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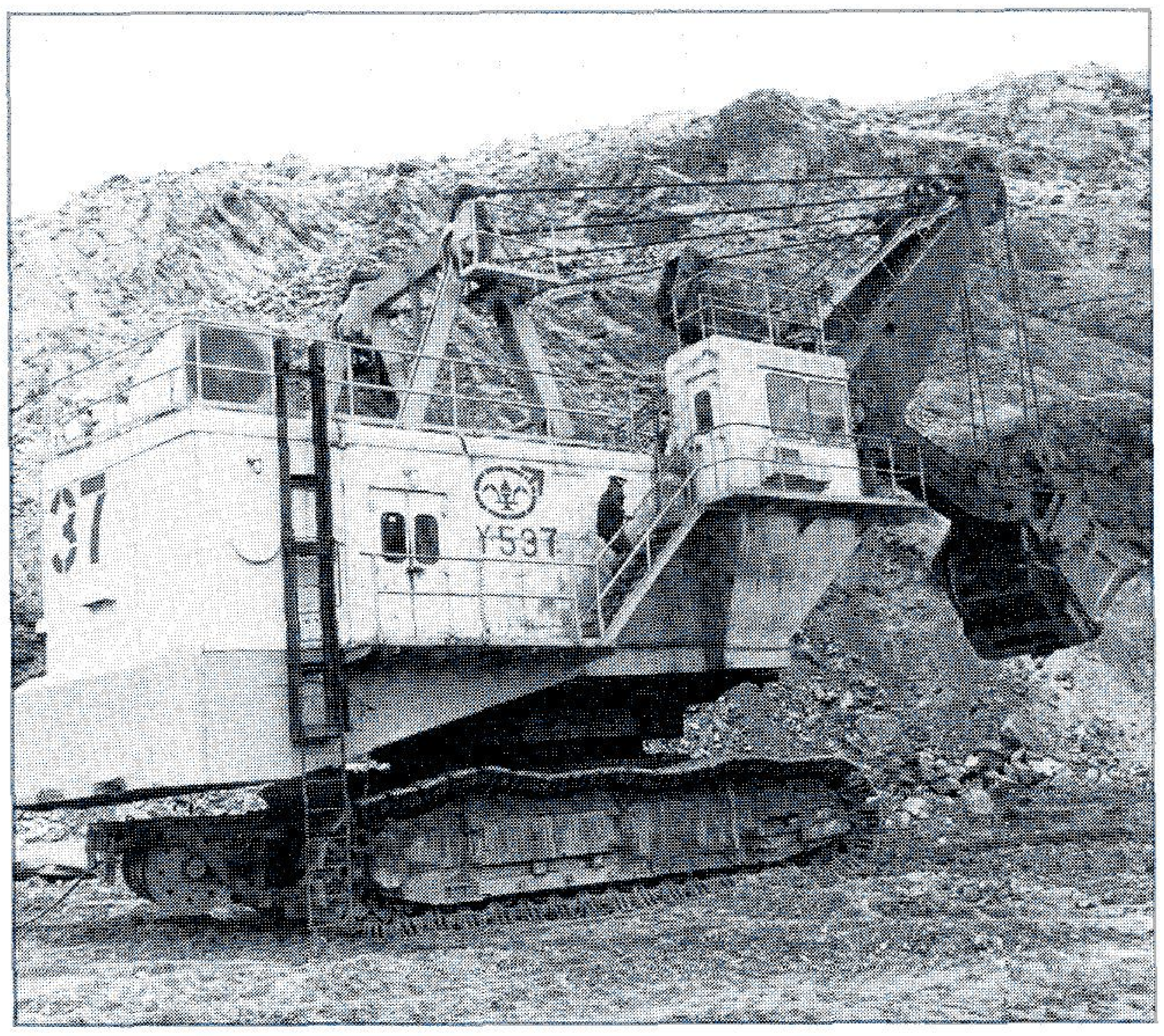
Machine-Condition Monitoring Using Vibration Analysis

A Case Study from an Iron-Ore Mine



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Machine-Condition Monitoring using Vibration Analysis

A Case Study from an Iron-Ore Mine

by *D.N.Brown & J.C.Jørgensen*
Brüel & Kjær

Introduction

Within the mining industry an increasing trend in equipment design towards larger, more complex and more productive units is being experienced. As equipment grows in both size and capital cost, so downtime reflects not only in increasing maintenance costs, but also in greater loss of production by an idle unit. This has resulted, therefore, in an increasing interest in maintenance schemes that allow maximum operating life. The one viable solution to this is *predictive maintenance* – measuring machine condition and repairing when and only when measurements indicate it necessary.

This Application Note details one such predictive maintenance scheme, at the Quebec Cartier Mine at Mount Wright, Canada. Here, vibration monitoring is being successfully employed in a number of the vital phases of the mining operation, with some impressive results.

On the **shovels** used for ore excavation, the condition of the motor-generator set, the hoist and swing transmission, and the hoist's Magnetorque® drive are monitored. On the **haulage trucks** used for transporting the ore to the primary crushing plant, the monitoring programme covers the diesel engine and generator. In the mine's **concentrator**, the autogeneous mills, pumps and conveyors are covered.

A detailed description of the monitoring programme at the Mount Wright mine is given here, together with a number of examples where vibration monitoring has been successfully used to detect and diagnose faults.

Vibration monitoring at the mine has resulted in considerable savings in plant maintenance costs. Several faults detected by the system, in particular those on the trucks, would have caused considerable damage had they not been discovered. After these encouraging results, a decision has been made by the maintenance section to intensify the monitoring programme to cover other critical plant-machinery. This programme will include, amongst others, monitoring of the blasthole rotary-drilling units, and increasing activity in monitoring of the ancillary equipment in the concentrator plant.

The Mine

The Quebec Cartier Mine at Mount Wright lies on the Quebec-Labrador Trough in Northern Canada and produces some 16 million tons of iron ore per year. The Mount Wright mine is an open-pit development 6400 m long by 1220 m wide and will ultimately sink 300 m below ground level. There are 1000 employed at the mine which has been in operation since 1976.

The Mining Process

After blasting, electric shovels load the broken rock onto diesel-electric trucks, which carry the ore to the mine's processing plant. The crude ore from the mine is primarily low-grade, requiring crushing and concentrating to remove waste. Two gyratory crushers reduce the ore to approximately 20 cm, which is then conveyed to silos that feed the concentrator. The concentrator consists of six cascade-type autogeneous grinding mills, spirals to separate the ground ore into concentrate and tailings, screens, and a large number of pumps and conveyors that move the ore through the various processing stages. The end product from the concentrator is a concentrate containing approximately 66,5% iron.

The Vibration Monitoring Programme

The vibration monitoring programme began in 1980 with the purchase of a Brüel & Kjær Type 3517 Portable Balancing and Analyzing Set. This set was successfully used to monitor the condition of a number of machines. It allowed the maintenance engineers to become familiar with vibration monitoring, and to obtain experience with the vibration signatures and their relevance for each type of monitored machine.

In particular, the 3517 was used on truck engines to look for engine/generator misalignment and bad mounting of the engine sub-frame. In one specific application, the 3517 was also used for evaluating the suspension of the trucks. On the shovels, the 3517 was used for checking misalignment and unbalance of the electric motors.

As experience with the system was gained, the number of monitored machines was increased, and more and more reliance was placed on the vibration monitoring programme. This culminated in the programme being upgraded in 1985 to a desk-top computer based system, capable of automatically detecting faults from vibration data recorded on tape. The system has powerful fault-diagnostic facilities and is capable of handling and storing large amounts of data.

The Computer-Based Monitoring System

A layout of this system is shown in Fig. 1. The system consists of a number of Accelerometers Type 4384, two Tape Recorders Type 7007, a High Resolution Signal Analyzer Type 2033, and software WT 9114 running on a Desk-Top Computer. A Type 2516 hand-held Vibration Meter is also available for spot-checking machine condition.

Recording Vibration Data

Vibration data is first recorded on tape from accelerometers attached to the machines. Where necessary, blocks were welded onto the monitored machines to assist measuring. This allows measurements to be easily made in the horizontal, vertical and axial directions, which can then be recorded simultaneously onto the tape recorder. The vibration signals, once recorded, can be analyzed back in the office by the Type 2033 FFT Analyzer under control of the computer.

Detecting Faults

Each machine has its own characteristic vibration signature, which can be obtained by looking at a frequency spectrum of the recorded vibration signal. Therefore, by regularly measuring vibration and comparing the machine's "current" frequency spectrum with its "original condition" ref-

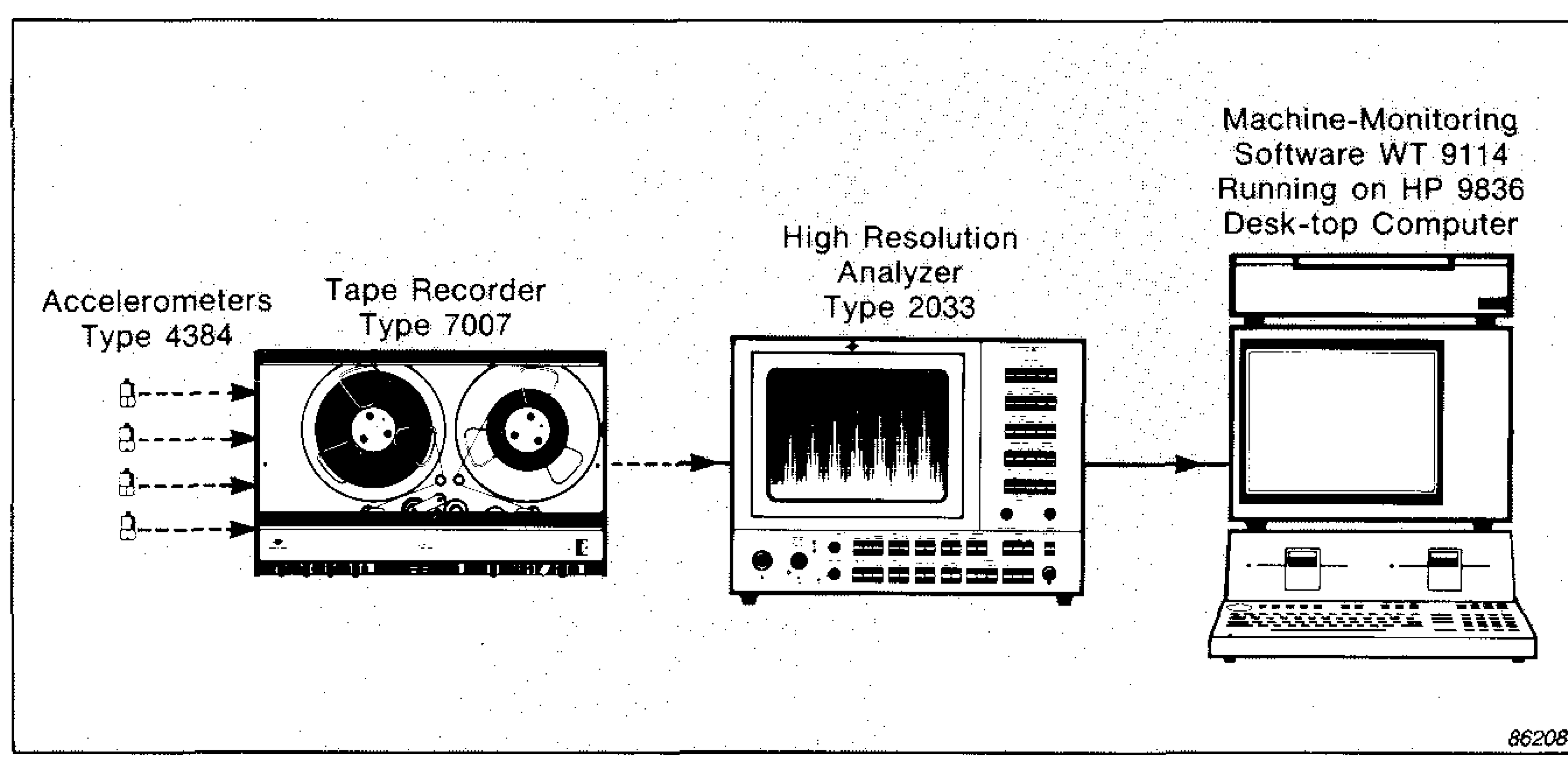

Fig. 1. Schematic layout of the monitoring system

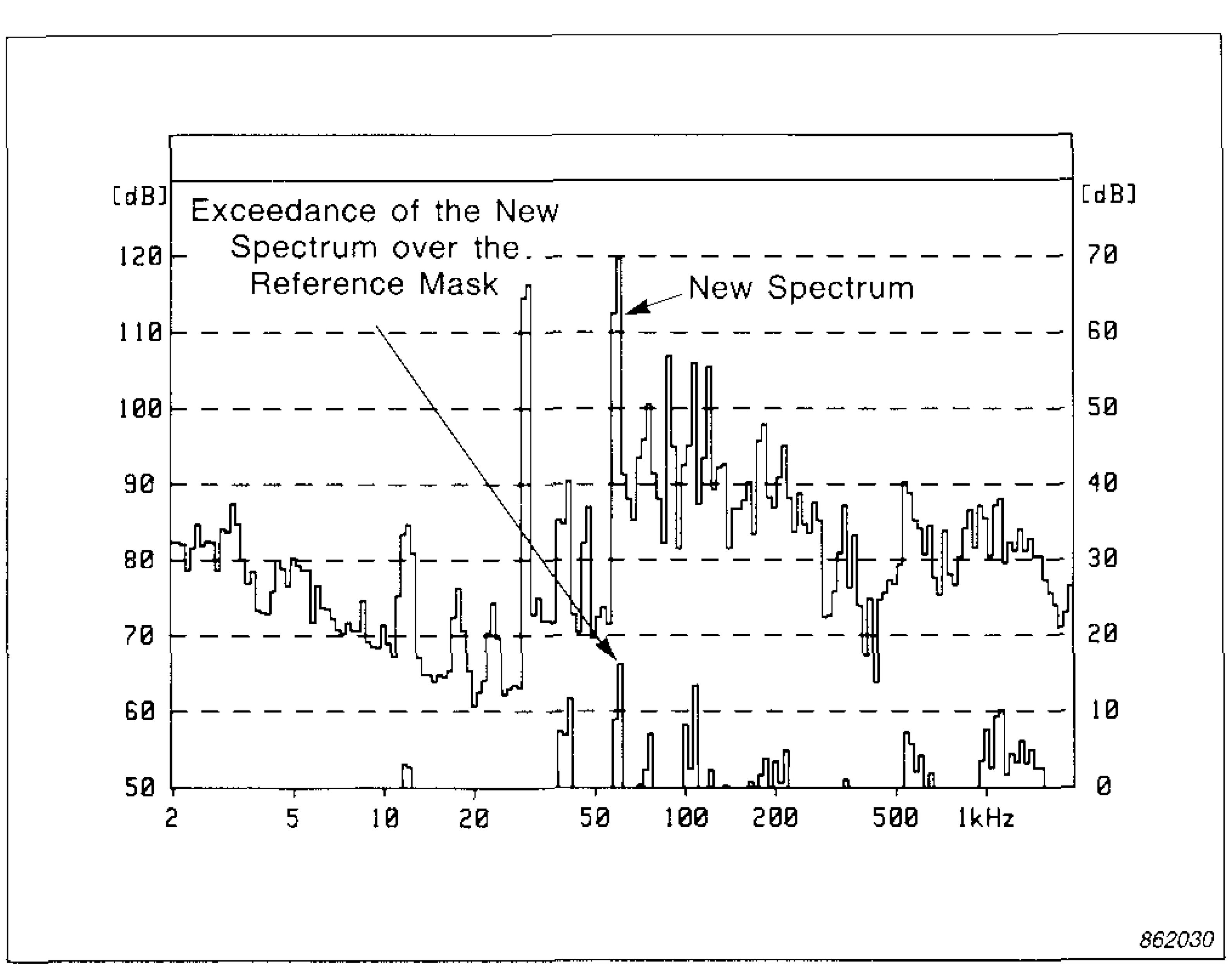

Fig. 2. An example of the log.-frequency scaled spectrum used for fault detection. The upper curve shows the current vibration spectrum, and the lower the frequency components from the current spectrum that have exceeded the reference spectrum

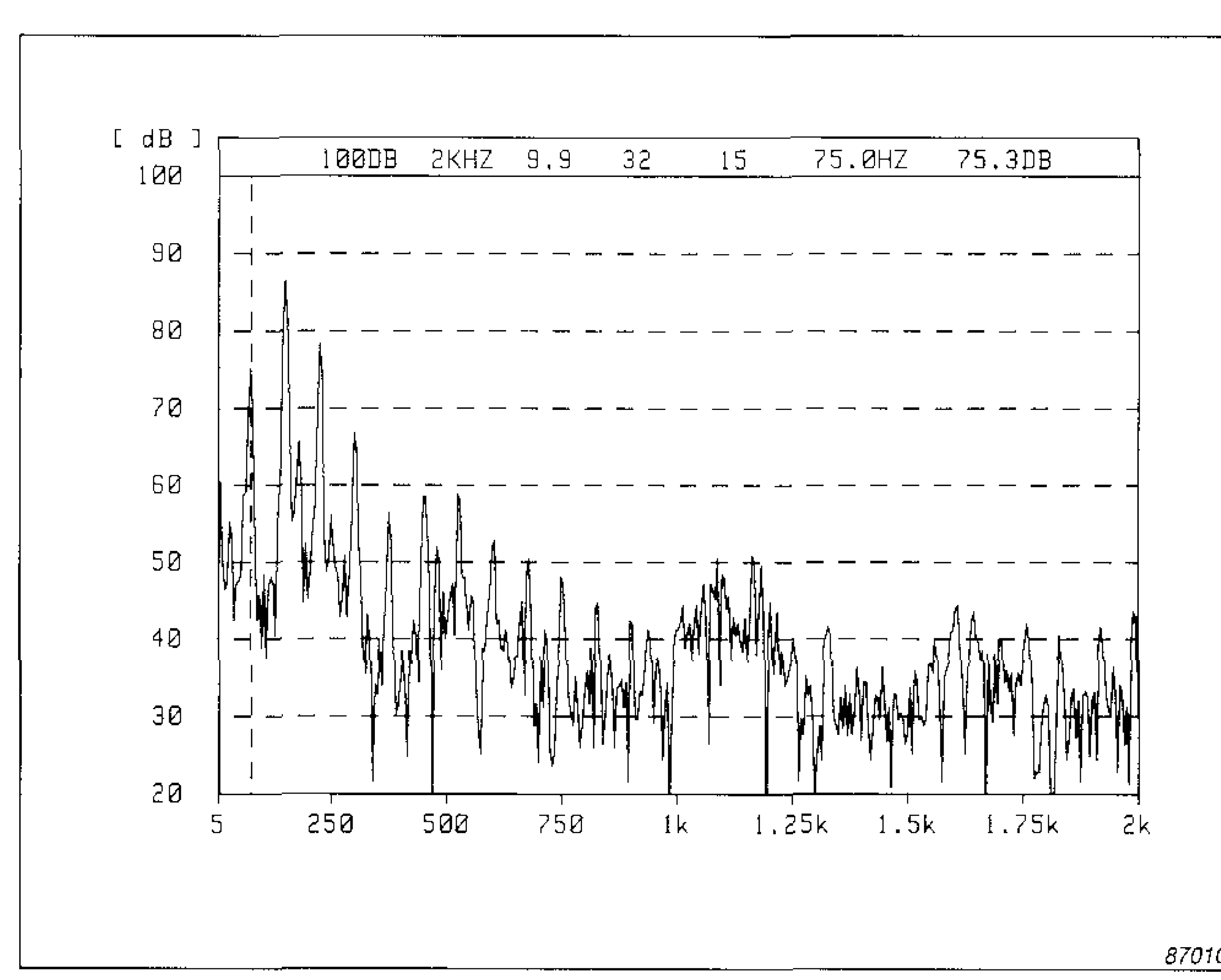

Fig. 3. An example of a narrowband spectrum used for fault diagnosis. The high resolution of the analyzer enables each frequency component to be accurately identified and matched to specific machine phenomena

erence spectrum, changes in the condition of the machine will be revealed. Fig. 2 shows an example of this fault detection procedure. The upper curve is the current spectrum, and the lower is the amount by how much the current spectrum has exceeded the reference spectrum.

The system further takes care of any speed changes that may occur between measurements, which could otherwise invalidate the spectrum comparison.

The technician who makes the tape recordings also makes the spectrum comparison. To carry out this spectrum comparison, all he has to do is replay the vibration data into the analyzer, call up the appropriate reference spectrum and execute the comparison program. Any increases will be automatically reported.

The maintenance engineers at the mine have built up considerable experience with both use of the system and of the vibration-characteristics of each monitored machine. This enables them to judge machine condition from a quick glance at the spectrum, and to place absolute vibration limits on particular machine parts.

High Fault-Detection Resolution

To enable the full range of faults to be detected, both high- and low-frequency components have to be displayed *in a single spectrum* with the same frequency-resolution. To enable this, the frequency spectrum used for the spectrum comparison is logarithmically scaled. In this type of format, the frequency resolution at a particular frequency is a percentage of the frequency concerned, allowing faults to be detected over a three decade frequency range.

Trend Analysis

As machine condition worsens, so the development of an increasing frequency component (or frequency range) over time can be seen using a trend analysis plot. A prediction is given of the time remaining before a pre-defined "danger" level is reached. Suspect points on the graph can be excluded from the prediction to gain a more accurate trend curve.

To obtain the best frequency range to trend on, the use of the **3–Dimensional Plot** facility can be employed. This feature shows how the pattern of frequency increases has been changing over time.

Fault Diagnosis

The high-powered fault diagnostic facilities of the system enable suspect faults to be pin-pointed to a specific machine component. These diagnostic facilities include narrowband zoom-analysis, cepstrum analysis, and sideband and harmonic cursors. An example of a narrowband spectrum is shown in Fig. 3.

Shovel Vibration Monitoring

There are a total of 13 electrically-powered shovels in operation at the mine, each with a 15 m^3 bucket capacity. These comprise; Bucyrus–Erie 295 B and 195 B1, P&H 2100 BL and Marion 201 M.

At present the shovel availability is approximately 65%. Vibration monitoring has played a major part in maintaining this high level, as just one year ago the availability was 45%. The main problems encountered are with the motor-generator (MG) Set which, at costs in the region of $250 000 for replacement and $100 000 for repair, represents a potentially considerable maintenance cost.

The monitoring programme for the shovels covers the following items:

Motor-Generator (MG) Set – unbalance and misalignment problems;
Hoist and Swing Transmission – gear and bearing problems;
Hoist Magnetorque® Drive – unbalance, bearing and operation problems.

Motor-Generator Set Measurement Programme

The MG-Set contains the main AC motor and the DC generators for the swing, hoist, crowd and propel motion. Problems due to unbalance and instal-

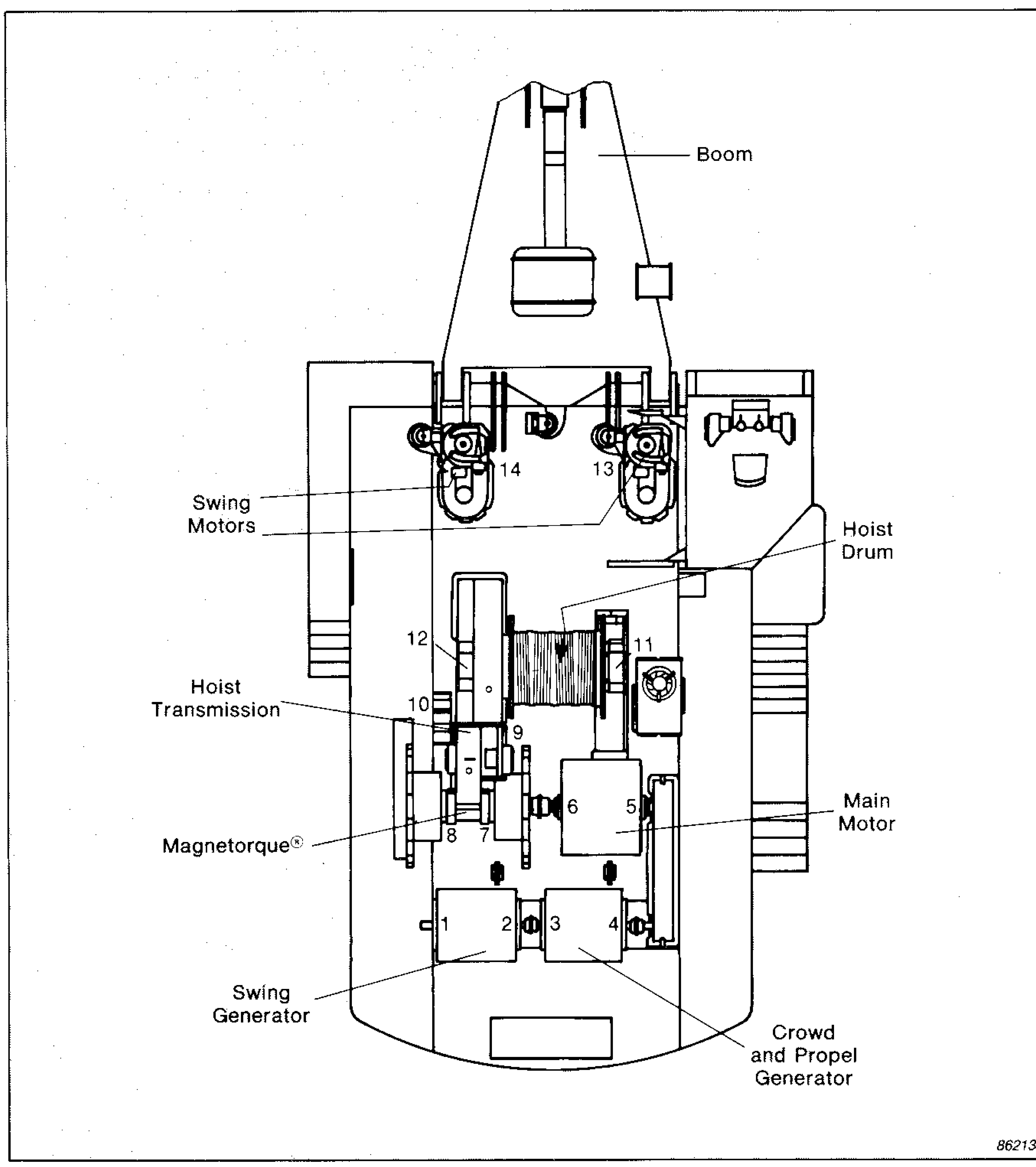

Fig. 4. Top view of the P&H shovels showing the measurement points used

lation- and progressive-misalignment are quite common, resulting in excessive wear and leading to a reduced operating life.

Figs. 4 and 5 show the measurement points on the two types of MG-Sets found in the shovels. Vibration measurements are first made on a new or reconditioned MG-set when it is in the maintenance shop, prior to fitting in the shovel. A reference spectrum for comparison is then recorded. Immediately after installation in the shovel another reference spectrum is recorded (this is to check for installation problems, usually misalignment, and sometimes transportation problems). Measurements are then made on the MG-Set every 1000 to 1200 hours, and spectrum comparisons made with both the reference spectra (although the measurement interval is now being decreased to every 600 hours to obtain more results for better trend analysis).

After spectrum comparison, the vibration levels of any increasing frequency components are checked against those in a standard and repairs are carried out if necessary. This standard has been drawn up from experience with the shovels and usually an increase of 20 dB is taken to indicate that immediate action is needed. If a problem is found and the levels are high, then the fault is immediately corrected. However, if the fault is only just beginning to develop, then this is recorded and a close watch kept on the component in future.

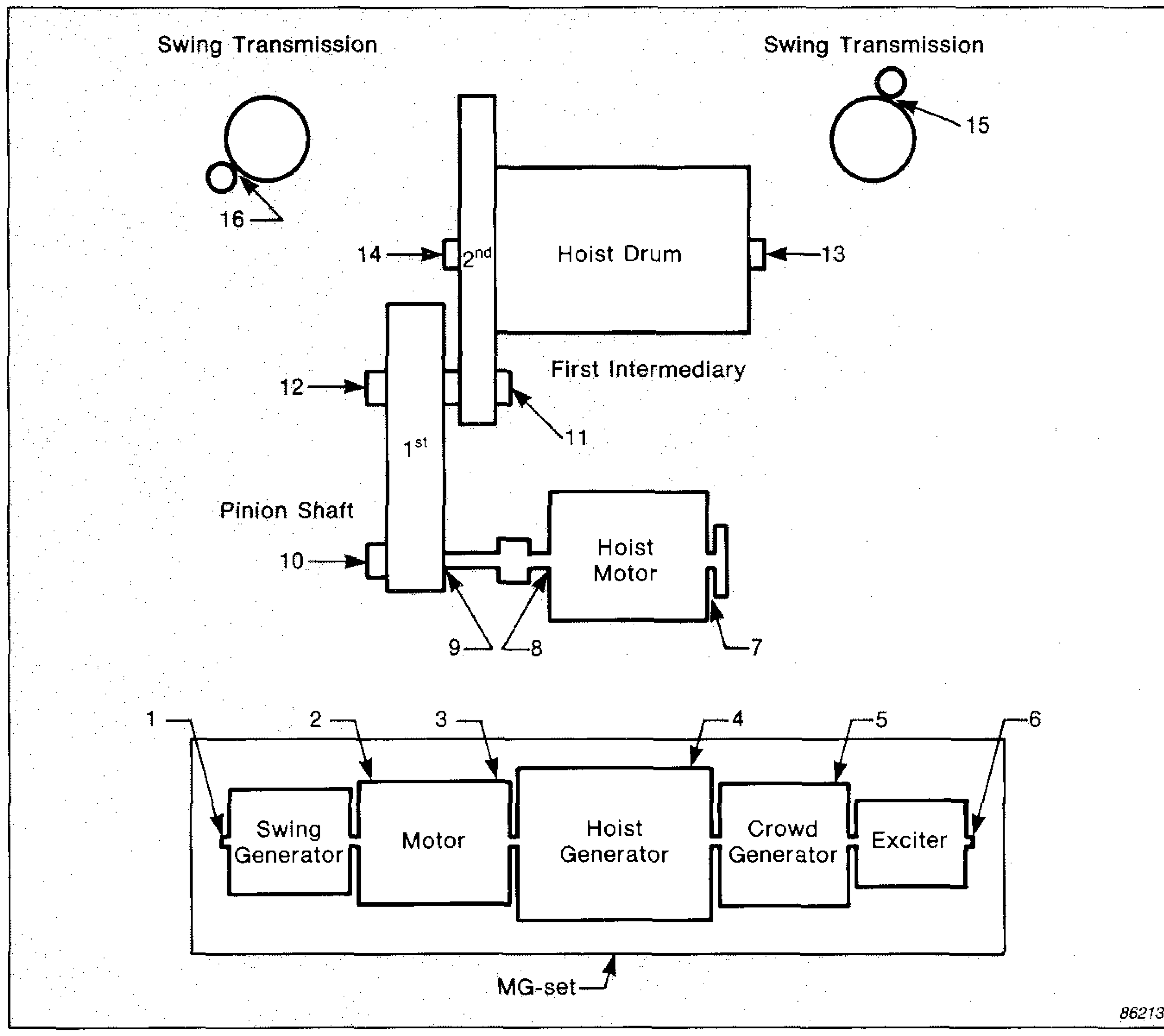

Fig. 5. Schematic (top) view of the Bucyrus–Erie and Marion shovels showing the measurement points used

Fault Detection Examples from the MG–Set

Experience has shown that **misalignment** of any of the components of an MG-Set could be identified by increasing vibration at twice the shaft rotational frequency (the 2nd harmonic).

Fig. 6 shows some examples indicating misalignment. The spectrum to the left shows a spectrum comparison on a Swing Generator, indicating a very high (>30dB) increase at the second harmonic, 60 Hz. The spectrum to the right shows an approximate 16 dB increase at the second harmonic on the Poney Motor, used to soft start the MG-Set. The motor is not mounted directly on the MG-Set base, but attached separately on a cantilever arrangement. Due to difficulties in installation, the motor is prone to misalignment problems.

An **unbalance** in any of the components of the MG-Set could be identified by increasing vibration at the shaft rotational frequency. An example of this is shown in Fig. 7, which shows a spectrum comparison from a Hoist Generator. This shows an increase of approximately 16 dB at 30 Hz, the Generator rotor frequency.

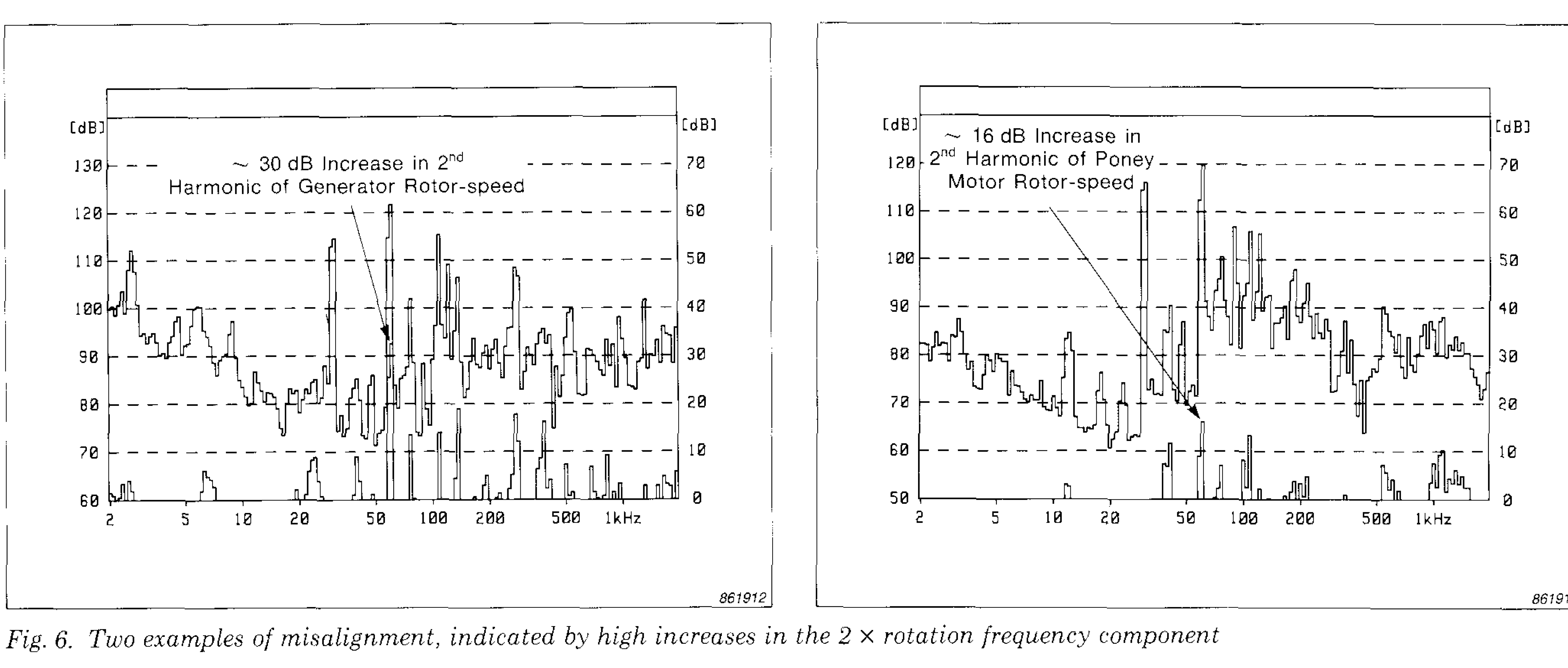

Fig. 6. Two examples of misalignment, indicated by high increases in the 2 × rotation frequency component

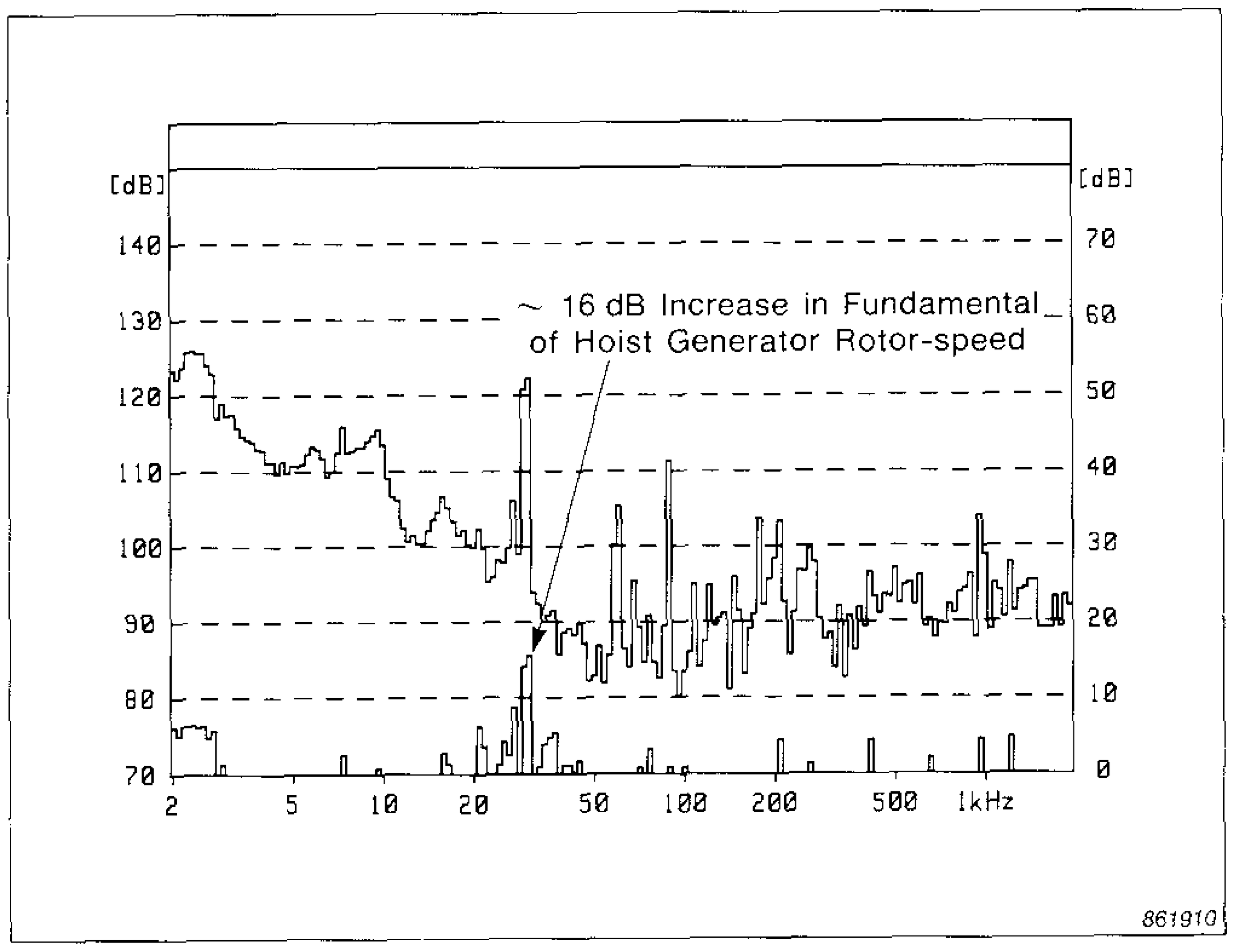

Fig. 7. An example of unbalance, indicated by a large increase at the rotation frequency

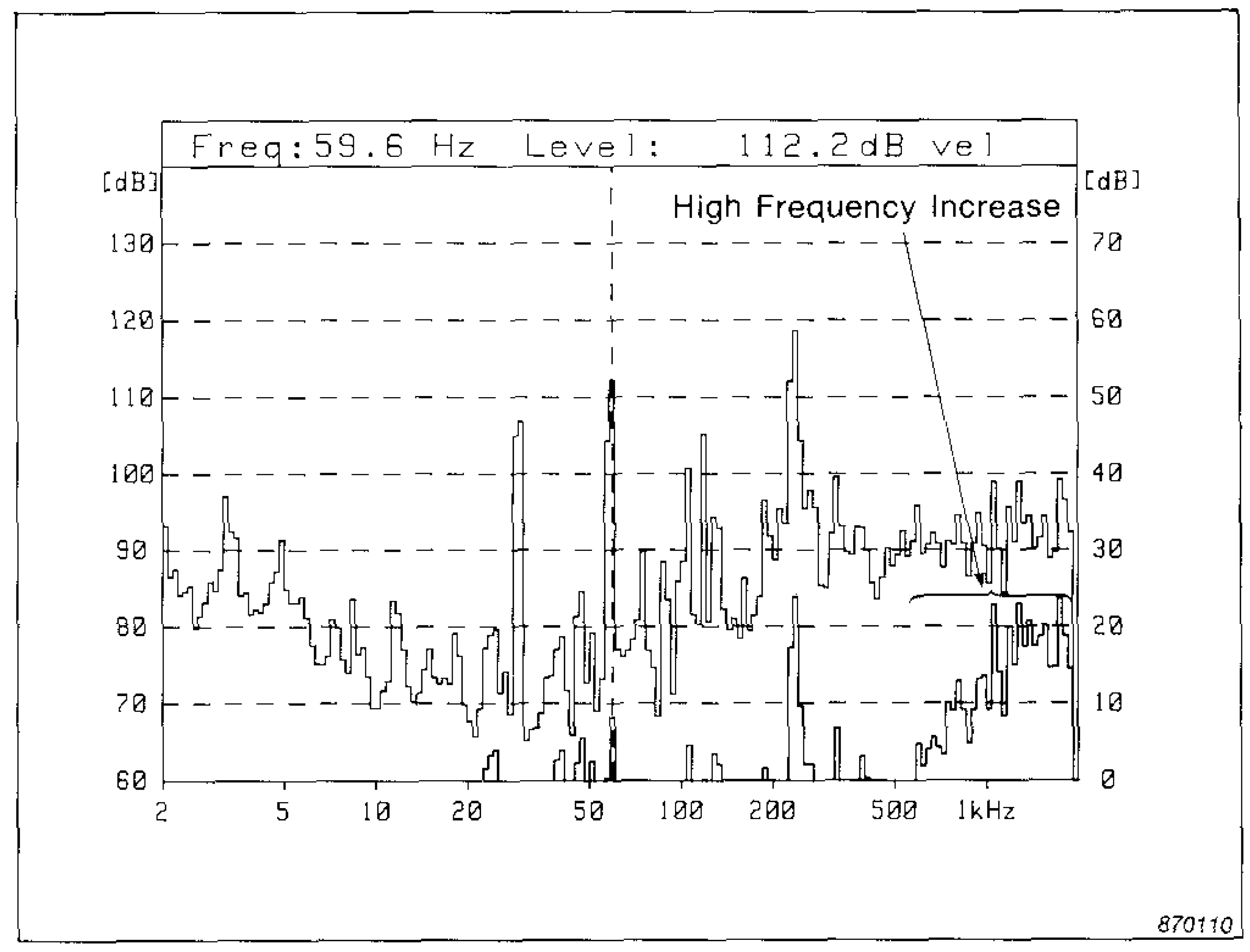

Fig. 8. Example from the Swing Generator. The increase in the 500 – 2000 Hz range was due to a rolling-element bearing problem

The example in Fig. 8 shows how a **rolling-element bearing fault** was detected on the Swing Generator of an MG-Set. Spectrum comparison measurements on the Swing Generator indicated a wide band of increases in the high frequencies, see Fig. 8. On inspection of the generator it was found that grease was packed in the bearing. This had resulted in poor lubrication, causing direct metal-to-metal contact of the bearing's rollers and races. This contact resulted in excitation of the bearing's resonant frequencies, which lie in the upper frequency range.

In another example an **electromagnetic fault** was tracked down on the main motor of an MG-Set, shown in Fig. 9. Following an overhaul, measurements were made on the motor and a strong 10 Hz harmonic series appeared in the frequency spectrum.

During measurement trials, it was discovered that cutting the power to the motor caused these harmonics to disappear immediately. This indicated an electrical/electromagnetic problem.

The motor was sent for inspection, and the clearance between rotor and stator was measured to be 1,2 mm on one side and 0,7 mm on the other. There had obviously been a machining problem when machining the fit for the bearing at the original overhaul. The electromagnetic vibration was therefore the result of the difference in magnetic field on the two sides of the rotor. This was corrected for and the measurements remade. The 10 Hz harmonic series had disappeared.

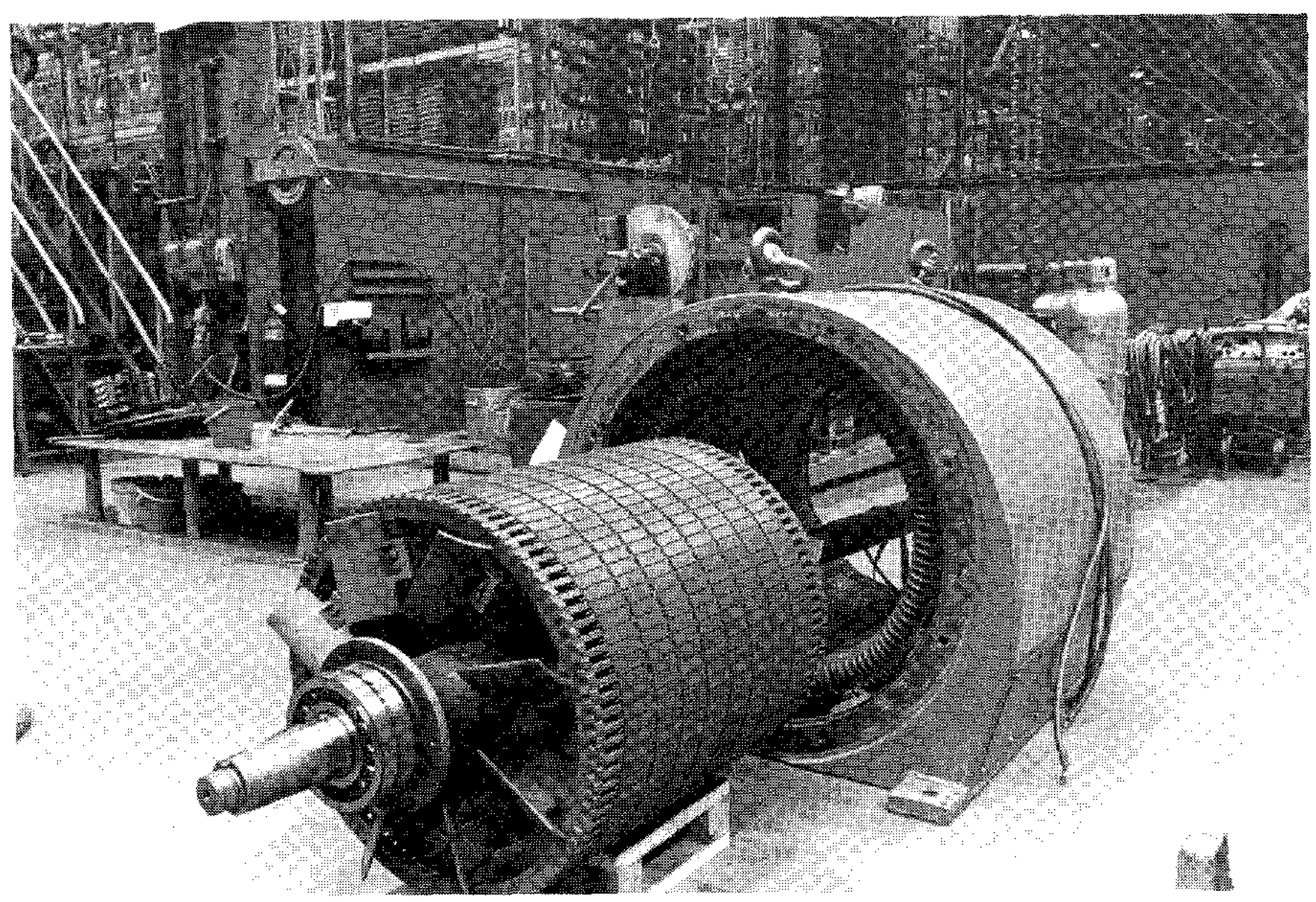

Fig. 9. The MG–set main motor on which the electromagnetic fault was diagnosed

Magnetorque® Measurement Programme

The Magnetorque® provides the drive for the hoist in the P & H shovels. This is a fairly complex piece of equipment which works on the principle of the eddy-current clutch. Fig. 10 shows the layout of the hoist's drive and transmission, and Fig. 11 the measurement positions.

Before the monitoring programme was started, the expected life of a Magnetorque® unit was approximately 1200 hours. However, with the aid of vibration monitoring this has been increased to 6000 hours. With the cost of a replacement unit in the region of $100000 and $50000 for a rebuild, this represents considerable savings.

Most problems in the Magnetorque® are derived from unbalance, bearing and operation problems. The unbalance is usually caused by dirt on two very large fans used for cooling of the field members, which are located at either end of the Magnetorque®. This unbalance can cause over-heating of the field windings and excessive load on the bearings. The operation problems are usually caused by the operator stalling the bucket too often into the rock face. This results in high increases in temperature which again increases wear.

Because the speed of the Magnetorque® is only constant for about 8 seconds (during lifting or dropping of the bucket), there is no time to record the necessary information to generate the logarithmically-scaled frequency spectrum for the automatic spectrum-comparison. Instead a narrowband analysis is made of the vibration signal for visual spectum comparison. Any frequencies of interest can then be studied using the powerful analysis facilities of the FFT analyzer.

Fig. 12 shows narrowband spectra from two different Magnetorques®. The spectrum to the left indicates normal running conditions. The spectrum to the right, however, shows an uncommon problem – that of misalignment between the Magnetorque® and the hoist gears. The misalignment shows itself clearly as a series of even harmonics of the drive motor fundamental (10 Hz), and a series of sidebands around the toothmeshing frequency (191,25 Hz) and its harmonics. The sideband spacing corresponds to the speed of the drive motor (10 Hz).

Hoist- and Swing-Transmission Measurements

In general, the problems that can be expected from the shovel's transmission are due to wear on gears, progressive misalignment etc. However, measurements made on the hoist and swing transmission suffer the same drawbacks as for the Magnetorque®, in that the speed is only constant for a few seconds, which is not enough to record enough information for an automatic spectrum-comparison.

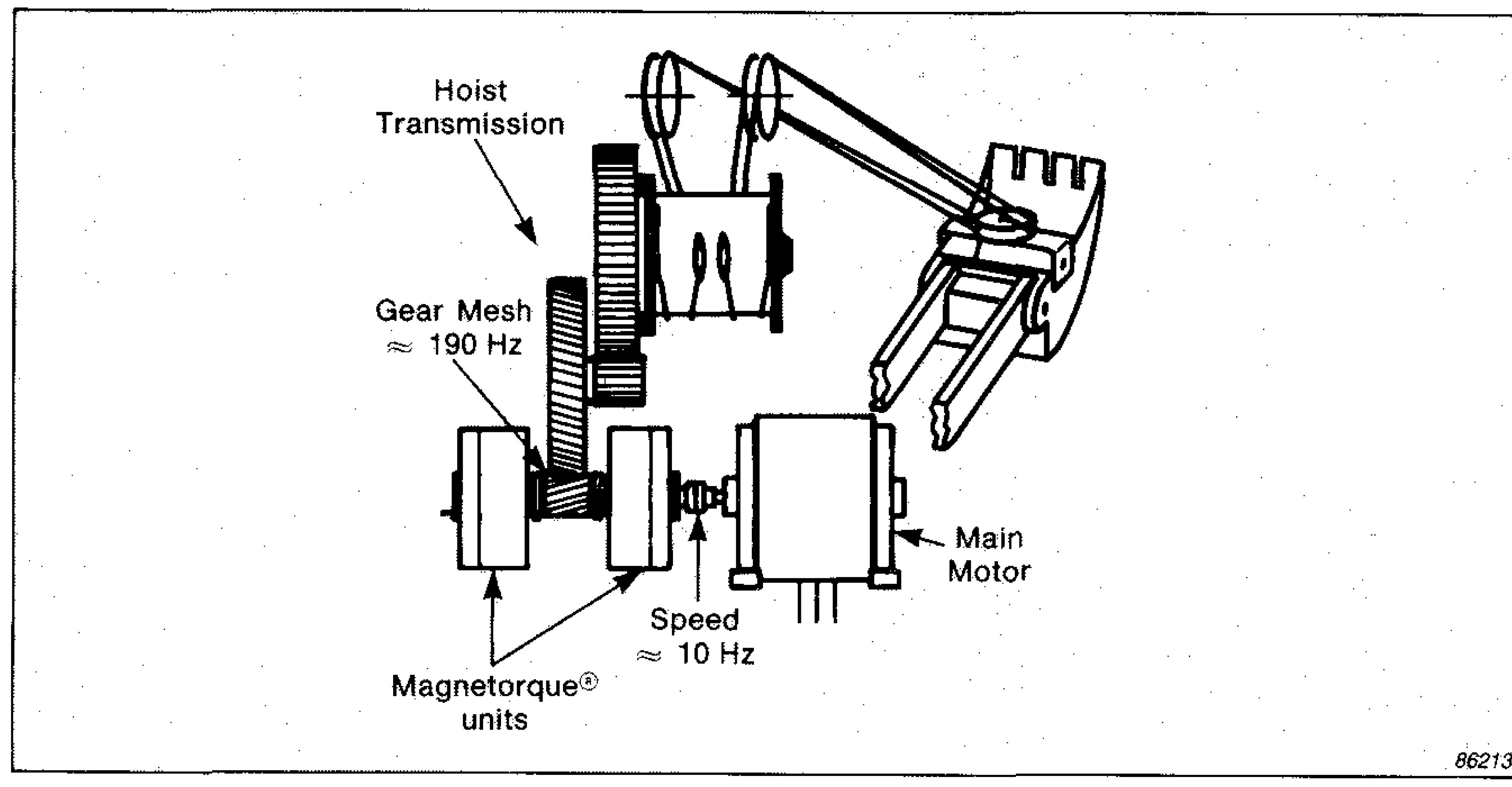

Fig. 10. Layout of the hoist's drive and transmission

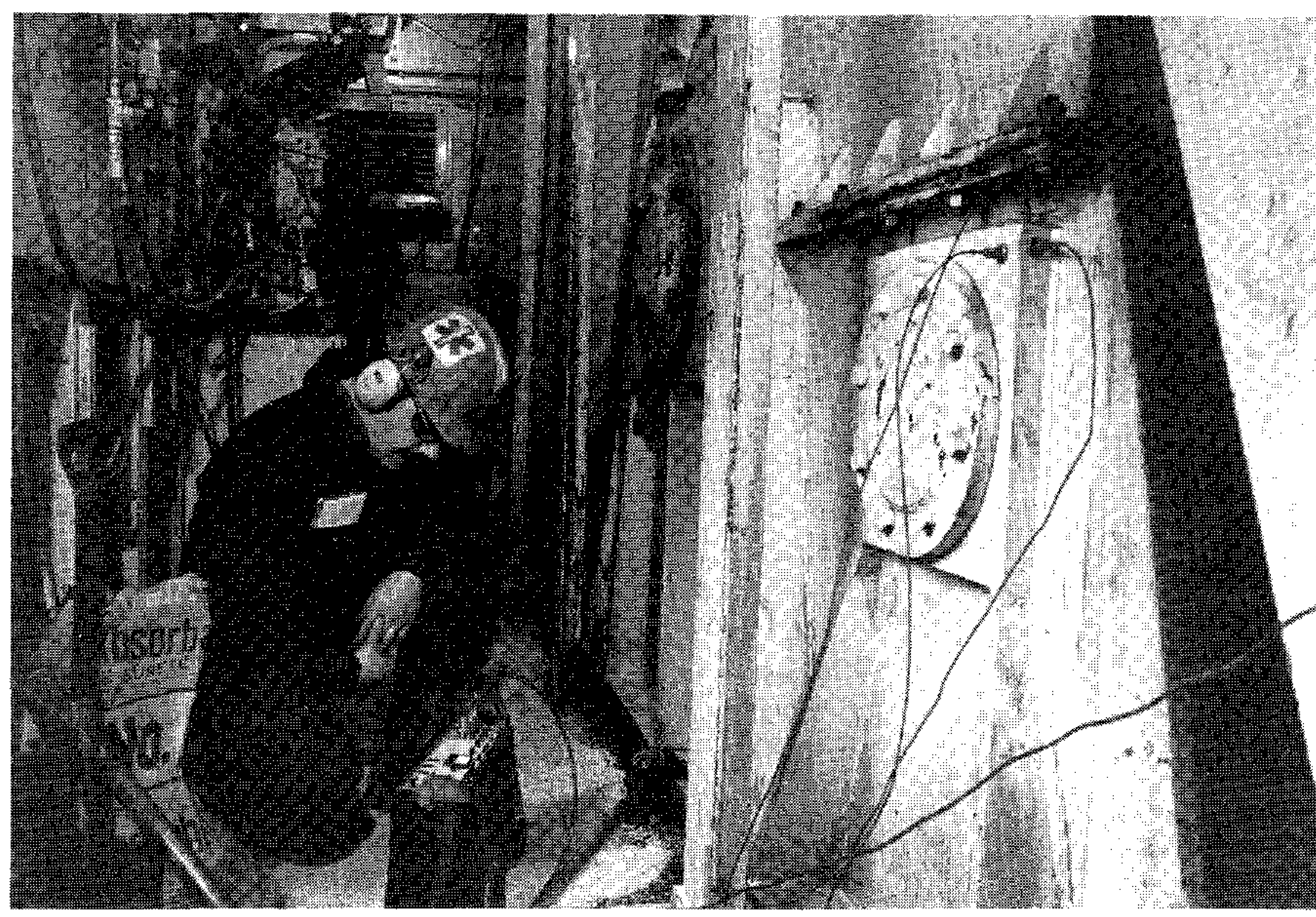

Fig. 11. Recording the vibration levels from the hoist-drive transmission. Measurements are made in the X, Y and Z directions

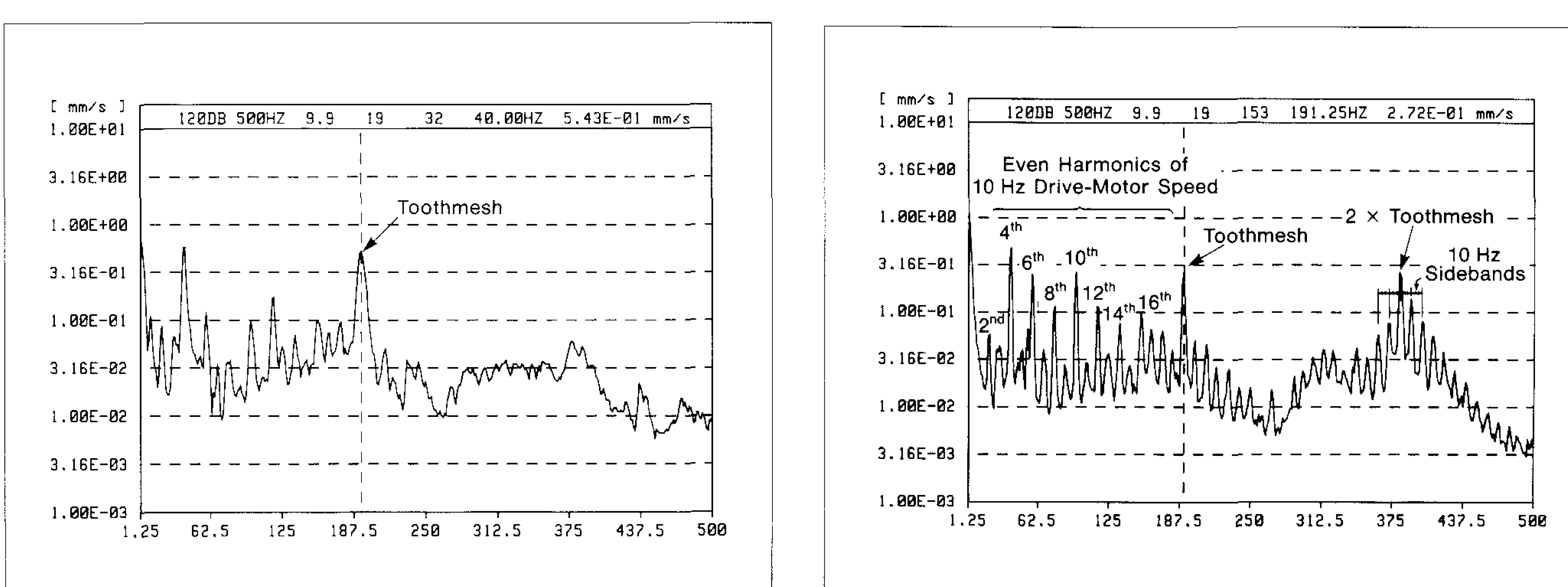

Fig. 12. Narrowband spectra from the Magnetorque®. The spectrum to the left shows the normal running conditions, whilst that to the right shows a misalignment problem

The measurements are made on the casing of the hoist-machinery gearbox. They are then presented in the form of histograms showing vibration level at the gear mesh of first intermediary (380 Hz) and of the bull gear (34 Hz).

One of the side-effects of worn transmission is that excessive vibrations are transmitted over the whole of the shovel structure. This causes excessive discomfort for the operator, and consequently regular vibration checks are made under the operator's seat. Measurements are made every 200 hours of shovel operation.

Truck Vibration Monitoring

The truck fleet at the mine consists of a total of 41 Wabco, Terex and Unit Rig diesel-electric trucks, each with a capacity of 170 tons. The trucks are powered by a 1600 BHP diesel engine driving a DC generator, which in turn drives an electric motor mounted on each of the rear wheel-sets. At a cost of approximately 1 million-$ each, these trucks represent a considerable investment.

Up to 1980, the diesel engines were always changed at 10000 hours. Now, with the aid of condition monitoring, the running time has been considerably increased and at present two engines have been running for over 18000 hours. Fig. 13 shows the average life of a truck engine before being removed for reconditioning.

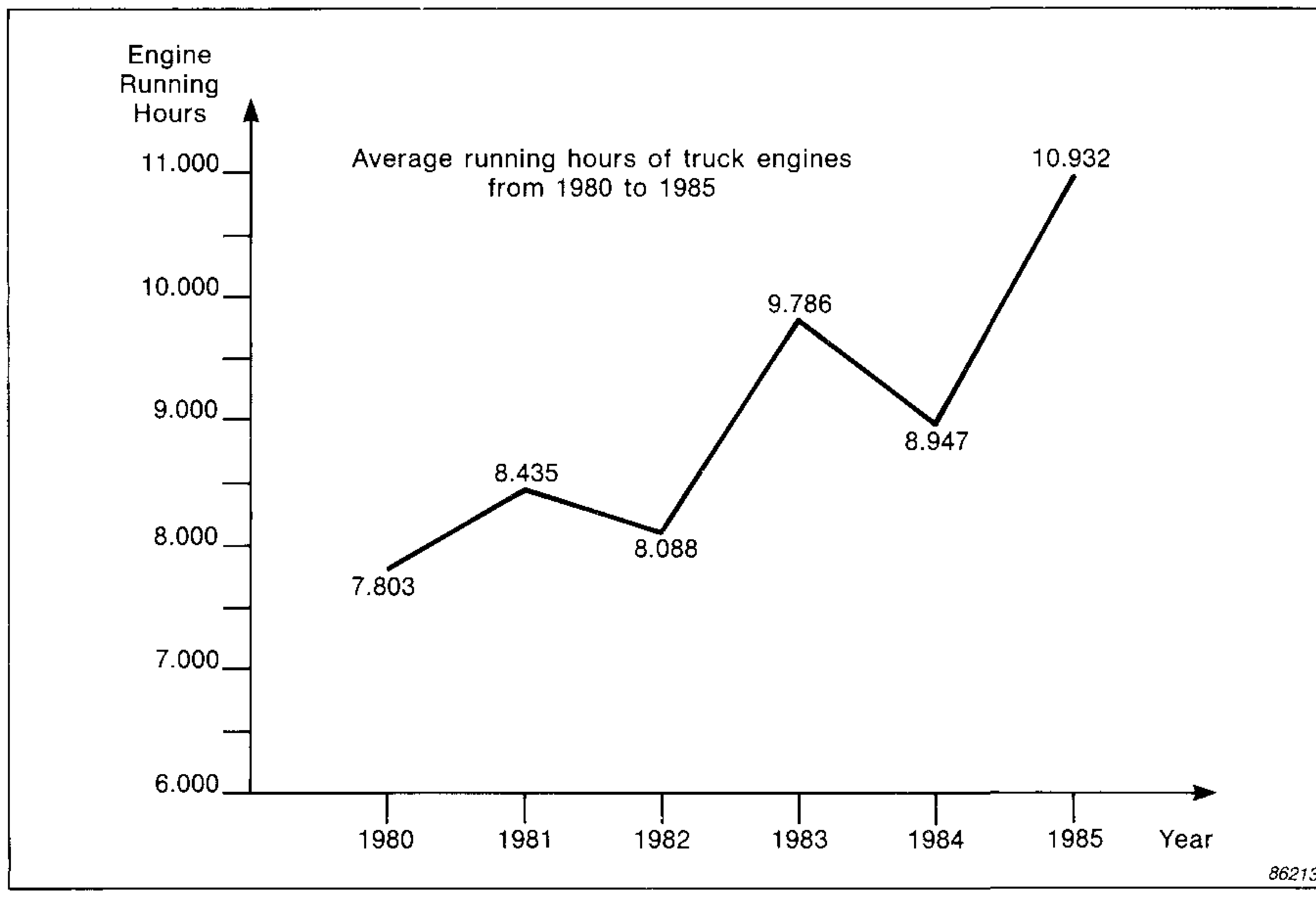

Fig. 13. Average life of truck engines

Faults Detected

The following lists some faults that have been detected by the vibration-monitoring system:

Diesel Engine/Generator – Misalignement of engine and generator, one cylinder not firing, bearing problems;
Cooling Fan – Bent blade, dirt on blade, out of balance, belt tightness;
Roots Blower – Wear on drive-shaft splines;
Blower–Exciter – Bad mounting of blower, unbalance due to dirt on blower;
Generator – Unbalance, misalignment.

Service Procedure

The trucks are brought in for service every 300 hours, during which time a vibration and oil analysis is made. The trucks are first cleaned, vibration data recorded on tape and then the engine oil changed and analysed. If a fault is detected then either the truck is repaired immediately or a work order made.

Vibration measurements are made on the front and back of the diesel engine, on the generator and on the blower-exciter.

Fan – Terex: (measured at 18 Hz)	Normal:	–116	dB
	Acceptable:	116,1 –125	dB
	Unacceptable:	125,1 –134	dB
	Danger:	134,1 –	dB
Engine – Unit-Rig, Wabco, Terex: (measured at 1 × RPM)	Normal:	–130	dB
	Acceptable:	130,1 –136,5	dB
	Unacceptable:	136,6 –143	dB
	Danger:	143,1 –	dB
Blower-Exciter – Terex: (measured at 1,4722 × RPM)	Normal:	–112	dB
	Acceptable:	112,1 –118	dB
	Unacceptable:	118,1 –124	dB
	Danger:	124,1 –	dB
Blower-Exciter – Unit-Rig, Wapco: (measured at 2 × RPM)	Normal:	–115,4	dB
	Acceptable:	115,5 –120,4	dB
	Unacceptable:	120,5 –125,4	dB
	Danger:	125,5 –	dB
Blowers – Unit-Rig, Wabco, Terex: (measured at 2,26 × RPM)	Normal:	– 96,5	dB
	Acceptable:	96,6 –102	dB
	Unacceptable:	102,1 –108	dB
	Danger:	108,1 –	dB

The following probability formulae were used to calculate the vibration limits:

Normal = $\overline{X} - \frac{\sigma}{2}$ and under Unacceptable = $\overline{X} + 1,5\ \sigma$

Acceptable = $\overline{X} + \frac{\sigma}{2}$ Danger = $\overline{X} + 1,5\ \sigma$ and over

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Table 1 Example from the standards drawn up for allowable truck vibration - for vertical measurements made at the front of the truck diesel engine

Data Analysis

After a spectrum comparison has been made, the technician checks the level of certain frequency components against a standard, an example of which is shown in Table 1. The stan-

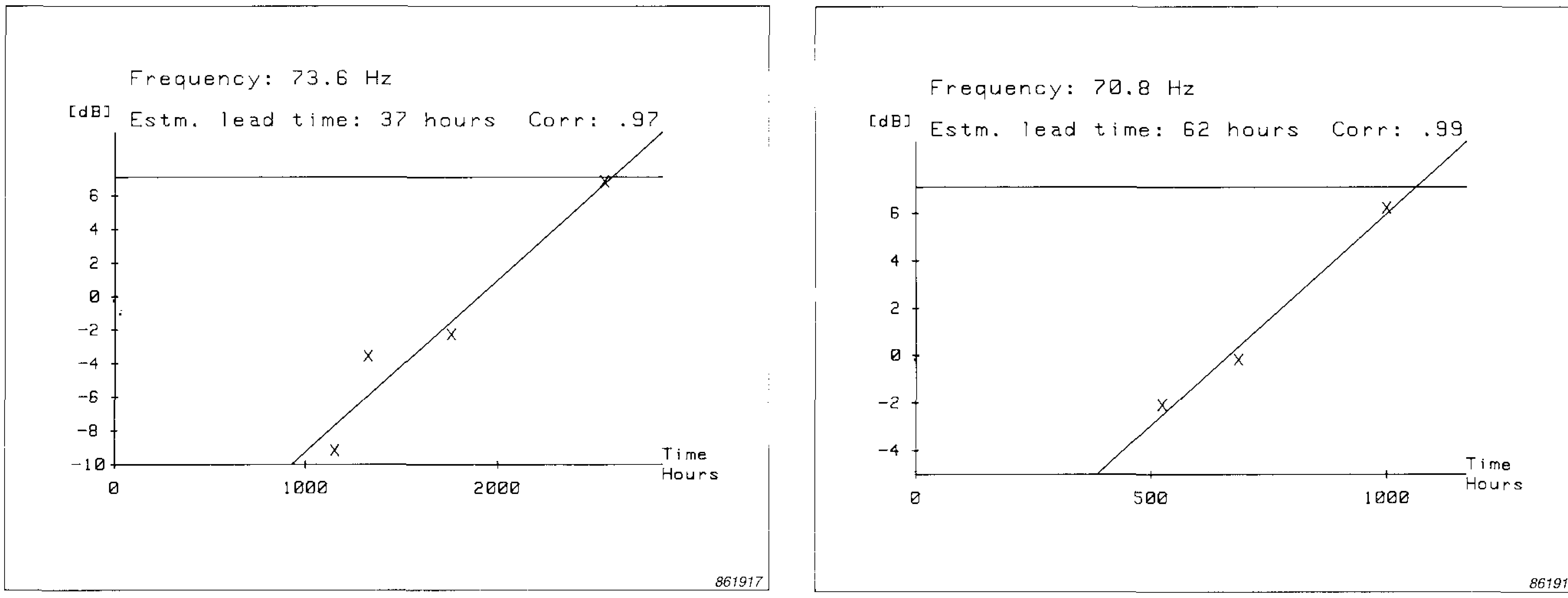


Fig. 14. Trend curves at blower drive-shaft rotational frequency. The trend to the left is for 73,6 Hz, and that to the right for 70,8 Hz

dard, which has been drawn up by the maintenance engineer, gives the absolute vibration levels that can be tolerated. These levels were obtained from statistical analysis of vibration levels recorded on the trucks.

The Roots Blower Drive-Shaft

A major problem arose concerning the drive shaft for the Roots Blower. A number of engines were destroyed after the splines locating the shaft into the drive-hubs stripped. The engine governor is driven by this shaft and, in the event of the shaft stopping, the engine would overspeed and eventually destroy itself. At a replacement cost in the region of $160000, such breakdowns could not be tolerated.

The problem first arose after a modification to the engine. This had an unfortunate side-effect which resulted in the blower-drive being constantly loaded and unloaded, and eventually wearing the splines at the end of the drive shaft. At this point, due to the seriousness of the problem, the life of a blower was restricted to 5000 hours. A decision was therefore made to monitor this problem with the aid of the vibration monitoring system. This proved successful and the blower life was raised to 15000 hours. The engine manufacturer was duly informed of the problem, and the design subsequently changed.

The problem was monitored using the spectrum comparison and trending facilities of the system. The problem could be characterised by an increasing vibration component at the rotation frequency of the blower drive-shaft. Fig. 14 shows trend curves made at this rotation frequency. The blower drive-shaft rotation frequency

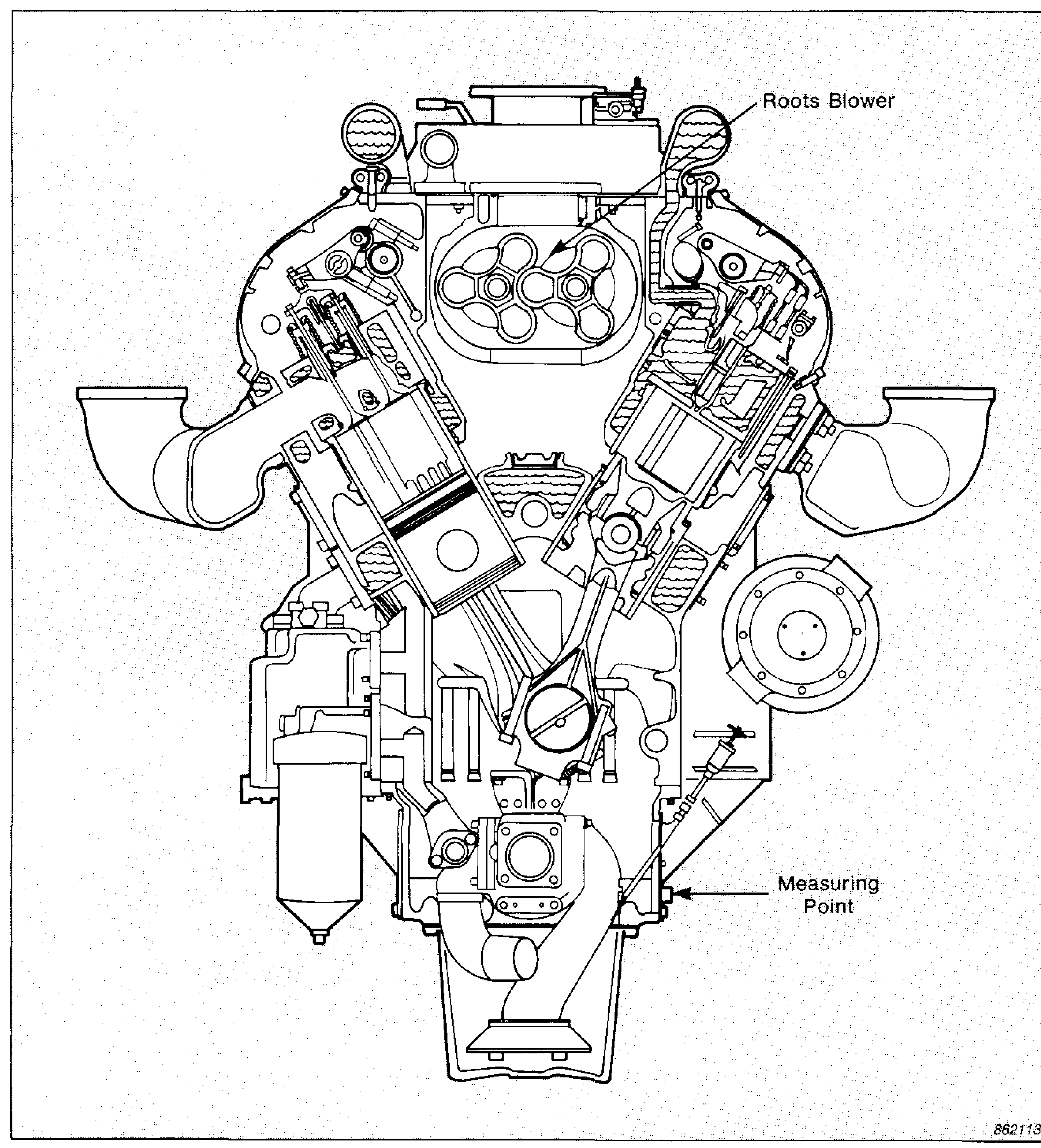


Fig. 15. The measurement point used on the truck engines to detect the Roots Blower drive problem

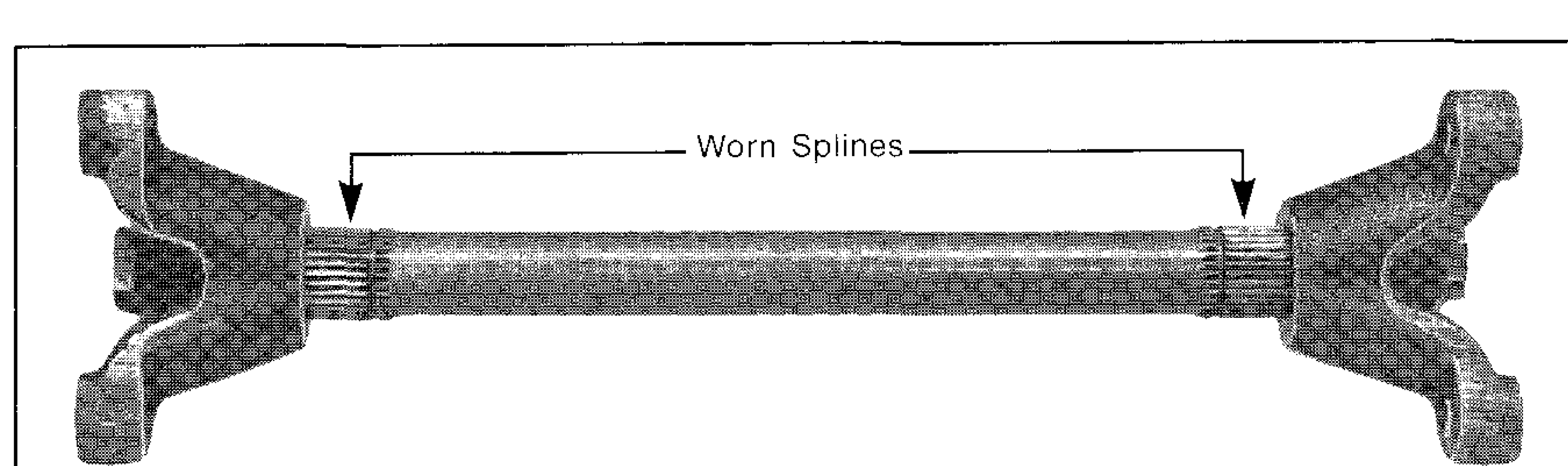


Fig. 16. The blower drive-shaft with the worn splines indicated

was 73,6 Hz or 70,8 Hz depending on the engine-test speed. The upper danger level shown is the maximum vibration level tolerated before repair. Fig. 15 shows a schematic layout of the engine, indicating the position of the Roots Blower and the measuring point used to detect the fault. Fig. 16 shows the blower drive-shaft.

This fault was detected on four trucks. In each case this resulted in the drive shaft and hubs being changed, at a cost of approximately 1% of the cost of a complete engine rebuild – a total saving of some $630 000.

The Fan

Fig. 17 shows a spectrum comparison clearly indicating the beginning of a problem at 17,8 Hz, the fan rotational frequency. Fig. 18 shows a trend curve at this frequency. The upper danger level shown is the maximum vibration level tolerated. The fan was subsequently rebalanced, and the levels dropped to normal values.

The Blower–Exciter

The blower–exciter assembly is mounted on top of the diesel engine and supplies both air-cooling for the generator and an excitation current for the generator fields.

The supply air for the blower is unfiltered, and a common problem is one of dirt on the blower causing an unbalance. In the example shown in Fig. 19, dangerous vibration levels were recorded from the assembly, as shown in the trend curve measured at the blower speed. The blower was subsequently removed and cleaned and the levels seen to drop.

General Engine Condition

The trend curve shown in Fig. 20 shows some interesting results. The curve indicates a steady upward trend in vibration level at the crankshaft frequency. This type of trend curve, in conjunction with other "health" indicators on the engine, could be effectively used as an indication of general wear in the engine. As soon as the vibration level approaches the danger level, an overhaul can be scheduled.

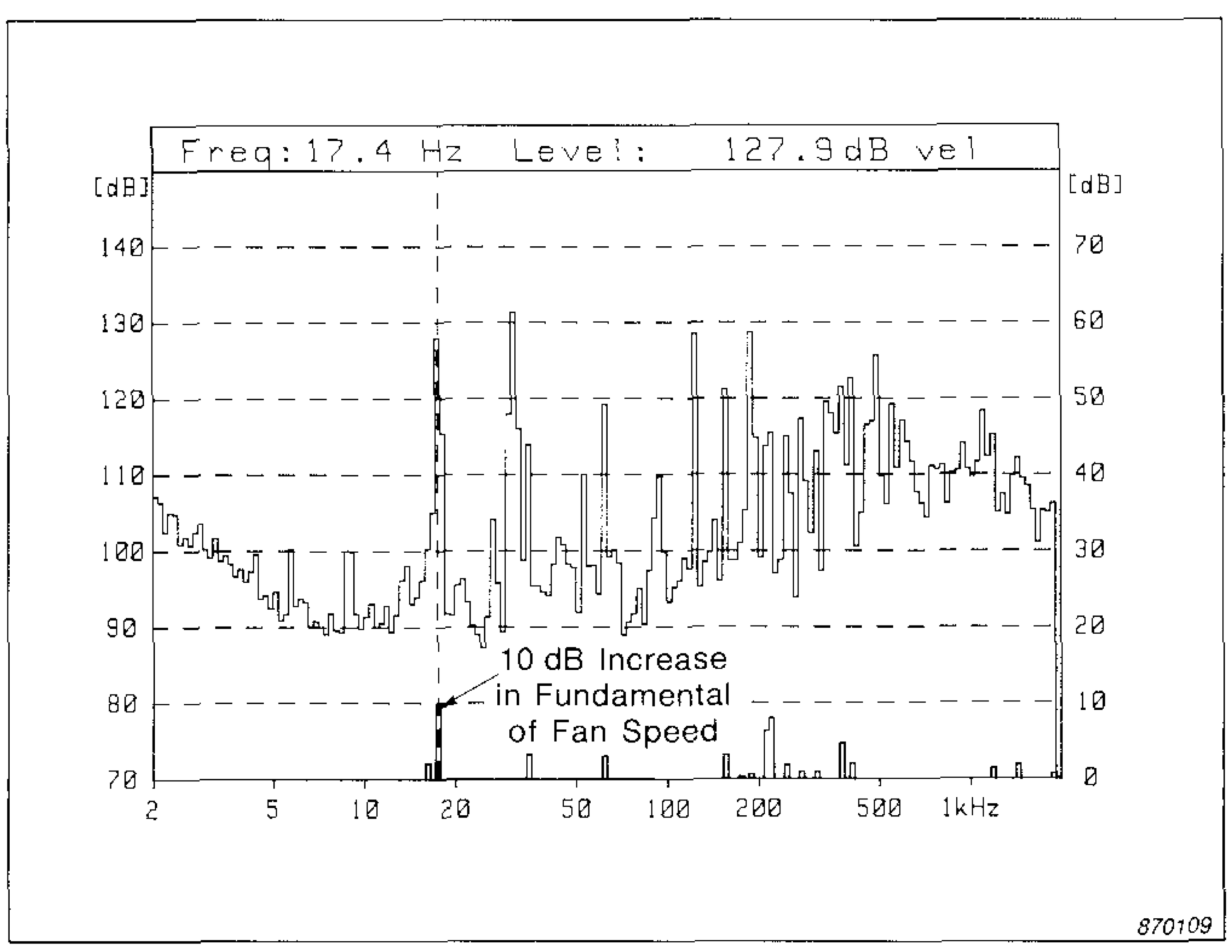


Fig. 17. Spectrum comparison showing the fan problem

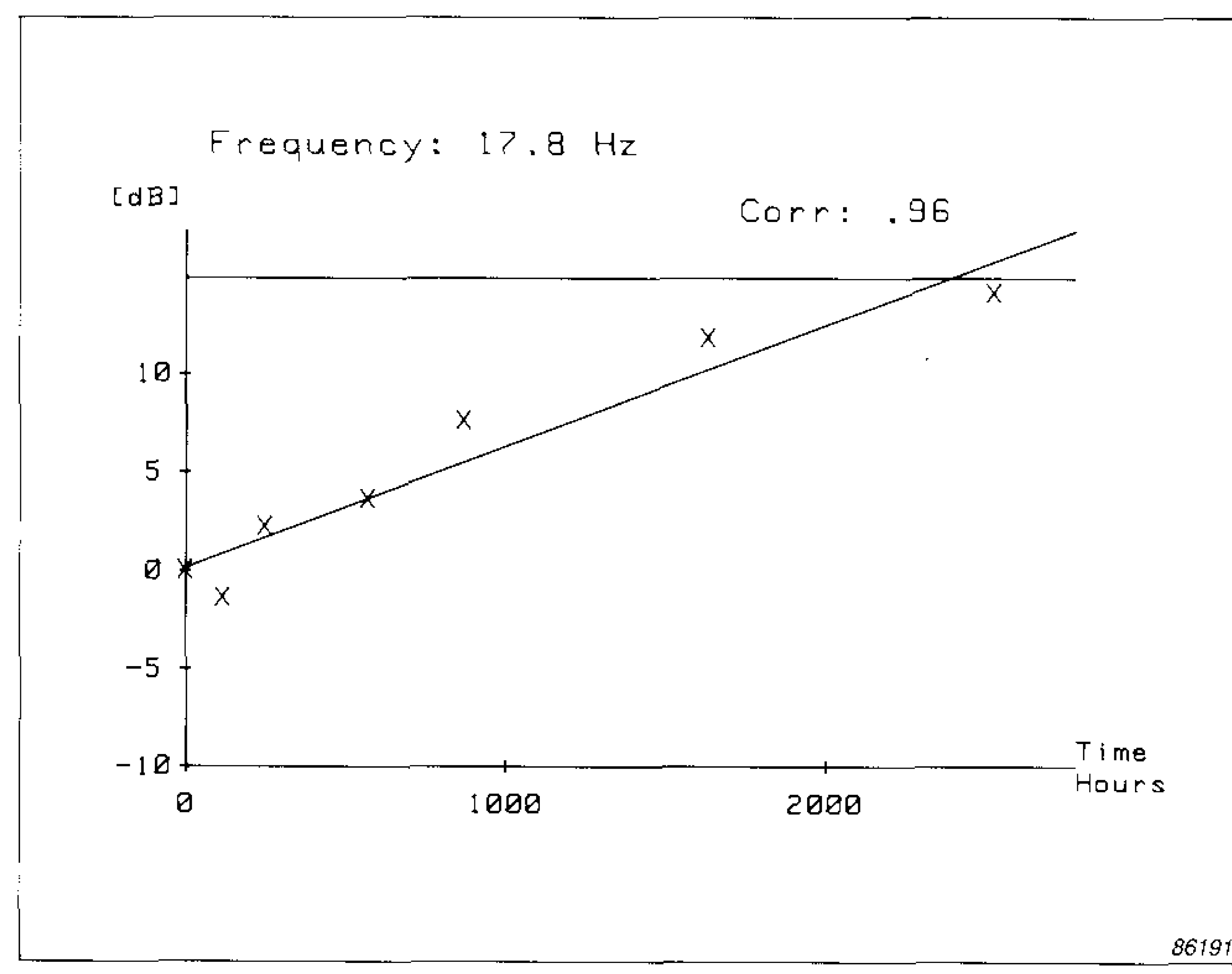


Fig. 18. Trend curve at fan rotational frequency clearly showing the fan problem

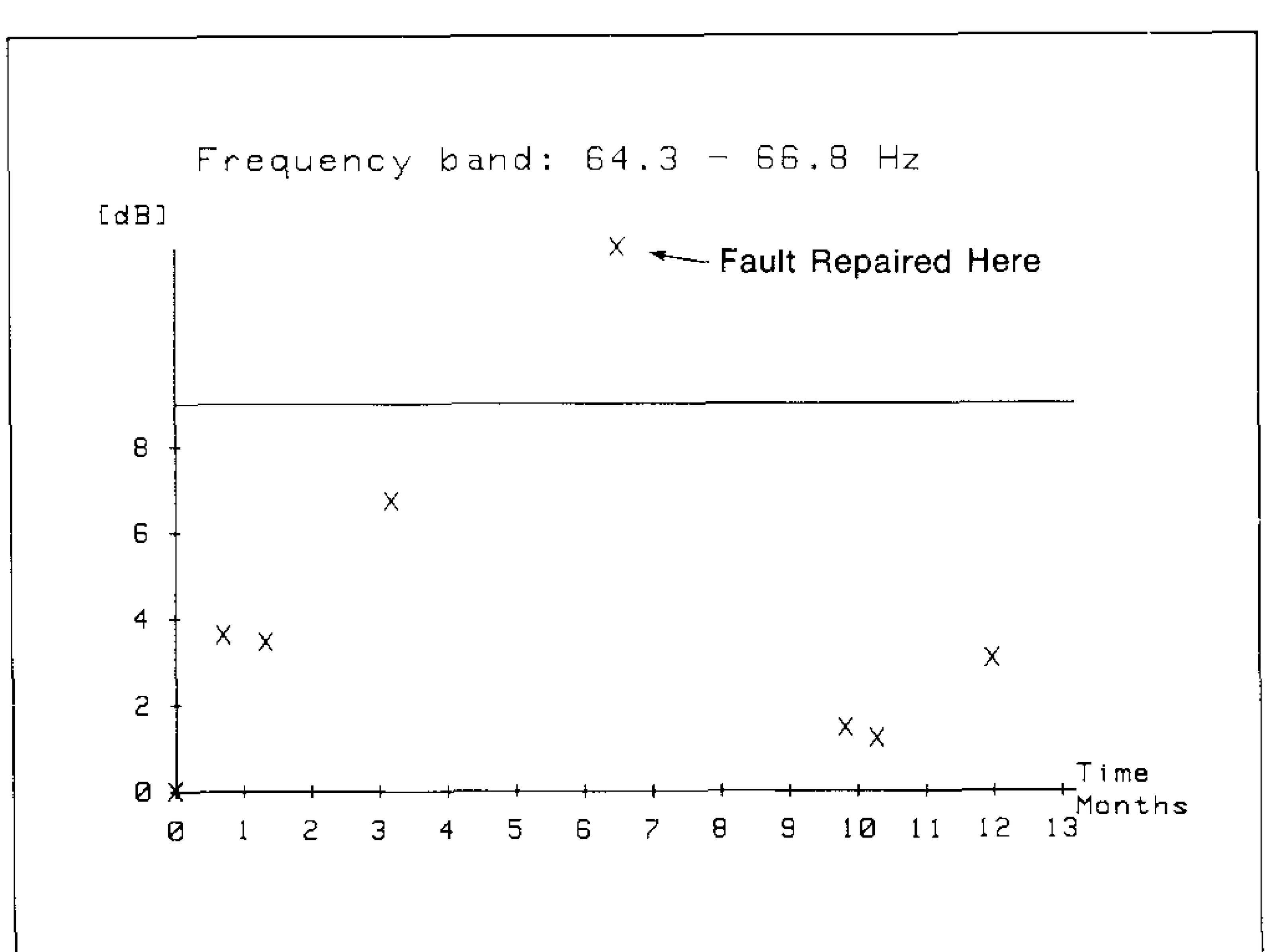


Fig. 19. Trend curve at the blower-exciter rotational frequency. The vibration level is seen to increase to danger levels and then drop-off after repair

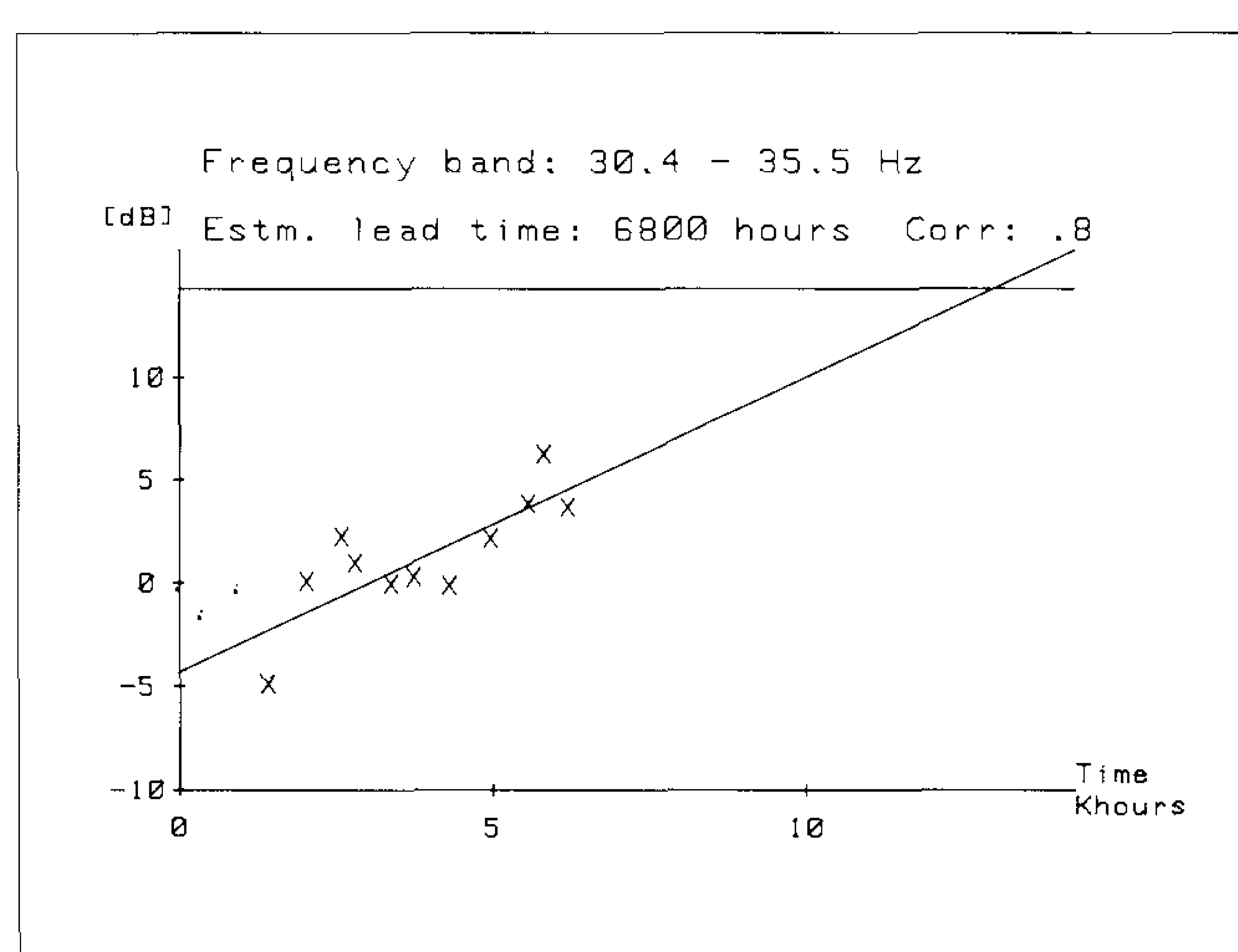


Fig. 20. Trend curve at the crankshaft frequency

Concentrator Vibration Monitoring

The Mount Wright concentrator is one of the largest beneficiating plants in the world, capable of handling 135 000 tons of crude ore daily. The concentrator houses six parallel circuits that comprise the ore grinding and concentrating equipment. The vibration monitoring programme covers the six autogeneous grinding mills, belt conveyor drives and several hundred pumps.

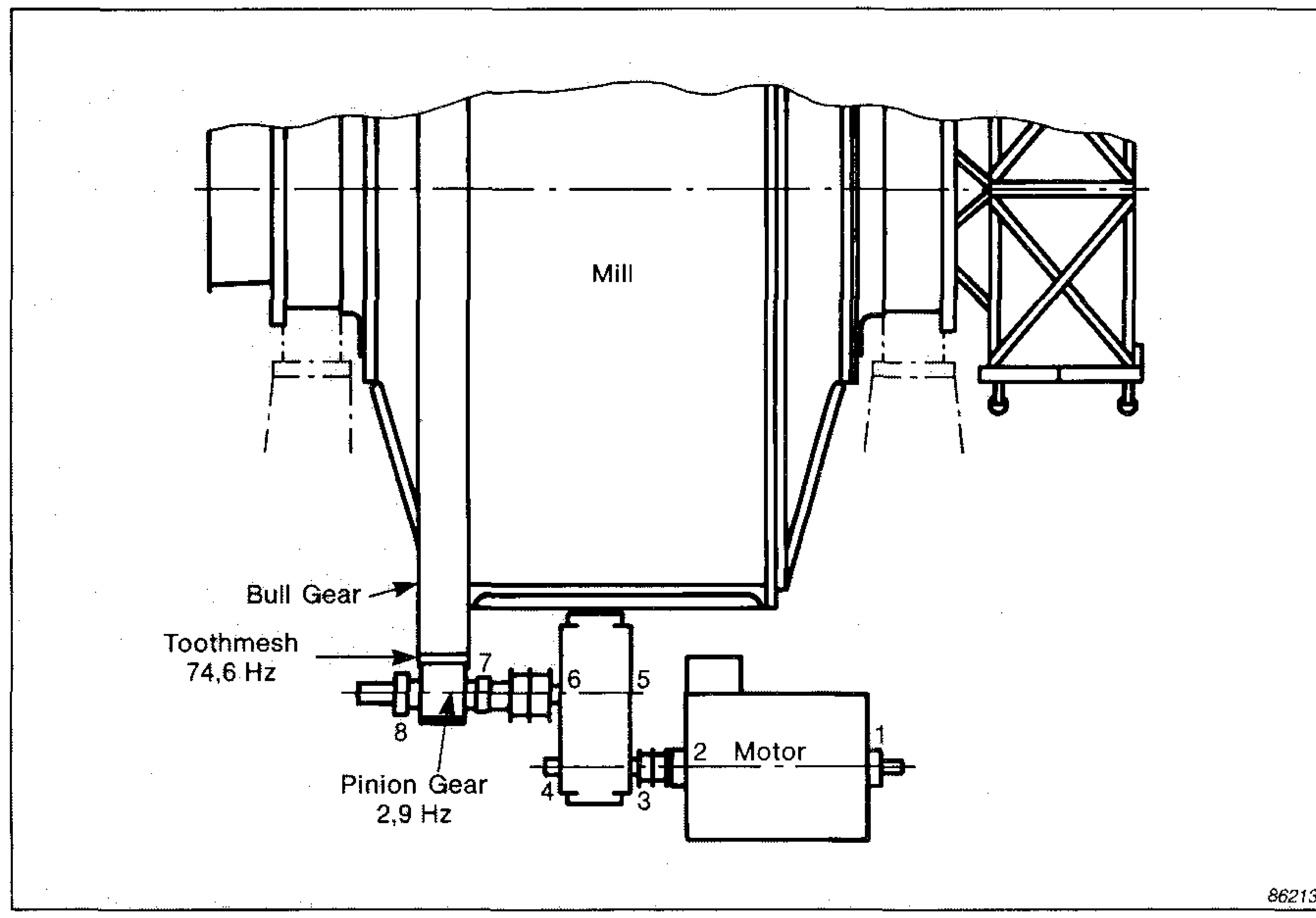


Fig. 21. Measuring points on the autogeneous mill drive

The Autogeneous Mill

The autogeneous mills are 32 ft diameter cascade type grinding-mills, powered by two 3000 HP motors coupled by gearboxes, see Fig. 21. Because of their importance to the concentrator operation, they have number one priority in the plant. Vibration measurements at 16 measuring points are taken from the drive section of one mill at weekly intervals.

The most common types of problem encountered are due to installation misalignment, bearing failures and gearing problems. Another problem which occasionally occurs is that the dowel-pins locating the bearing pillar-block for the drive often break, thus causing misalignment between pinion and bull gear.

Figs. 22 and 23 show examples of narrowband spectra taken from the gearbox. In Fig. 22 can be seen a very dominant toothmesh frequency from the pinion and mill bull-gear, together with a strong harmonic series. Fig. 23 shows a zoomed narrowband spectrum around the toothmesh fundamental, showing a pattern of sidebands with a spacing of 3 Hz, which corresponds to the pinion gear rotational frequency. At first it was thought that the problem was one of misalignment. However, after careful examination of the spectra, it was deduced that the cause of these prominent patterns in the spectra was from a mismatch in wear patterns between the pinion and bull-gear, and possibly slight eccentricity of the pinion gear. The pinion gear was relatively new, whereas the bull-gear had not been changed for sometime.

Pumping Systems and Main Conveyors Drive-Section

As the concentrating process is a wet process, a large number of pumps are in use. These include: Special purpose tailing pumps for pumping the fine abrasive fluids; vertical direct-drive process water pumps; vacuum pumps for the filtering tables; and the mill pumping systems for scalping, screening and recycling.

The tailing pumps are checked every 3 months. Each mill pumping system is measured once every sixth week

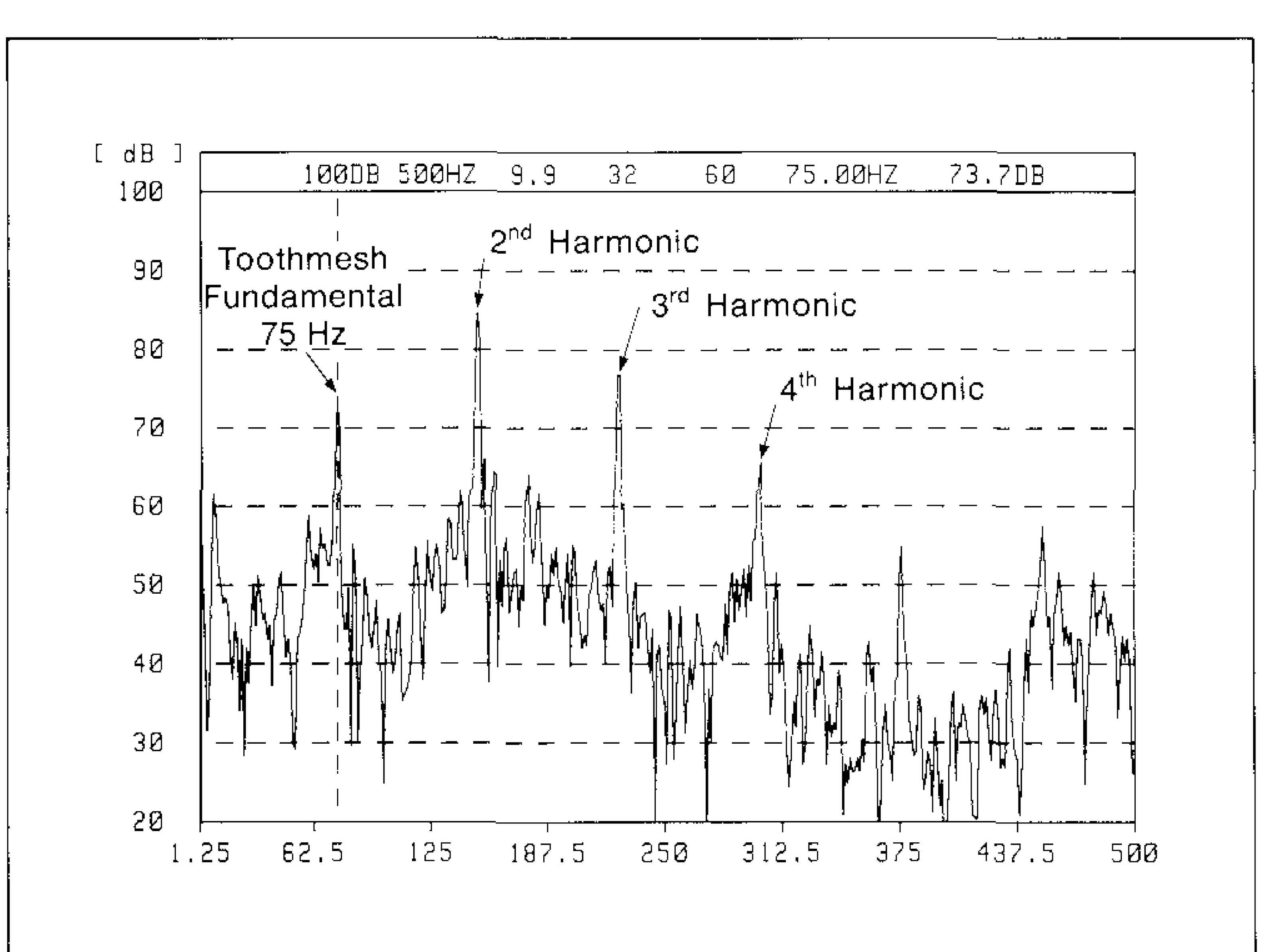


Fig. 22. Narrowband spectrum from the mill gearbox, showing a strong harmonic series at the pinion/bull-gear toothmesh frequency

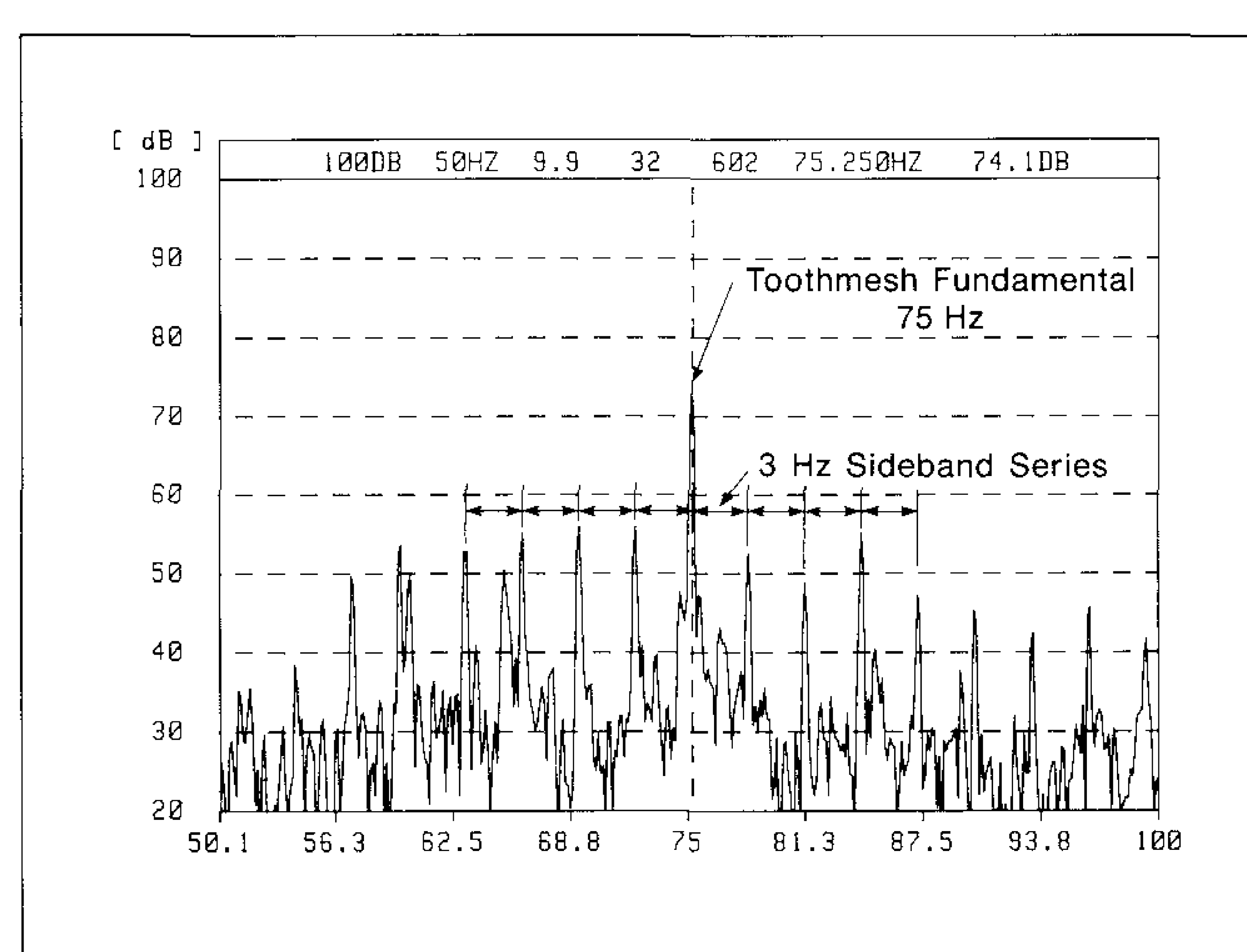


Fig. 23. Zoomed narrowband spectrum about the pinion/bull-gear toothmesh, showing a marked sideband pattern

(1 line is measured per week), and the vacuum pumps for the filtering tables every 2 months.

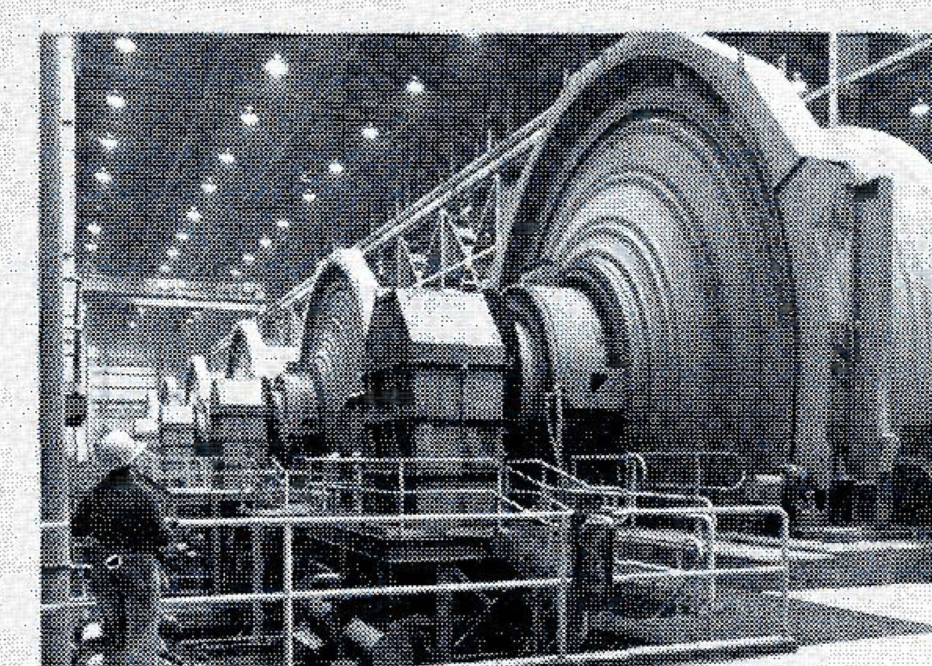
Typical fault processes monitored are: Bearing and gearing problems, and misalignment etc. On the tailing pumps, which have a fluid drive, pedestal bearing problems are often found due to misalignment of the motor, pump and fluid drive.

Vibration measurements from the conveyor are taken at relatively long intervals due to the lack of manpower. Typical problems are related to misaligment, bearings and gears.

Proposed Monitoring Programme

Due to the very large number of measuring points (in the thousands), it is not really feasible for two technicians to make tape recordings at regular, short intervals. It is therefore now being considered to use the Type 2516 broadband Vibration Meter for a quick, regular spot-check of the condition of the pumps and conveyor-drives, thus providing protection against a sudden worsening of condition. An analysis from tape recorded measurements could then be made at intervals realistic for the present manpower availability, or when the 2516 indicated increasing vibration levels.

Conclusions



The shovels, trucks and mills represent three vital stages in the iron-ore production process, and this Case Study has clearly shown vibration-monitoring to be an extremely powerful tool for the plant's maintenance engineers.

With results like: "4 truck engines saved from destruction"; "Average truck engine life increased from 7800 hours to 10900 hours"; "Shovel availability increased from 45% to 65%"; "Magnetorque® life increased from 1200 hours to 6000 hours",... the investment put into the monitoring system has clearly paid for itself a good number of times.

Starting small, and developing the vibration monitoring programme into the present desk-top computer based system, the maintenance engineers have been able to build up tremendous experience with the monitored machines. This has allowed them to draw up detailed measurement procedures and enable the technicians to make quick decisions about machine condition from comparisons with vibration limits for individual machine components.

The authors wish to extend their gratitude to the engineers from the Maintenance Section at the Mount Wright development, for all their help in gathering information for this Application Note.

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