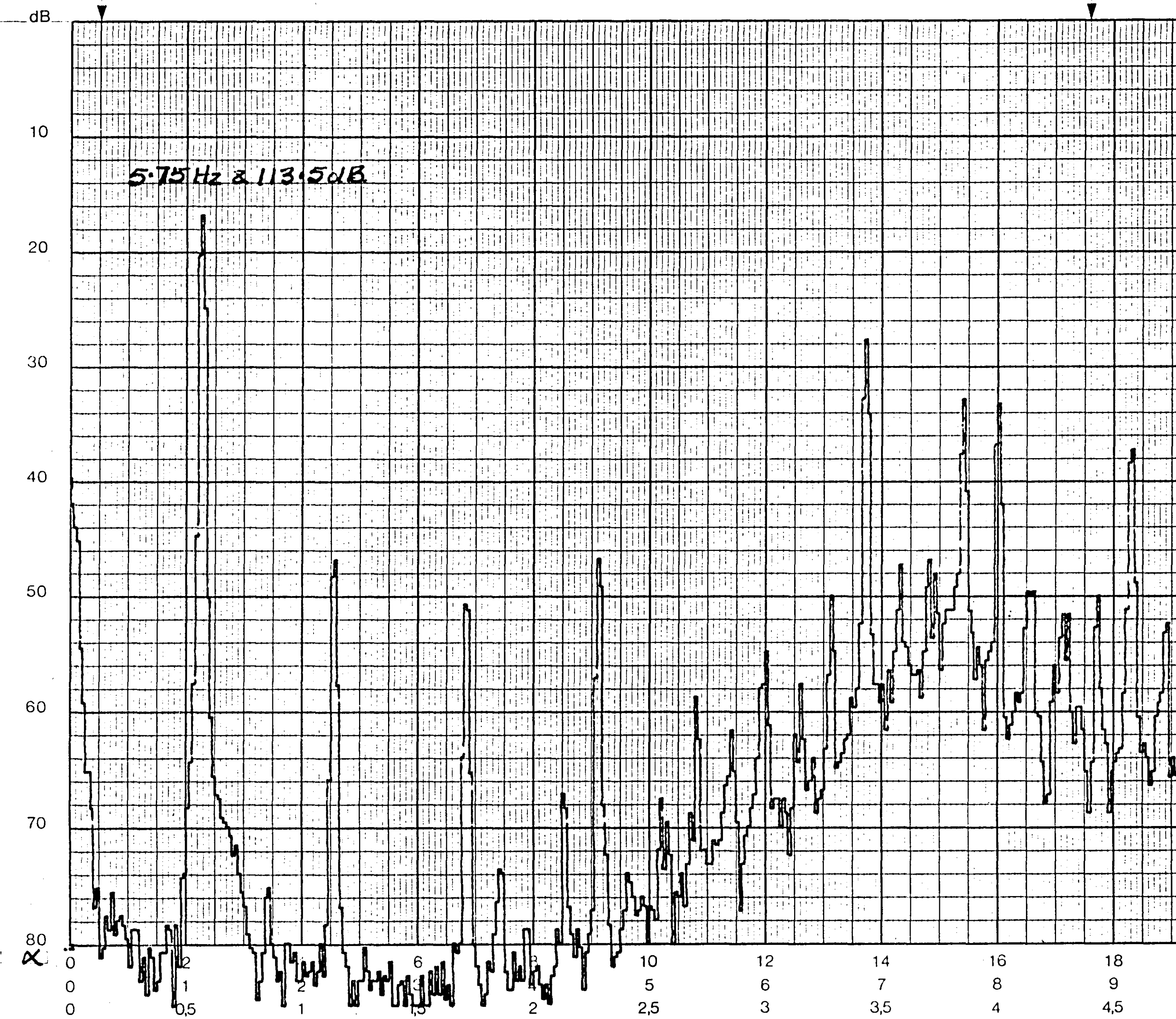
5·75Hz = 113·5dB

Free axle

Record No.: Test 2.

Date: 11/6/84.

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter 1m/s² FSD)

Schenk ram disp ± 1mm

Frequency ≃ 6 Hz

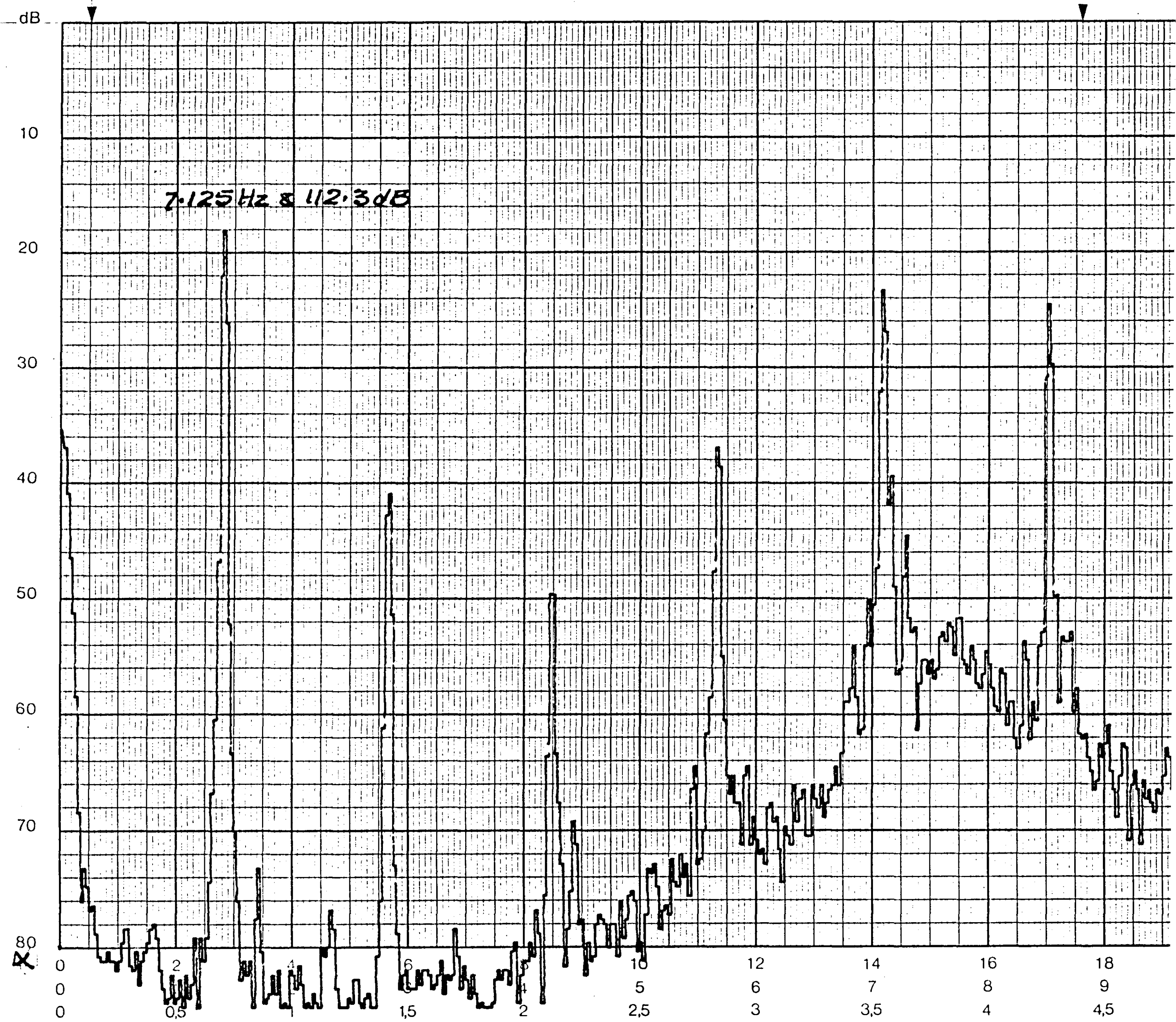
7·125 Hz = 112.3 dB

Free axle

Record No.: Test 2

Date: 11/6/84

Sign.: [signature]



Measuring Object:

324

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120 dB

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel

Tyre acceleration
(V. Meter = 1 m/s² FSD)

Schenk ram disp ± 1 mm.

Frequency ≃ 8 Hz

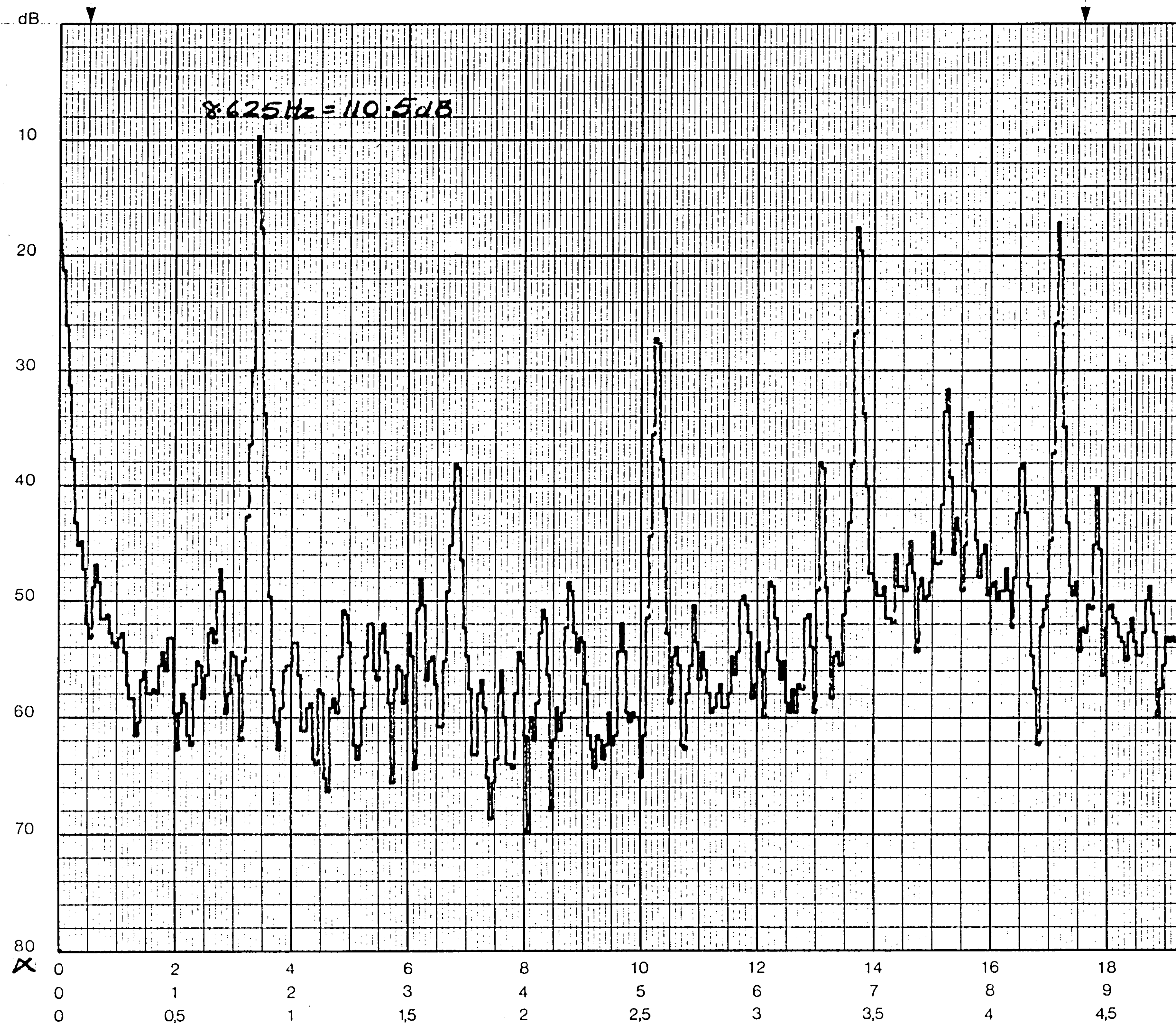
8·625 Hz = 110·5 dB

Free axle

Record No.: Test 2.

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: 120
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration.
(V.Meter = 1m/s²FSD)

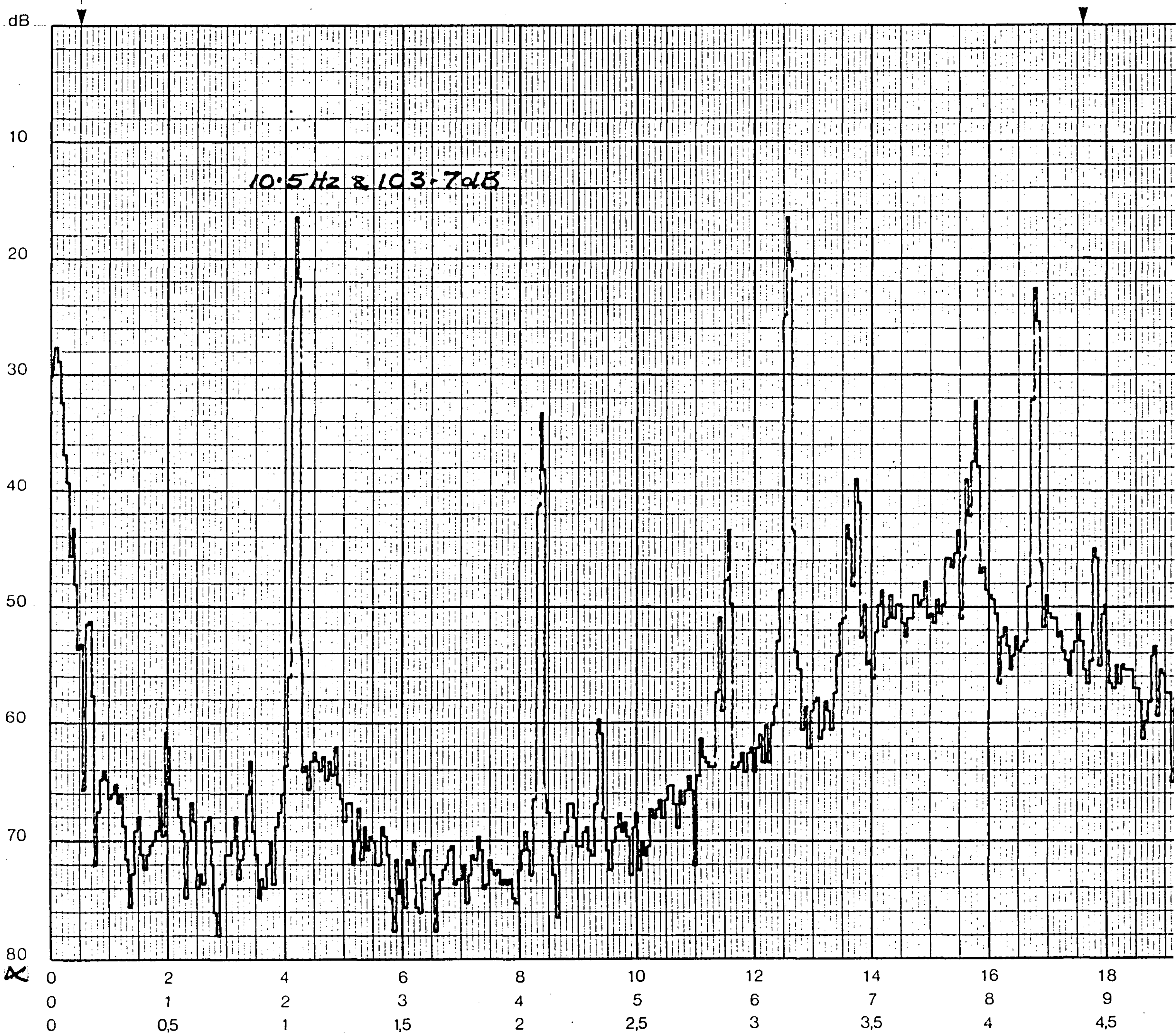
Schenk ram disp ±1mm.

Frequency ≃ 10Hz.

10·5Hz = 103·7dB

Free axle

Record No.: Test 2.
Date: 11/6/84
Sign.: [signature]



QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

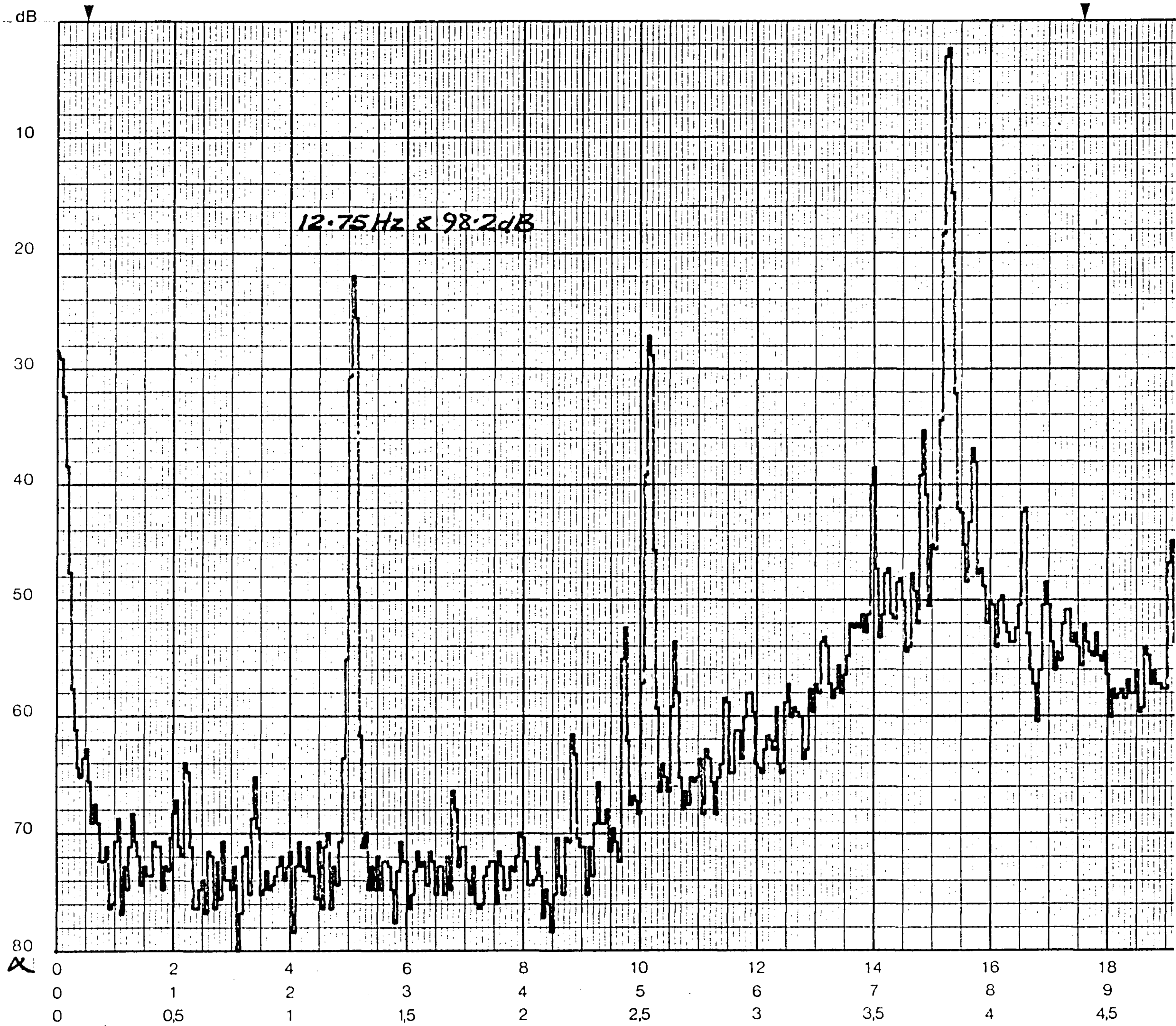
Full Scale Level: 120 dB
F. S. Frequency: 50.
Weighting: Hanning
Average Mode: Lin.
No. of Spectra: 5.
Comments JCB Wheel.

Tyre acceleration.
(V.Meter = 1m/s²FSD)

Schenk ram disp ± 1mm

Frequency ≃ 12.5Hz.

12.75 Hz = 98.2dB



327

Free axle

Record No.: Test 2.
Date: 11/6/84
Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 130.

F. S. Frequency: 100

Weighting: Hanning.

Average Mode: Lin

No. of Spectra: 10.

Comments: JCB Wheel.

Tyre acceleration

(V.Meter = 1m/s² FSD

Schenk ram disp ±1mm.

Frequency ≃ 12·5Hz

12·75Hz = 98·2dB

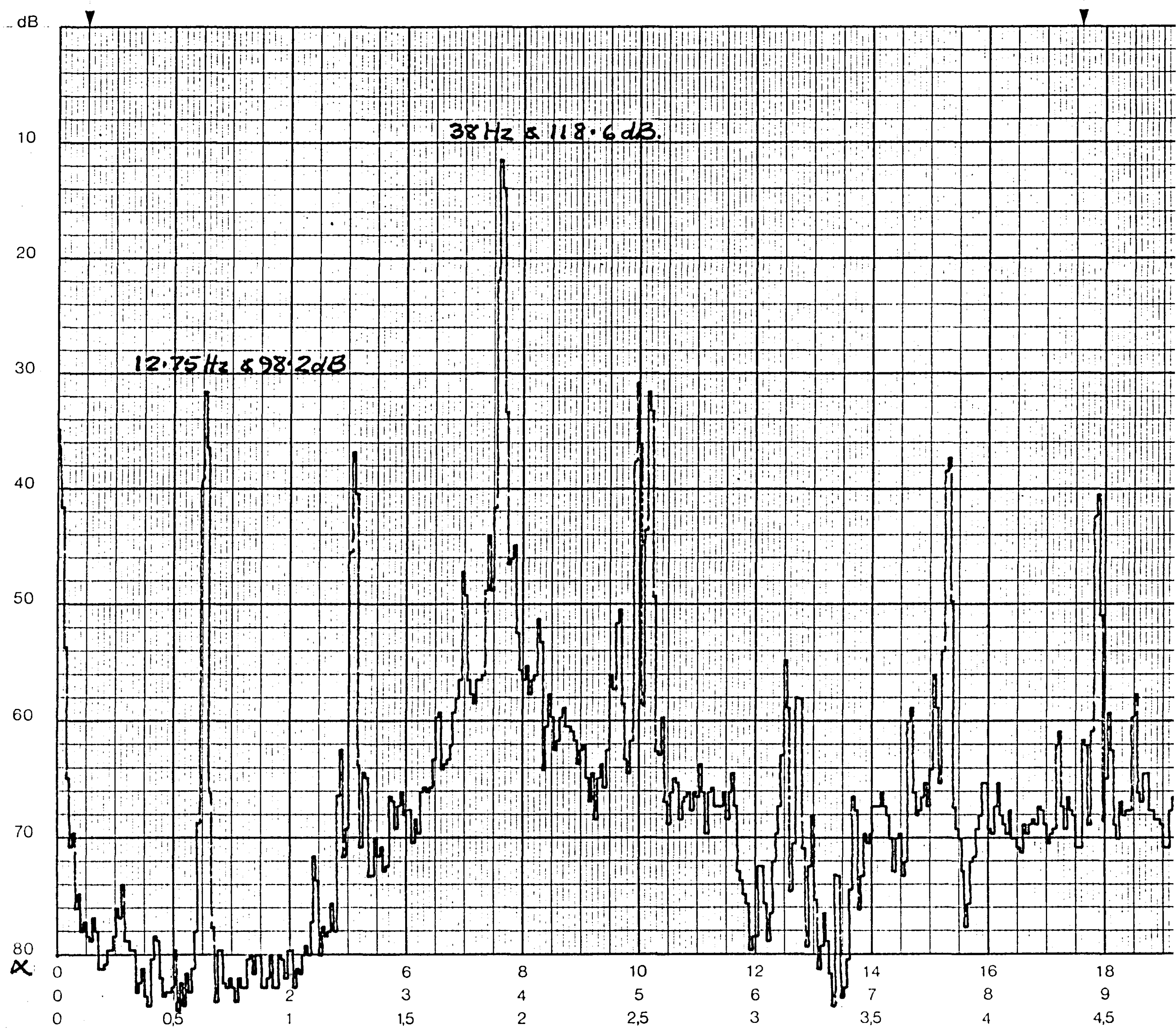
328 38Hz = 118·6dB

Free axle

Record No.: Test 2.

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expanded

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter 1m/s² FSD)

Schenk ram disp. ± 1.5mm.

Frequency ≈ 1 Hz.

1 Hz = 110·7 dB.

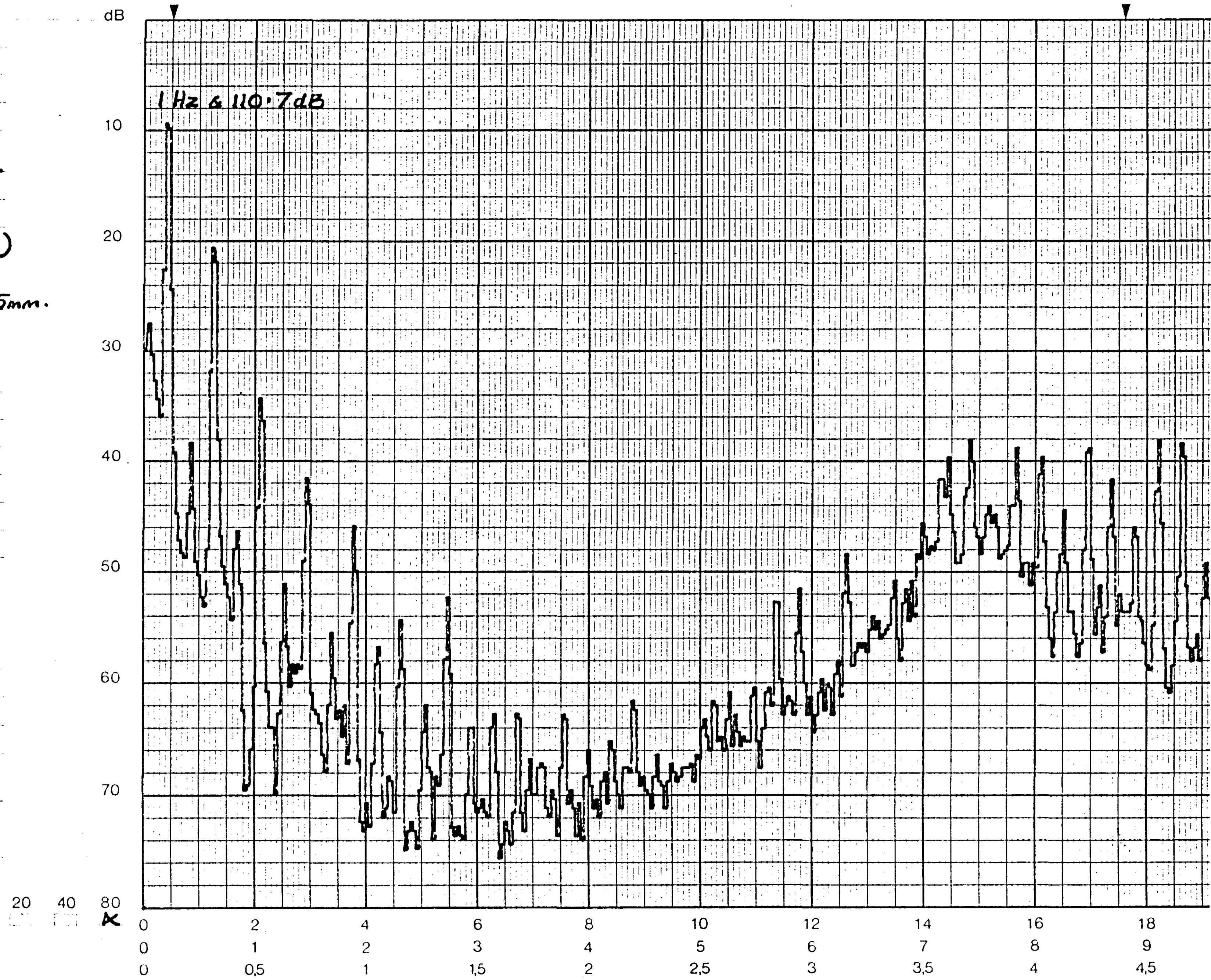
329

Free axle

Record No.: Test 3.

Date: 11/6/84

Sign.:



QP 1002

Measuring Object:

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V. Meter 1 m/s² FSD)

Schenk ram disp ±1·5mm

Frequency ≈ 1·25Hz

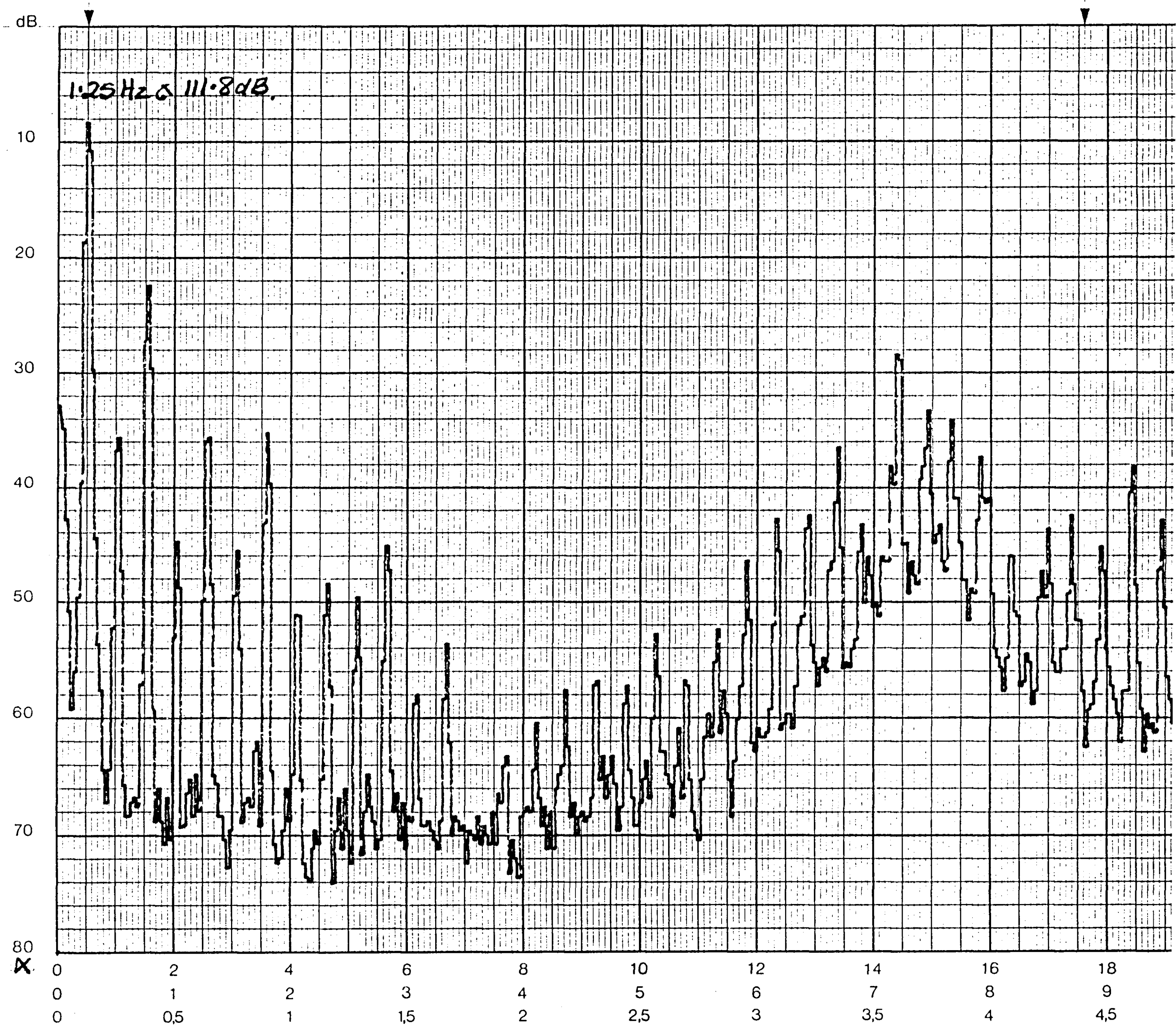
1·25Hz = 111·8dB.

Free axle.

Record No.: Test 3

Date: 11/6/84

Sign.: [signature]



Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments:

JCB Wheel.

Tyre acceleration (V.Meter 1m/s² FSD.

Scherk ram disp. ±1·5mm.

Frequency ≈ 1·6 Hz

1·625 Hz = 117·7dB,

331

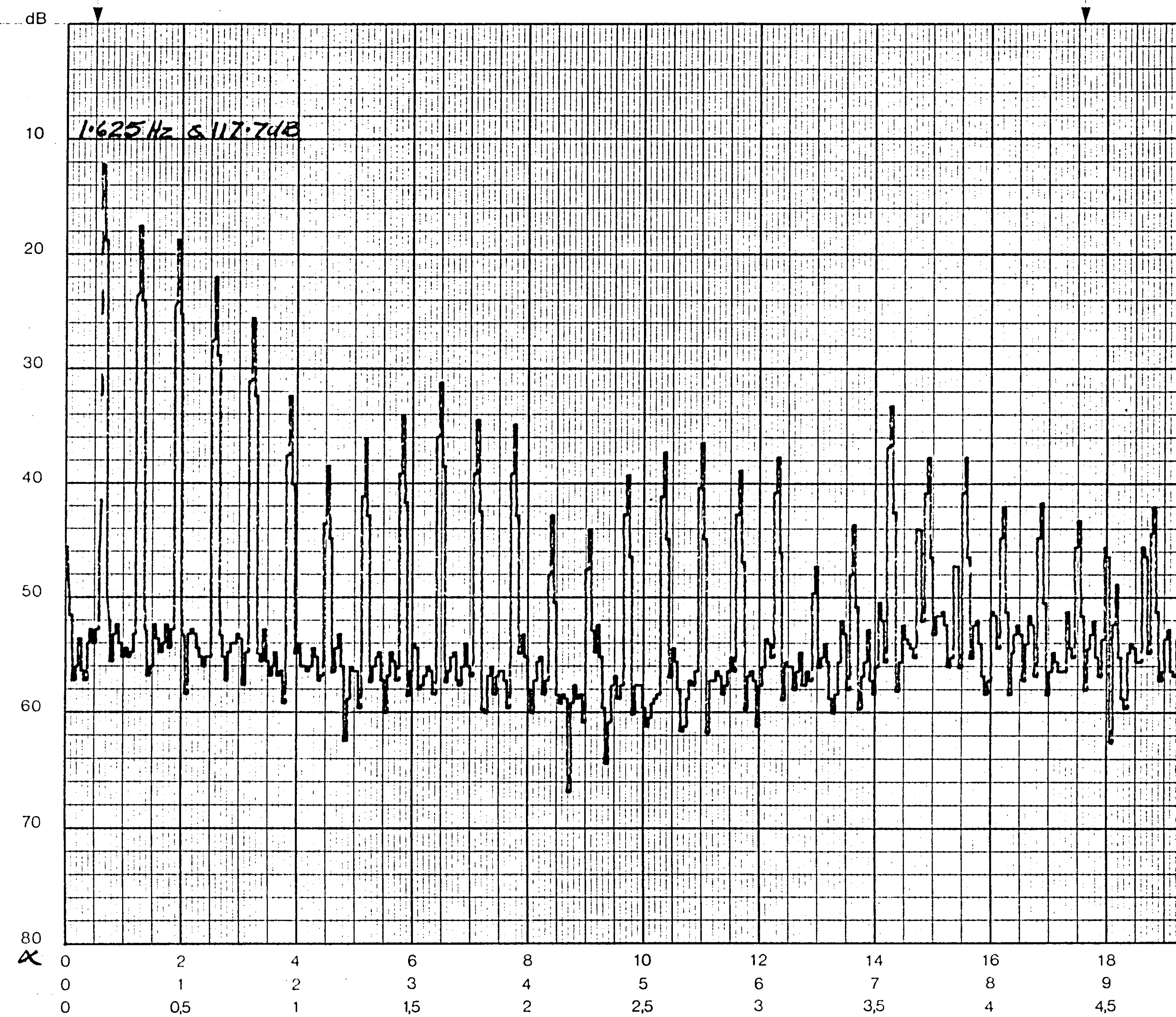
Free axle.

Record No. Test 3.

Date: 11/6/84

Sign.:

Time Function Start: seconds End: seconds Not Expanded: Expand



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments:

JCB Wheel.

Tyre acceleration
(V.Meter 1m/s² FSD)

Frequency ≃ 2Hz

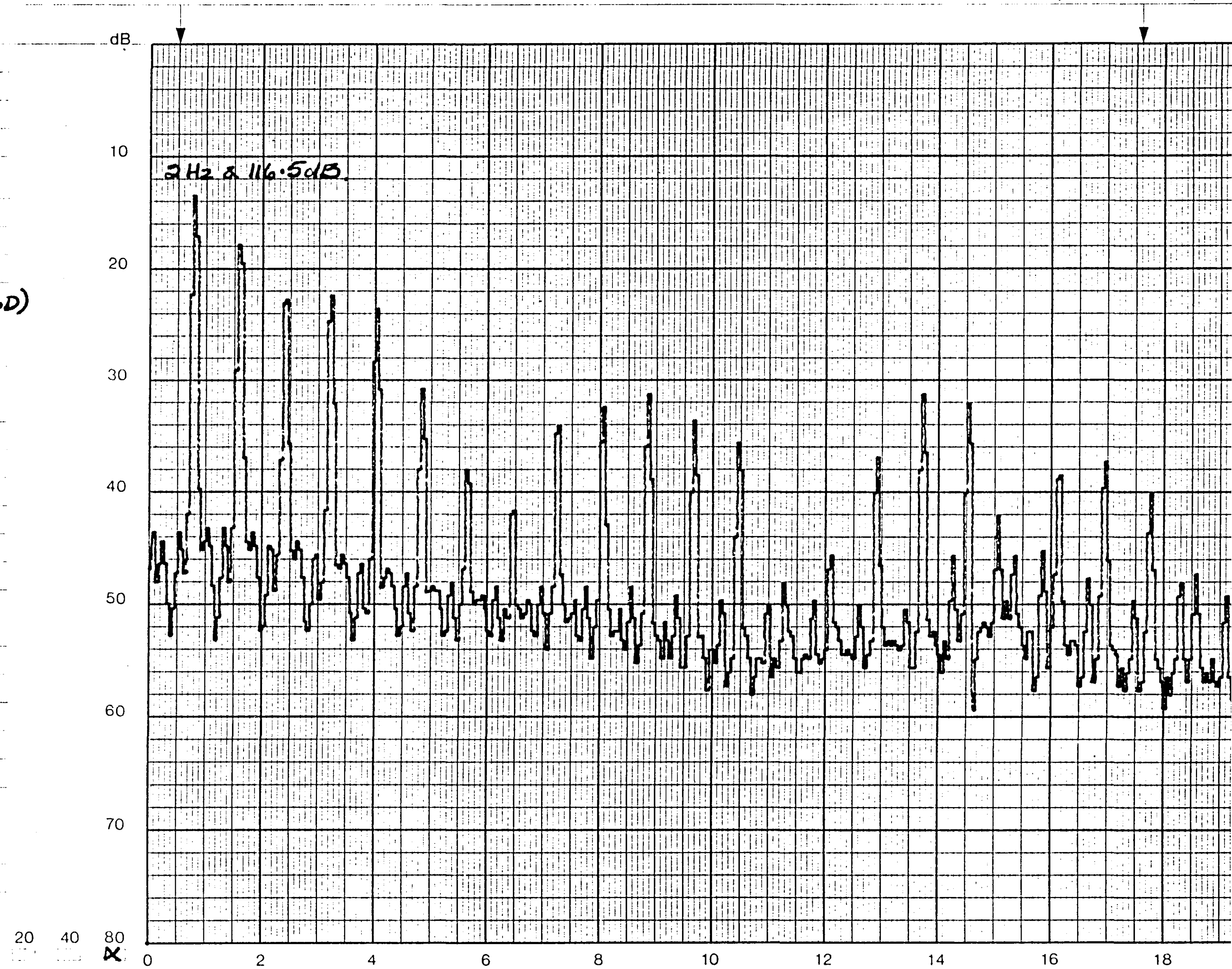
2Hz = 116·5dB.

Free axle.

Record No.: Test 3.

Date: 11/6/84

Sign.:



Measuring Object:

332

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments:

JCB. Wheel

Tyre. acceleration
(V. Meter 1m/s² FSD)

Schenk ram disp ± 1.5mm

Frequency ≃ 2.5 Hz

2.5Hz = 120.2dB.

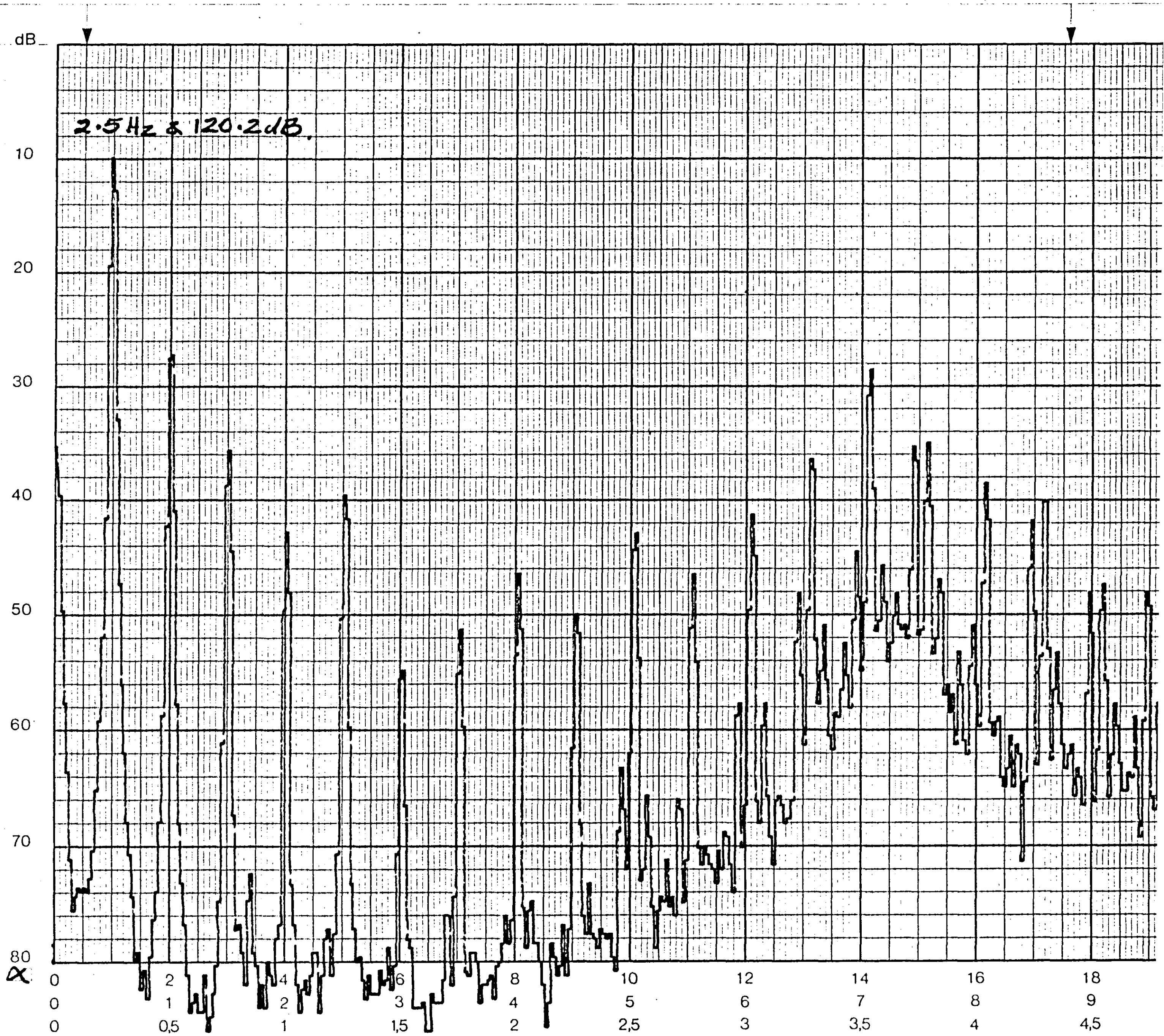
333

Free axle

Record No.: Test 3.

Date: 11/6/84

Sign.:



QP 1002

Measuring Object:

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5.

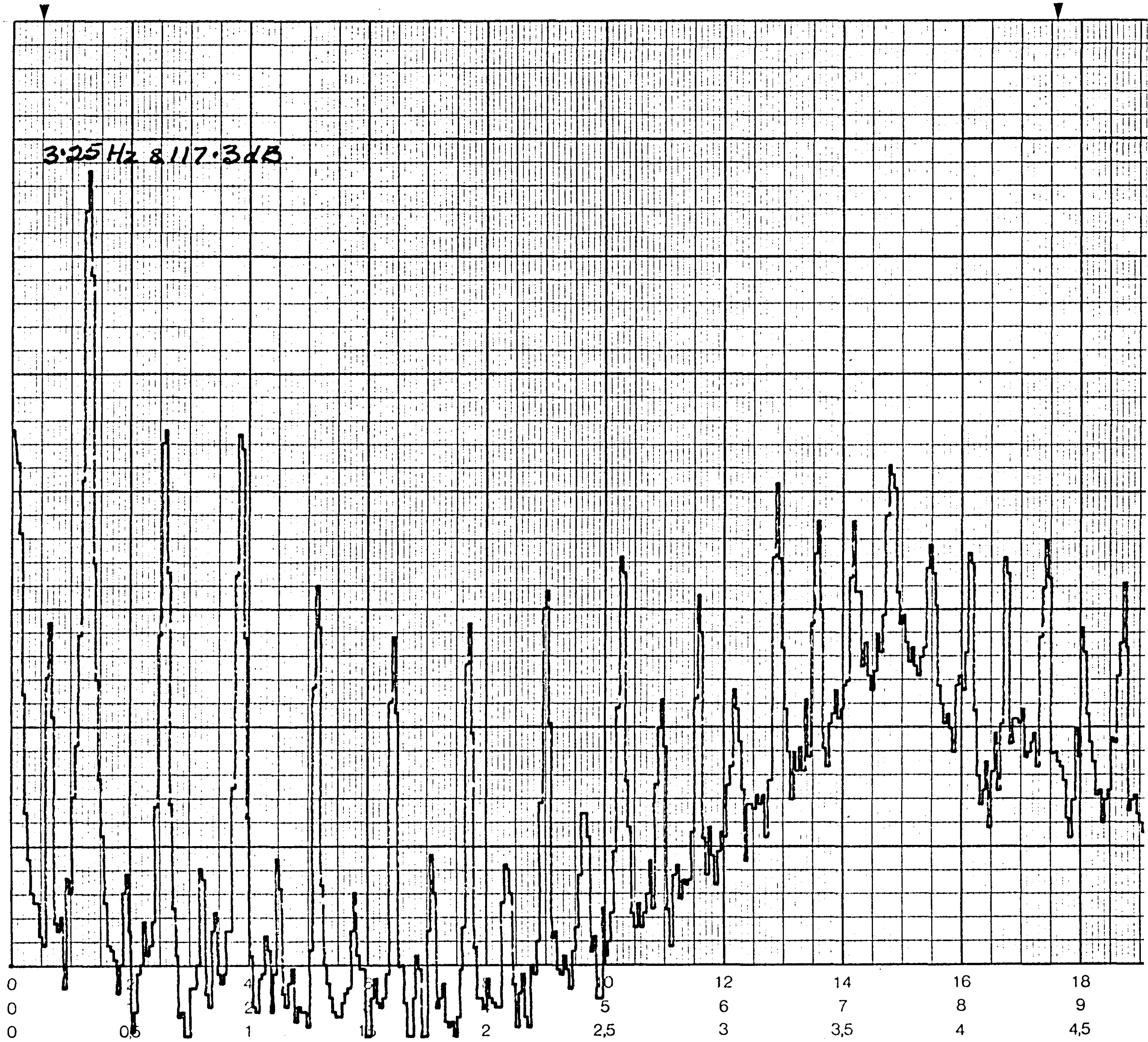
Comments:

JCB Wheel.

Tyre acceleration.
(V.Meter $1 m/s^2$ FSD)

Frequency ≃ 3·15 Hz.

3·25 Hz = 117·3 dB.



Free axle

Record No.: Test 3.

Date: 11/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments:
JCB Wheel.

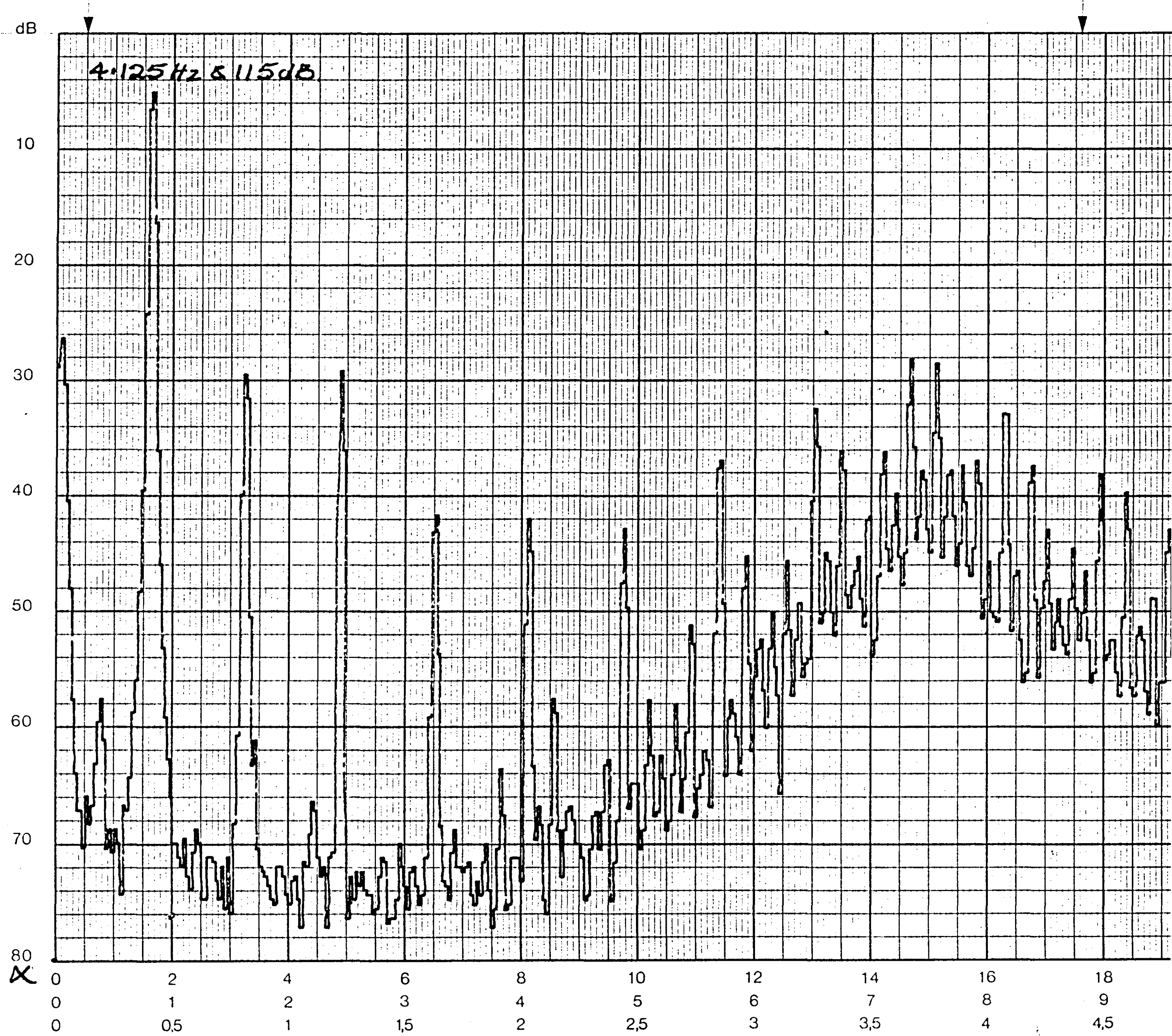
Tyre acceleration
(V.Meter $1 m/s^2$ FSD)

Frequency ≈ 4 Hz.

4·125 Hz = 115 dB

Free axle.

Record No.: Test 3.
Date: 11/6/84
Sign.:



QP 1002
Measuring Object:

Brüel & Kjær

Full Scale Level: 120
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments:
JCB Wheel.

Tyre acceleration
(V. Meter 1m/s²FSD)

Frequency ≃5Hz

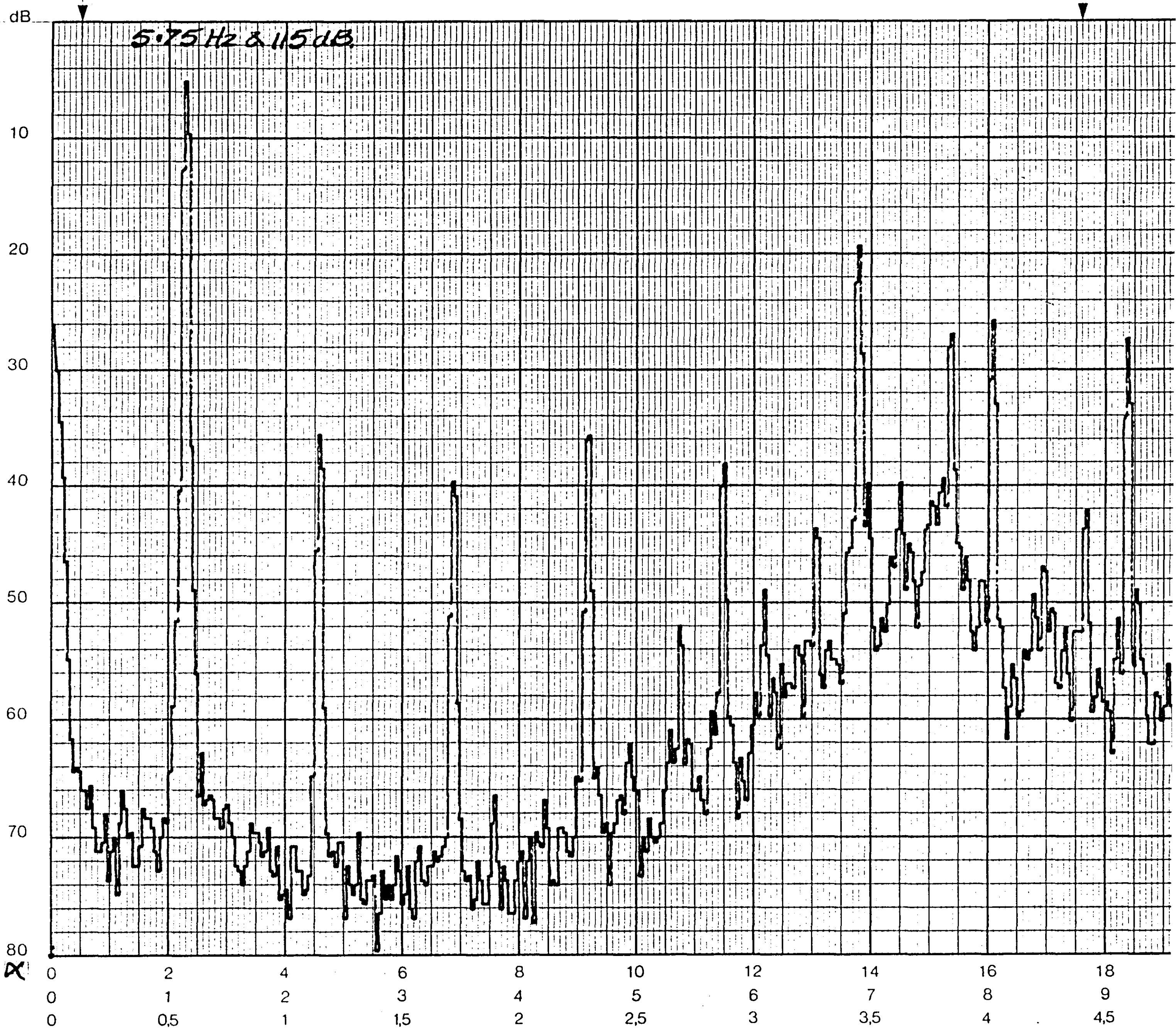
5.75Hz = 115dB

336

Free axle

Record No.: Test 3
Date: 11/6/84
Sign.:

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments:
JCB Wheel.

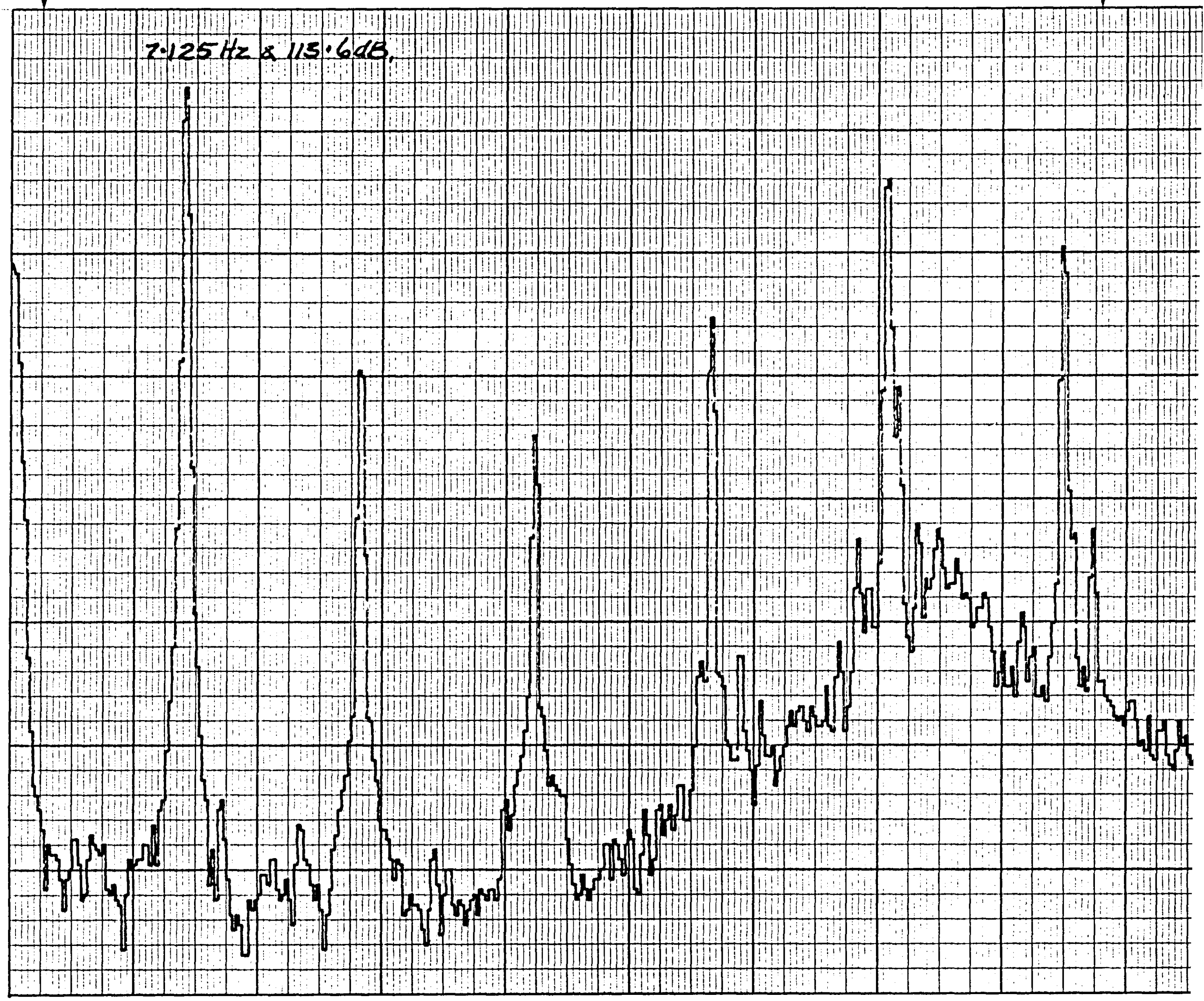
Tyre acceleration
(V. Meter 1m/s² FSD)

Frequency ≃ 6·3Hz.

7·125 Hz = 113·6 dB

Free axle.

Record No.: Test 3
Date: 11/6/84
Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 5

Comments:

JCB Wheel.

Tyre: acceleration
(V. Meter $1 m/s^2$ FSD)

Frequency ≃ 8 Hz

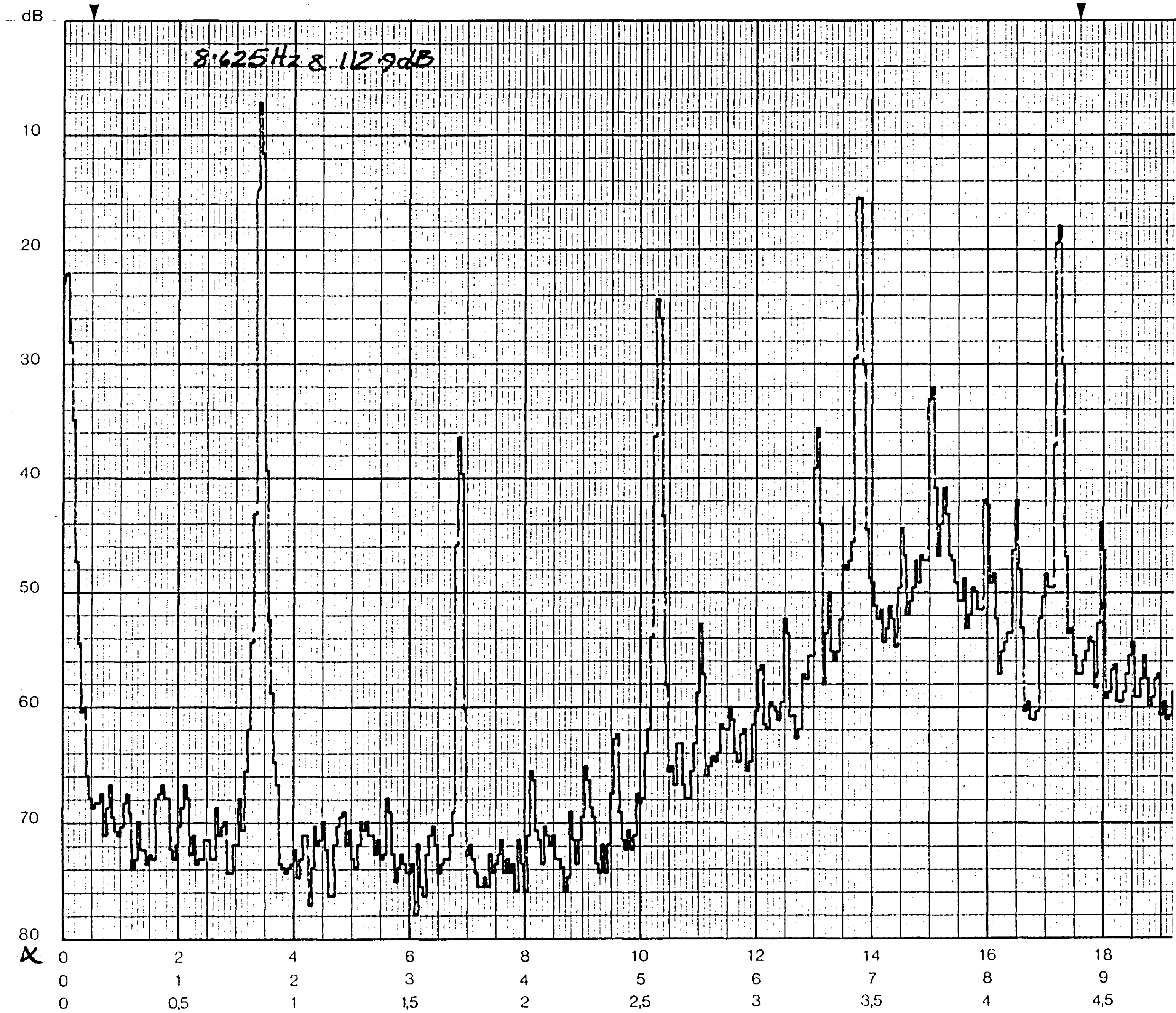
8·625Hz = 112·9dB

Free axle

Record No.: Test 3

Date: 11/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 110
F. S. Frequency: 50
Weighting:
Average Mode:
No. of Spectra: 5

Comments:
JCB Wheel.

Tyre acceleration
(V. Meter 1m/s² FSD)

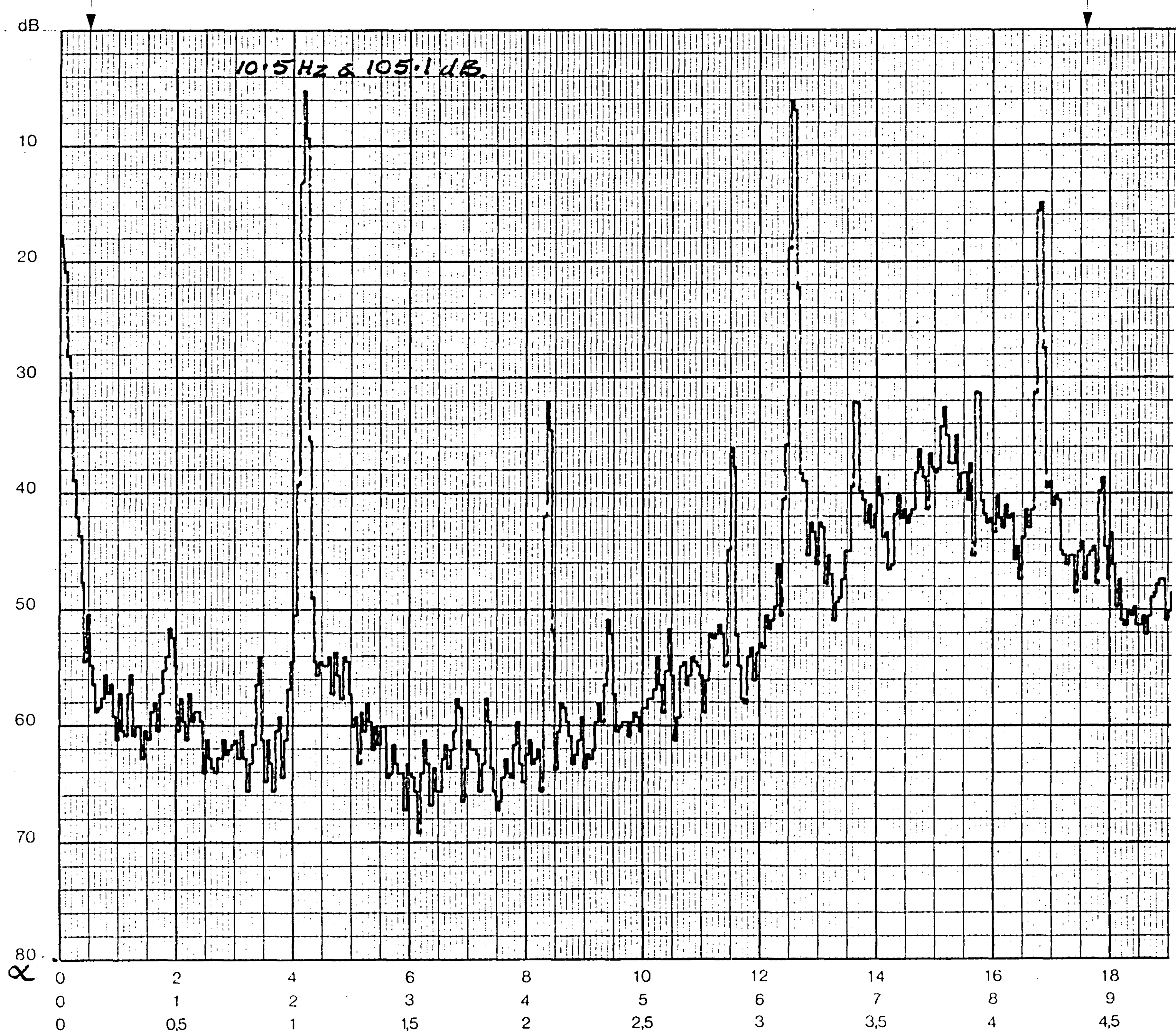
Schenk ram disp ±1.5mm

Frequency ≃ 10 Hz

10.5 Hz = 105.1 dB

Free axle

Record No.: Test 3
Date: 11/6/84
Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120
F. S. Frequency: 50
Weighting:
Average Mode:
No. of Spectra: 5

Comments:
JCB Wheel.

Tyre acceleration.
(V.Meter 1m/s² FSD)

Scheak ram disp ±1·5mm

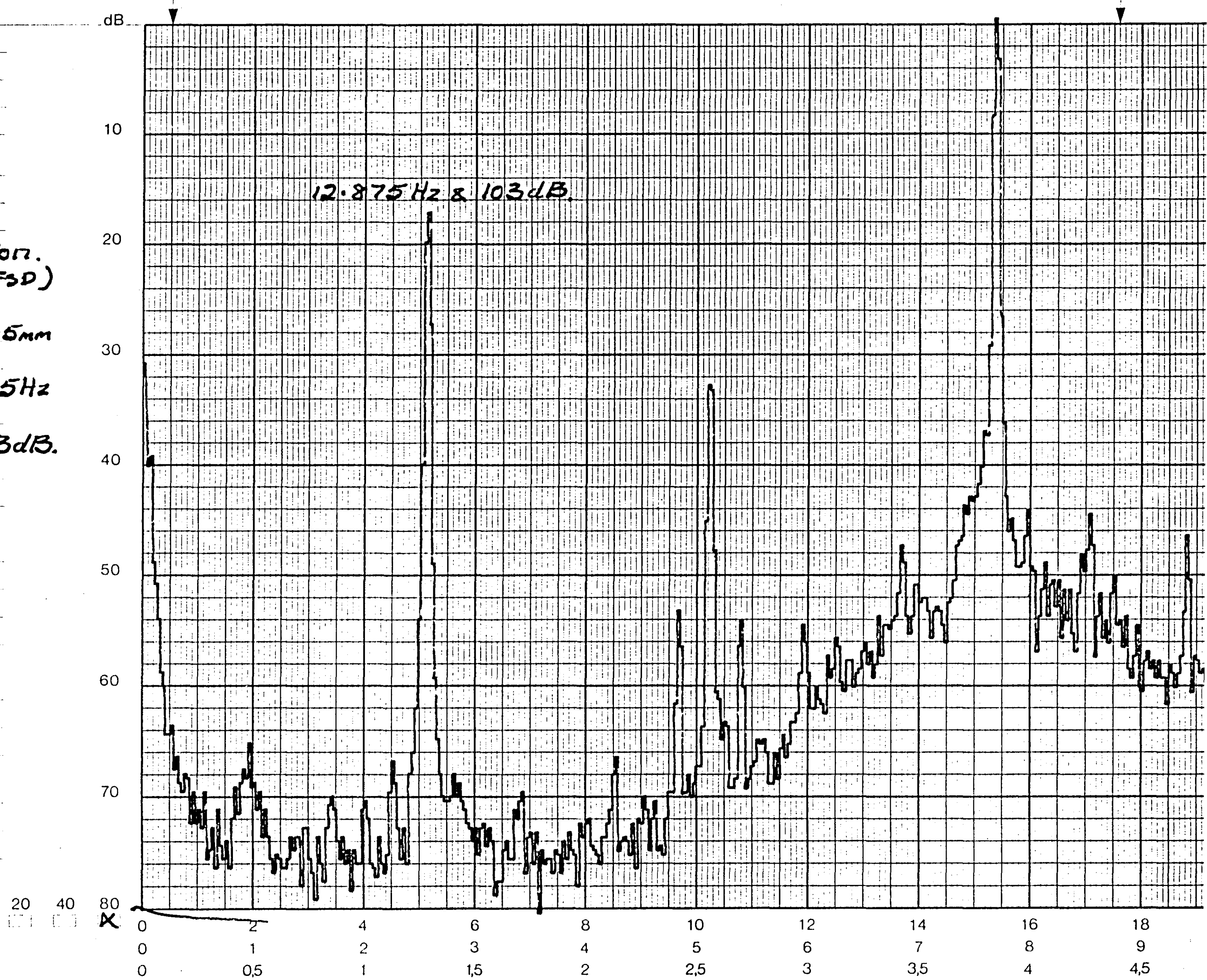
Frequency ≃ 12·5Hz

12·875 Hz = 103dB.

340

Free axle

Record No.: Test 3.
Date: 11/6/84
Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V.M. = 1m/s² FSD).

Schenk ram ±2mm

Frequency 1 Hz.

Value 111·8dB.

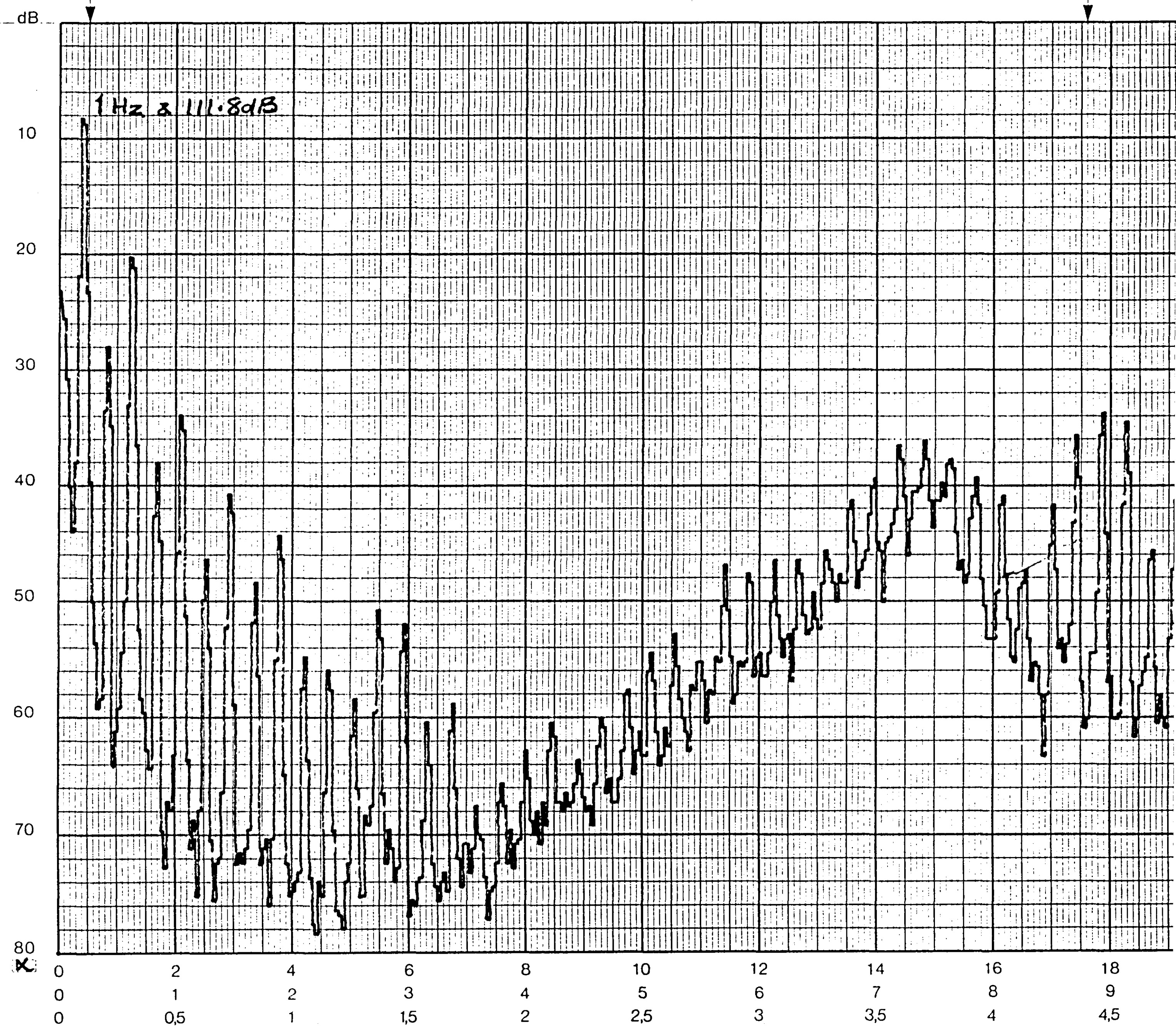
341

Free axle

Record No.: Test 4.

Date: 11/6/84

Sign.: [signature] Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 6.
Comments: JCB. Wheel.

Tyre acceleration
(V.M. = 1m/s² FSD)

Schenk ram ± 2mm.

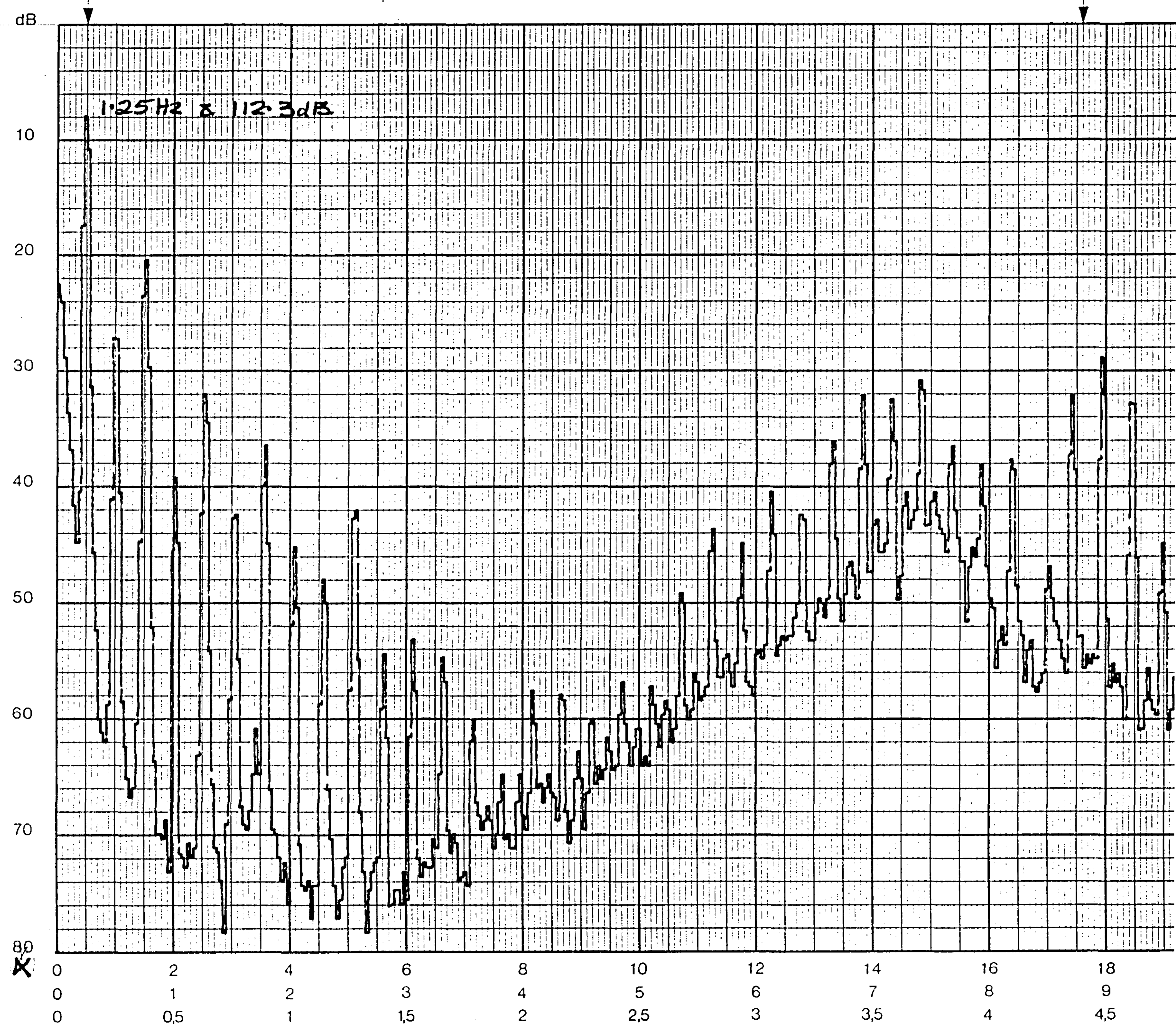
Frequency 1·25 Hz

Value 112·3dB

342

Free axle

Record No.: Test 4.
Date: 11/6/84.
Sign.: [signature]



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120 dB
F. S. Frequency: 50.
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 6.

Comments: JCB Wheel.

Tyre acceleration
(V.M = 1m/s² FSD)

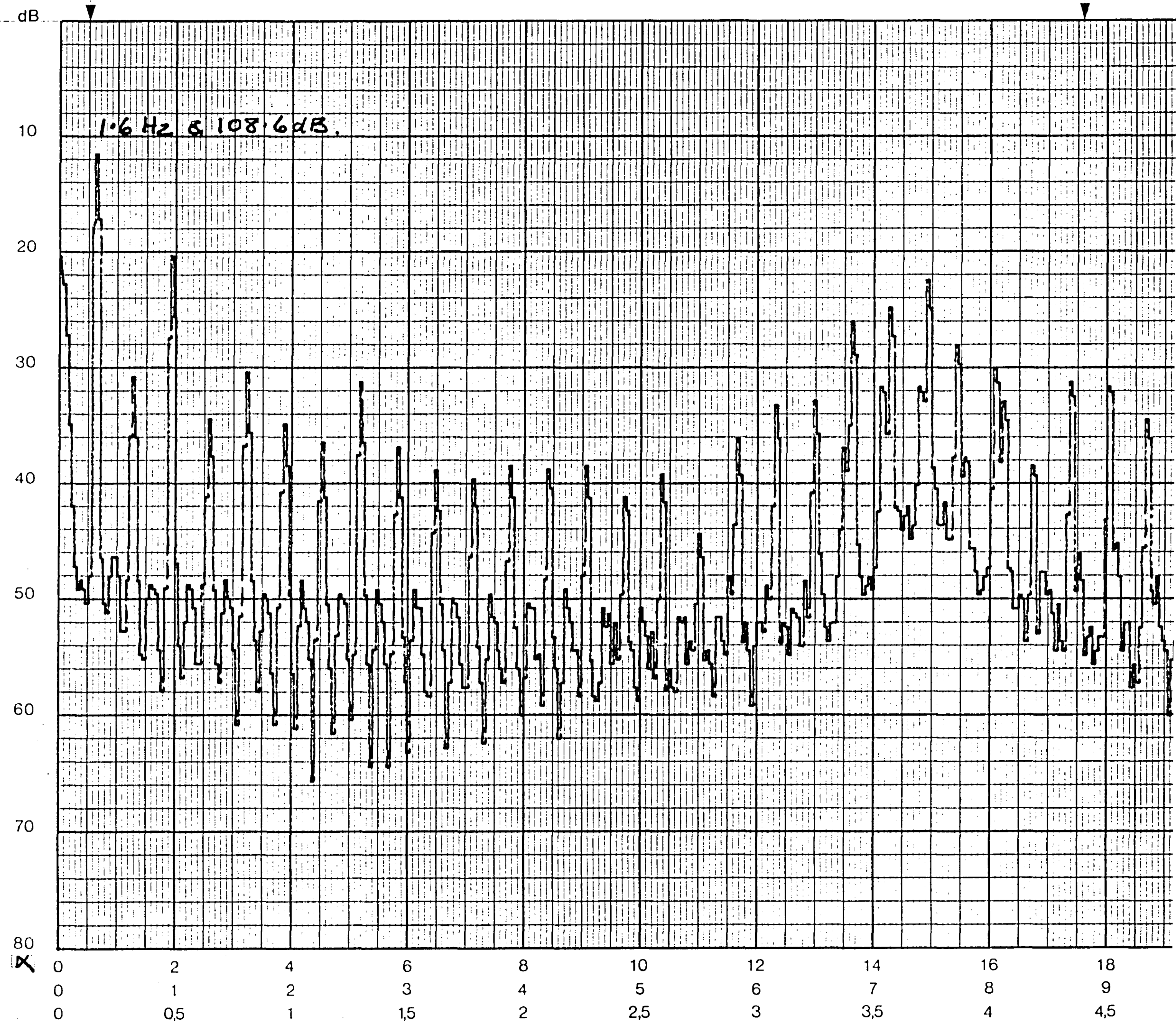
Schenk ram ±2mm.

Frequency 1·6 Hz.

Value 108·6dB.

Free axle.

Record No.: Test 4.
Date: 11/6/84.
Sign.: Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expanded

Full Scale Level: 120. dB
F. S. Frequency: 50.
Weighting: Hanning.
Average Mode: Lin
No. of Spectra: 5.

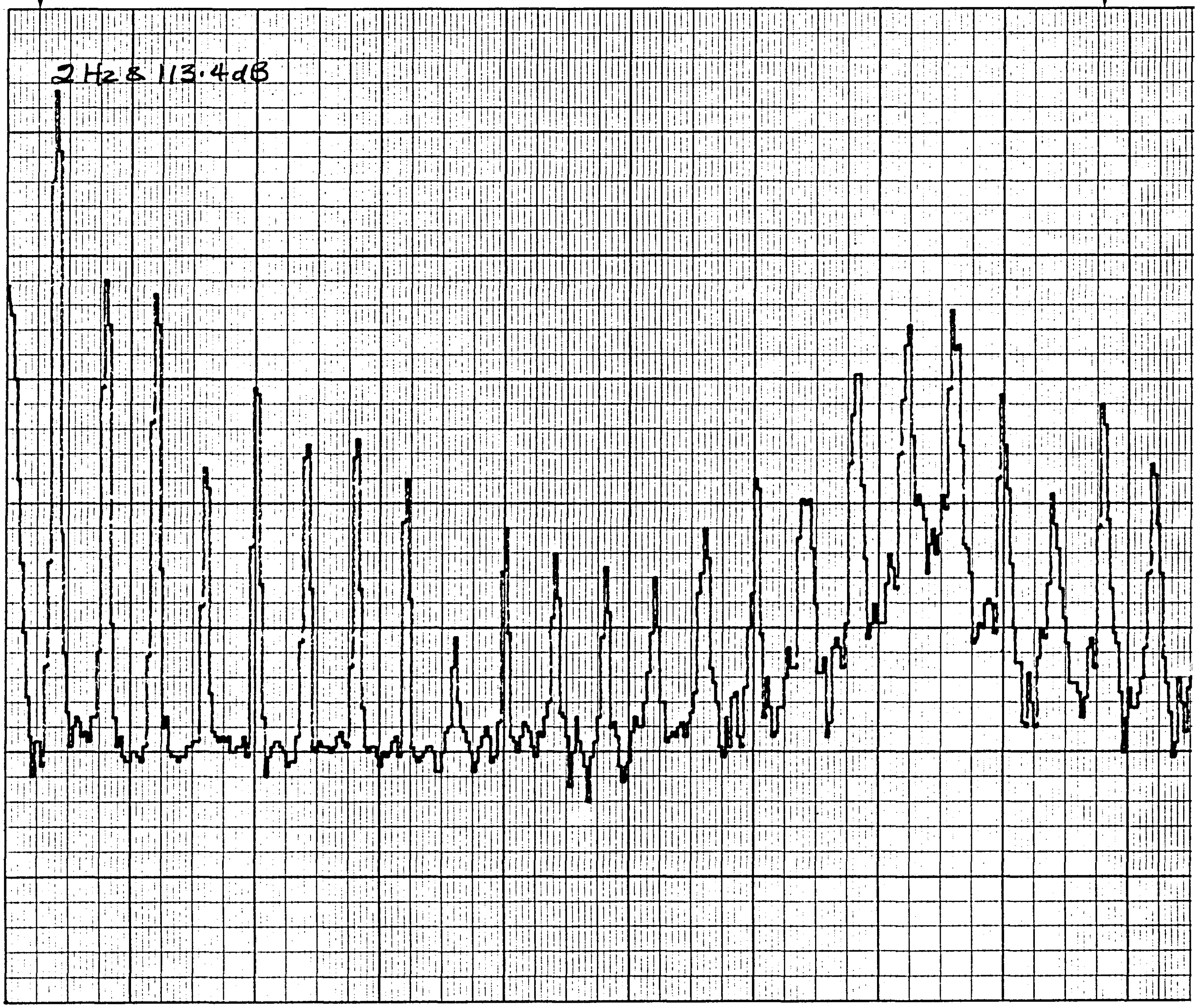
Comments: J.C.B. Wheel.

Tyre acceleration
(V.M. = 1m/s² FSD)

Schenk ram ±2mm

Frequency 2Hz

Value 113·4dB



Record No.: Test 4.
Date: 11/6/84.
Sign.: D Douglas

QP 1002

Measuring Object:

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanc

Full Scale Level: 130.
F. S. Frequency: 50
Weighting: Hanning.
Average Mode: Lin.
No. of Spectra: 5

Comments: JCB Wheel.

Tyre acceleration
(V.M = 1m/s^2 FSD).

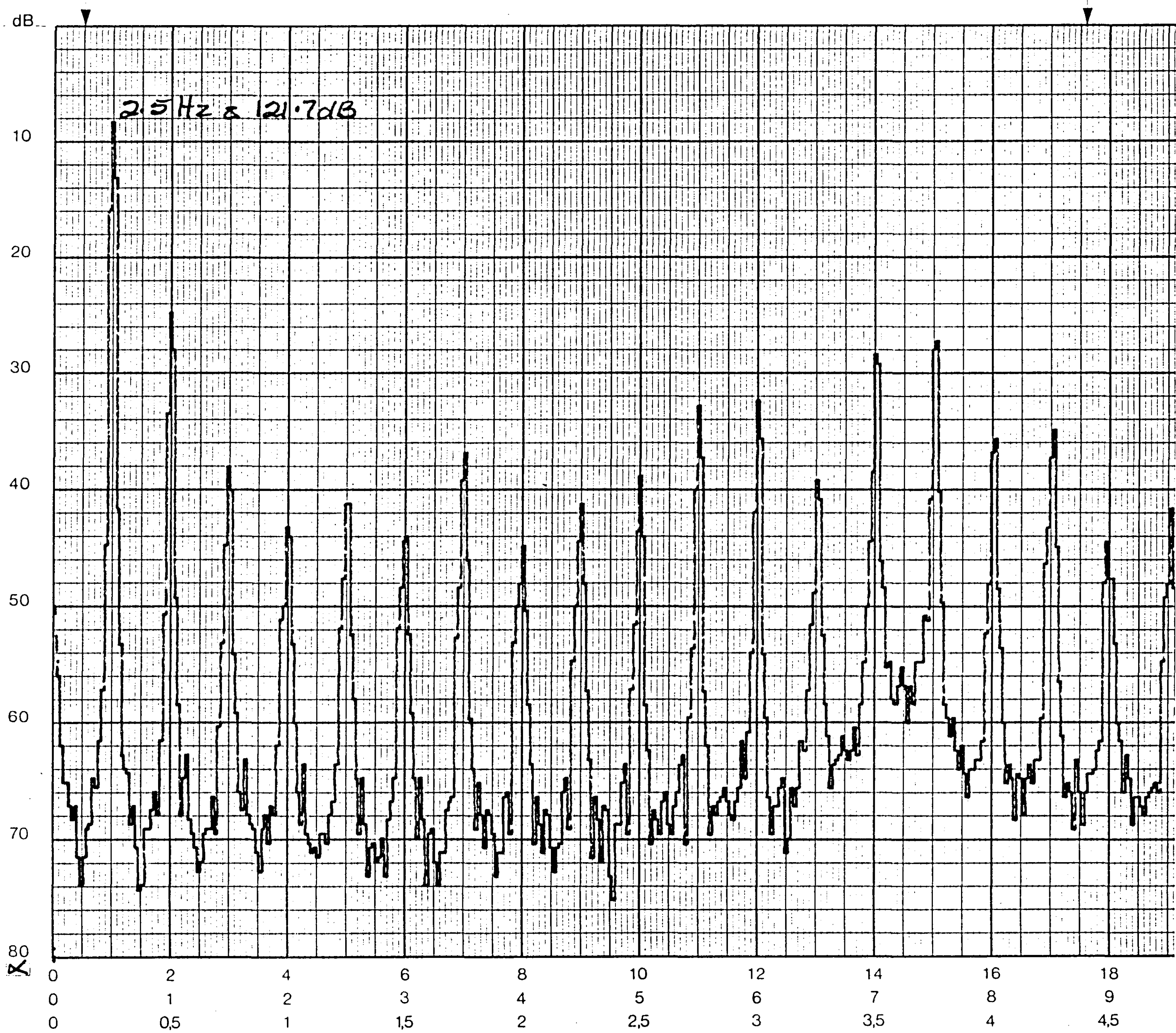
Shenk ram ±2.0mm.

Frequency 2.5 Hz

Value 121.7 dB.

Free axle

Record No.: Test 4.
Date: 11/6/84.
Sign.: [signature]



Measuring Object:

345

QP 1002

Brüel & Kjær

Time Function Start: ' seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 130.
F. S. Frequency: 50.
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 6.

Comments: JCB Wheel.

Tyre acceleration
(V.M. = 1m/s² FSD)

Ram ± 2mm.

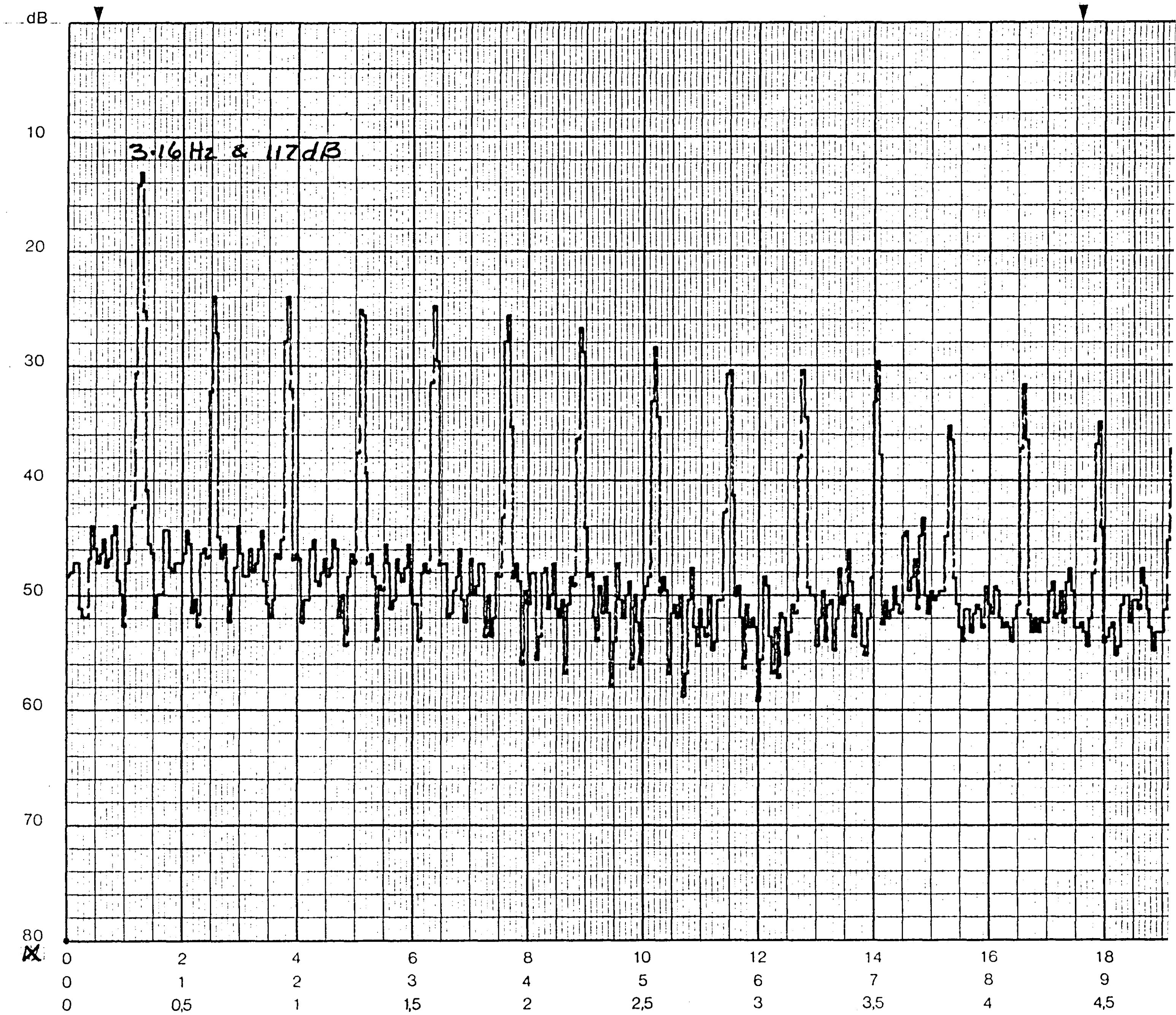
Frequency 3·16 Hz

Value 117dB

346

Free axle.

Record No.: Test 4.
Date: 11/6/84
Sign.: [signature]



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanc

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5.

Comments: JCB Wheel.

Tyre acceleration.
(V.M = 1m/s² FSD)

Ram ±2mm.

Frequency 4Hz.

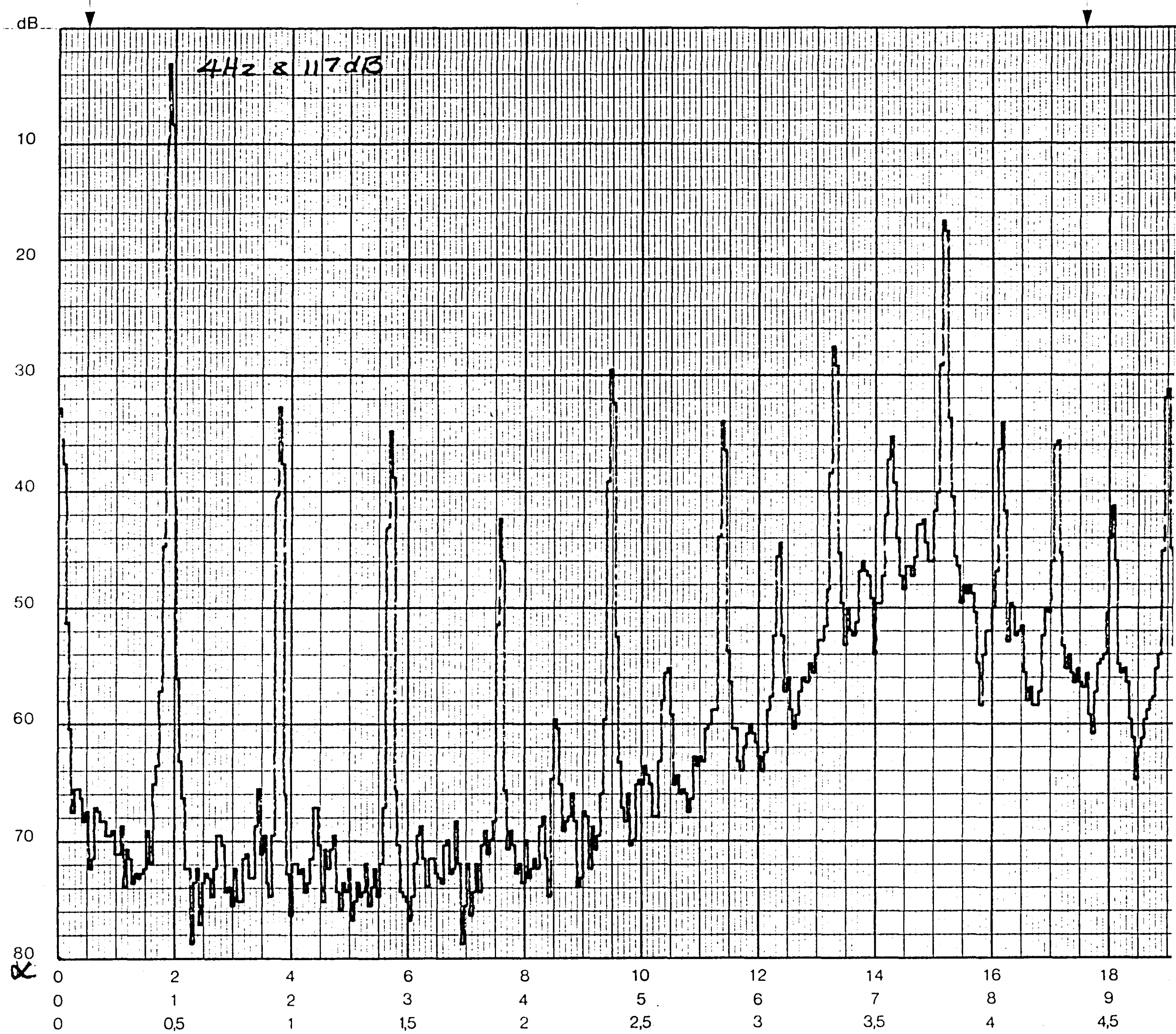
Value 117 dB

Free axle.

Record No.: Test 4.

Date: 11/6/84.

Sign.: S. Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 6

Comments: JCB Wheel.

Tyre acceleration
(V.M. 1m/s² FSD)

Ram ± 2mm.

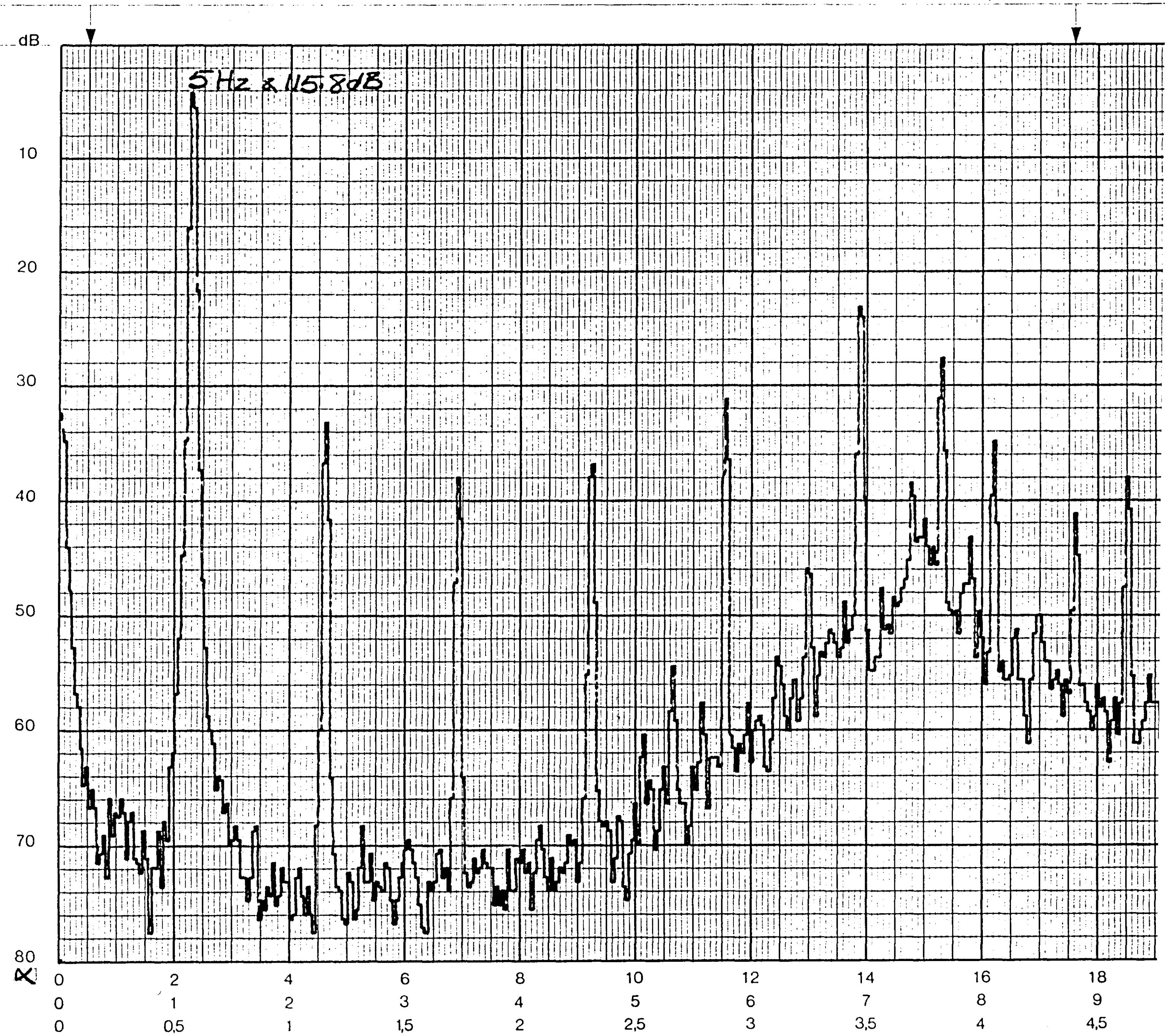
Frequency 5Hz

Value 115·8dB

Free axle

Record No.: Test 4.
Date: 11/6/84.
Sign.: [illegible]

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand



Measuring Object:

348

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120

F. S. Frequency: 50.

Weighting: Hanning.

Average Mode: Lin.

No. of Spectra: 6.

Comments: JCB Wheel.

Tyre acceleration.
(V.M. $1m/s^2$ FSD)

Ram ± 2mm

Frequency 6·3Hz.

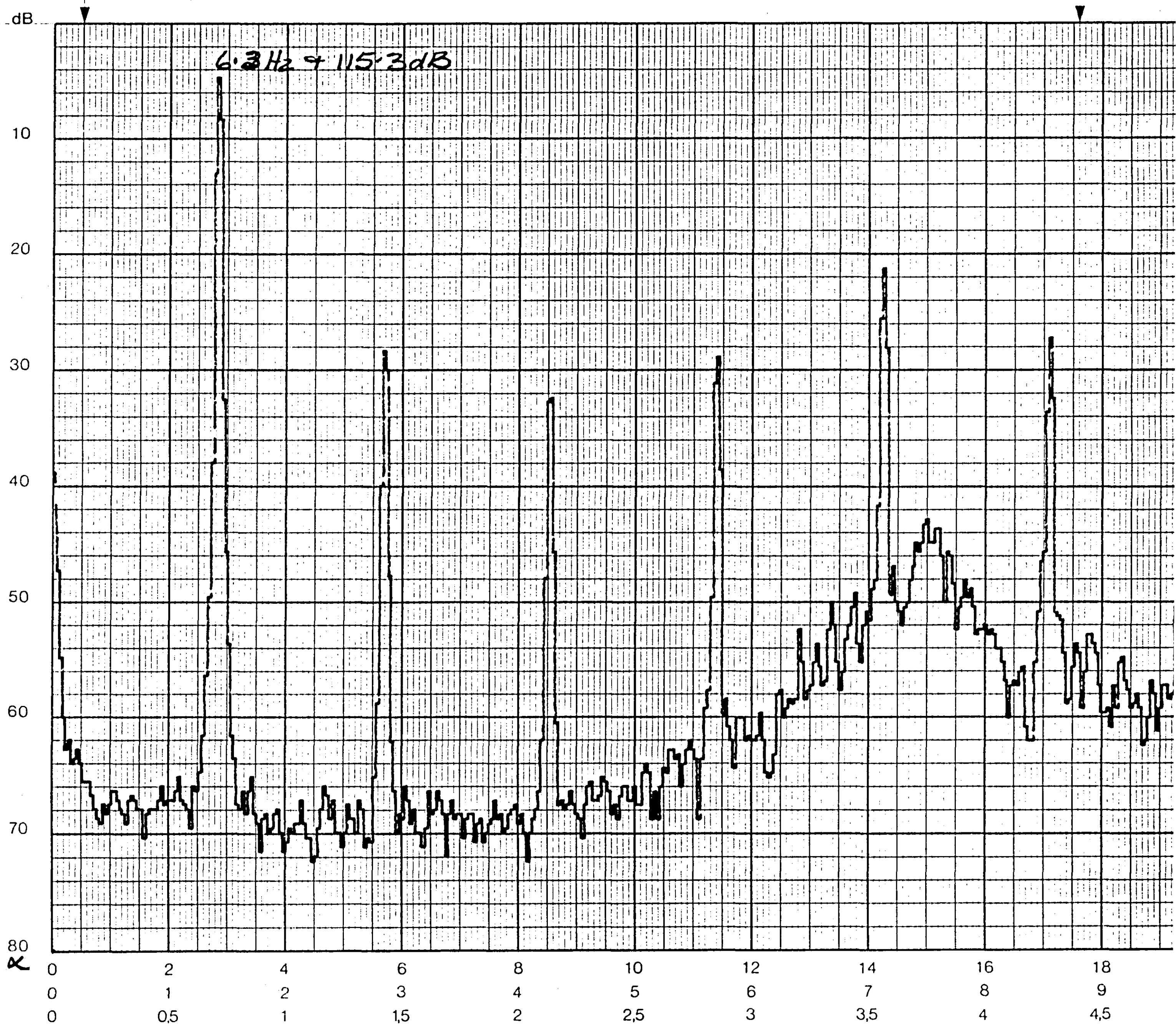
Value 115·3dB.

Free axle.

Record No.: Test 4.

Date: 11/6/84.

Sign.: [signature]



Measuring Object:

349

QP 1002

Brüel & Kjær

Full Scale Level: 120. dB
F. S. Frequency: 50
Weighting: Hanning.
Average Mode: Lin.
No. of Spectra: 6.
Comments: JCB Wheel.

Tyre acceleration.
(V.M 1m/s² FSD)

Ram ± 2mm.

Frequency 8Hz.

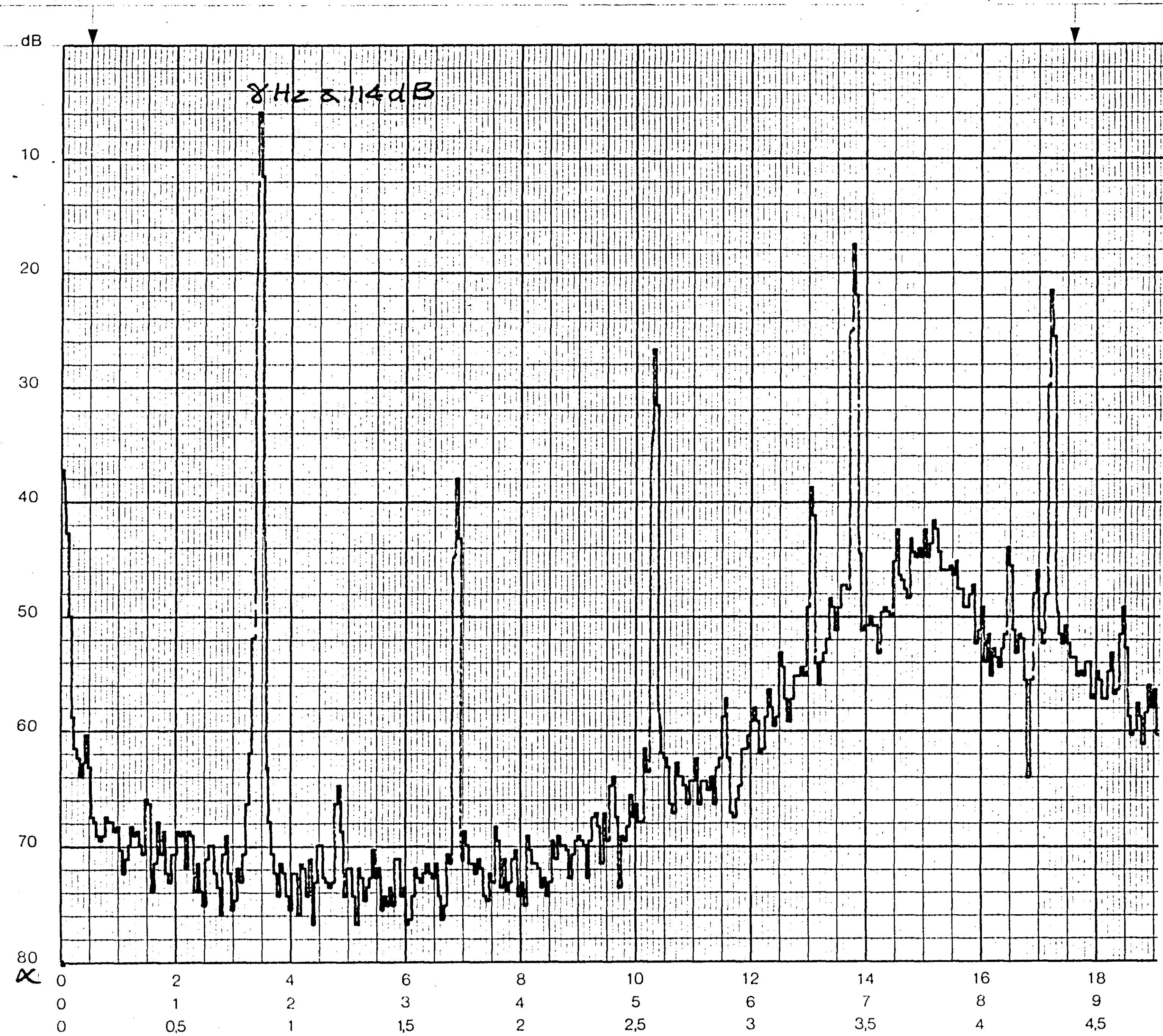
Value 114 dB

Free axle.

Record No.: Test 4.
Date: 11/6/84.
Sign.: [signature]

350

Time Function Start: seconds End: seconds Not Expanded: Expand



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expanded

Full Scale Level: 120.

F. S. Frequency: 50

Weighting: Hanning.

Average Mode: Lin.

No. of Spectra: 5.

Comments: JCB Wheel.

Tyre acceleration.
(VM 1m/s² FSD)

Ram ± 2mm.

Frequency 10 Hz

Value 106.4dB

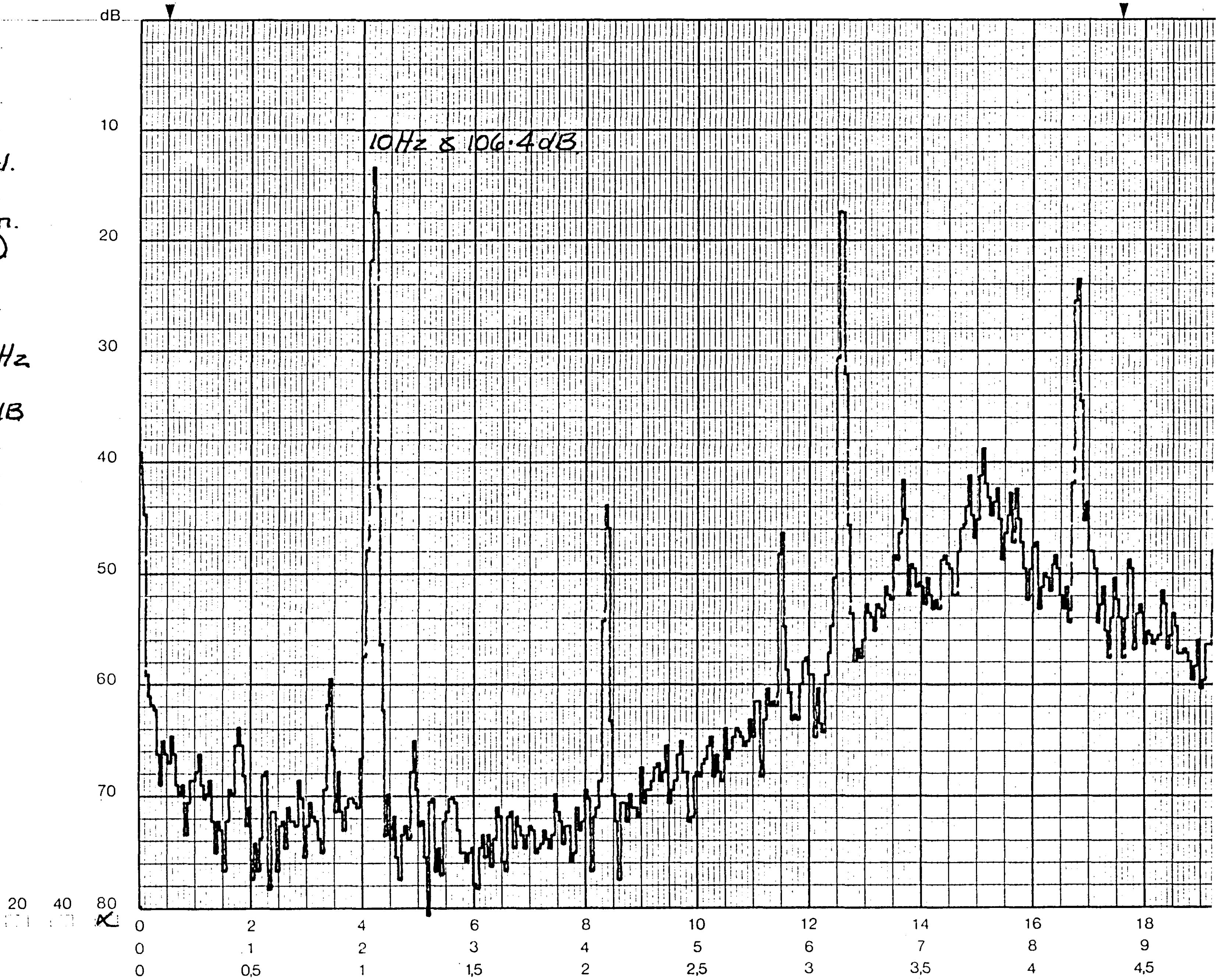
351

Free Axle.

Record No.: Test 4.

Date: 11/6/84.

Sign.: D Douglas



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expand

Full Scale Level: 130

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 6

Comments: JCB Wheel.

Tyre acceleration (V.M. 1m/s² FSD)

Ram ± 2mm

Frequency 12·5Hz

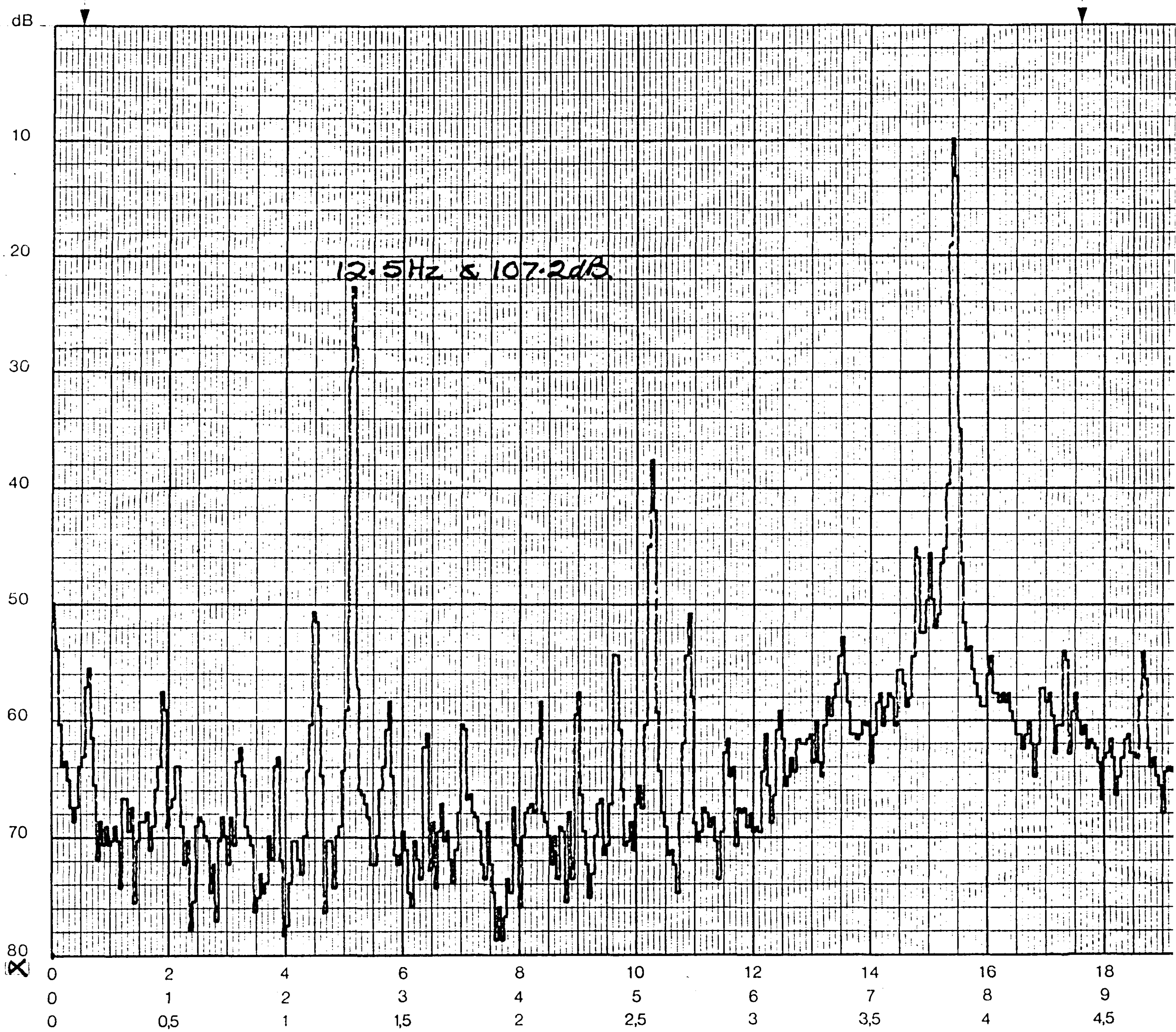
Value 107·2dB

Free axle.

Record No.: Test 4.

Date: 11/6/84.

Sign.: S Douglas



Measuring Object:

QP 1002

APPENDIX 'H'

Graphical presentation of axle acceleration, ram displacement and ram force at one-third octave centre frequencies from 1Hz to 10Hz.

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expan

Full Scale Level: 100 dB.

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel.

~~Setzen~~

axle acceleration.

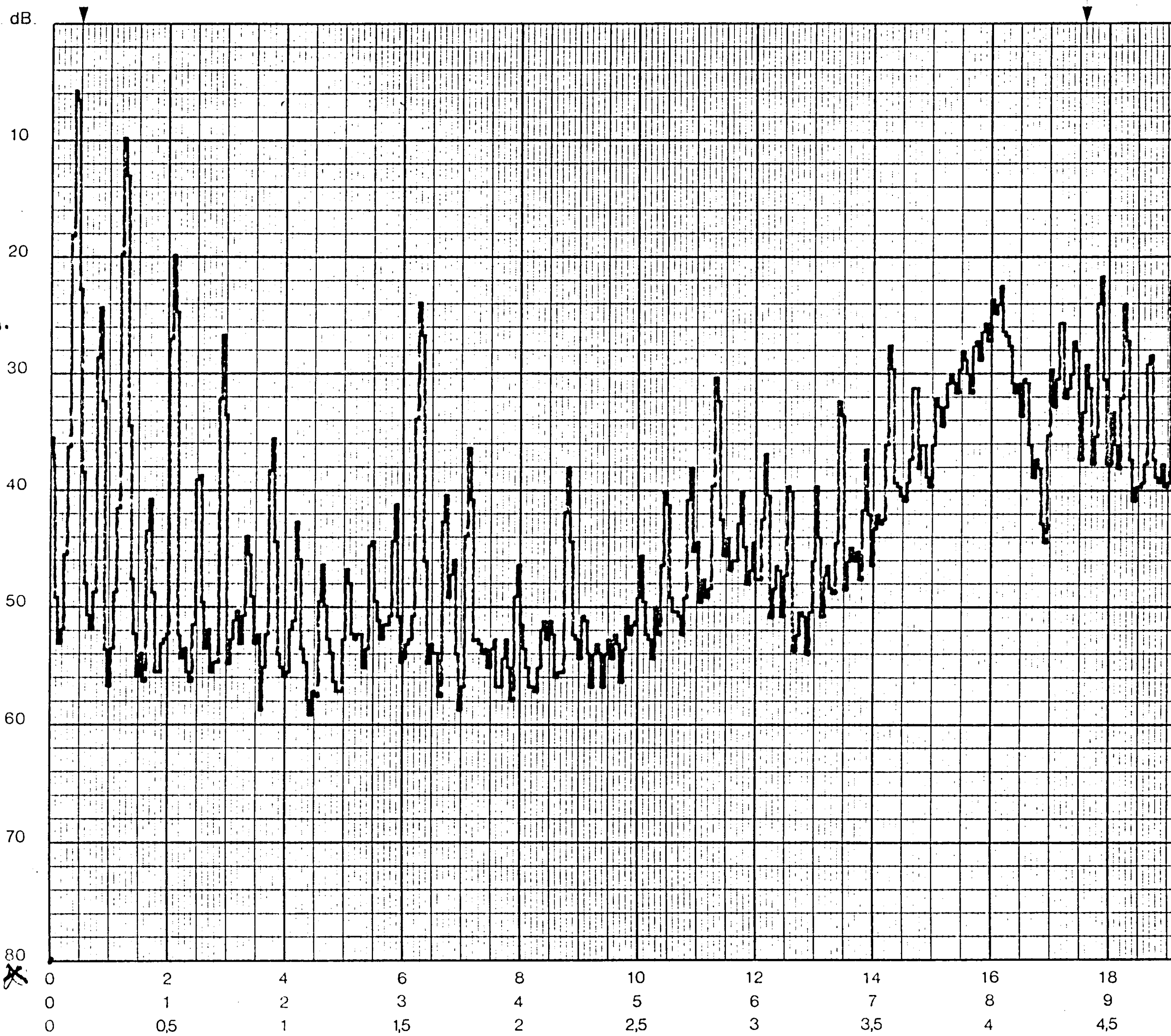
(Vib meter : 1m/s² FSD)

Schenk ram disp = ± 1·5mm.

Frequency = 1 Hz.

1 Hz value = 94·1 dB.

354



Record No.: Axle Dyn: 1

Date: 15/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 110 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

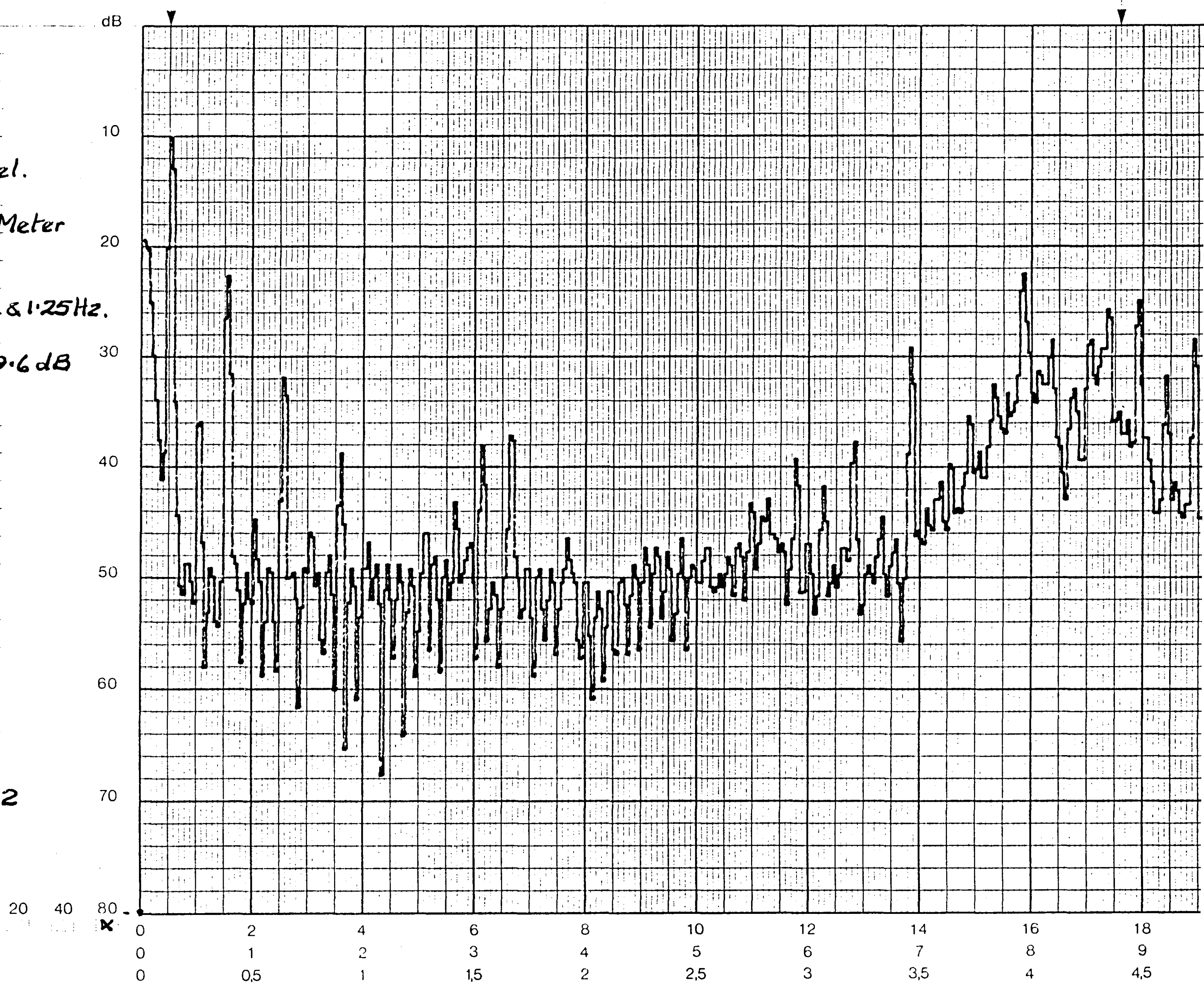
Comments: JCB Wheel.

axle accel - Vib Meter
1 m/s² FSD.

Schenk ram ±1·5mm & 1·25Hz.

1·25 Hz value = 99·6 dB

355



Record No.: Axle Dyn 2
Date: 15/6/84
Sign.:

Measuring Object:

QP 1002

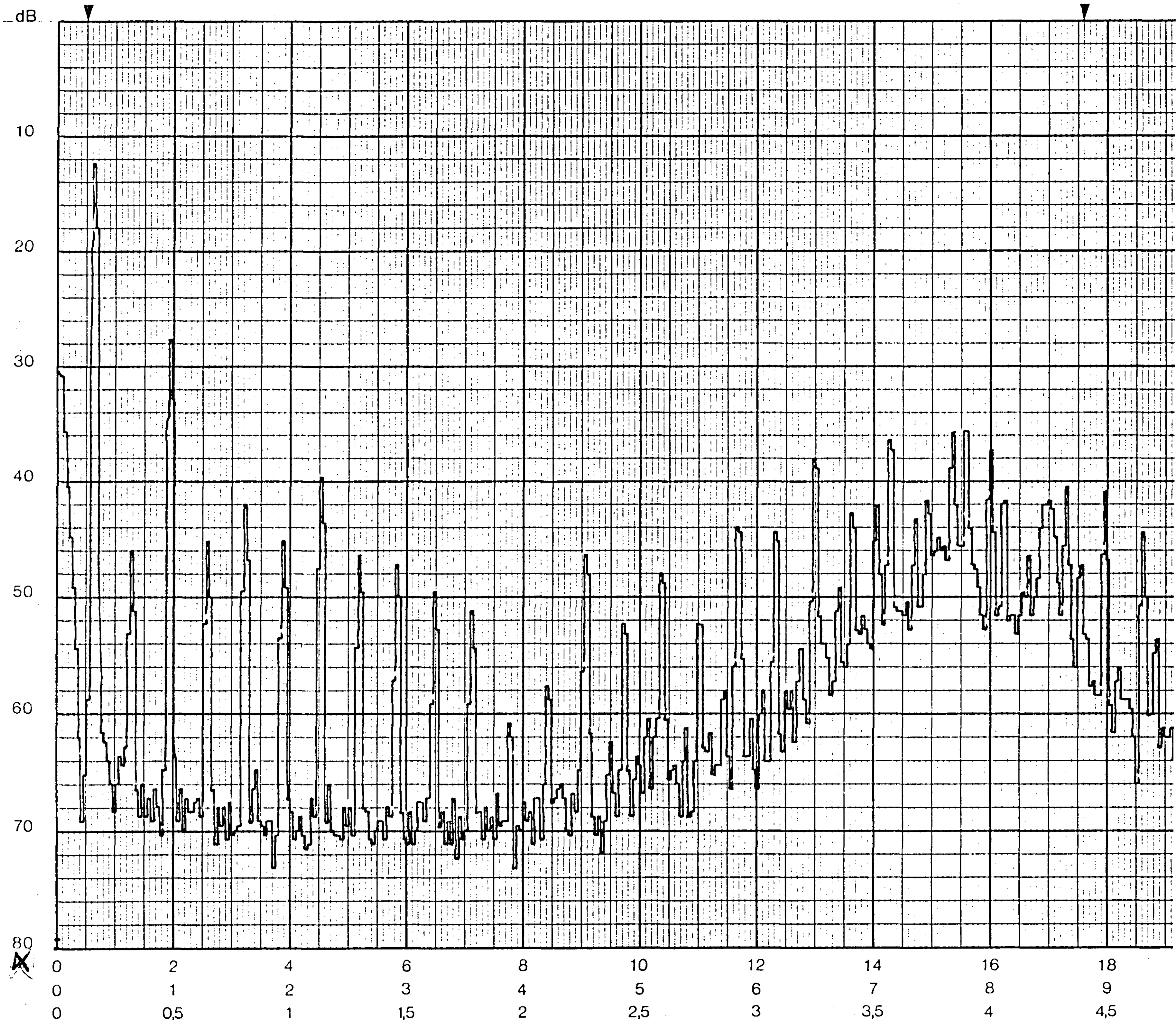
Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 6
Comments: JCB Wheel

axle accel - Vib Meter
1m/s² FSD

Schenk ram ± 1·5mm
@ 1·6 Hz



Measuring Object:

Record No. AXLE Dyn 2.
Date: 15/6/84.
Sign.:

QP 1002

Brüel & Kjær

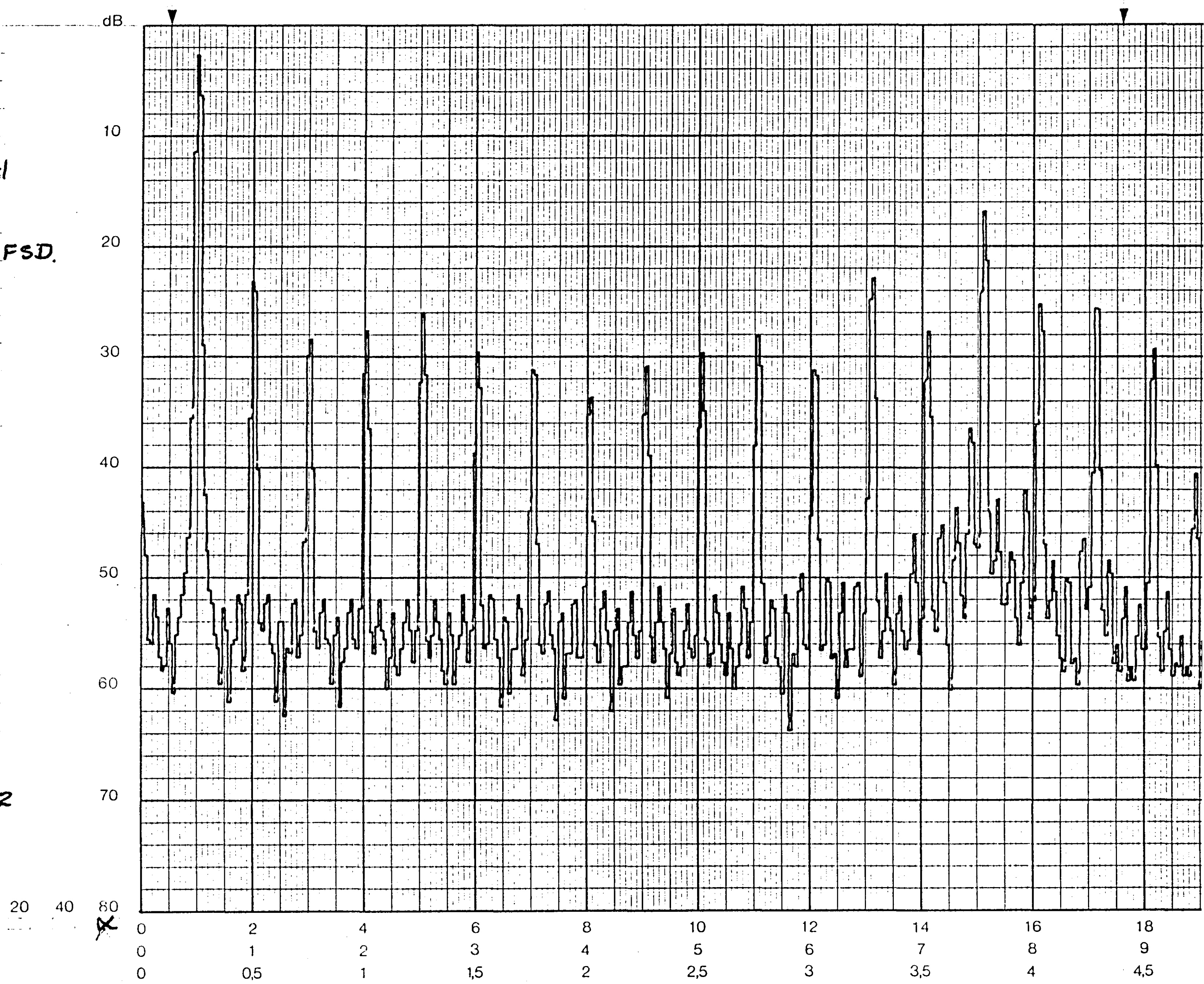
Time Function Start: seconds End: seconds Not Expanded: Expan

Full Scale Level: 120 dB
F. S. Frequency: 500
Weighting: Hamming
Average Mode: Lin
No. of Spectra: 5

Comments: JCB Wheel

axle accel.
Vib Meter 1m/s² FSD.

Ram ±1.5mm
@ 2.5 Hz.



Record No.: Axle Dyn 2
Date: 15/6/84
Sign.:

QP 1002

Measuring Object:

Brüel & Kjær

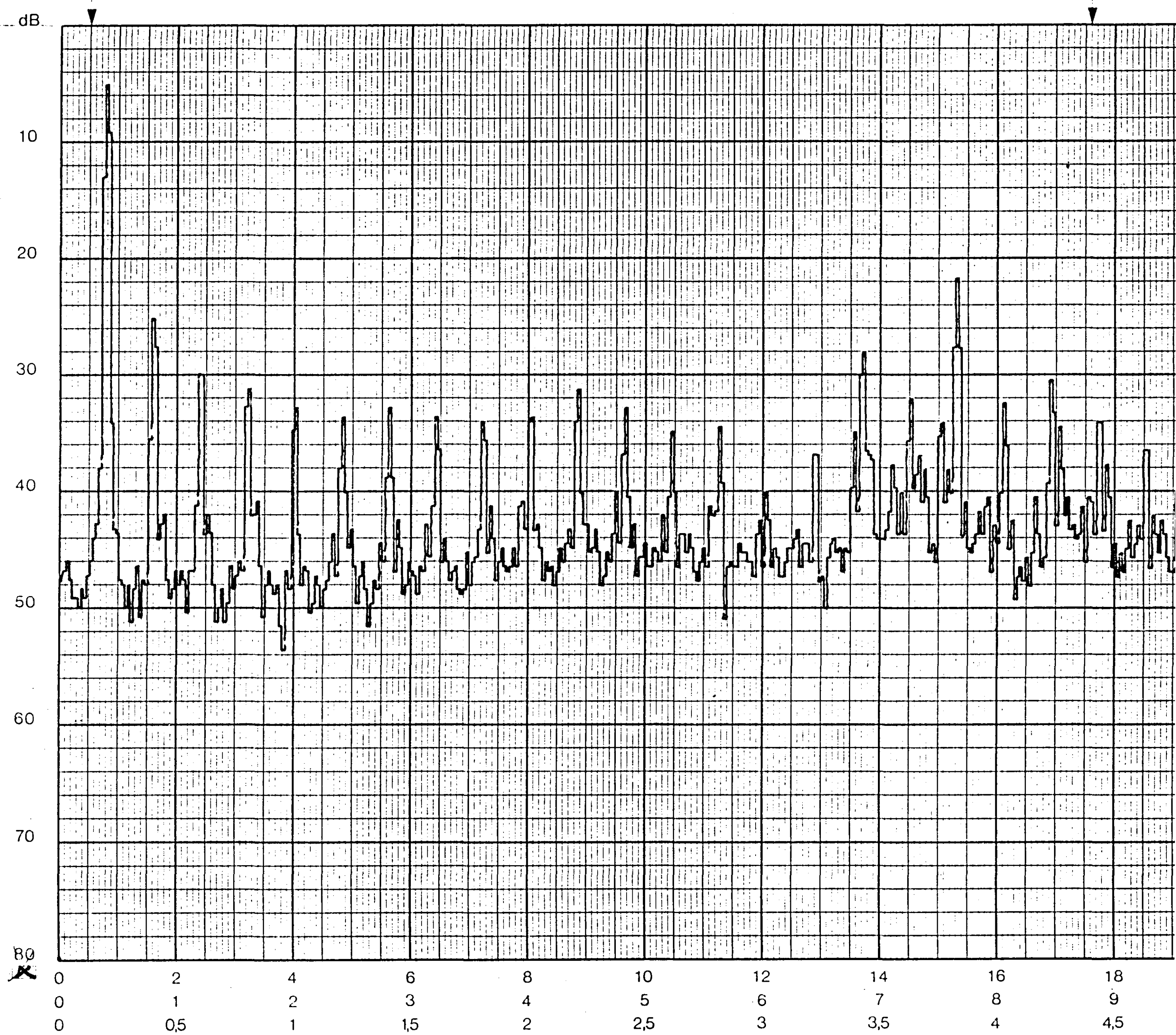
Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments: JCB Wheel

axle accel - Vib Meter
1 m/s² FSD

Rem ± 1.5 mm.
@ 2Hz

Time Function Start: seconds End: seconds Not Expanded: ☐ Expan



20 ☐ 40 ☐ 80 ☒

Measuring Object:

Record No.: Axle Dyn 2.
Date: 15/6/84
Sign.:

QP 1002

Brüel & Kjær

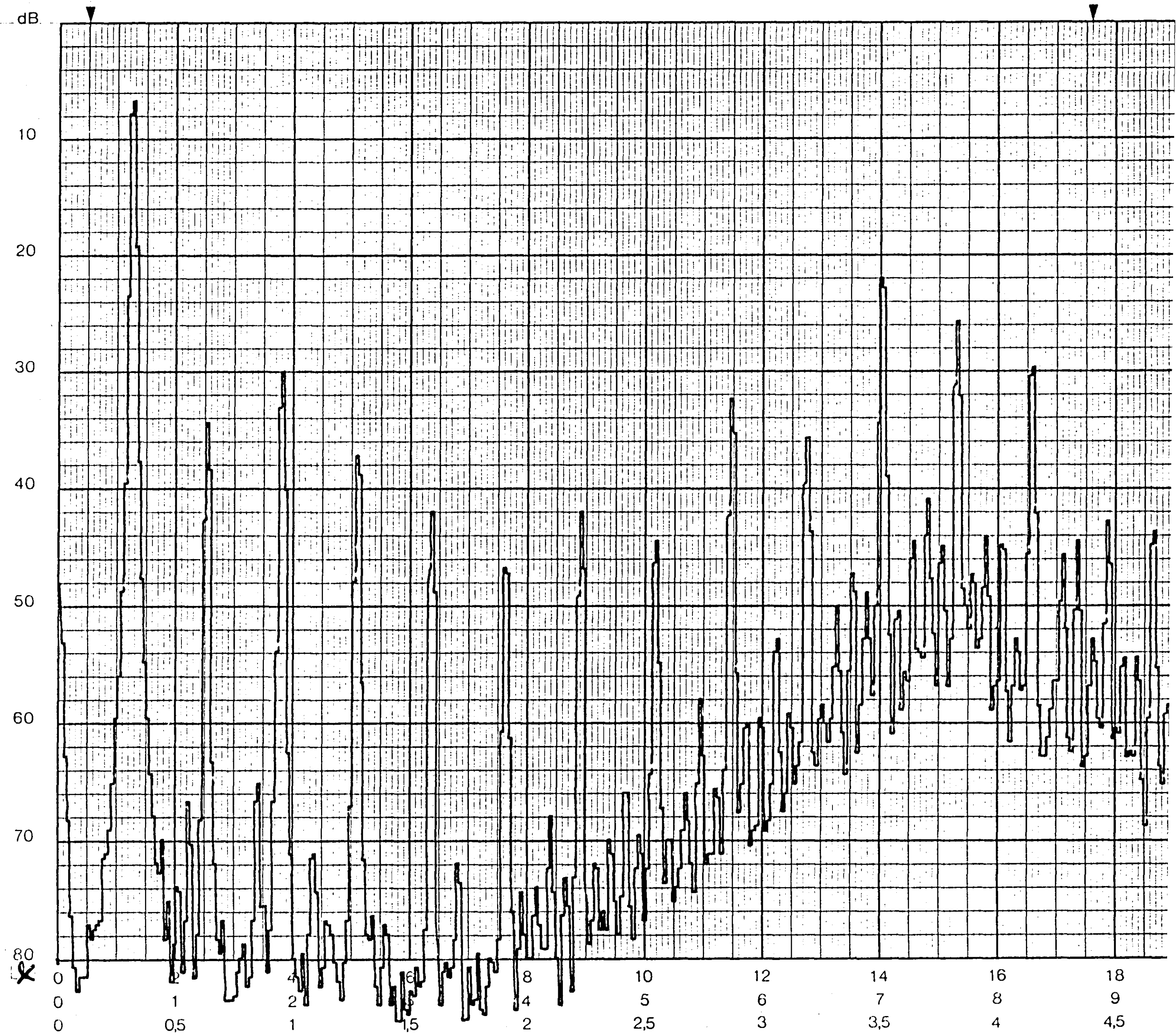
Time Function Start: seconds End: seconds Not Expanded: ☐ Expan

Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5
Comments: JCB Wheel

axle accel.
Vib Meter 1m/s² FSD

Ram ±1.5 mm
@ 3.16 Hz

359



Record No.: Axle Dyn 2.
Date: 15/6/84
Sign.:

QP 1002

Measuring Object:

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expan

Full Scale Level: 120 dB

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

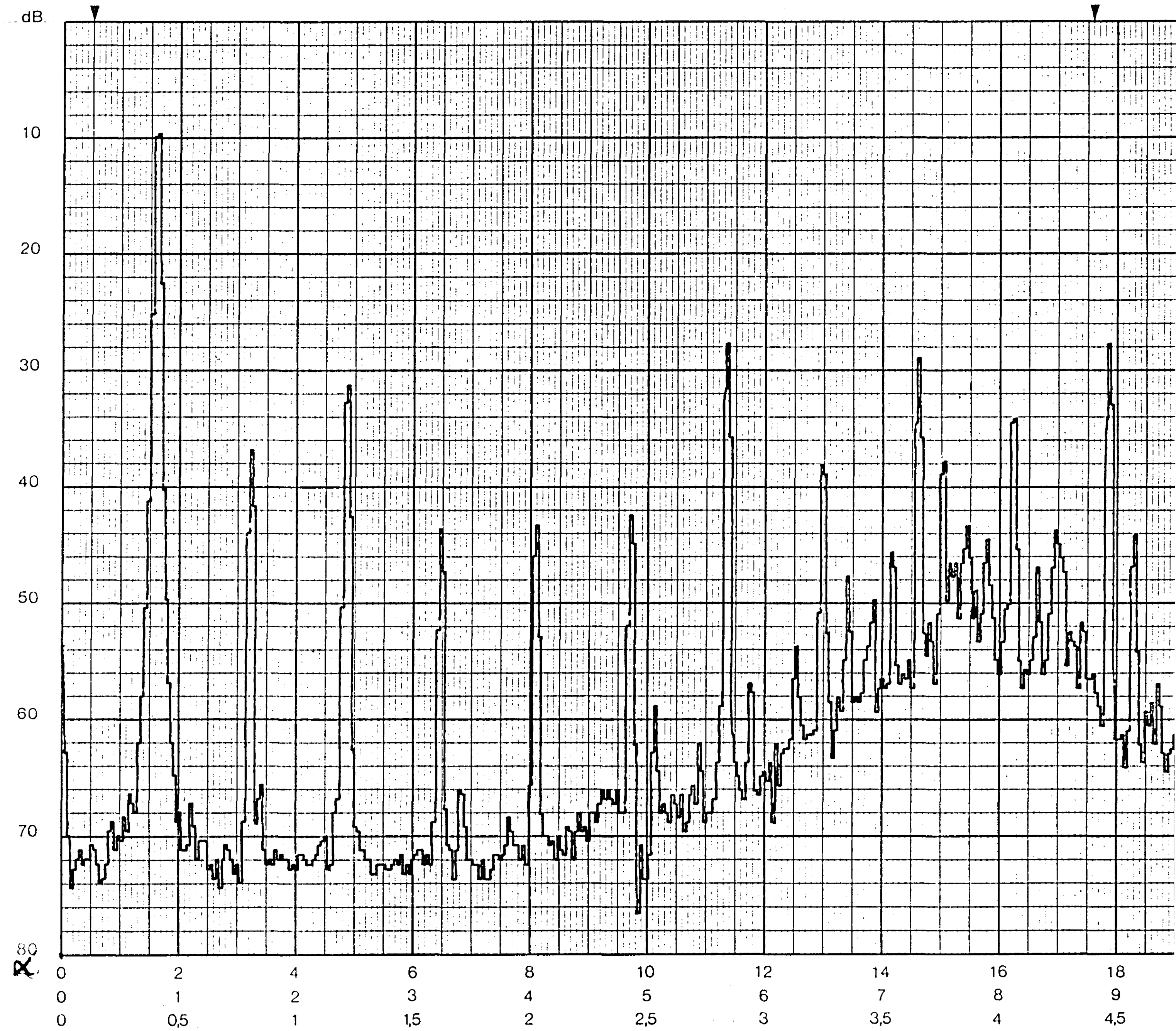
No. of Spectra: 5

Comments: JCB Wheel

axle accel.
VibMeter 1m/s² FSD

Ram ± 1.5mm
@ 4 Hz

360



Measuring Object:

Record No.: Axle Dyn 2.

Date: 15/6/84

Sign.: [signature]

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120 dB

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel

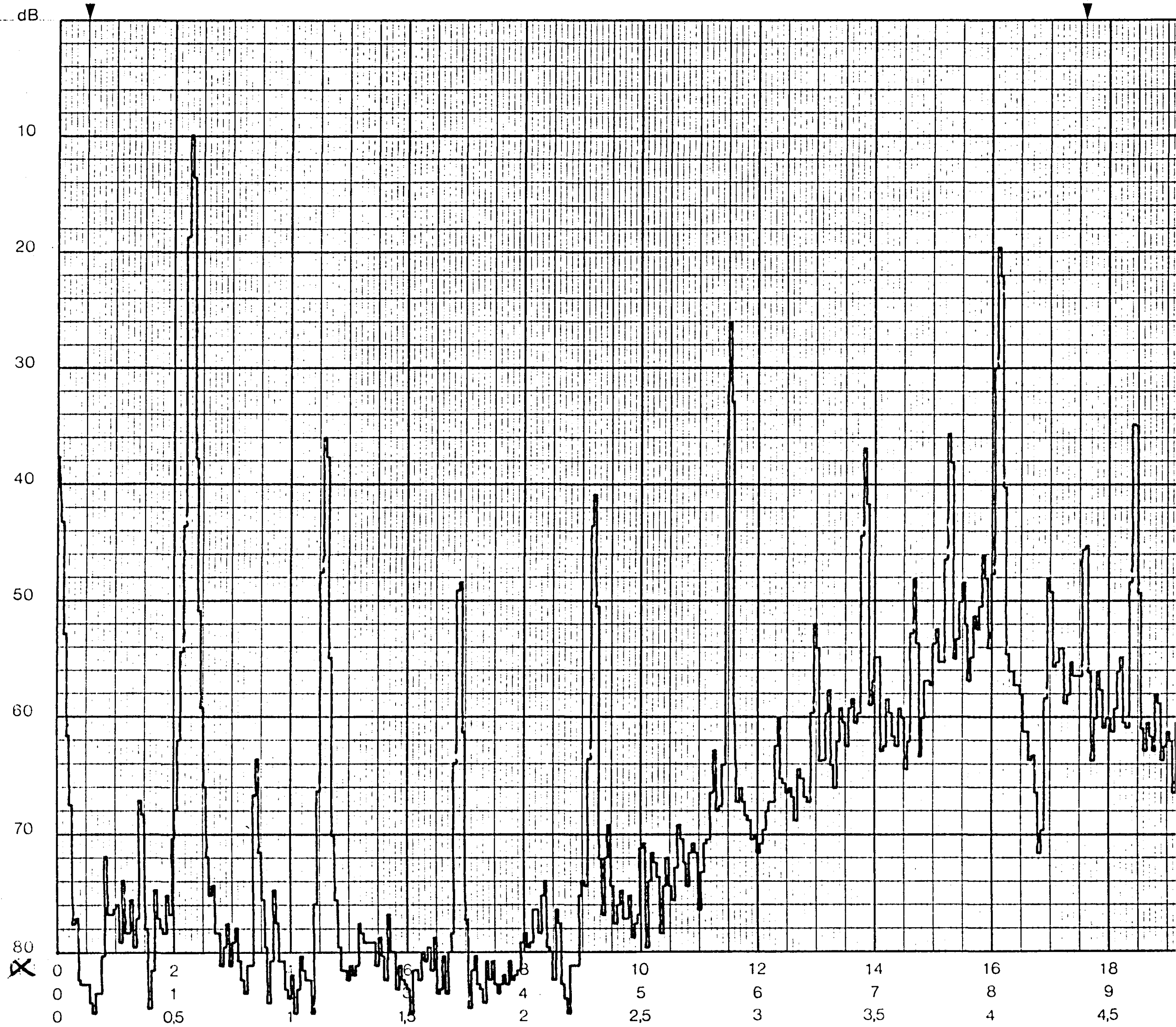
axle accel.
V.M. 1m/s² FSD

Ram ±1·5mm
@ 5 Hz.

Record No.: Axle Dyn 2.

Date: 15/6/84.

Sign.:



Measuring Object:

QP 1002

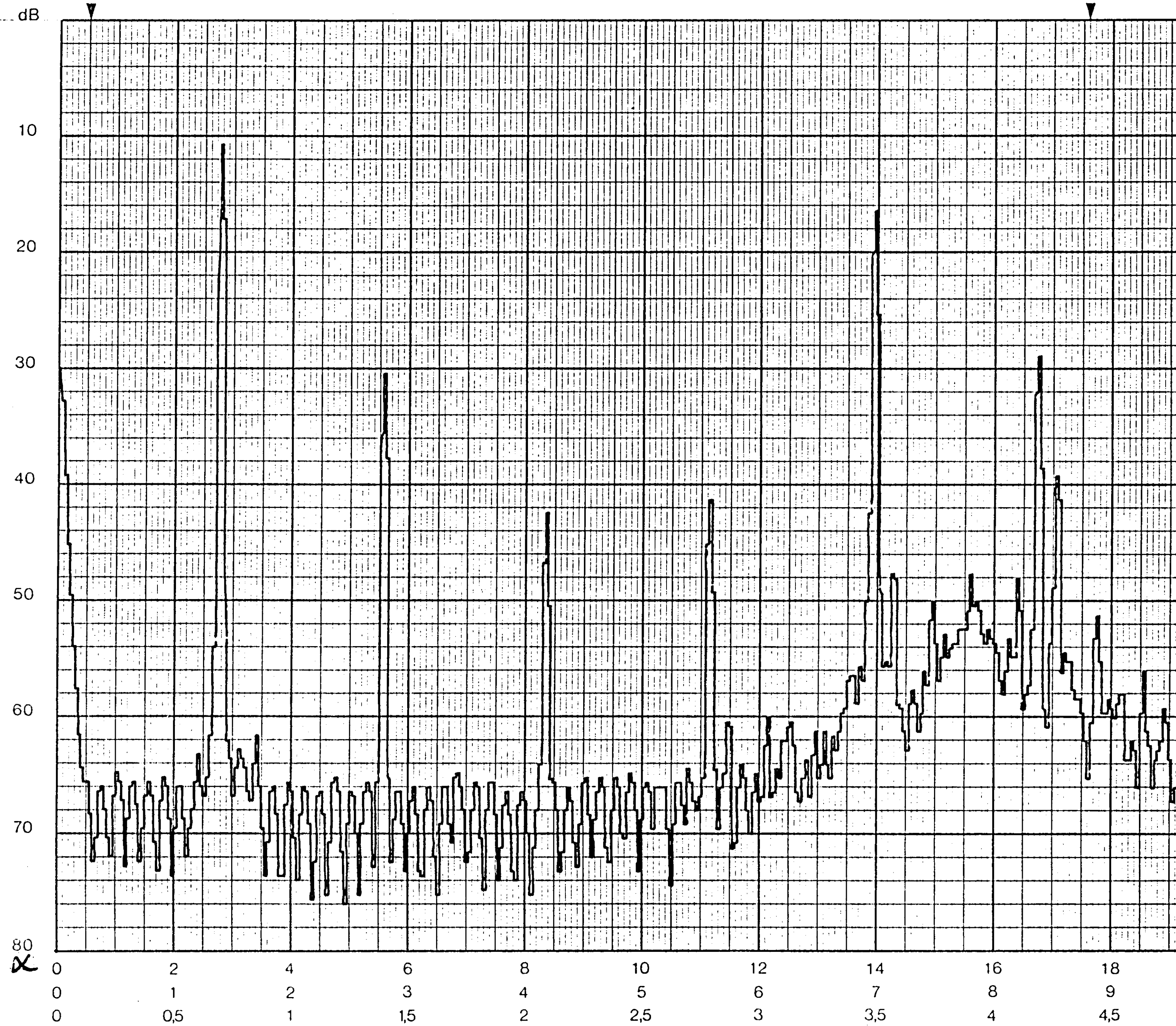
Brüel & Kjær

Full Scale Level: 120
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5
Comments: JCB Wheel

axle acceln.
V.M. 1m/s² FSD

Ram ±1.5mm
@ 6.3Hz

Time Function Start: seconds End: seconds Not Expanded: Expanded



Measuring Object:

362

Record No.: Axle Dyn 2
Date: 15/6/84
Sign.:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expanded

Full Scale Level: 120

F. S. Frequency: 50

Weighting: Hanning

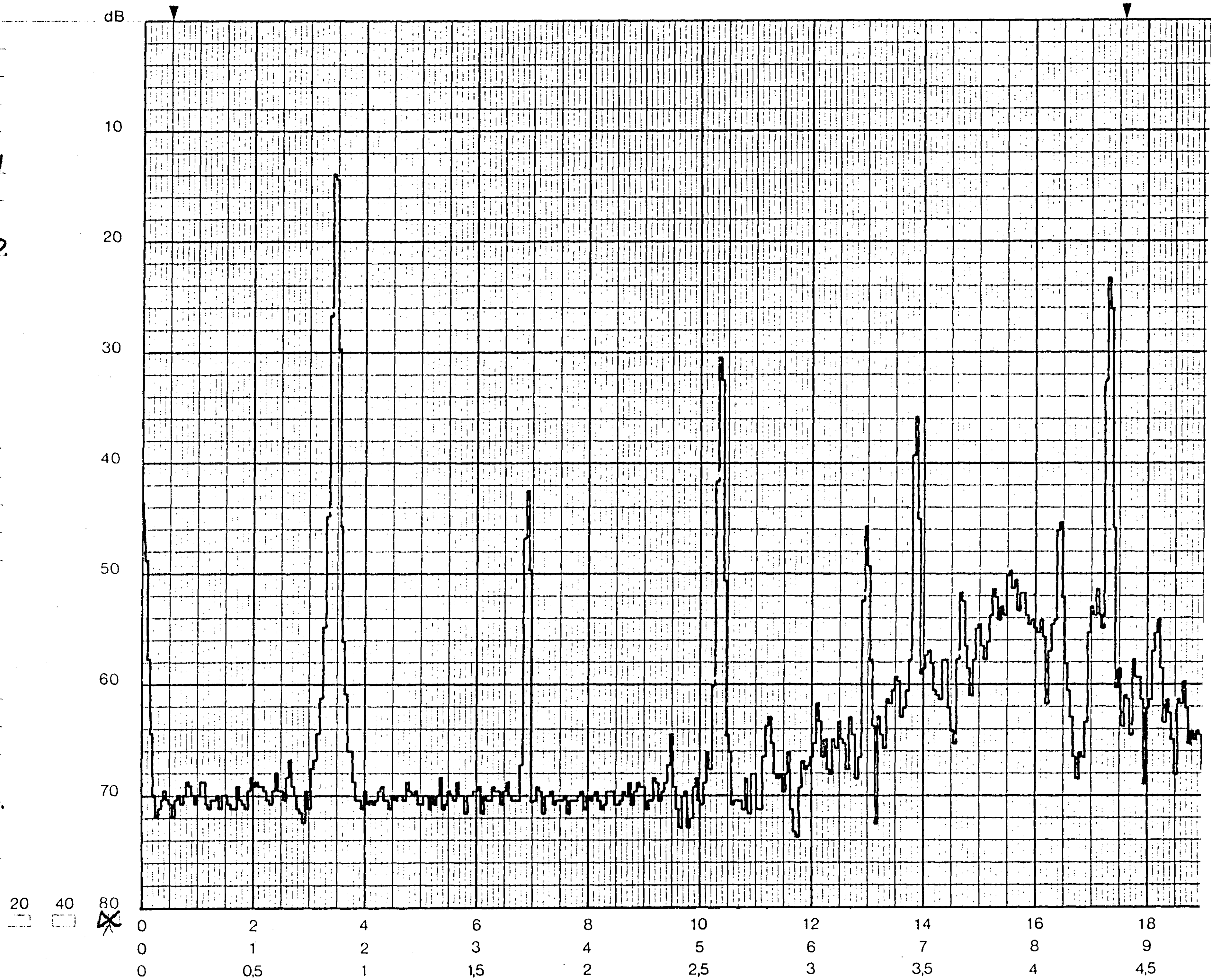
Average Mode: Lin

No. of Spectra: 5

Comments: JCB Wheel

axle acceln.
V.M. $1 m/s^2$ FSD.

Ram ± 1.5 mm
@ 8 Hz.



Record No.: Axle Dyn 2.

Date: 15/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

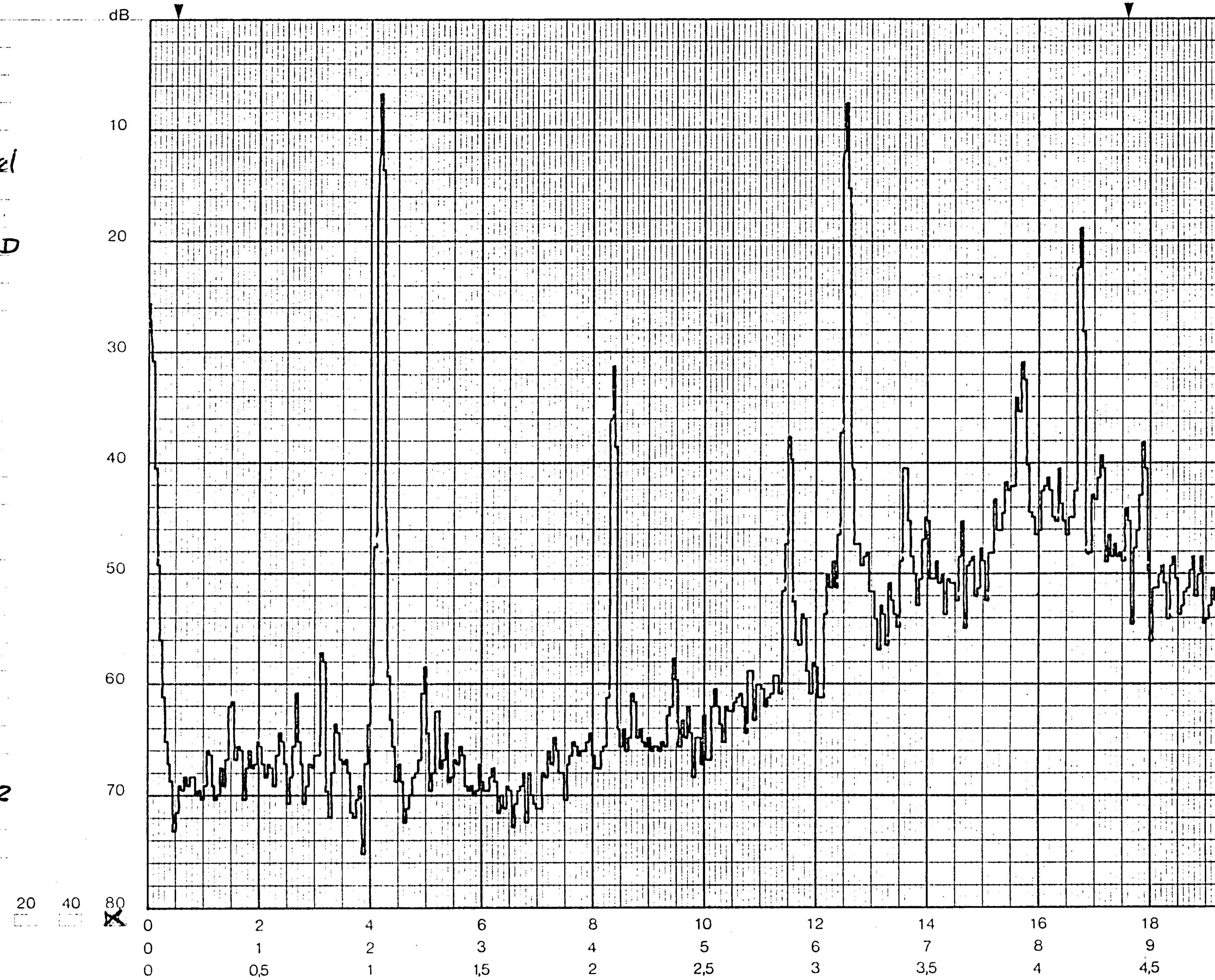
Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 110
F. S. Frequency: 50.
Weighting: Hanning.
Average Mode: Lin
No of Spectra: 5

Comments: JCB Wheel

axle acceln.
V.M. 1m/s² FSD

Ram ± 1.5 mm
@ 10 Hz.



Measuring Object:

Record No.: Axle Dyn 2
Date: 15/6/84
Sign.:

QP 1002

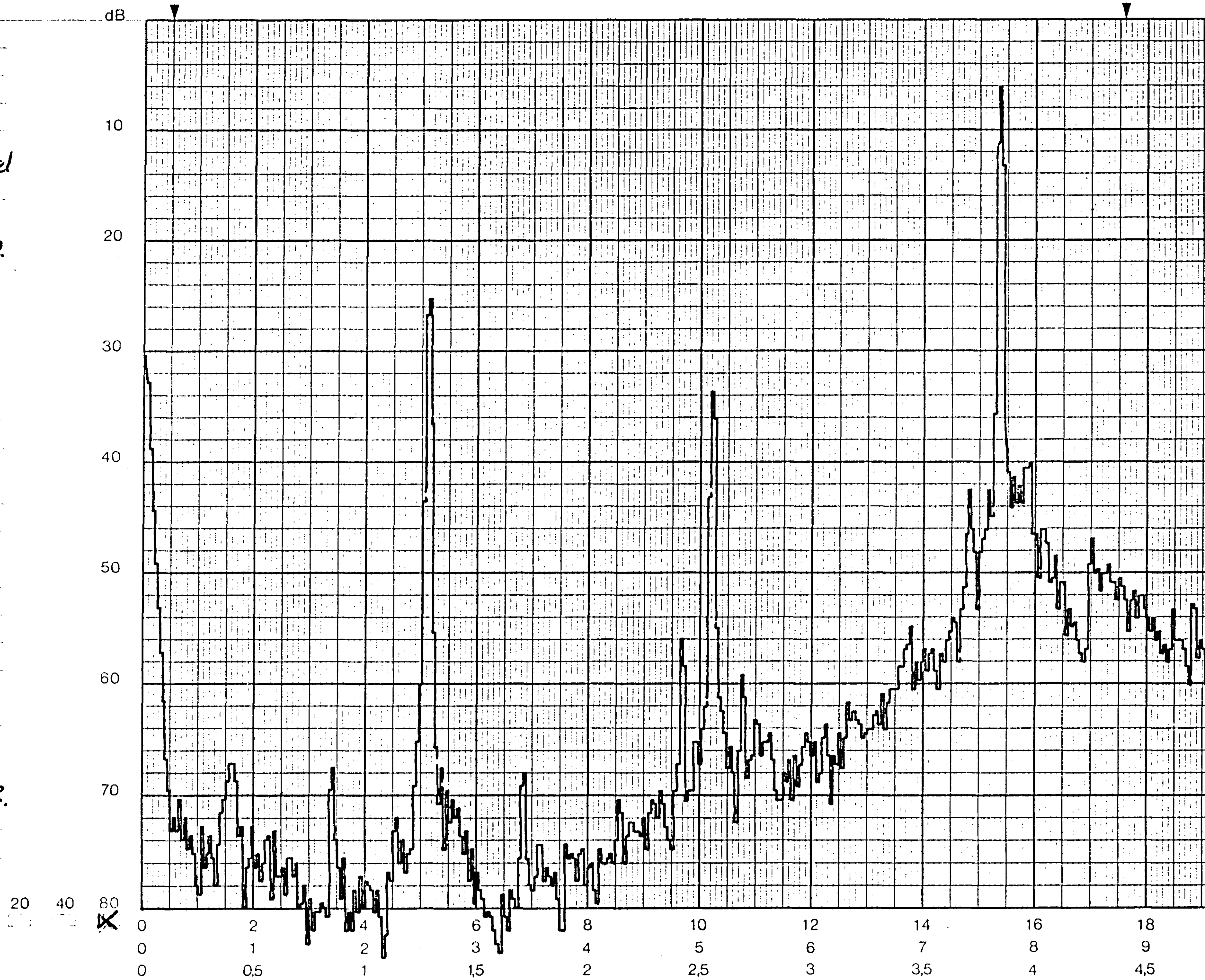
Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: [ ] Expand

Full Scale Level: 120 dB
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No of Spectra: 5
Comments: JCB Wheel

axle accel.$^{n.}$
V.M. $1 m/s^2$ FSD

Ram ± 1·5 mm
@ 12·5 Hz



Record No.: Axle Dyn 2.
Date: 15/6/84.
Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hamming

Average Mode: Lin

No. of Spectra: 5

Comments:

Schenk ram displacement.

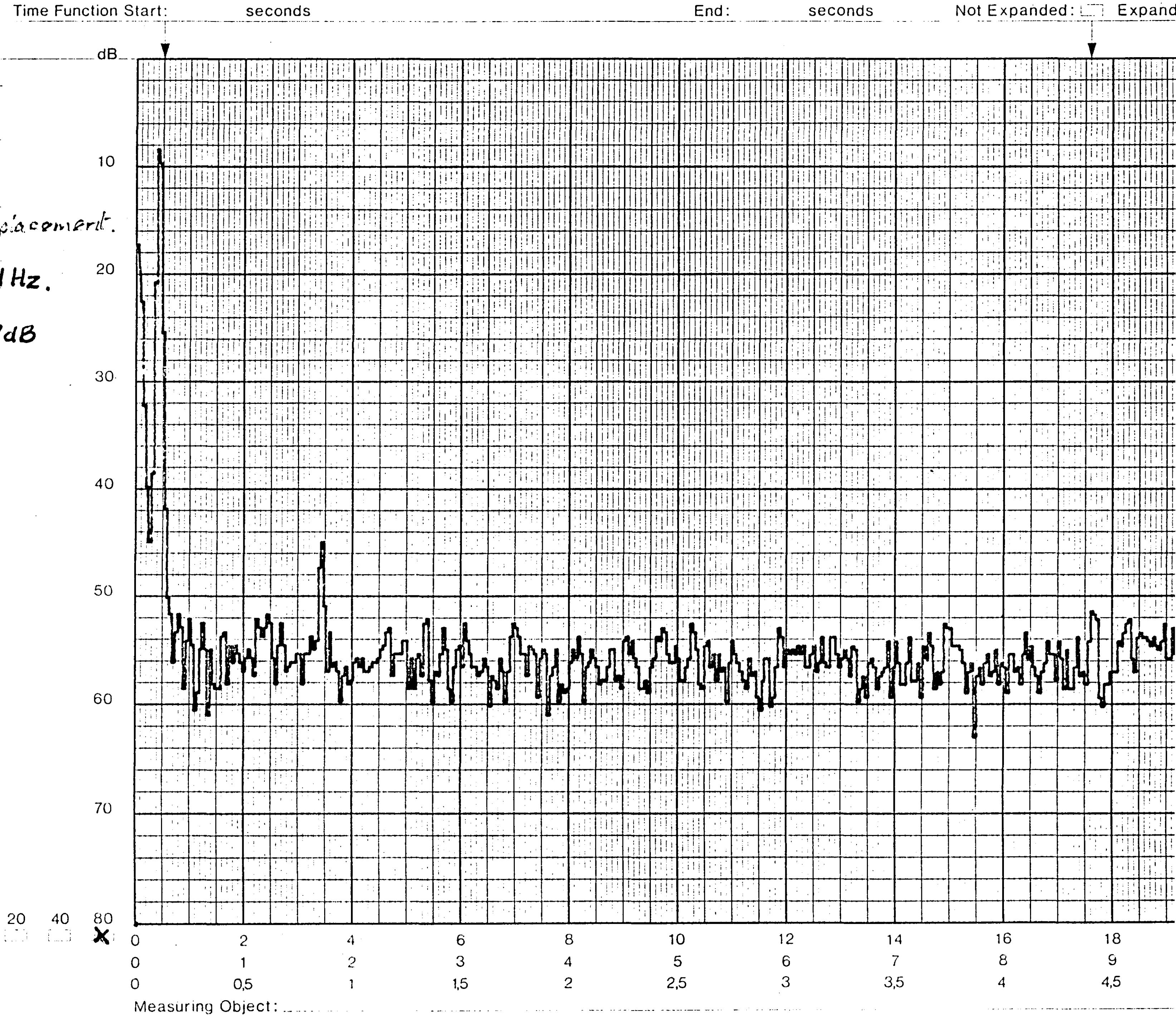
Rum ± 1·5mm at 1Hz.

1 Hz value = 91·7dB

Record No.: Rum D:1

Date: 15/6/84

Sign.: SD.



QP 1002

Brüel & Kjær

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments:

Schenk ram disp^t

Ram ±1·5mm at 1·25Hz.

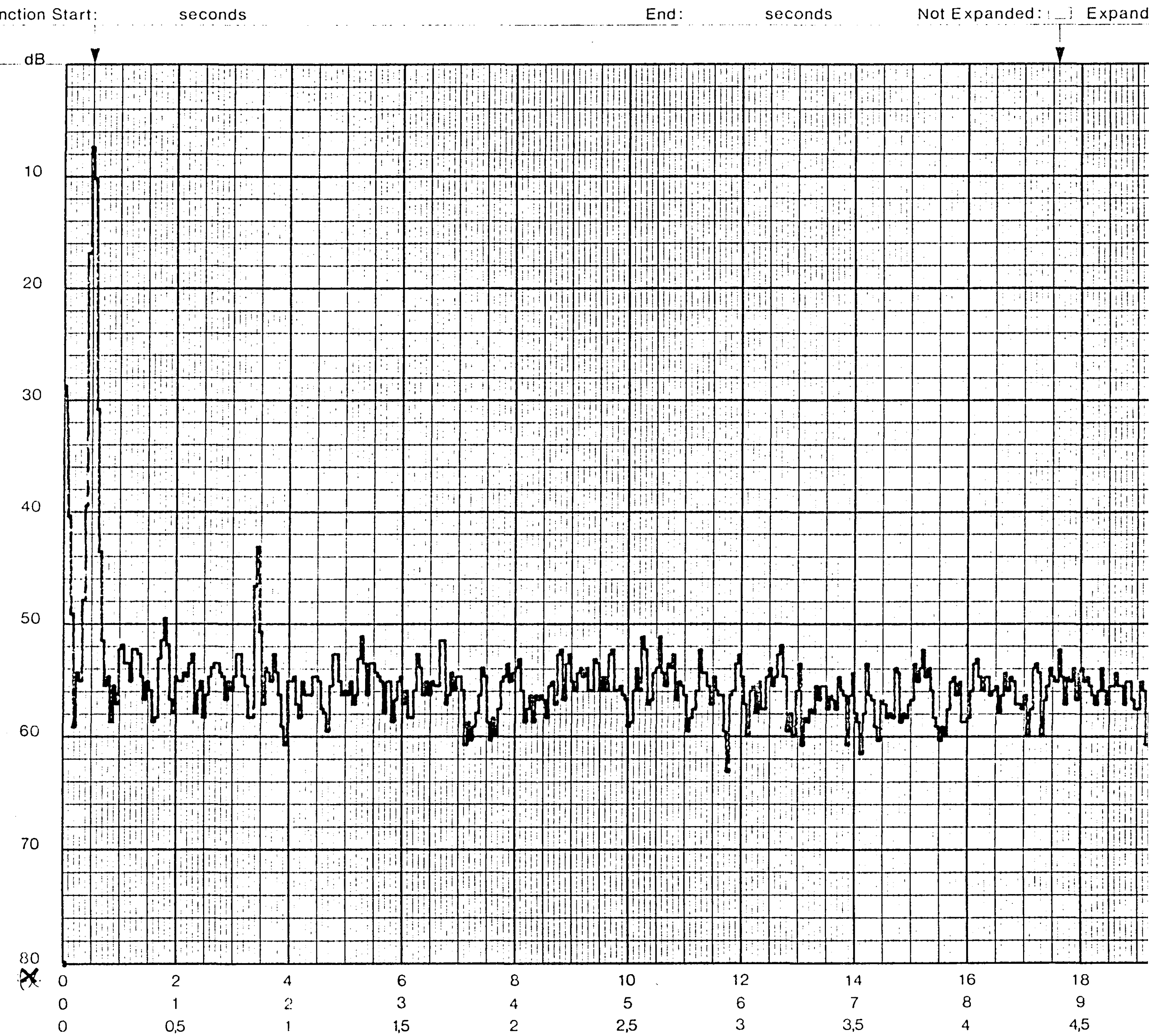
1·25 Hz value = 92·4 dB

367

Record No.: Ram D:2

Date: 15/6/84

Sign.: [signature]



Measuring Object:

QP 1002

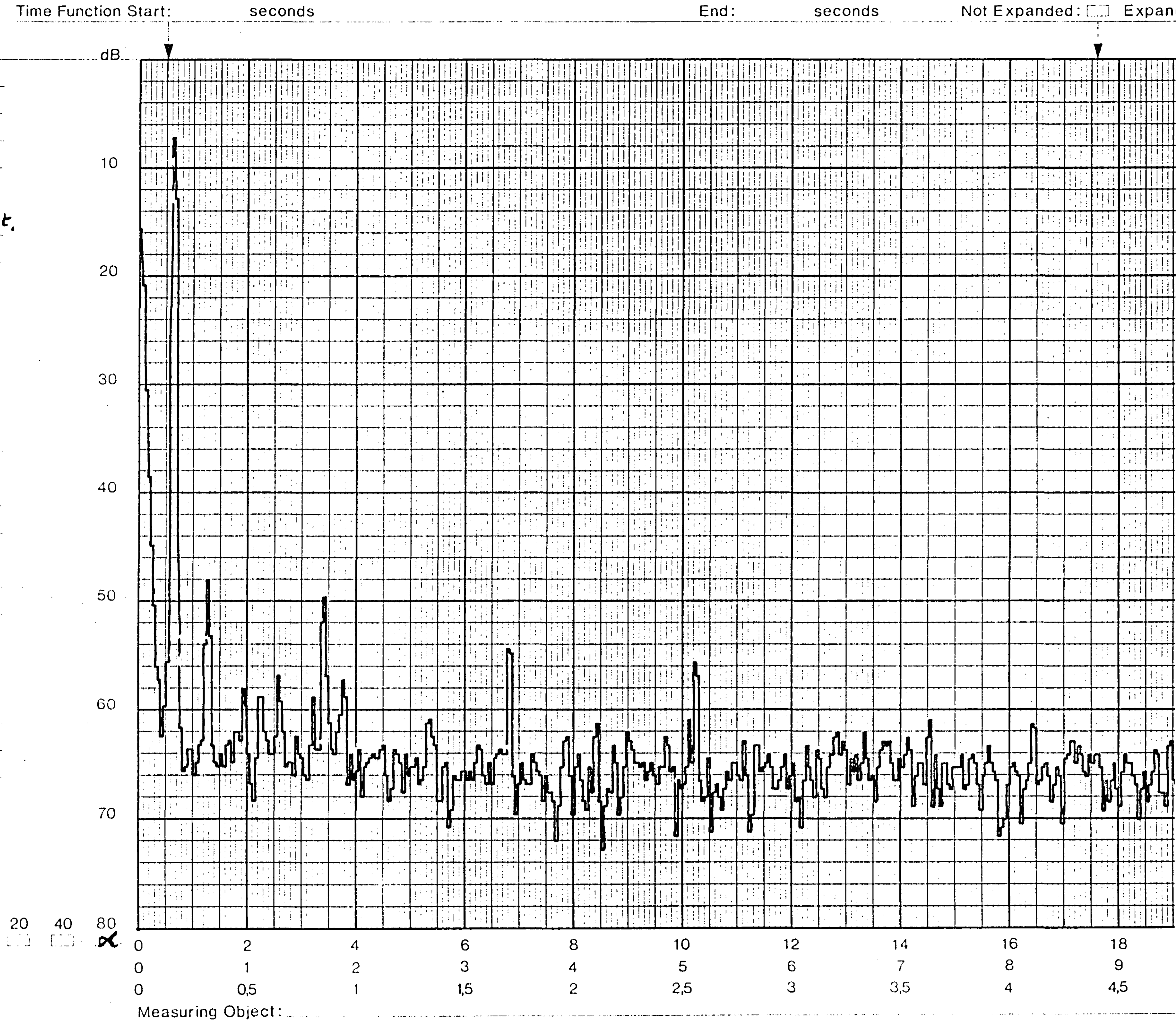
Brüel & Kjær

Full Scale Level: 100
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 5

Comments:
Schenk ram displ^{t}.

Ram $\pm$1·5mm
@ 1·6 Hz

Record No.: Ram D 2
Date: 15/6/84
Sign.:



368

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin.

No. of Spectra: 5.

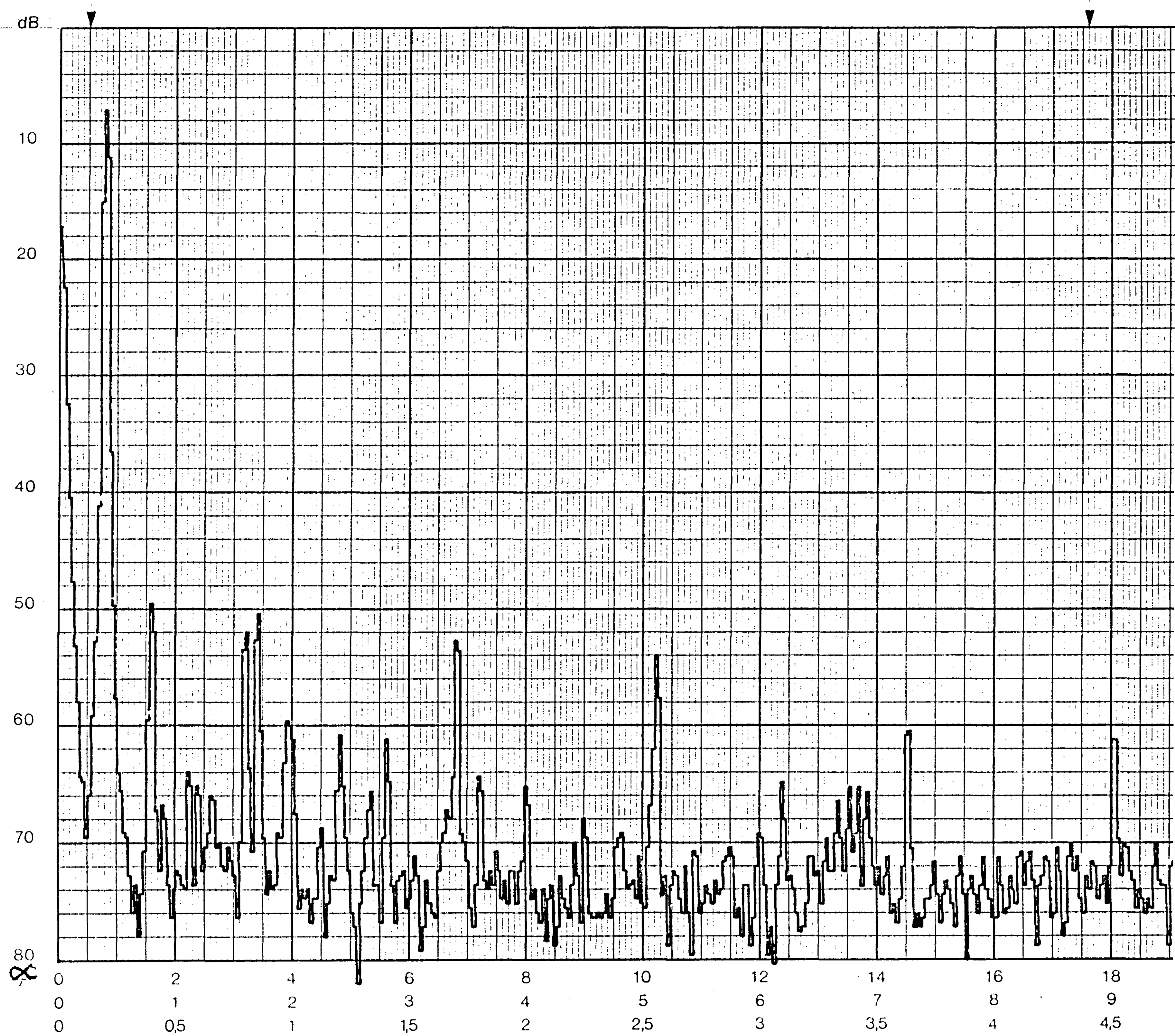
Comments:

Schenk ram dispt.

Ram ±1.5mm

@ 2Hz

369



Record No.: Ram D 2.

Date: 15/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expan

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

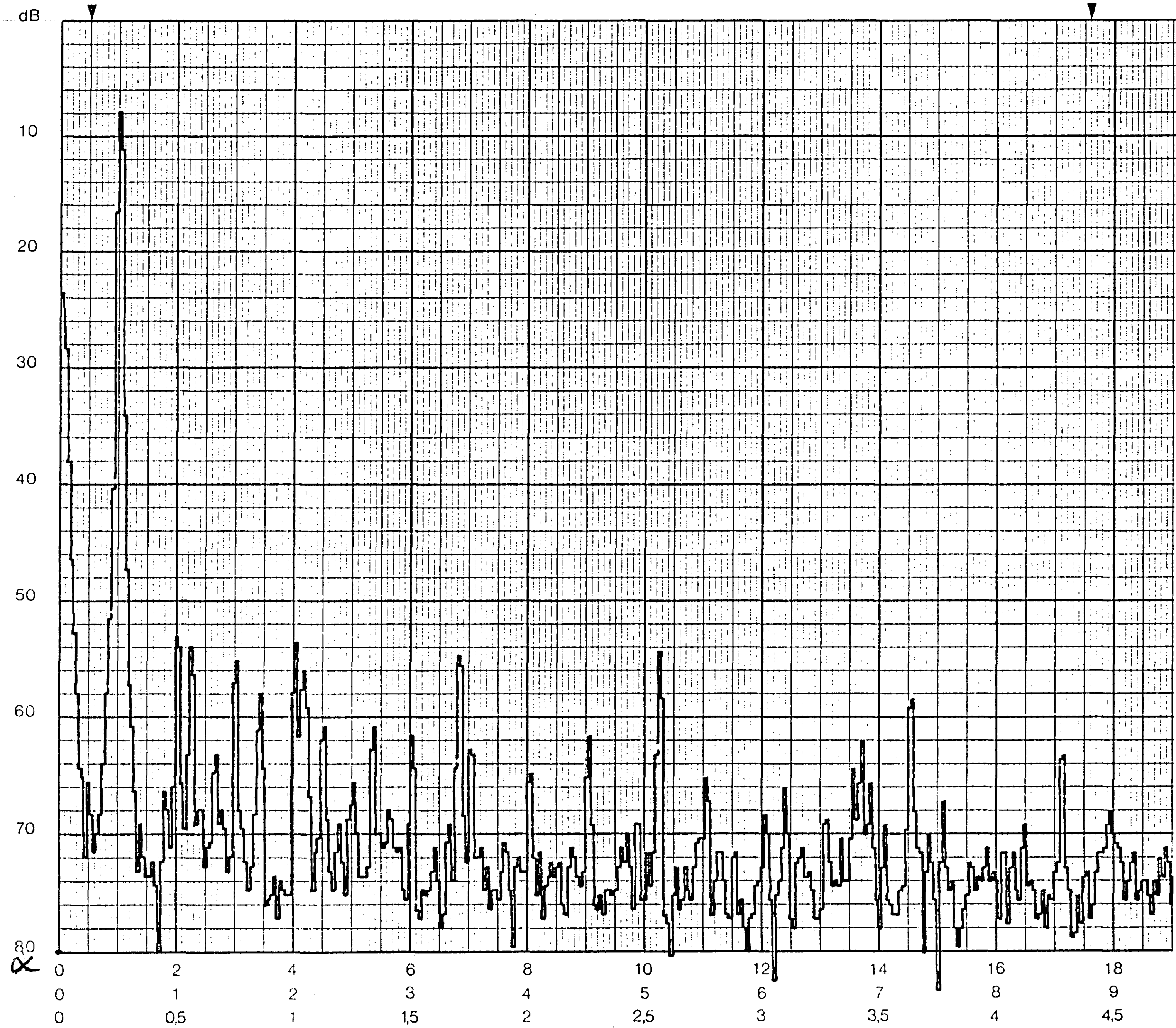
No. of Spectra: 5

Comments:

Schenk ram dispt.

Ram ± 1·5 mm
@ 2·5 Hz.

370



Measuring Object:

Record No.: Ram D. 2

Date: 15/6/84

Sign.:

QP 1002

Brüel & Kjær

Time Function Start: .... seconds .... End: .... seconds .... Not Expanded: ☐ Expand

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hanning

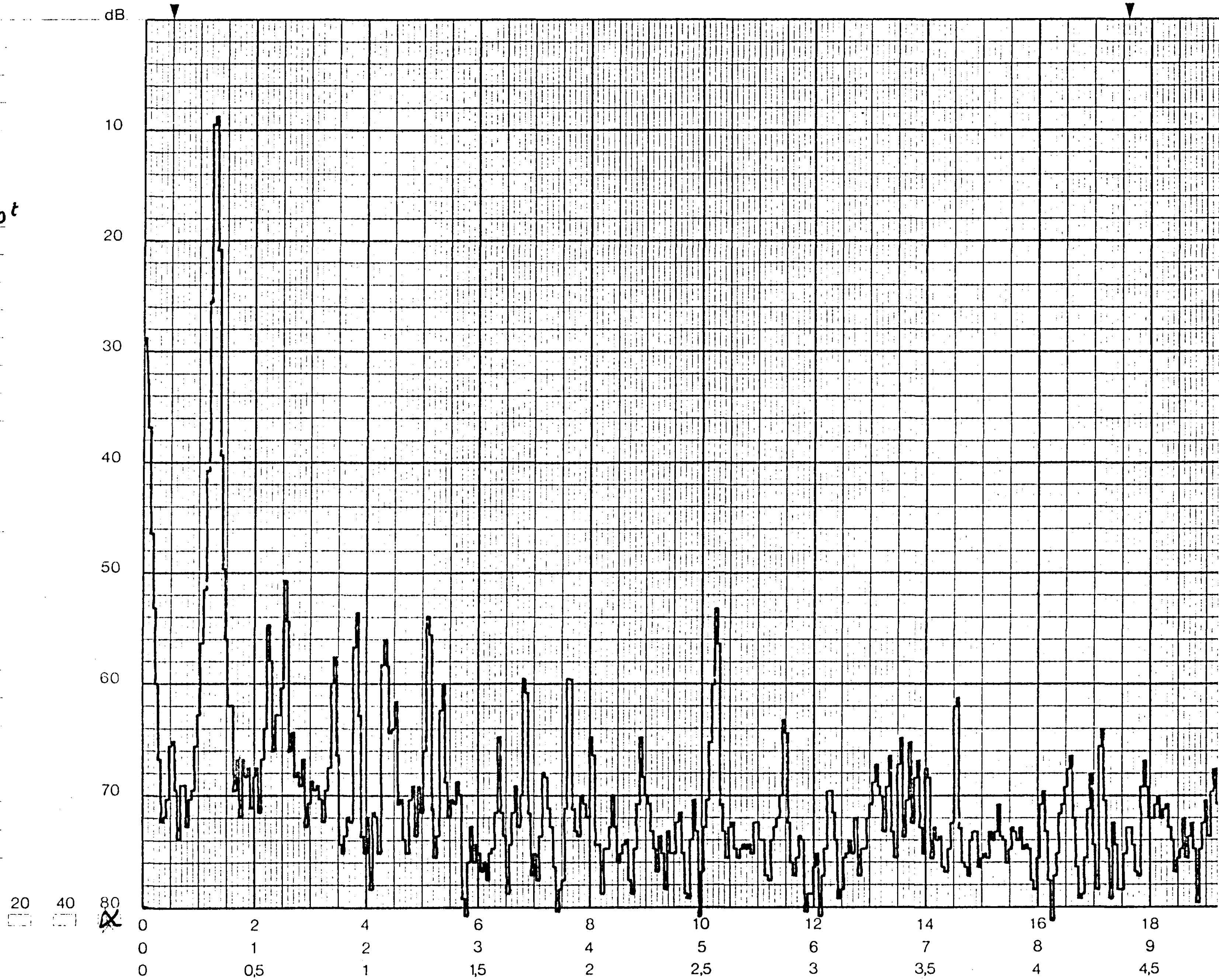
Average Mode: Lin

No. of Spectra: 5

Comments:

Schenk ram disp^t

Ram ±1·5mm
@ 3·16 Hz



Measuring Object: ....

Record No.: Ram D. 2

Date: 15/6/84

Sign.: [signature]

371

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 5

Comments:

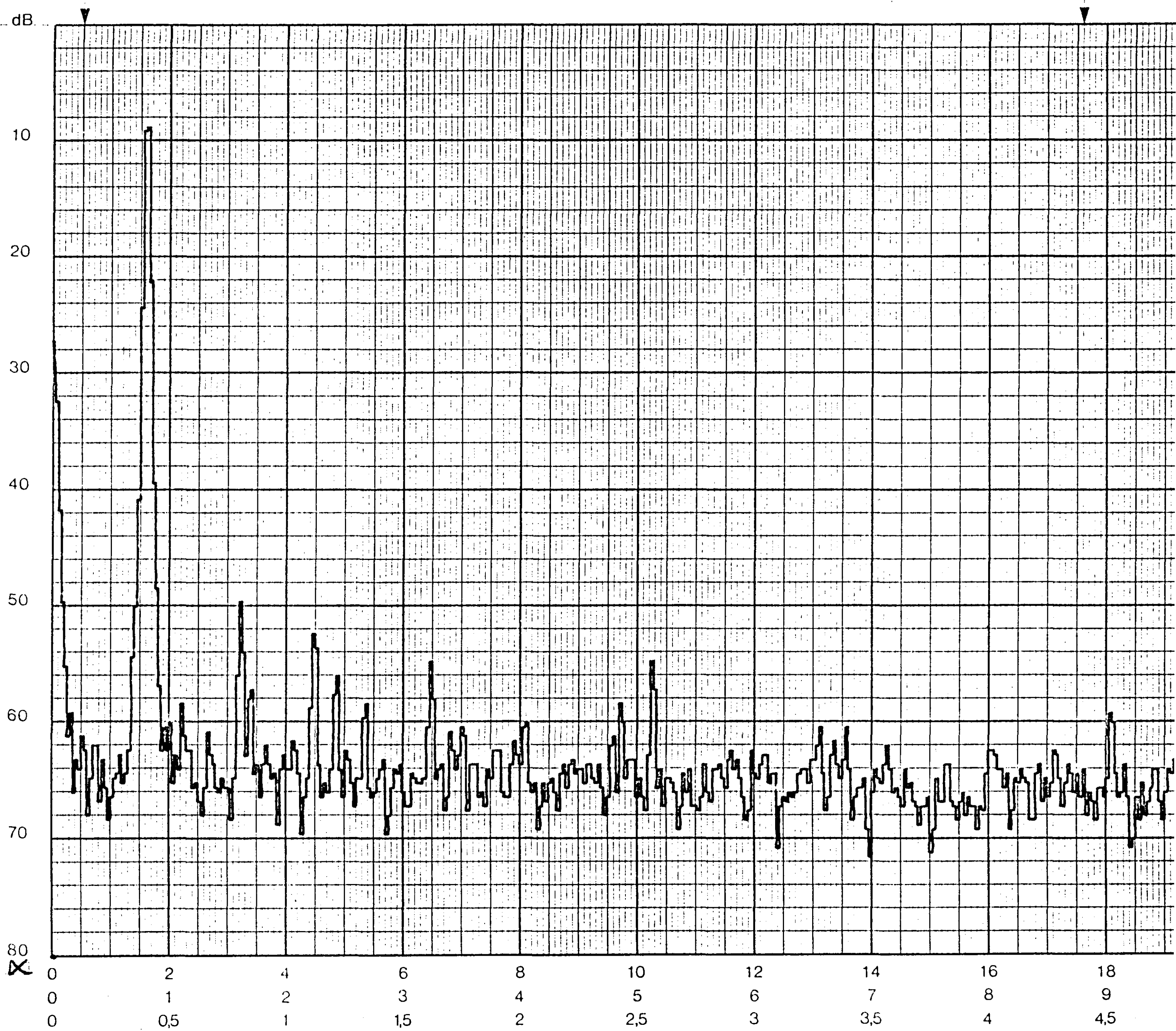
Schenk ram dispt.

Ram ± 1.5mm
@ 4 Hz.

Record No.: Ram D 2.

Date: 15/6/84

Sign.:



Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: ______ seconds   End: ______ seconds   Not Expanded: ☐ Expanded

Full Scale Level: 100 dB

F. S. Frequency: 50

Weighting: Hanning

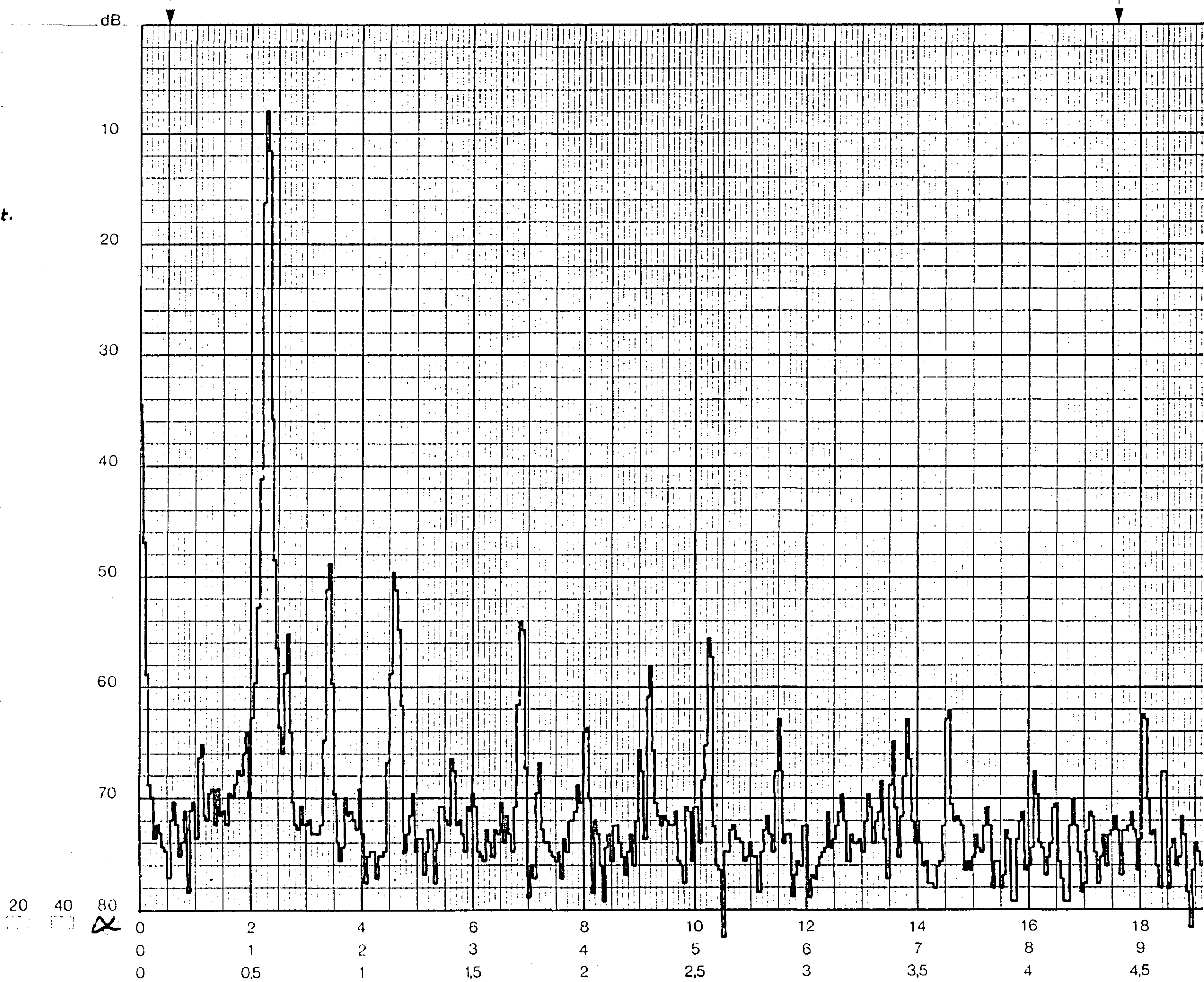
Average Mode: Lin

No. of Spectra: 5

Comments:

Schenk ram dispt.

Ram ± 1·5 mm
@ 5 Hz



Record No.: Ram D 2

Date: 15/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin.

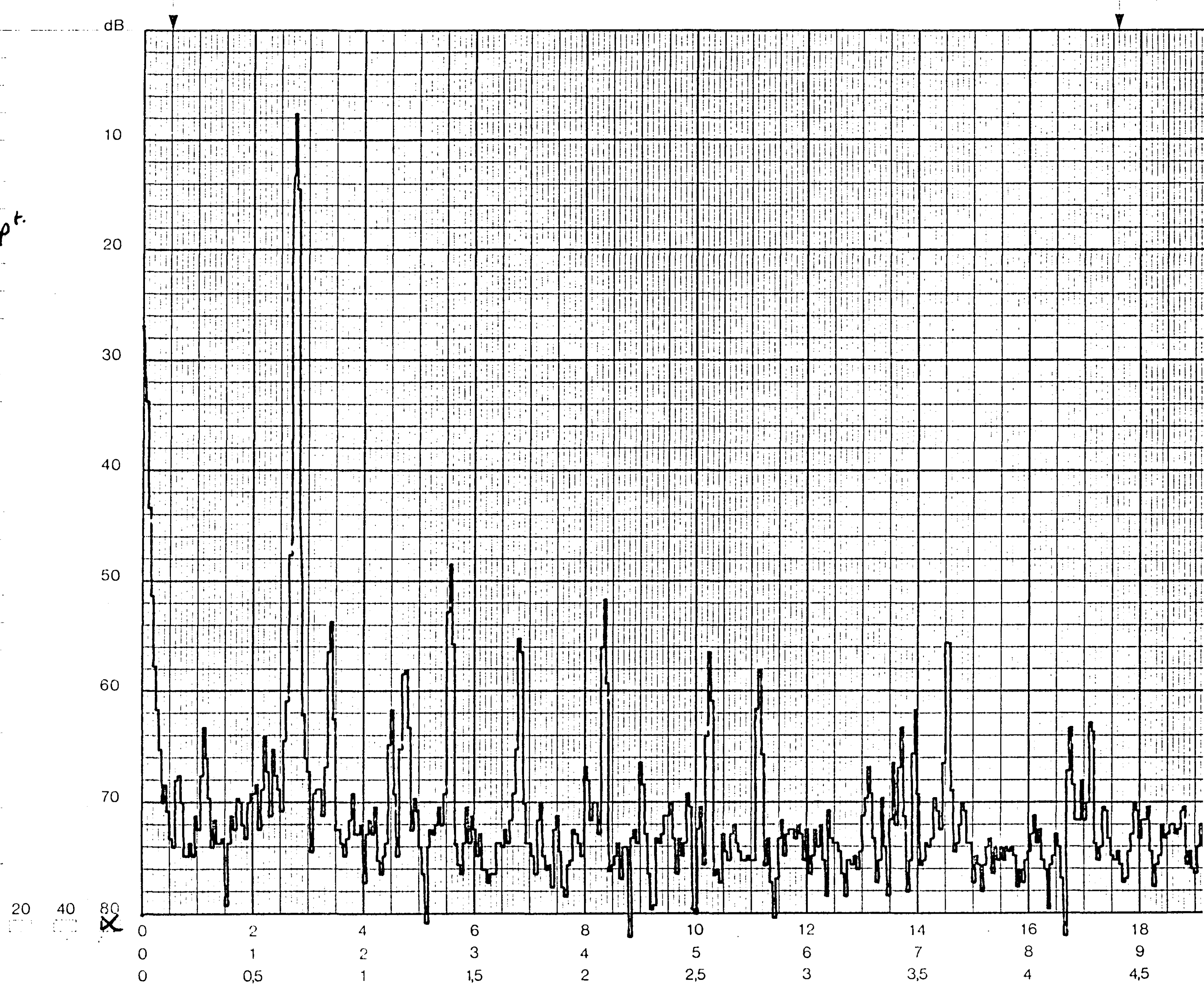
No. of Spectra: 5

Comments:

Schenk ram dispt.

Ram ± 1.5 mm
& 6.3 Hz

Time Function Start: seconds End: seconds Not Expanded: Expand



Measuring Object:

Record No.: Ram D2

Date: 15/6/84

Sign.:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 100 dB

F. S. Frequency: 50

Weighting: Hanning

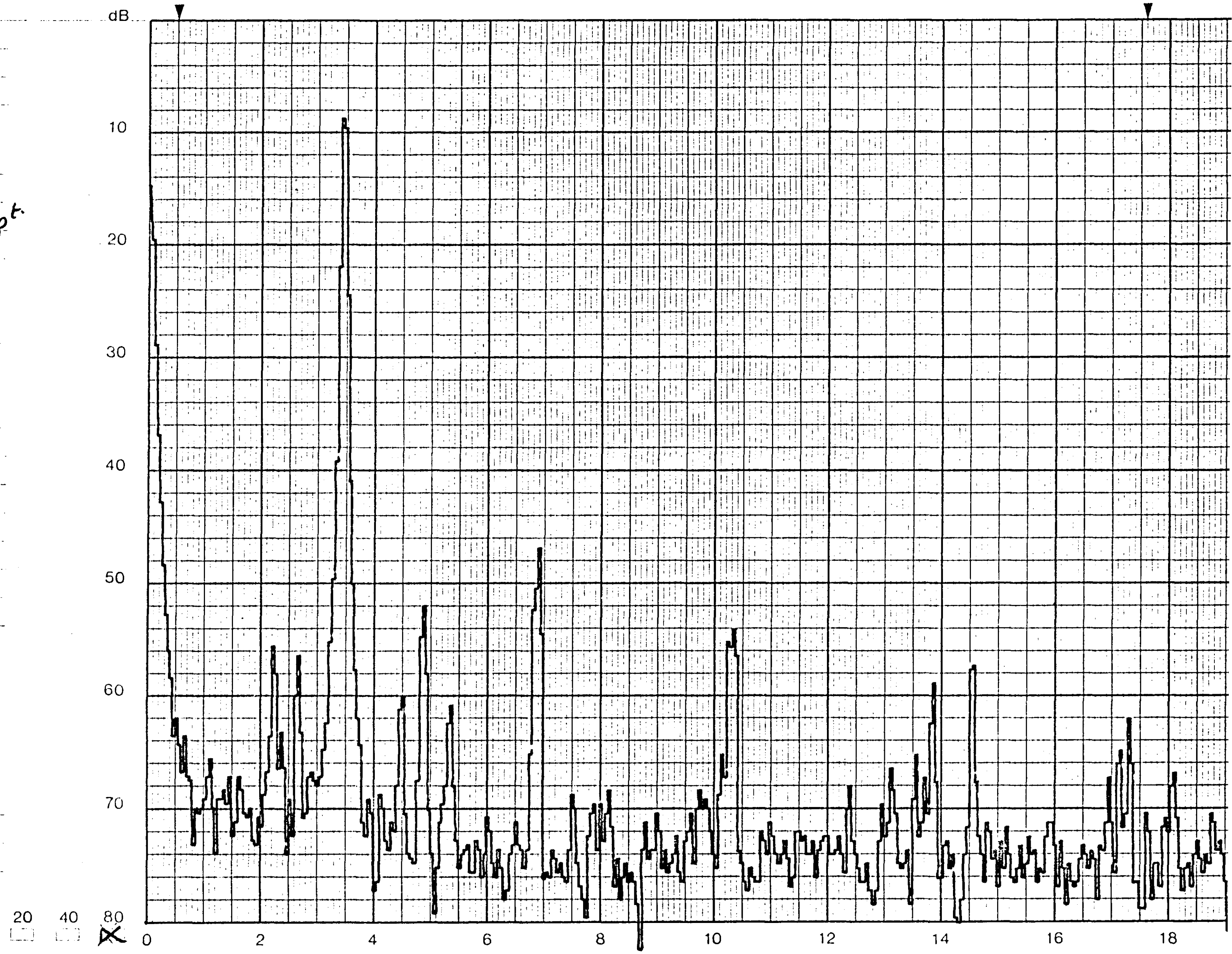
Average Mode: Lin

No. of Spectra: 5

Comments:

Schenk ram dispt.

Ram ± 1·5 mm
@ 8 Hz



Record No.: Ram D 2

Date: 15/6/84

Sign.:

QP 1002

Measuring Object:

Brüel & Kjær

Full Scale Level: 100

F. S. Frequency: 50

Weighting: Hanning

Average Mode: Lin

No of Spectra: 5

Comments:

Schenk ram dispt

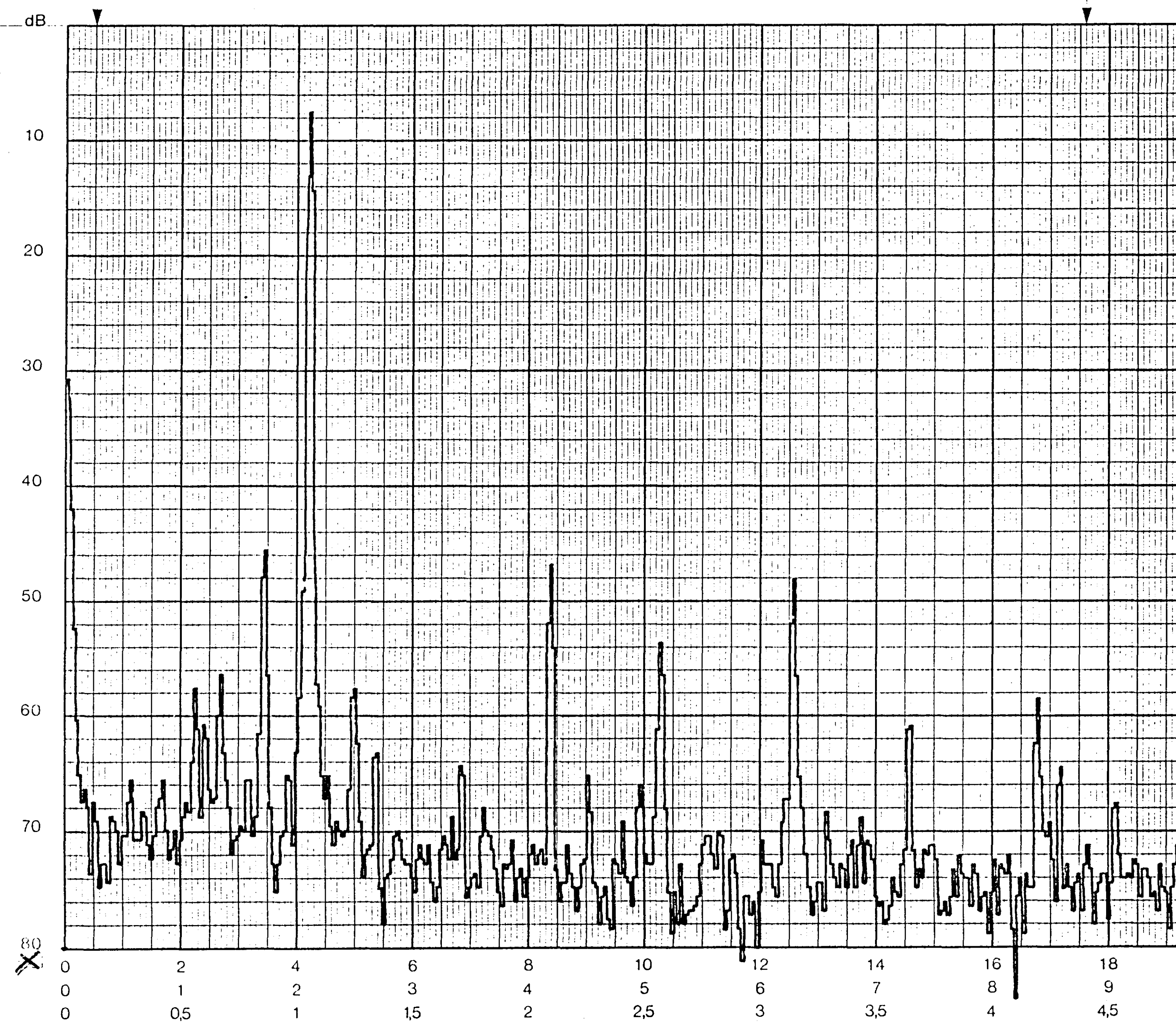
Ram ± 1.5mm
@ 10 Hz.

Record No.: Ram D 2

Date: 15/6/84.

Sign.:

Time Function Start: seconds End: seconds Not Expanded: Expand



Measuring Object:

QP 1002

Brüel & Kjær

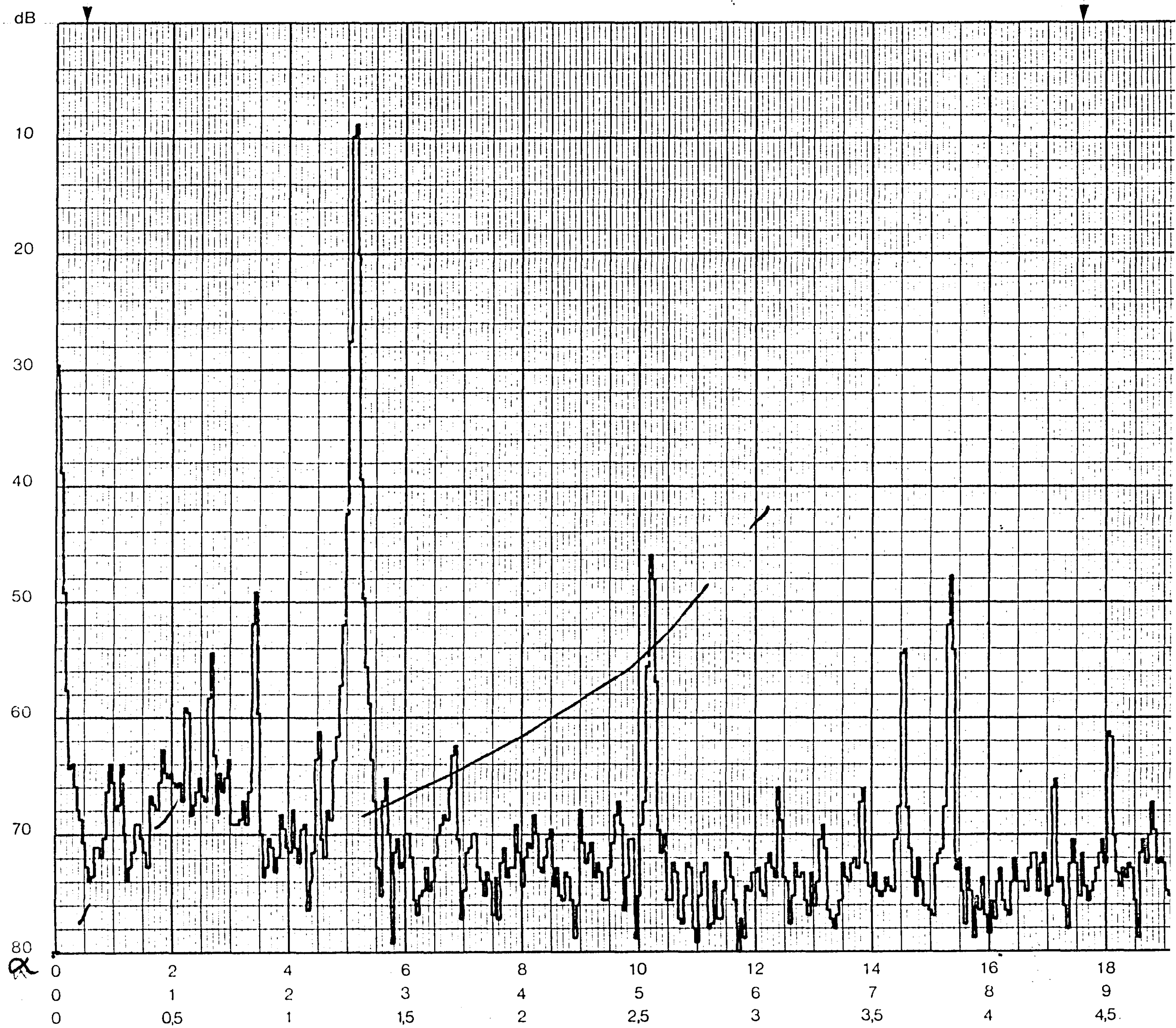
Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 100
F. S. Frequency: 50
Weighting: Hanning
Average Mode: Lin
No of Spectra: 5

Comments:

Schenk ram dispt

Ram ±1·5mm
@ 12·5 Hz.



Measuring Object:

Record No. Ram D2
Date: 15/6/84
Sign.:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 110 dB

F. S. Frequency: 100

Weighting: Hanning

Average Mode: Lin

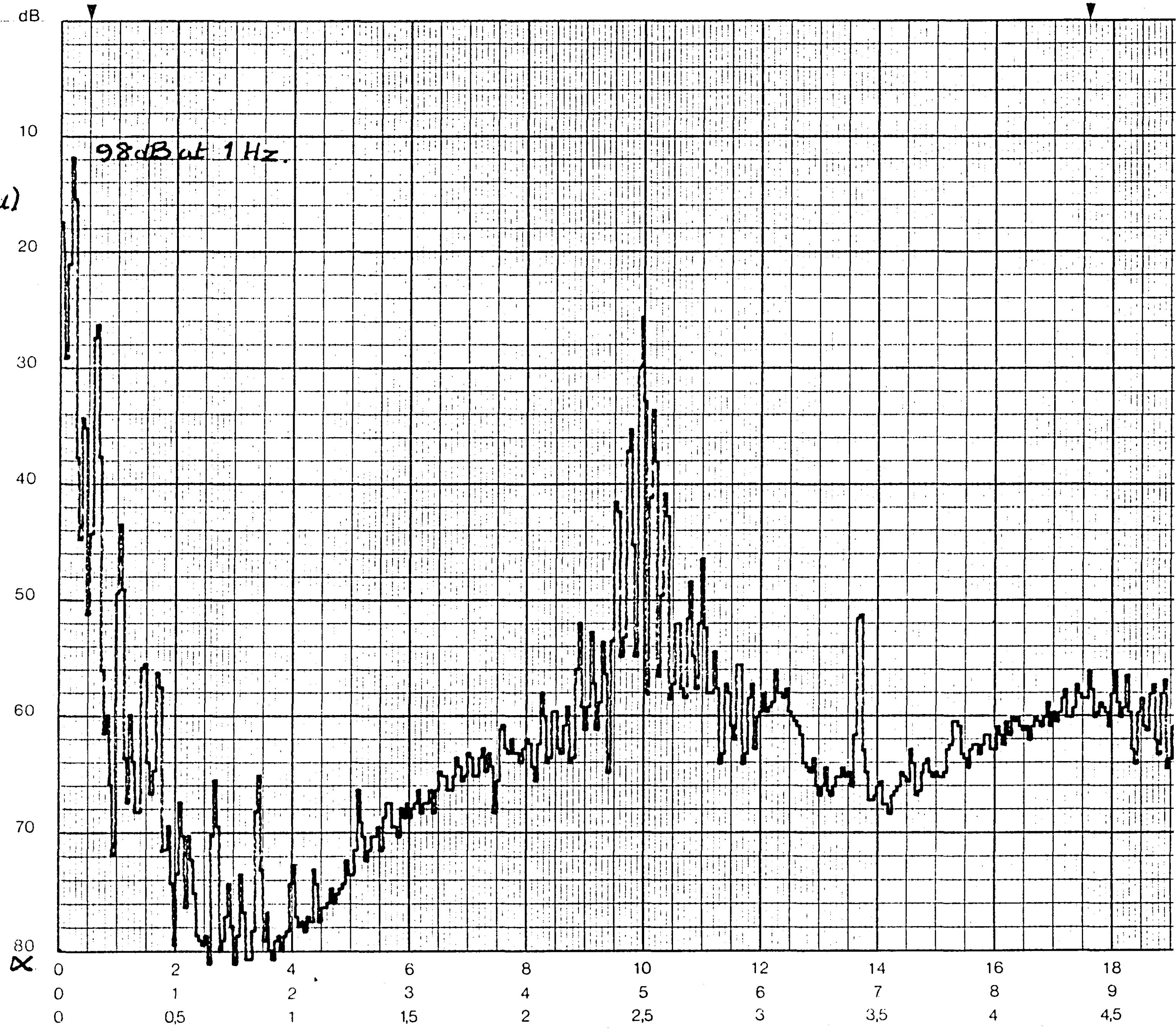
No. of Spectra: 11

Comments:

Schenk ram force (load)

ram ±1.5mm at 1 Hz.

1 Hz value = 98dB.



Measuring Object:

378

Record No.: Ram F : 1

Date: 15/6/84

Sign.:

QP 1002

Brüel & Kjær

Time Function Start: seconds

End: seconds

Not Expanded: ☐ Expand

Full Scale Level: 110

F. S. Frequency: 100

Weighting: Hamming

Average Mode: Lin.

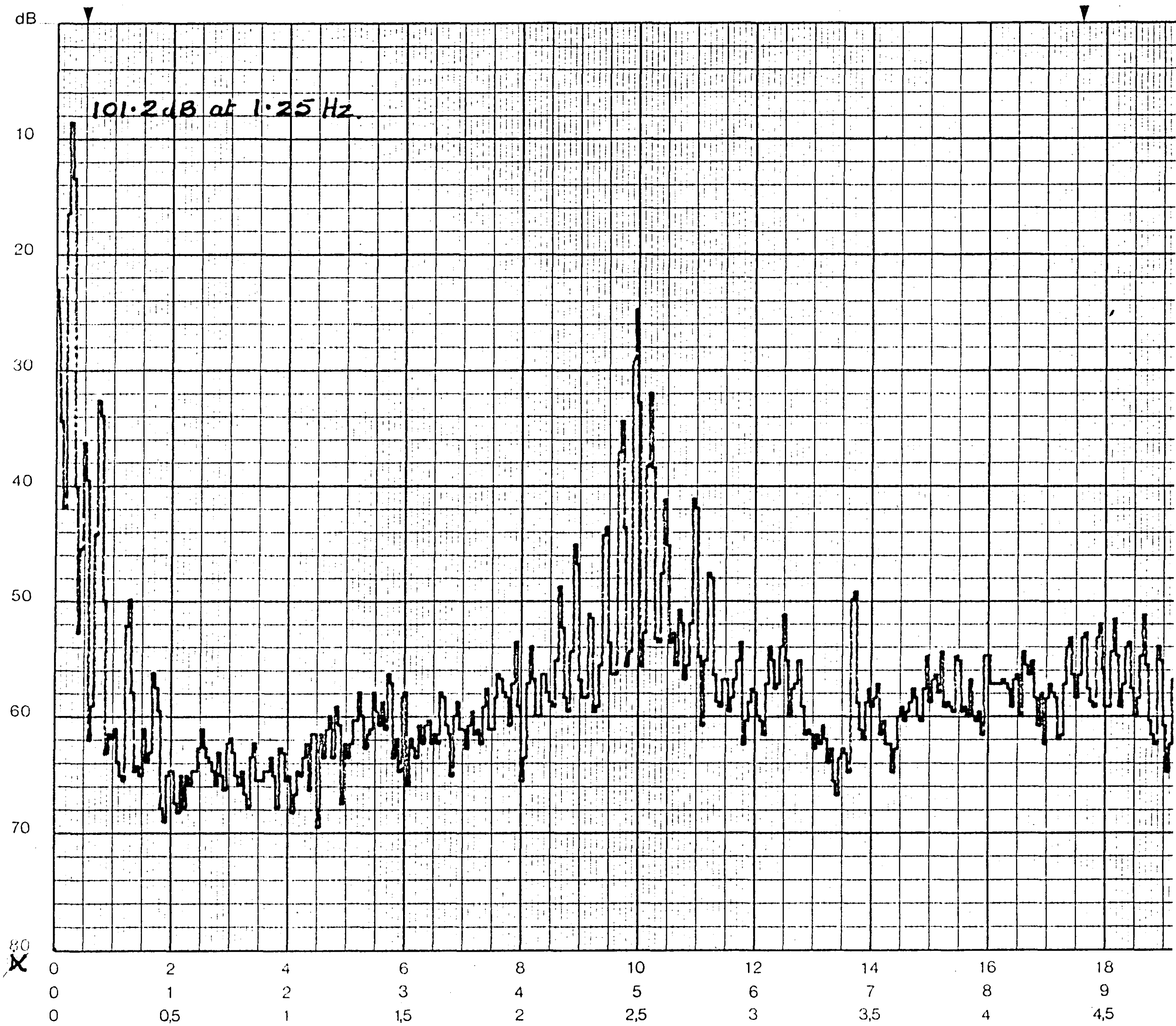
No. of Spectra: 5

Comments:

Schenk ram force (load)

ram ± 1·5 mm at 1·25 Hz

1·25 Hz value = 101·2 dB.



Measuring Object:

Record No.: Ram F : 2

Date: 15/6/84

Sign.: SG

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 110 dB

F. S. Frequency: 100

Weighting: Hamming

Average Mode: Lin

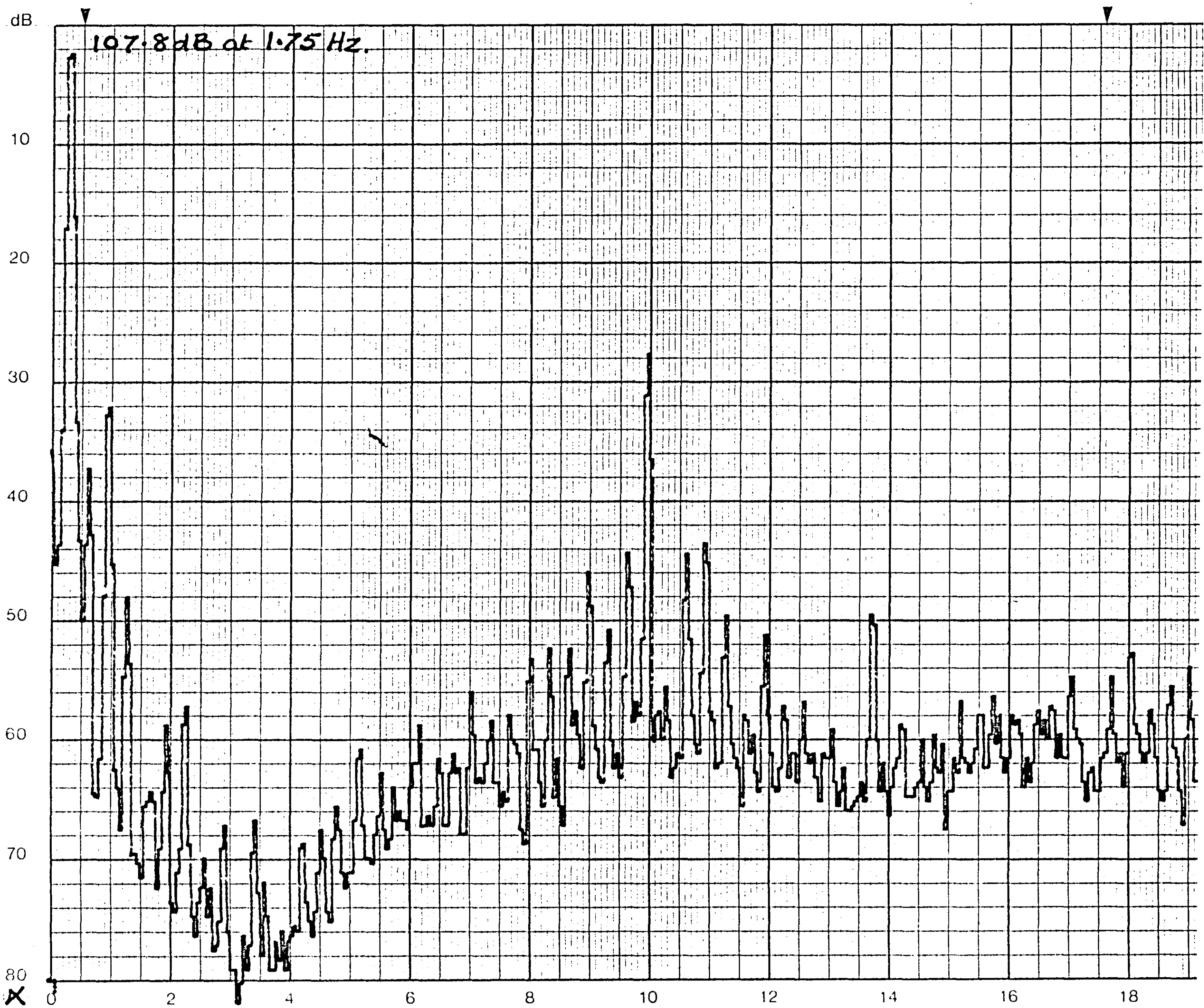
No. of Spectra: 10

Comments:

Schenk ram force (load)

ram ±1.5mm at 1.6 Hz.

1.75 Hz value = 107.8dB



Record No.: Rum F: ~~4~~.

Date: 15/6/84.

Sign.: [signature]

20 40

QP 1002

Measuring Object:

Brüel & Kjær

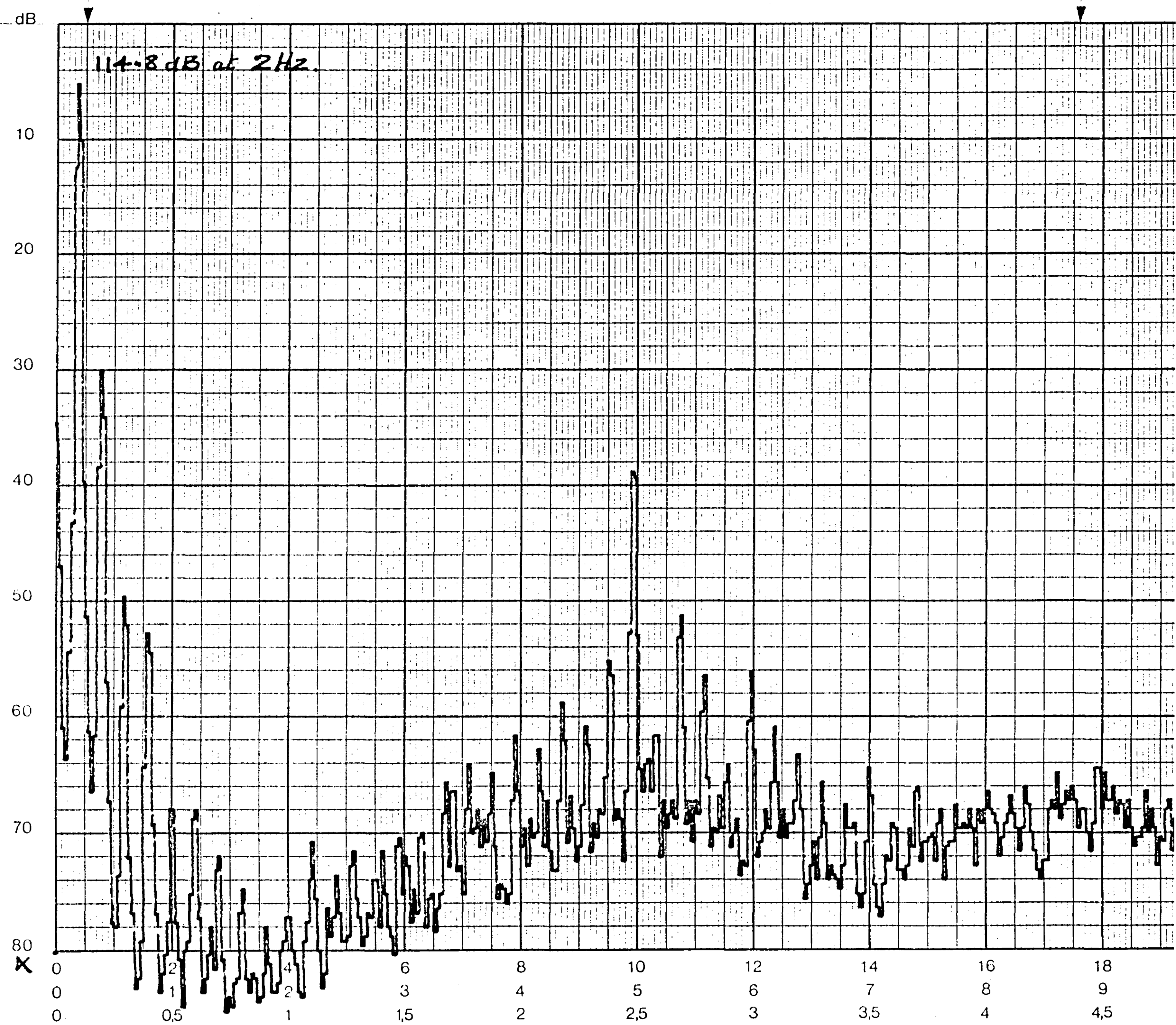
Time Function Start: seconds End: seconds Not Expanded: Expanded

Full Scale Level: 120 dB
F. S. Frequency: 100
Weighting: Hamming
Average Mode: Lin
No. of Spectra: 10

Comments:
Schenk ram force (load)

ram ±1.5mm at 2 Hz.

2 Hz value = 114.8dB



Record No.: Ram F: 3
Date: 15/6/84.
Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: ☐ Expand

Full Scale Level: 120 dB

F. S. Frequency: 100

Weighting: Hamming

Average Mode: Lin

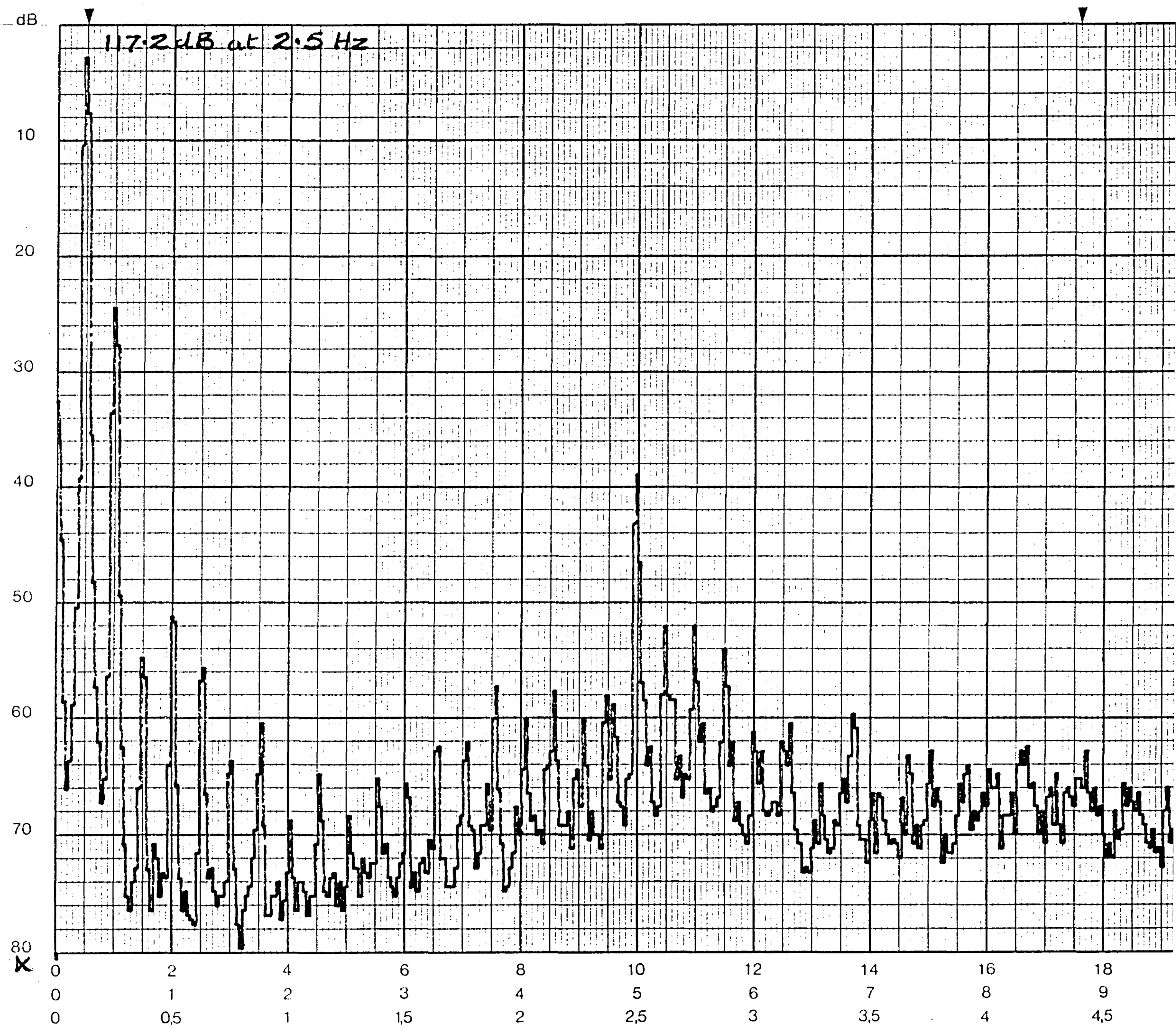
No. of Spectra: ~~100~~ 10

Comments:

Schenk ram Force (load)

ram ±1·5mm at 2·5 Hz.

2·5Hz value = 117·2dB



Record No.: Ram F: 5.

Date: 15/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Full Scale Level: 120 dB

F. S. Frequency: 100

Weighting: Hamming

Average Mode: Lin

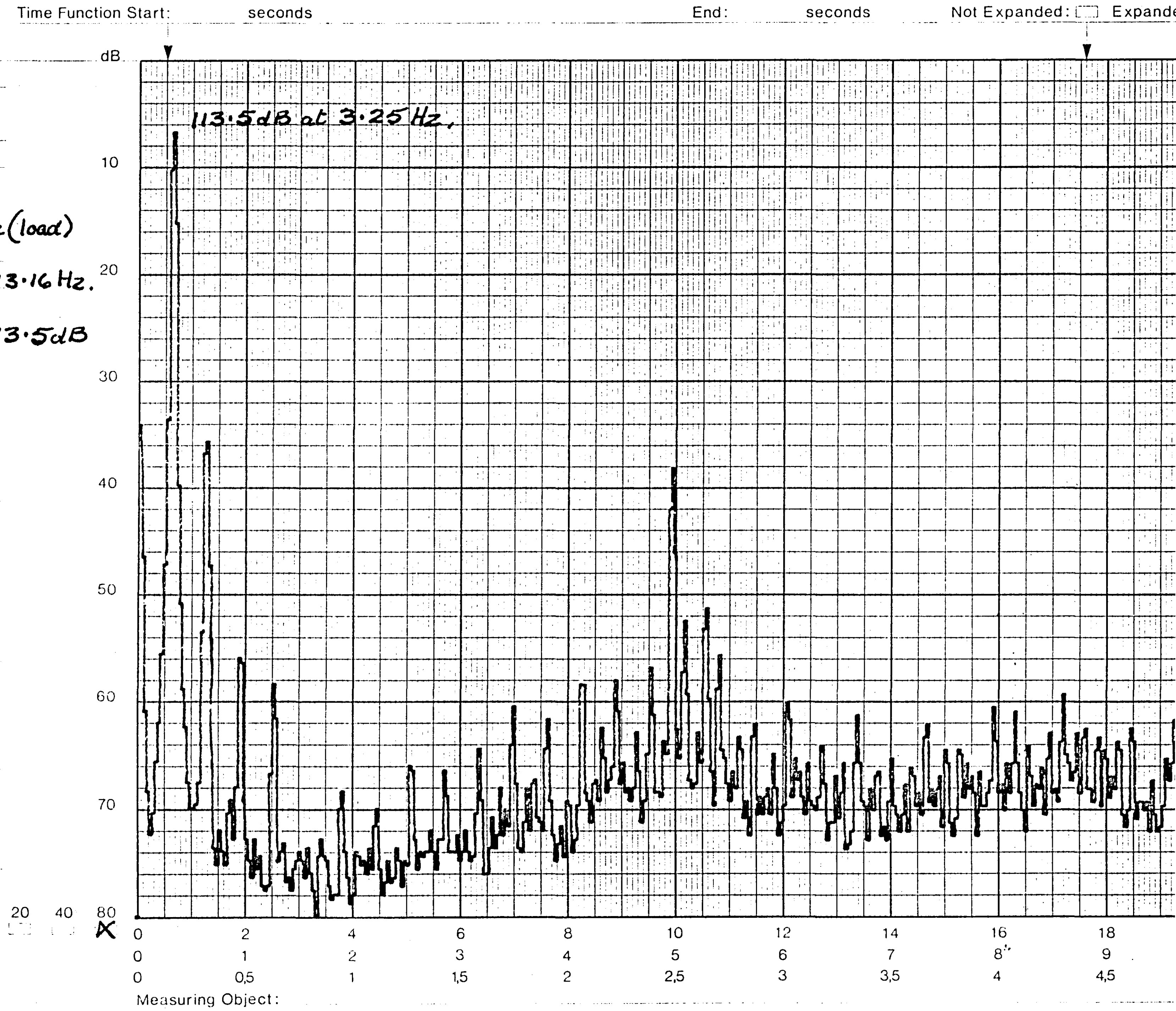
No. of Spectra: 10

Comments:

Schenk ram force (load)

ram ± 1·5 mm at ≃ 3·16 Hz.

3·25 Hz value = 113·5 dB



Record No.: RumF: 6.

Date: 15/6/84.

Sign.:

QP 1002

Brüel & Kjær | Time Function Start: ...... seconds | End: ...... seconds | Not Expanded: [ ] Expand

Full Scale Level: 120

F. S. Frequency: 100

Weighting: Hanning

Average Mode: Lin.

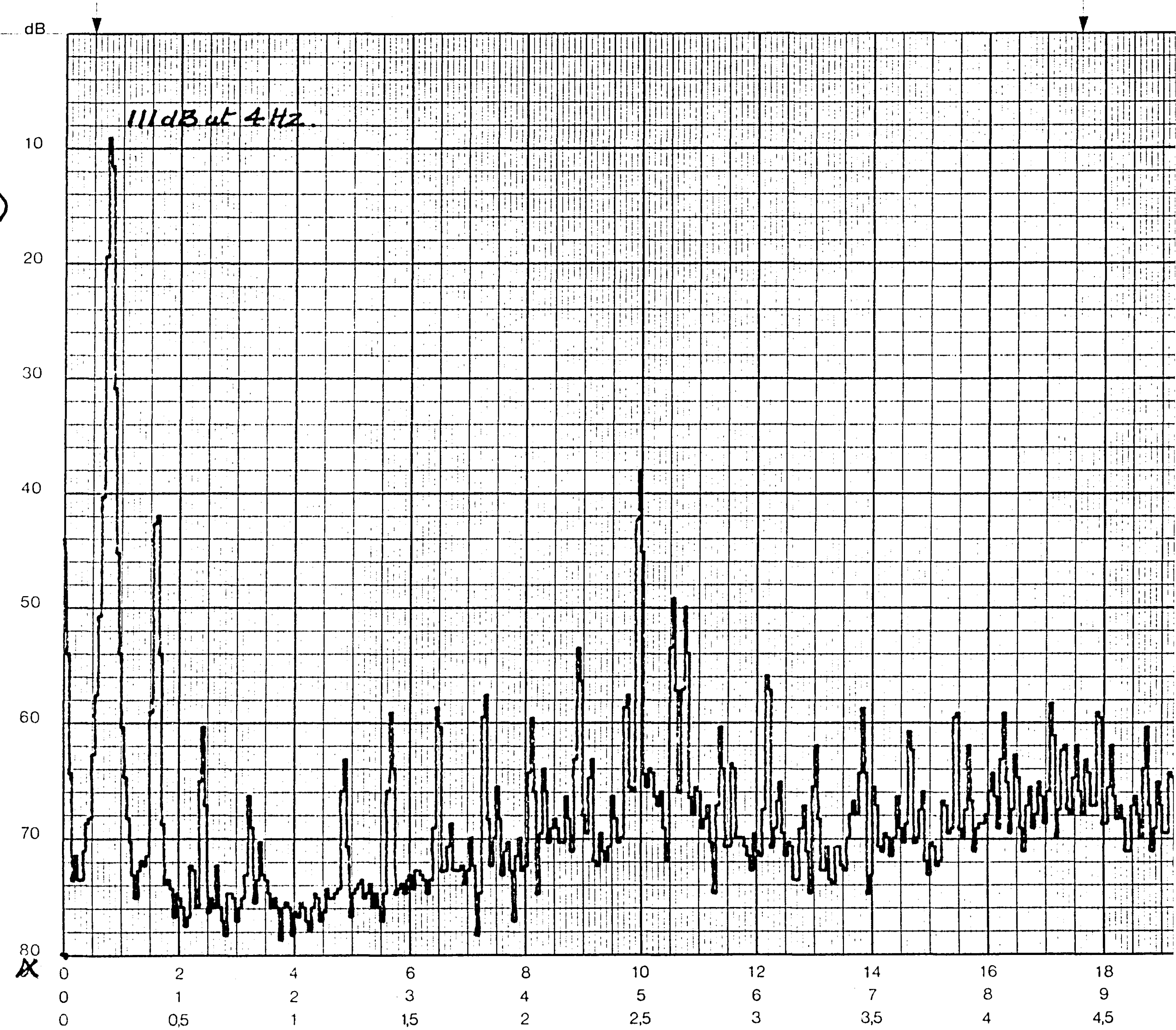
No. of Spectra: 10

Comments:

Schenk ram force (load)

ram ±1·5mm at 4Hz

4Hz value = 111 dB



Record No.: Ram F : 7

Date: 15/6/84

Sign.:

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expanded:

Full Scale Level: 120

F. S. Frequency: 100

Weighting: Hanning

Average Mode: Lin

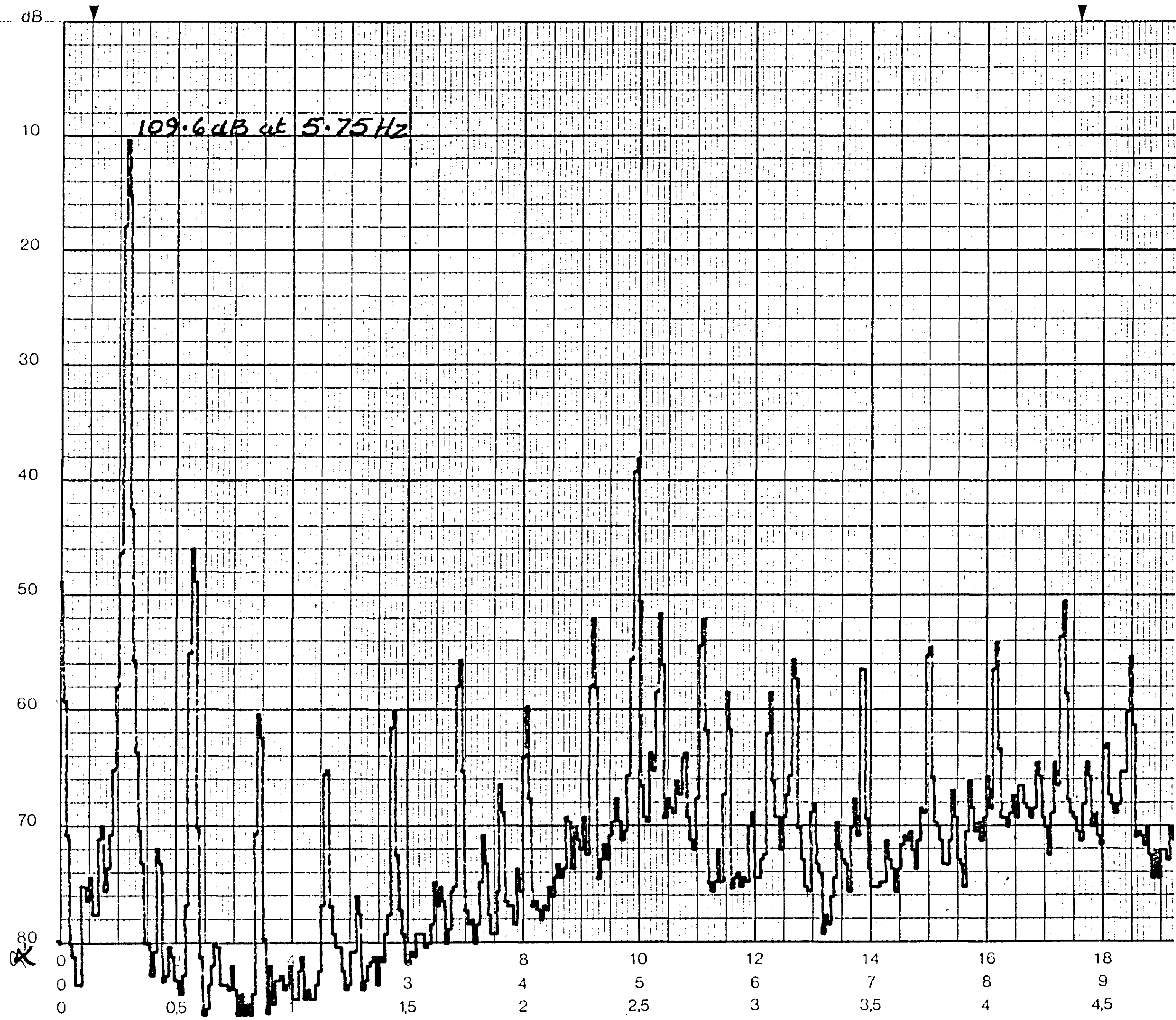
No. of Spectra: 10

Comments:

Schenk ram force (load)

ram ±1·5mm at ≃5Hz.

5·75 Hz value = 109·6dB



Record No.: Ram F : 8

Date: 15/6/84.

Sign.:

Measuring Object:

QP 1002

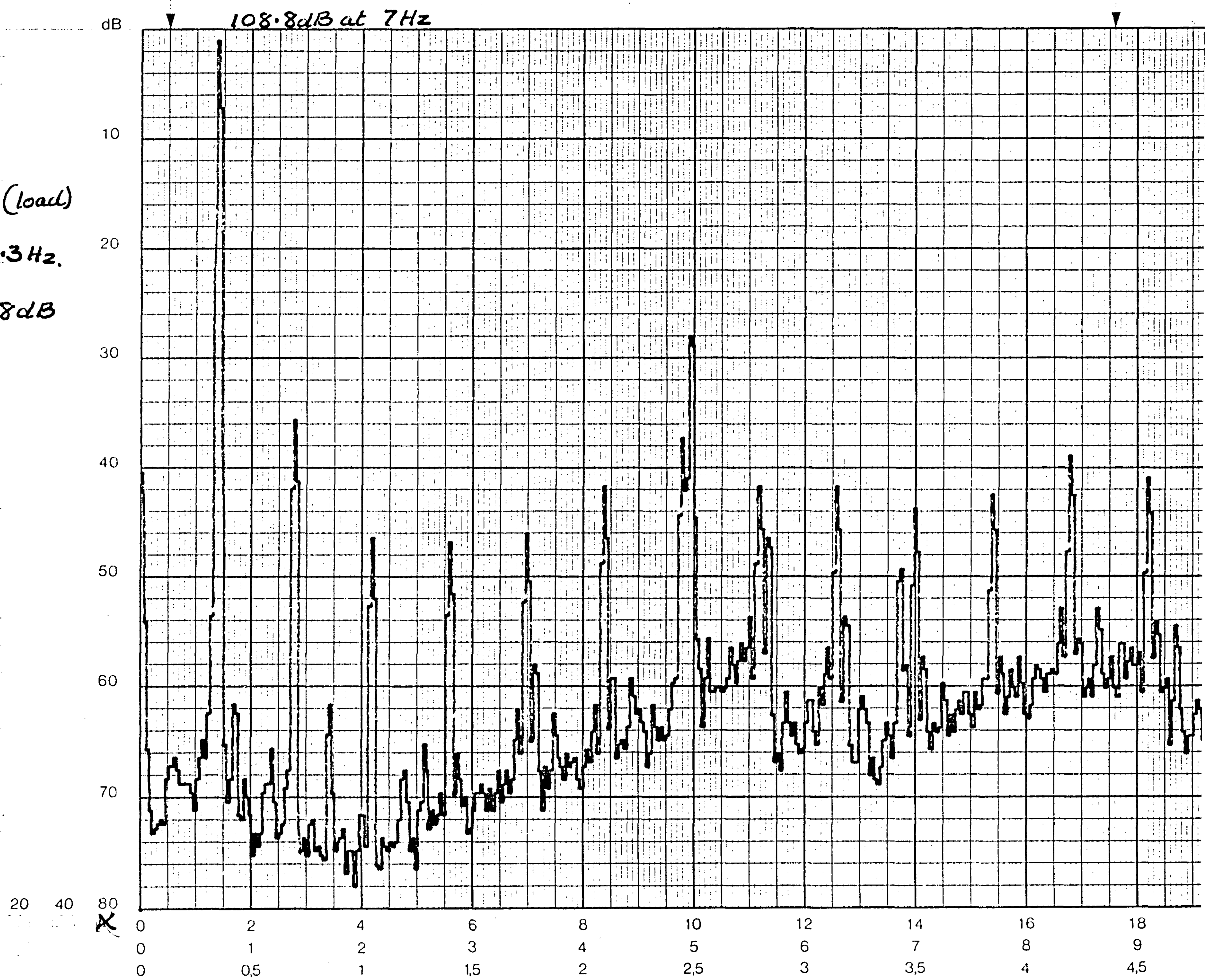
Brüel & Kjær | Time Function Start: seconds | End: seconds | Not Expanded: ☐ Expand

Full Scale Level: 110.
F. S. Frequency: 100
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 10

Comments:
Schenk ram force (load)

ram ±1·5mm at ≃6·3 Hz.

7Hz value = 108·8dB



Record No.: RamF: 9.
Date: 15/6/84.
Sign.:

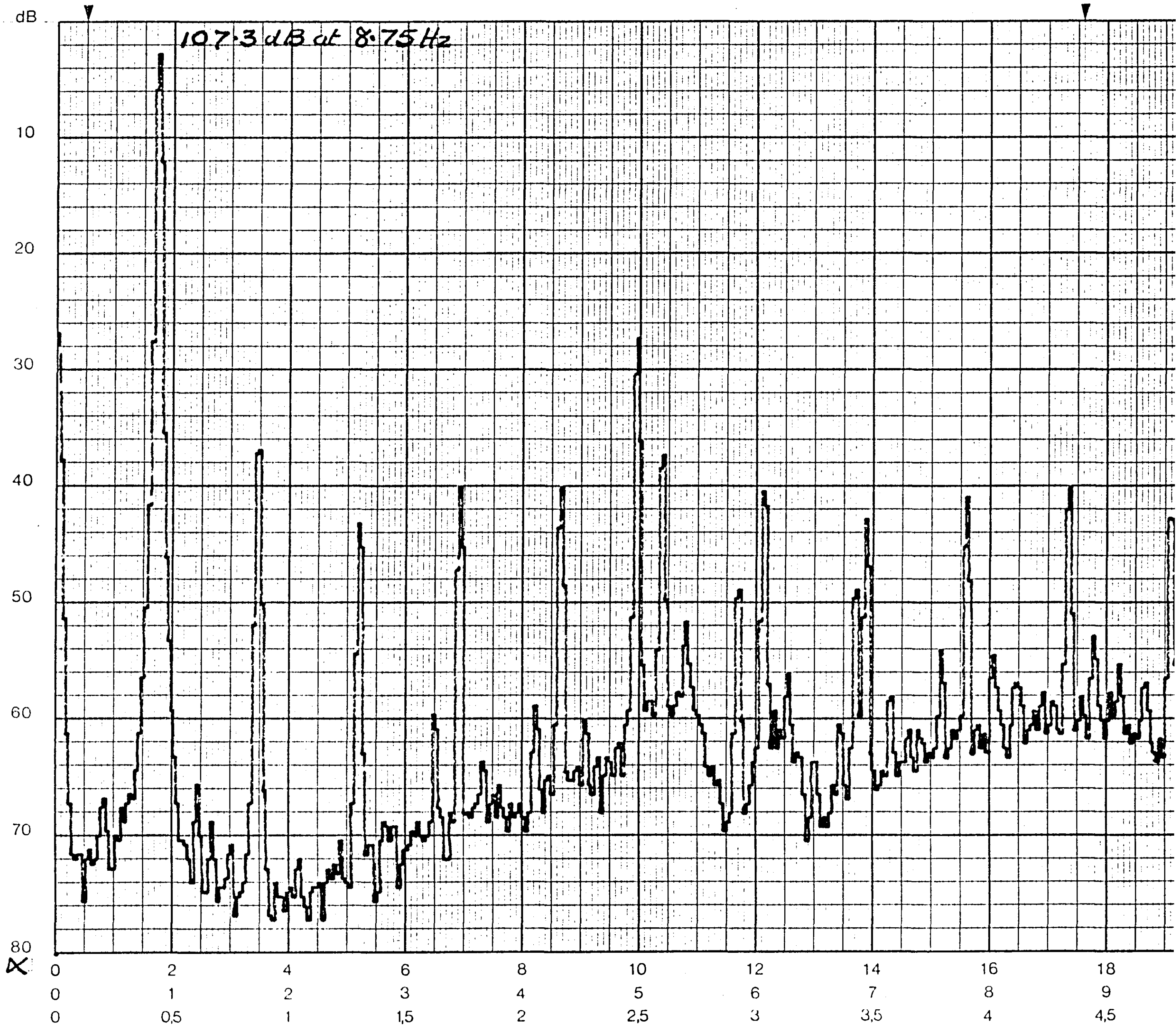
Measuring Object:

QP 1002

Brüel & Kjær Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 110
F. S. Frequency: 100
Weighting: Hanning
Average Mode: Lin
No. of Spectra: 10

Comments:
Schenk ram force (load)
ram ±1·5 mm at ≃ 8 Hz.
8·75 Hz = 107·3 dB



Record No.: Ram F: 10
Date: 15/6/84.
Sign.:

20 40 80 X

Measuring Object:

QP 1002

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expand

Full Scale Level: 110 dB

F. S. Frequency: 100

Weighting: Hanning

Average Mode: Lin

No. of Spectra: 1010

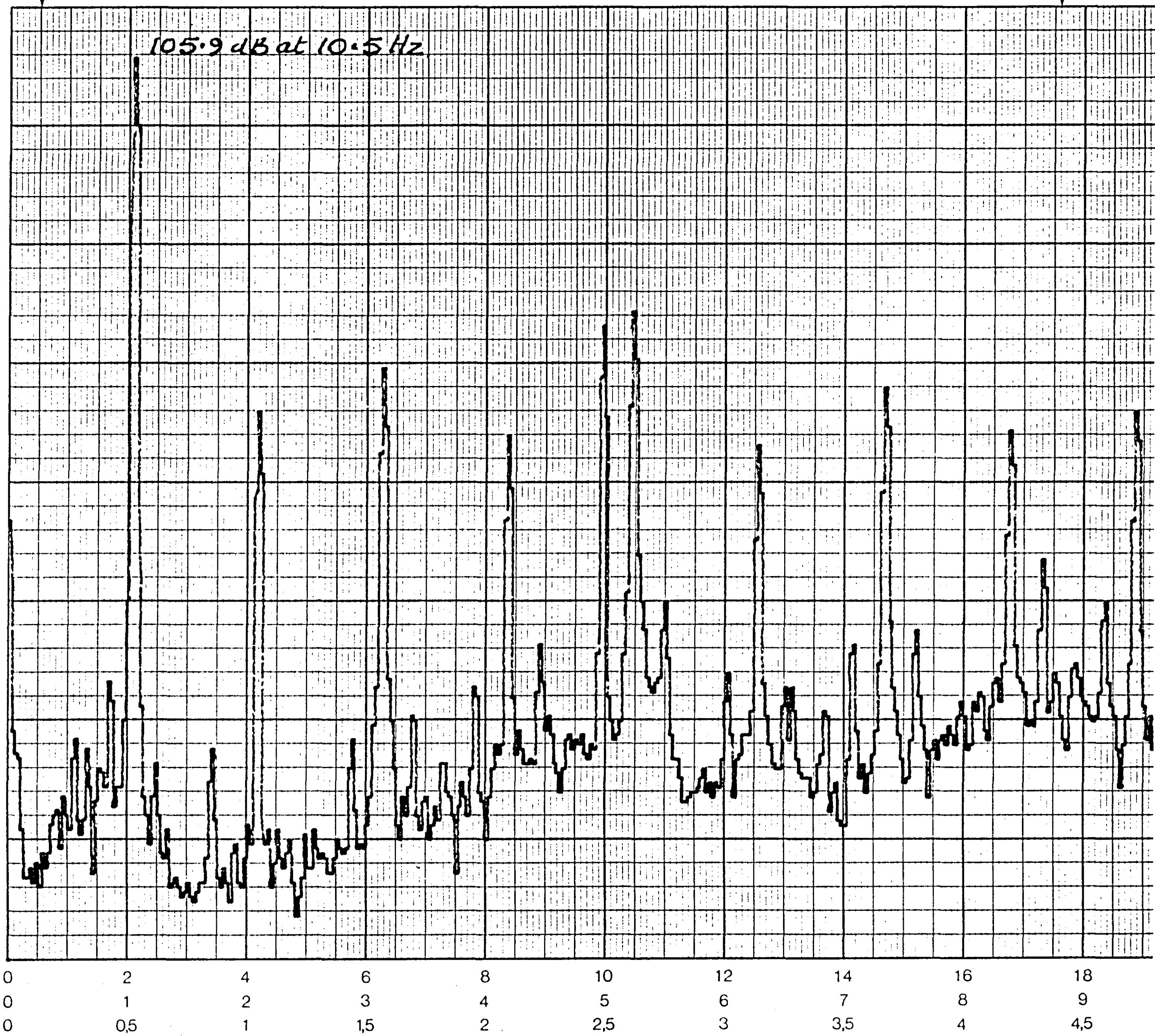
Comments:

Schenk ram force (load)

ram ±1·5mm at ≈10 Hz

10·5 Hz value = 105·9 dB

388



Record No. RamF: 11

Date: 15/6/84.

Sign.:

20 40 80

QP 1002

Measuring Object:

Brüel & Kjær

Time Function Start: seconds End: seconds Not Expanded: Expan

Full Scale Level: 110

F. S. Frequency: 100

Weighting: Hanning.

Average Mode: Lin

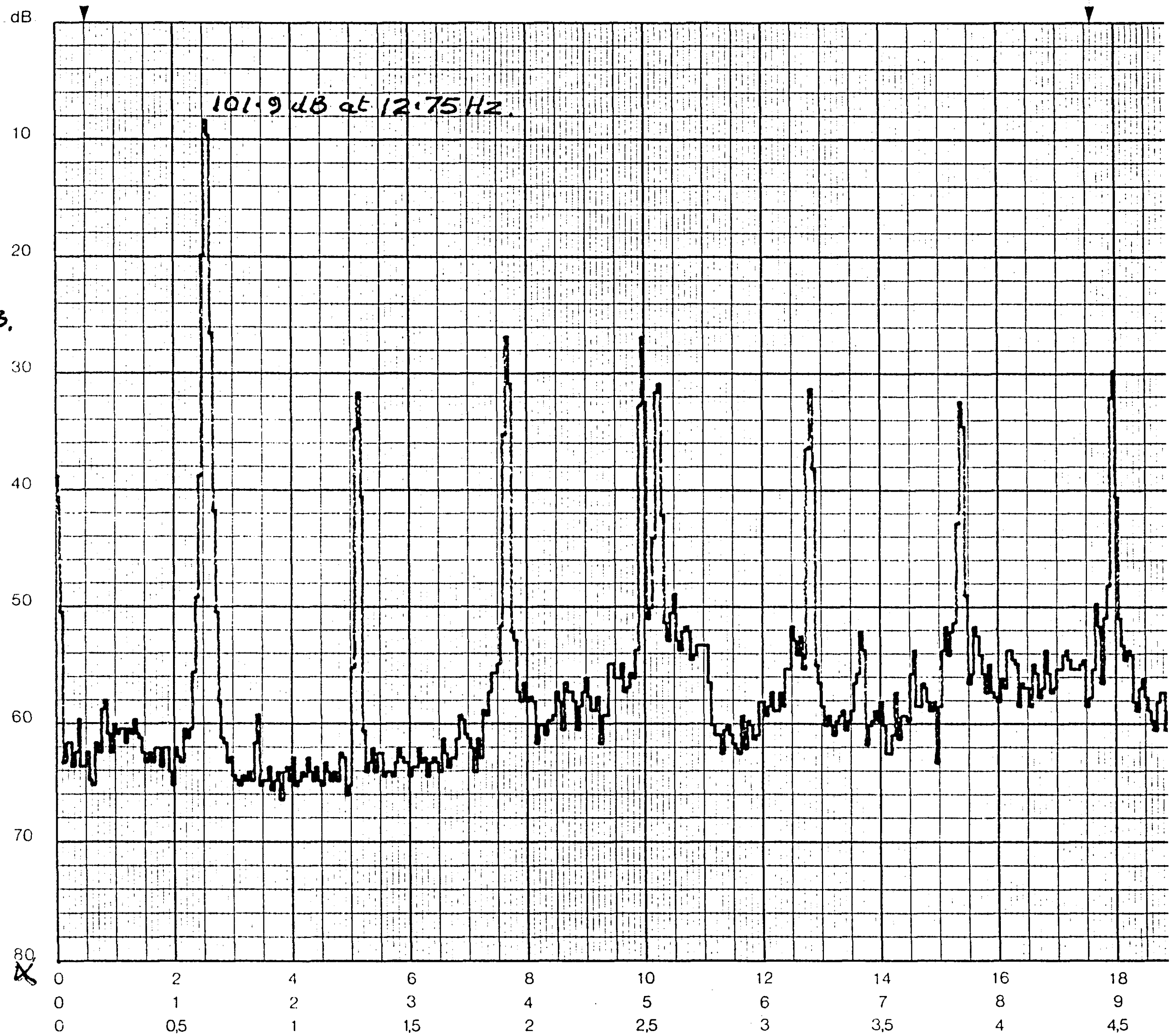
No. of Spectra: 10

Comments:

Schenk ram force (load)

ram $\pm 1{\cdot}5$mm at $\simeq 12{\cdot}5$Hz.

$12{\cdot}\cancel{7}5$ Hz value = $101{\cdot}9$ dB.



Record No.: Ram F: 12

Date: 15/6/84.

Sign.:

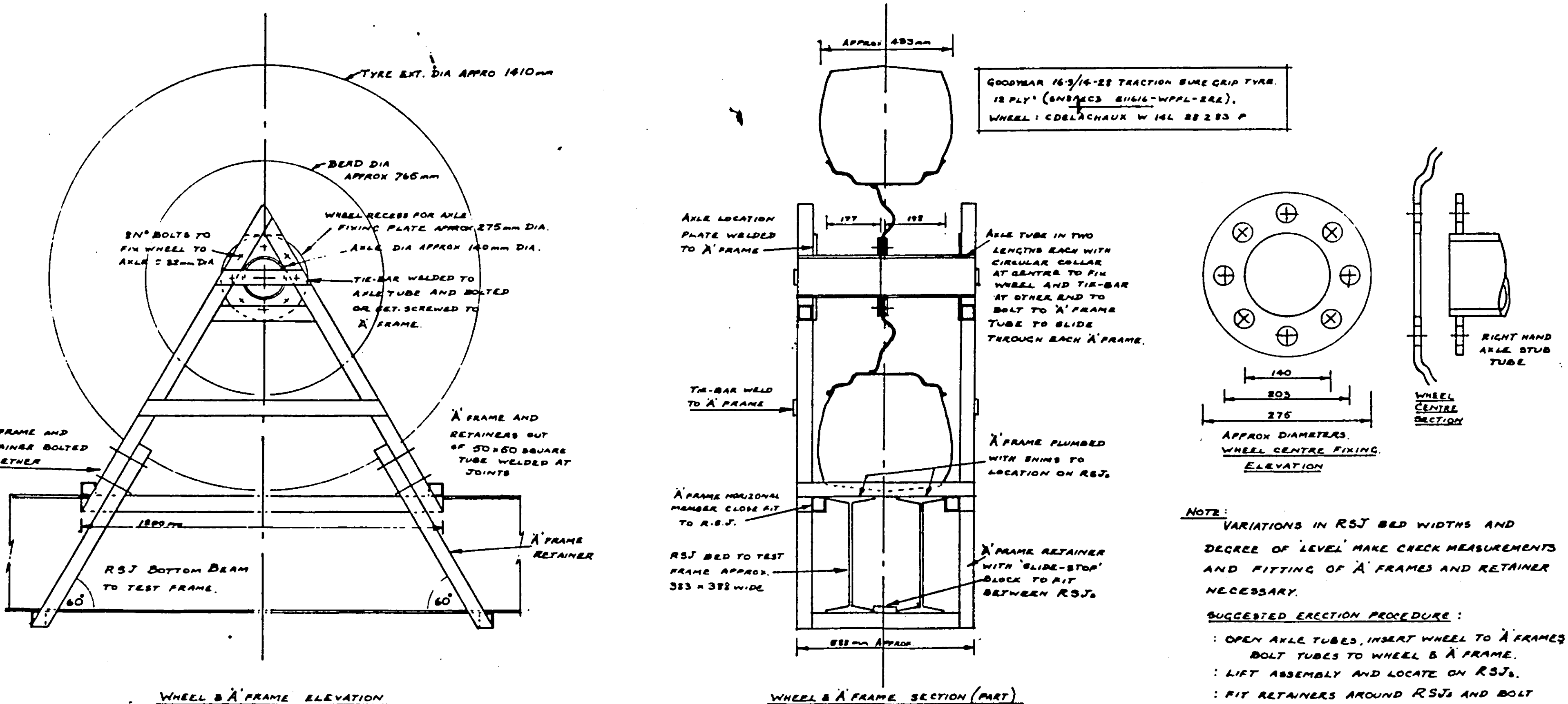
20 40 80

QP 1002

Measuring Object:

APPENDIX I

Drawing for the construction of the 'A' frame support to the drive wheel during static wheel tests.



NOTE: VARIATIONS IN RSJ BED WIDTHS AND DEGREE OF 'LEVEL' MAKE CHECK MEASUREMENTS AND FITTING OF 'A' FRAMES AND RETAINER NECESSARY.

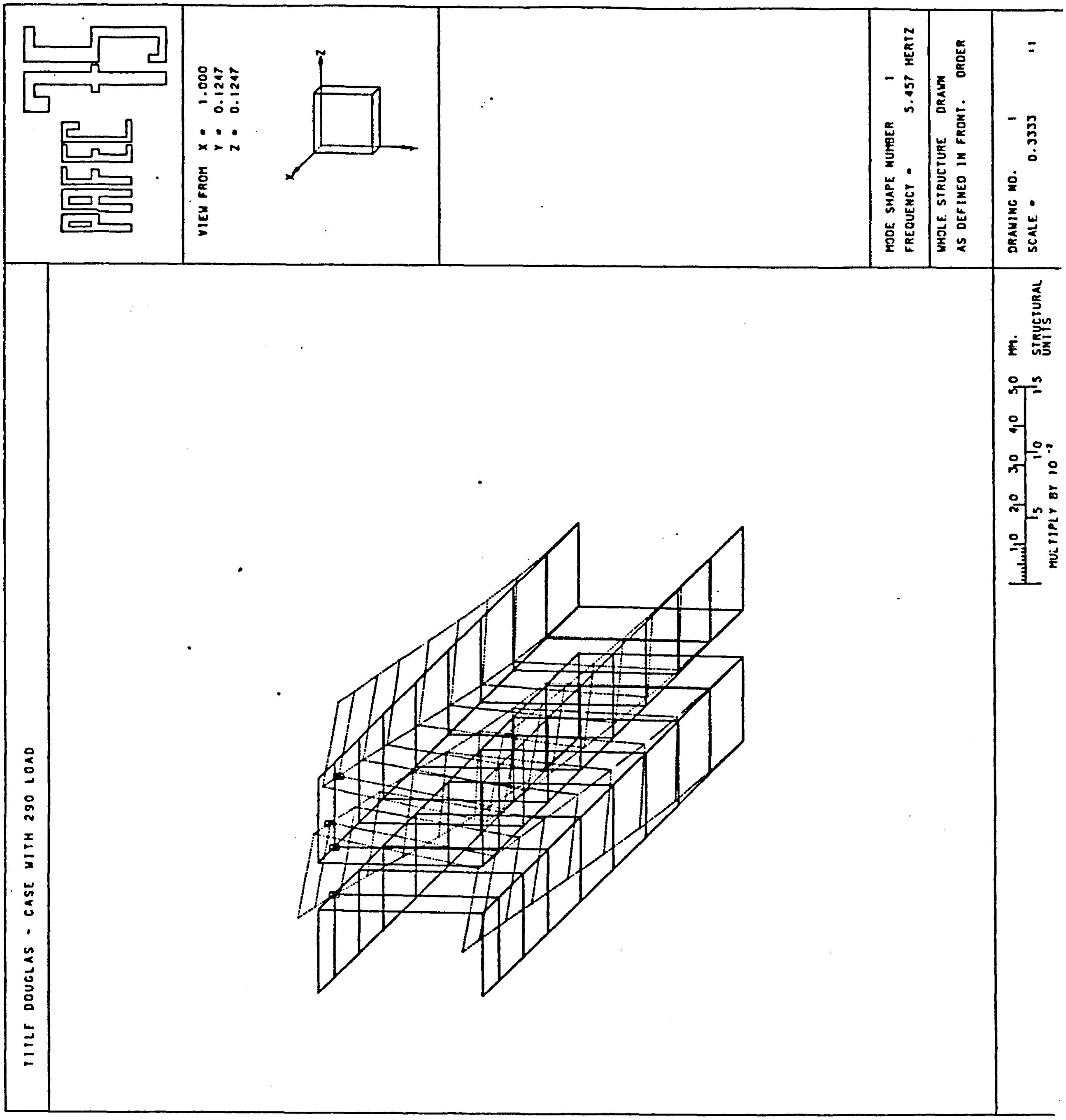
SUGGESTED ERECTION PROCEDURE :

: OPEN AXLE TUBES, INSERT WHEEL TO 'A' FRAMES BOLT TUBES TO WHEEL & 'A' FRAME.
: LIFT ASSEMBLY AND LOCATE ON RSJs.
: FIT RETAINERS AROUND RSJs AND BOLT TO 'A' FRAMES

D. DOUGLAS - DEPT. OF BUILDING — 'A' FRAME SUPPORT TO JCB 3CX DRIVE WHEEL FOR FREQUENCY RESPONSE TESTS. — NOV 1983.

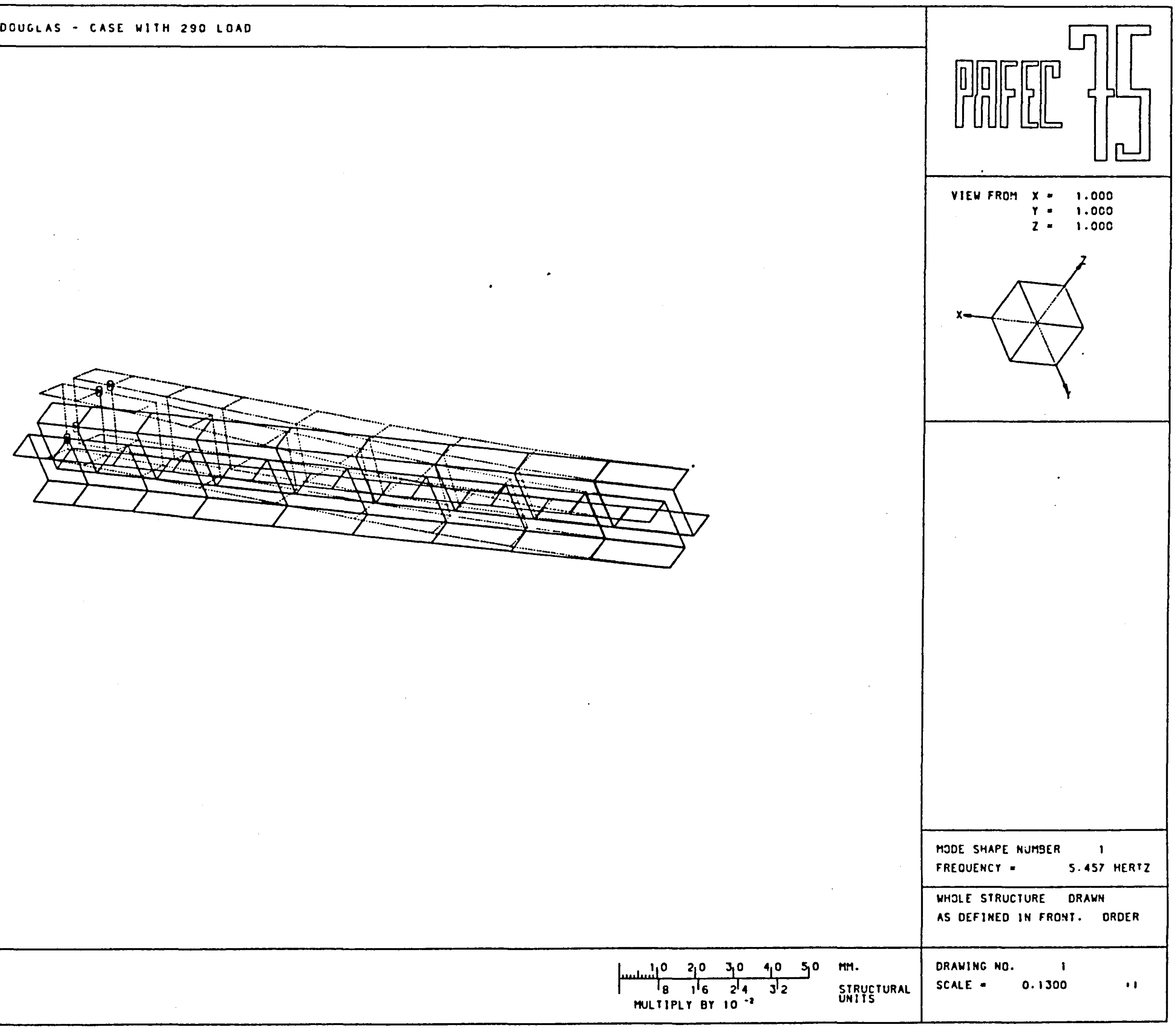
A P P E N D I X   J

Computer diagrams illustrating the first three frequency modes of the cantilever frame for drive wheel vibration response tests

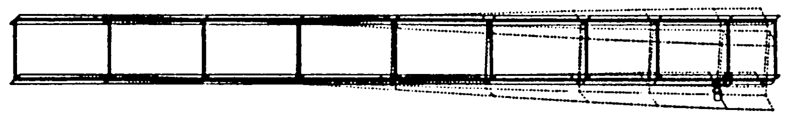


User E452 File GDOAGLAS CALCOMP plotted on 31/10/85 at 18:04:49
Plot file 5289 for GUNSON

TITLE DOUGLAS - CASE WITH 290 LOAD

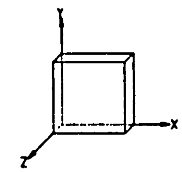


TITLE DOUGLAS - CASE WITH 290 LOAD



PAFEC 75

VIEW FROM X = 0.1247
Y = 0.1247
Z = 1.000



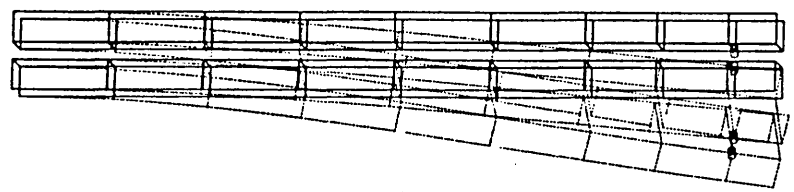
MODE SHAPE NUMBER 1
FREQUENCY = 5.457 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

10 20 30 40 50 MM.
1 2 3 4 5 STRUCTURAL UNITS
MULTIPLY BY 10 $^{-1}$

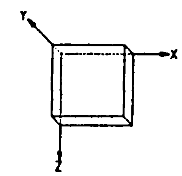
DRAWING NO. 1
SCALE = 0.1000 :1

TITLE DOUGLAS - CASE WITH 290 LOAD



PAFEC 75

VIEW FROM X = 0.1247
Y = 1.000
Z = 0.1247



MODE SHAPE NUMBER 1
FREQUENCY = 5.457 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

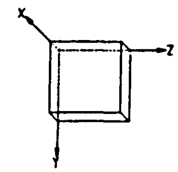
10 20 30 40 50 MM.
1 2 3 4 5 STRUCTURAL UNITS
MULTIPLY BY 10^{-1}

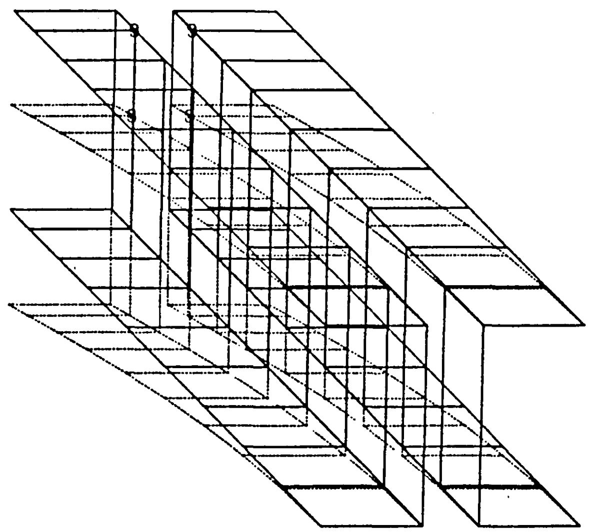
DRAWING NO. 1
SCALE = 0.1000 :1

TITLE DOUGLAS - CASE WITH 290 LOAD

PAFEC 75

VIEW FROM X = 1.000
Y = 0.1247
Z = 0.1247





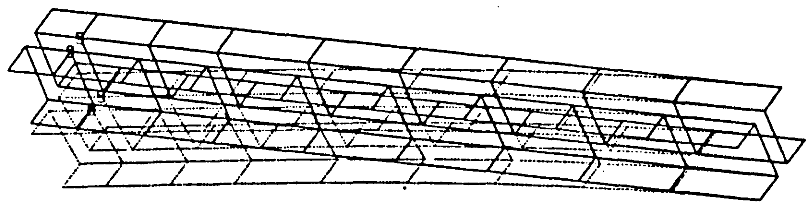
MODE SHAPE NUMBER 2
FREQUENCY = 11.79 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

10 20 30 40 50 MM.
5 10 15 STRUCTURAL UNITS
MULTIPLY BY 10^{-2}

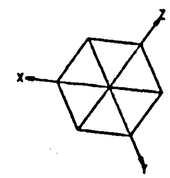
DRAWING NO. 2
SCALE = 0.3333 :1

TITLE DOUGLAS - CASE WITH 290 LOAD



PAFEC 75

VIEW FROM X = 1.00C
Y = 1.000
Z = 1.000



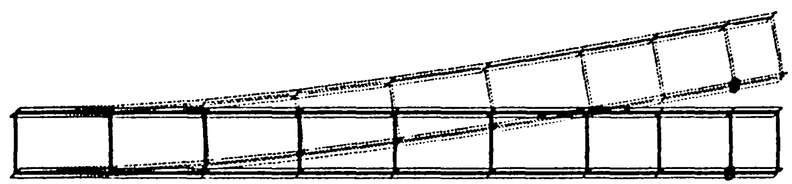
MODE SHAPE NUMBER 2
FREQUENCY = 11.79 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

10 20 30 40 50 MM.
8 16 24 32 STRUCTURAL UNITS
MULTIPLY BY 10 -1

DRAWING NO. 2
SCALE = 0.130C :1

TITLF DOUGLAS - CASE WITH 290 LOAD



PAFEC 75

VIEW FROM X = 0.1247
Y = 0.1247
Z = 1.000

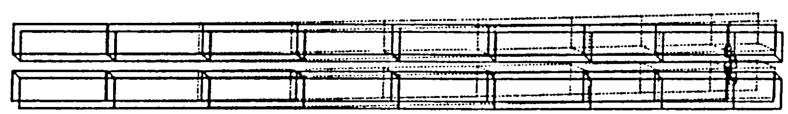
MODE SHAPE NUMBER 2
FREQUENCY = 11.79 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

DRAWING NO. 2
SCALE = 0.1000 :1

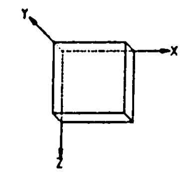
10 20 30 40 50 MM.
1 2 3 4 5 STRUCTURAL UNITS
MULTIPLY BY 10 $^{-1}$

TITLE DOUGLAS - CASE WITH 290 LOAD



PAFEC 75

VIEW FROM X = 0.1247
Y = 1.000
Z = 0.1247



MODE SHAPE NUMBER 2
FREQUENCY = 11.79 HERTZ

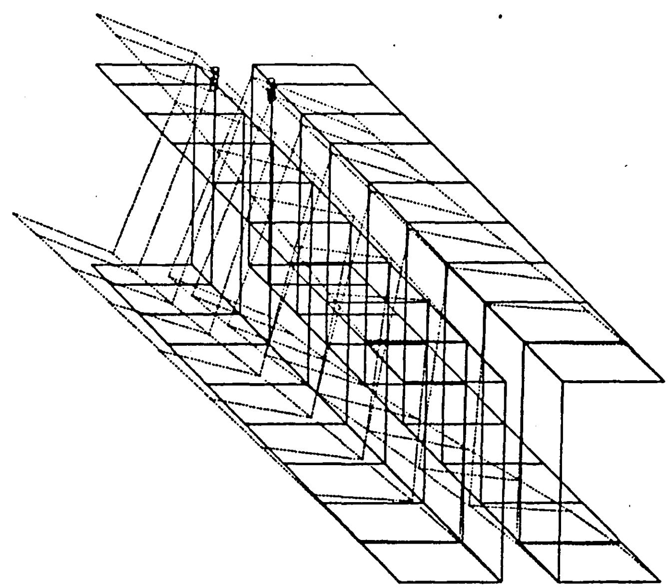
WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

1.0 2.0 3.0 4.0 5.0 MM.
1 2 3 4 5 STRUCTURAL UNITS
MULTIPLY BY 10 $^{-1}$

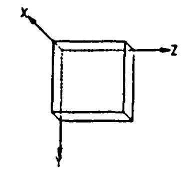
DRAWING NO. 2
SCALE = 0.1000 :1

TITLE DOUGLAS - CASE WITH 290 LOAD

PAFEC 75



VIEW FROM X = 1.000
Y = 0.1247
Z = 0.1247



MODE SHAPE NUMBER 3
FREQUENCY = 31.00 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

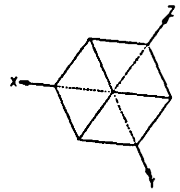
10 20 30 40 50 MM.
5 10 15 STRUCTURAL UNITS
MULTIPLY BY 10^{-2}

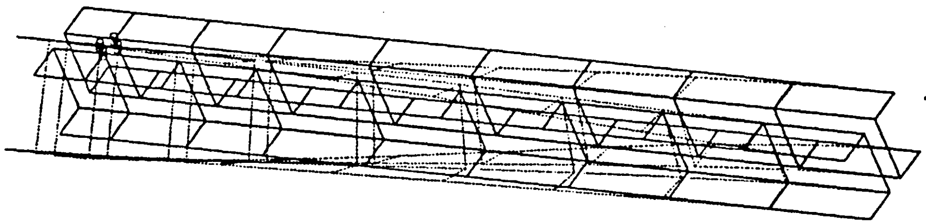
DRAWING NO. 3
SCALE = 0.3333 : 1

TITLE DOUGLAS - CASE WITH 290 LOAD

PAFEC 75

VIEW FROM X = 1.000
Y = 1.000
Z = 1.000





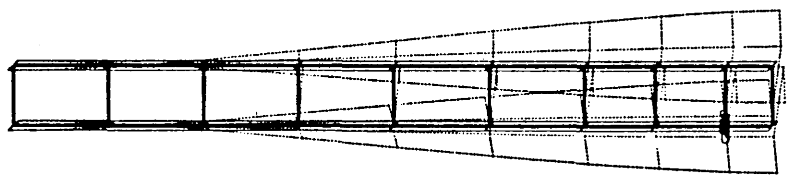
1.0 2.0 3.0 4.0 5.0 MM.
8 16 24 32 STRUCTURAL UNITS
MULTIPLY BY 10 $^{-2}$

MODE SHAPE NUMBER 3
FREQUENCY = 31.00 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

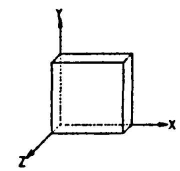
DRAWING NO. 3
SCALE = 0.1300

TITLF DOUGLAS - CASE WITH 290 LOAD



PAFEC 75

VIEW FROM X = 0.1247
Y = 0.1247
Z = 1.000

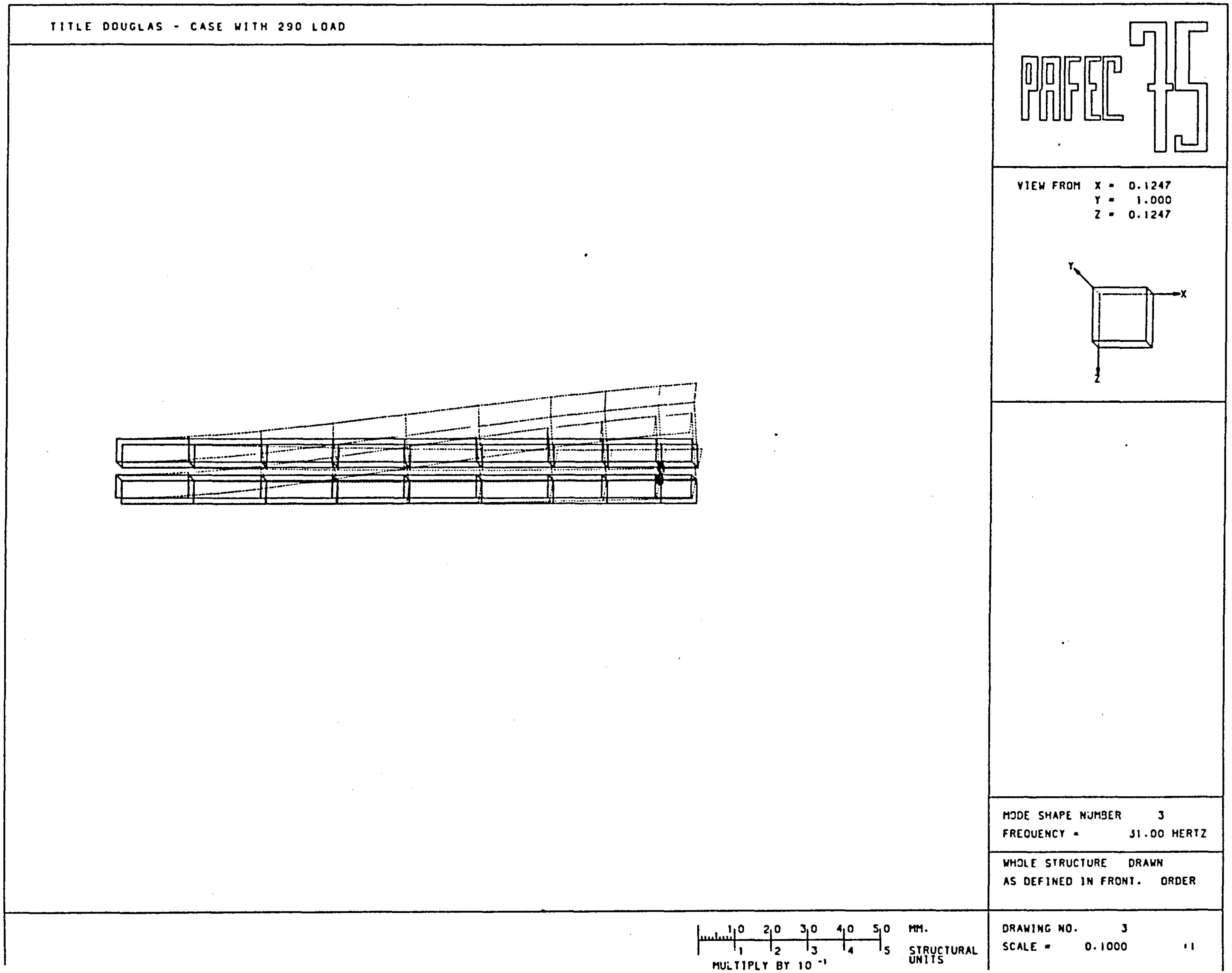


MODE SHAPE NUMBER 3
FREQUENCY = 31.00 HERTZ

WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER

10 20 30 40 50 MM.
1 2 3 4 5 STRUCTURAL UNITS
MULTIPLY BY 10 $^{-1}$

DRAWING NO. 3
SCALE = 0.1000 :1


TITLE DOUGLAS - CASE WITH 290 LOAD
PAFEC 75
VIEW FROM X = 0.1247
Y = 1.000
Z = 0.1247
Y
X
Z
MODE SHAPE NUMBER 3
FREQUENCY = 31.00 HERTZ
WHOLE STRUCTURE DRAWN
AS DEFINED IN FRONT. ORDER
DRAWING NO. 3
SCALE = 0.1000 :1
1.0 2.0 3.0 4.0 5.0 MM.
1 2 3 4 5 STRUCTURAL UNITS
MULTIPLY BY 10 -1

<u>A P P E N D I X   K</u>

Completed questionnaire sheets from the interviews with drivers of JCB 3C Excavator-Loader vehicles

D Douglas, Department of Building, Sheffield City Polytechnic

"Questionnaire to drivers of wheeled earth-moving vehicles concerning their awareness of and response to vibrations produced by the vehicles when travelling".

This questionnaire is part of a private research study towards the award of the degree, Master of Philosophy, from the Council for National Academic Awards. The necessary measurements of vibrations have been carried out and this final part is to ascertain and integrate the opinions of drivers concerning their assessment of comfort.

If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 3 years 6 months

(b) in your present employment; — years 4 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
		✓	✓		✓		

Ques 5 Is this disturbance still noticeable after you have finished work? *✓Yes __No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

10 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 2 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Reference to Questions 5 & 6: the effect is noticeable but only for a short time with this vehicle (newer than most he has driven). The driver can get quite a shaking from some of the older (more used) machines.

Thank you for your time and assistance.

D Douglas

D Douglas

D Douglas, Department of Building, Sheffield City Polytechnic

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 3 years 6 months

(b) in your present employment; — years 6 months

Ques 2 On average, how many days each week do you drive such a vehicle? 3 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ~~No~~

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
		✓		✓			

Ques 5 Is this disturbance still noticeable after you have finished work? * ~~Yes~~ No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

____ minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 5 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Thank you for your time and assistance.

D Douglas

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 6 years __ months

(b) in your present employment; __ years 2 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
	✓				✓	✓	✓

Ques 5 Is this disturbance still noticeable after you have finished work? *__Yes ✓ __No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

30 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. NEW TO 3 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Thank you for your time and assistance.

D Douglas

D. Douglas

D Douglas, Department of Building, Sheffield City Polytechnic

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 6 years 3 months

(b) in your present employment; 6 years 3 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
	✓	✓		✓	✓		

Ques 5 Is this disturbance still noticeable after you have finished work? *✓ Yes __ No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

15 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. NEW – 3 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

certain tests which are carried out push the machine harder than it would normally work, thus exagerating some of the effe listed overleaf.

Thank you for your time and assistance.

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 6 years 5 months

(b) in your present employment; 6 years 5 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
	✓			✓	✓		

Ques 5 Is this disturbance still noticeable after you have finished work? *✓Yes __No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

VARIES. minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. NEW TO 3 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Note Ref. Question three.
As a test driver using different machines daily, with various types of seats. I find a well sprung seat does not have such a disturbing effect on the body as a more solid type of seat.

Thank you for your time and assistance.

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 8 years 6 months

(b) in your present employment; 3 years — months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ~~No~~

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck ✓	Shoulders ✓	Arms	Back ✓	Stomach	Hips	Legs

Ques 5 Is this disturbance still noticeable after you have finished work? * Yes ✓ ~~No~~

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

10 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 5 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

The effect of the rough ride lasts just a short time, it's something you get used to driving this type of machine.

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 8 years 9 months

(b) in your present employment; 6 years 3 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck ✓	Shoulders ✓	Arms	Back	Stomach ✓	Hips	Legs

Ques 5 Is this disturbance still noticeable after you have finished work? * ✓ Yes __ No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

15 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 4 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Driver's comment: The ride is a bit rough at times and it makes the shoulders ache. It takes about 15 mins or so to lose the feeling after work.

Thank you for your time and assistance.

D Douglas

D Douglas

D Douglas, Department of Building, Sheffield City Polytechnic

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 10 years – months

(b) in your present employment; 2 years – months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
	✓	✓	✓				

Ques 5 Is this disturbance still noticeable after you have finished work? *✓ Yes __ No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

30 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 5 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Driver considered that the vehicle bounced too much when travelling over rough ground.

Thank you for your time and assistance.

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 12 years __ months

(b) in your present employment; 10 years 3 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

	✓			✓	✓	✓	
Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs

Ques 5 Is this disturbance still noticeable after you have finished work? *__Yes __No ✓

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

_____ minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. __3__ years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Thank you for your time and assistance.

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 12 years 3 months

(b) in your present employment; 5 years 6 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ~~No~~

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck ✓	Shoulders ✓	Arms	Back	Stomach ✓	Hips	Legs

Ques 5 Is this disturbance still noticeable after you have finished work? *__Yes ~~No~~

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

(say) 15 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 5 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Driver's observations - "you get a lot of bounce from the rear end which shakes-up your body - your stomach, and shoulders and neck. You get used to it after a while but it's always noticable - lasts sometime 10 mins, sometimes 20 mins afterwards - but you get used to it."

Thank you for your time and assistance.

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 12 years 6 months

(b) in your present employment; 4 years 9 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
	✓	✓		✓	✓		

Ques 5 Is this disturbance still noticeable after you have finished work? *Yes ✓ No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

10/15 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 3 to 5 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Driver's observation: a driver has to expect some vibration from these vehicles; the vibration is generally in the body but sometimes it is felt in the legs - that is mainly when digging though.

Thank you for your time and assistance.

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 12 years 6 months

(b) in your present employment; 4 years 3 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck ✓	Shoulders ✓	Arms	Back ✓	Stomach ✓	Hips	Legs

Ques 5 Is this disturbance still noticeable after you have finished work? * Yes ✓ No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

10 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 3 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Thank you for your time and assistance.

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 15 years – months

(b) in your present employment; 8 years – months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
	✓	✓	✓				

Ques 5 Is this disturbance still noticeable after you have finished work? * Yes ✓ No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

15 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 3 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Driver's observation: a driver is sure to get some vibration being seated over the large wheels, there is quite a lot of bounce from these wheels.

Thank you for your time and assistance.

D Douglas

D Douglas

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 16 years __ months

(b) in your present employment; __ years 2 months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head	Neck	Shoulders	Arms	Back	Stomach	Hips	Legs
	✓			✓	✓		✓

Ques 5 Is this disturbance still noticeable after you have finished work? *__Yes __No ✓

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

_____ minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. NEW TO __3__ years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Thank you for your time and assistance.

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If you will take a few minutes of your time to answer the following questions for me I shall be most grateful.

Ques 1 How long have you been employed to drive wheeled earth-moving vehicles?

(a) in total: 18 years – months

(b) in your present employment; 5 years – months

Ques 2 On average, how many days each week do you drive such a vehicle? 5 days per week

Ques 3 When the vehicle is being driven forwards or backwards do you notice any unpleasant effects from the movement? *Yes ✓ No

Ques 4 If the answer to Ques 3 is 'Yes' please indicate (by a ✓) which of the following parts of your body this disturbance most noticeably effects.

Head ✓	Neck ✓	Shoulders ✓	Arms	Back	Stomach	Hips	Legs

Ques 5 Is this disturbance still noticeable after you have finished work? *__Yes ✓ __No

Ques 6 If the answer to Ques 5 is 'Yes' please state the length of time (eg 10 mins, 30 mins etc).

20 minutes

Ques 7 Please state the approximate age of the vehicle which you drive most often. 3 years.

Ques 8 If you have any observations concerning the 'ride-comfort' of these vehicles which are not covered by the above questions, or you wish to add notes about any of your answers, please list them overpage.

*Please tick (✓) the appropriate answer.

Observations and/or Notes

Driver observed that neck ache was most noticeable after a day's work on rubber-tyred vehicles. He considered that he was liable to get neck and shoulder ache much more readily now than when he first started driving the vehicles.

Thank you for your time and assistance.

D Douglas

D Douglas