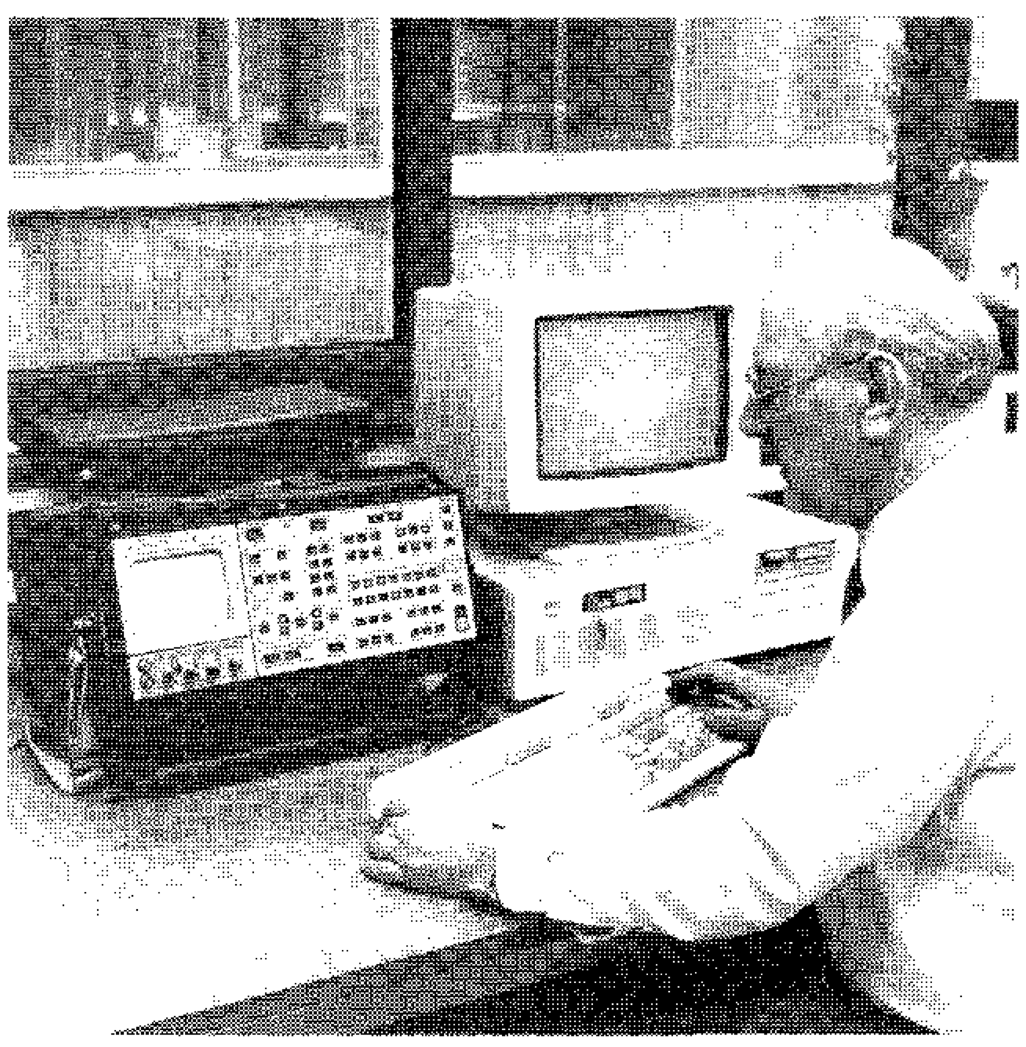
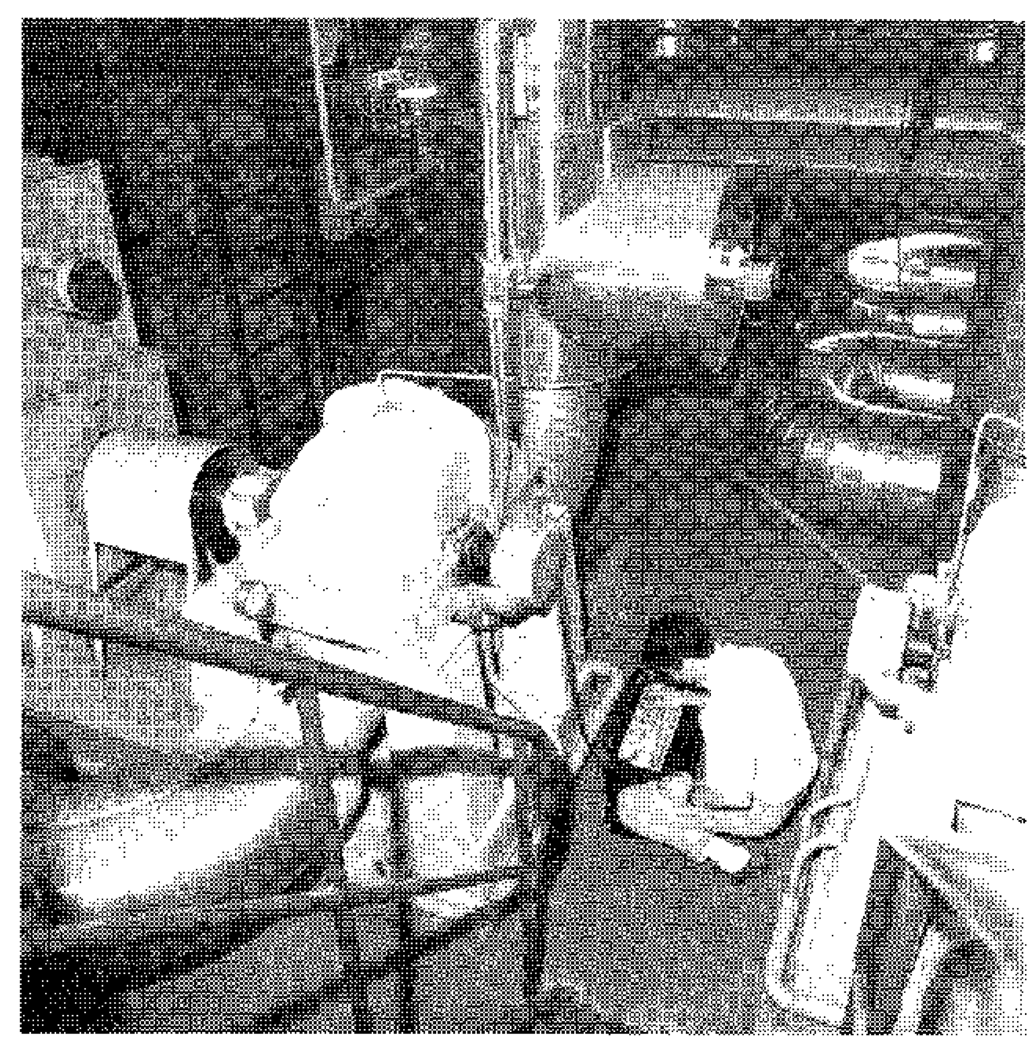
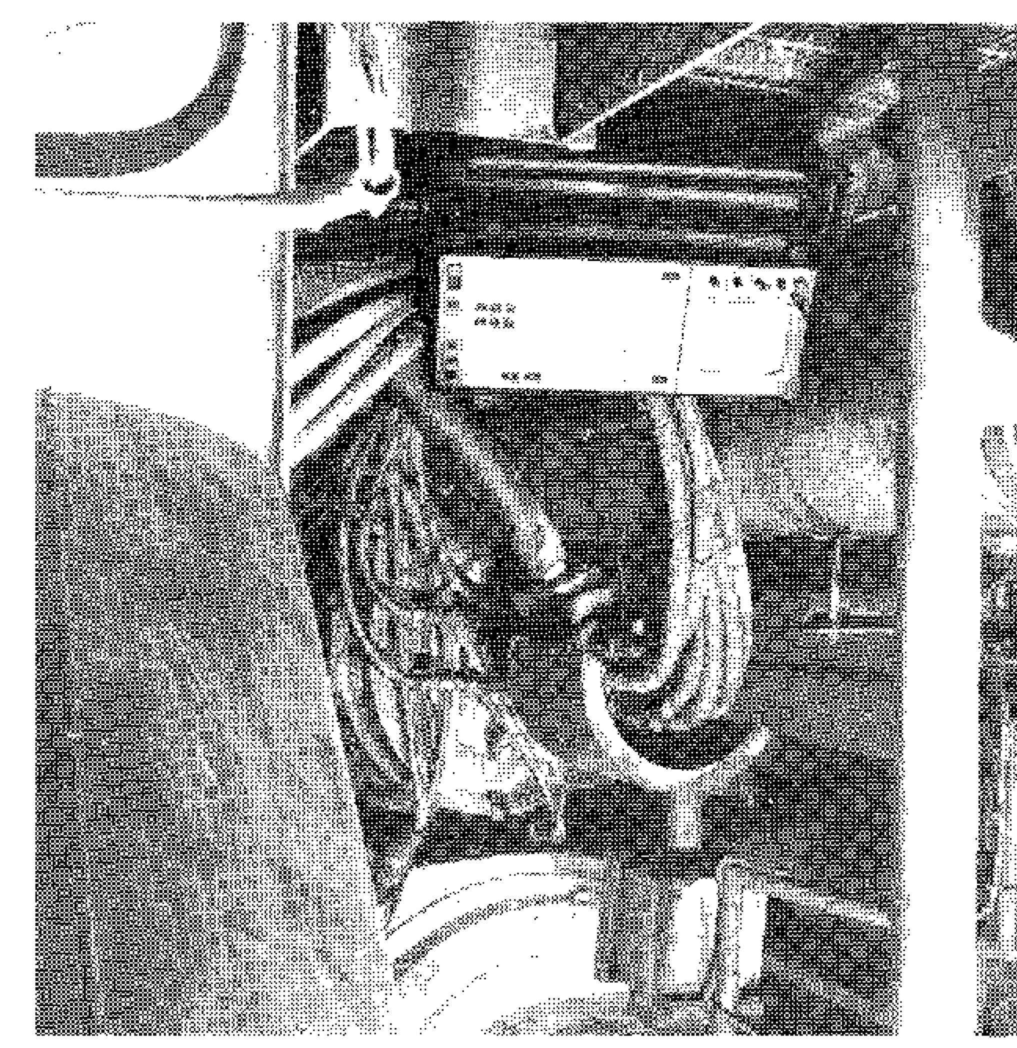
Application Notes

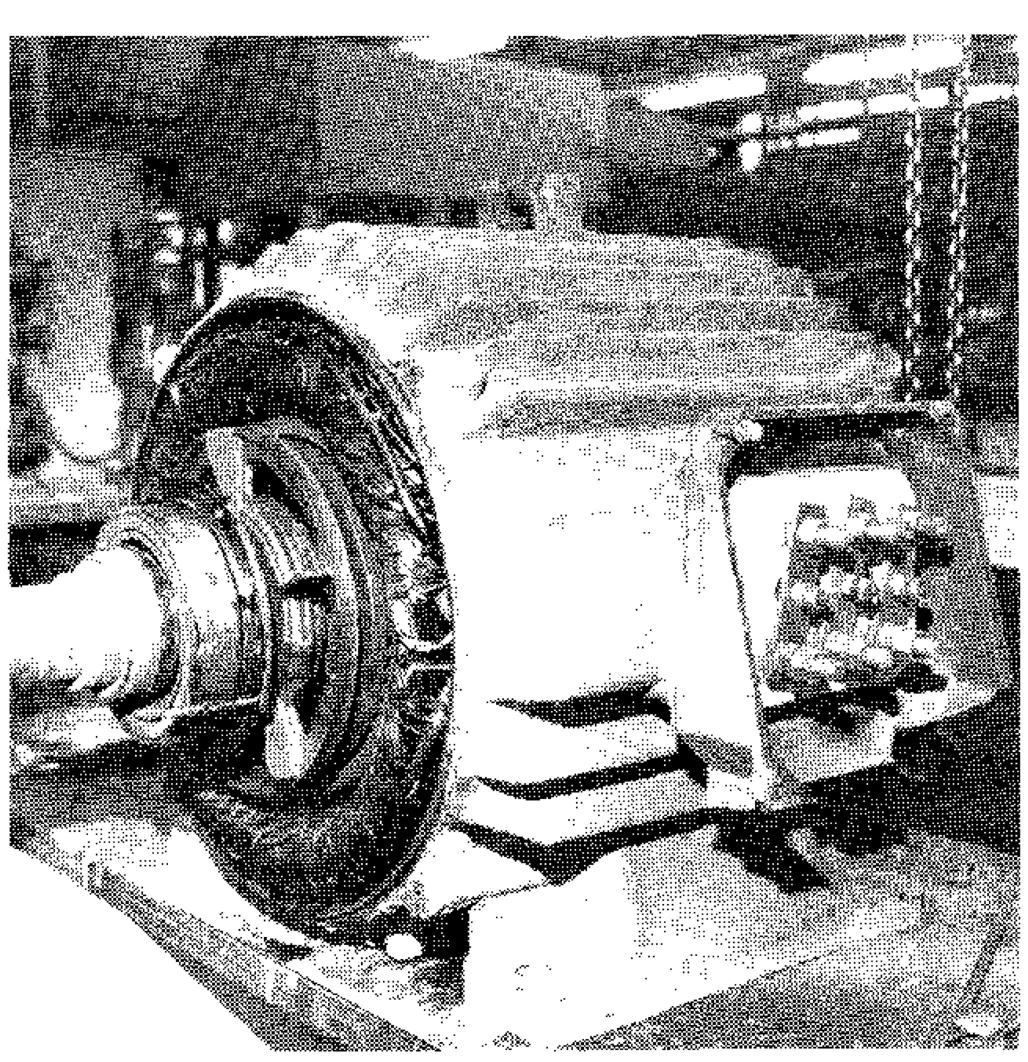
Diagnosis of Vibration Problems in Holland

Case Studies from the Groenpol Vibration Consultancy

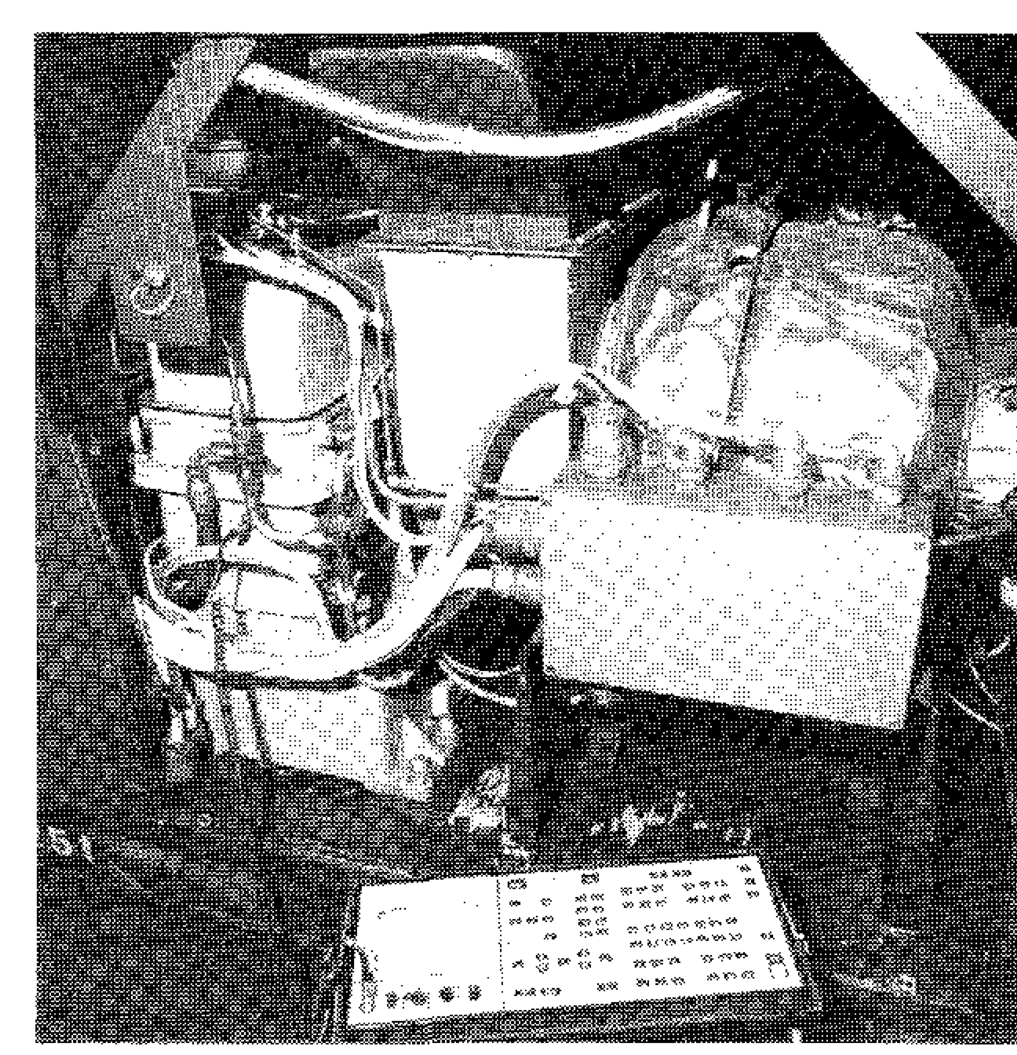


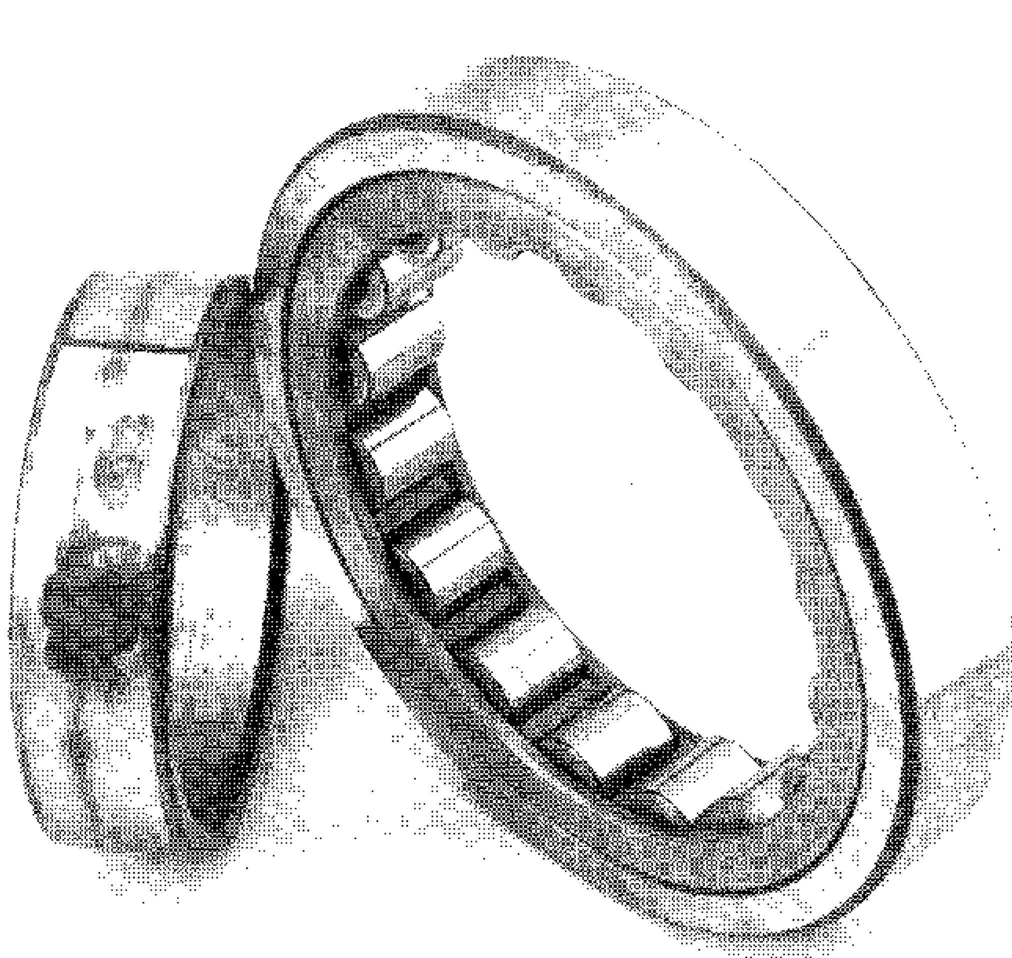


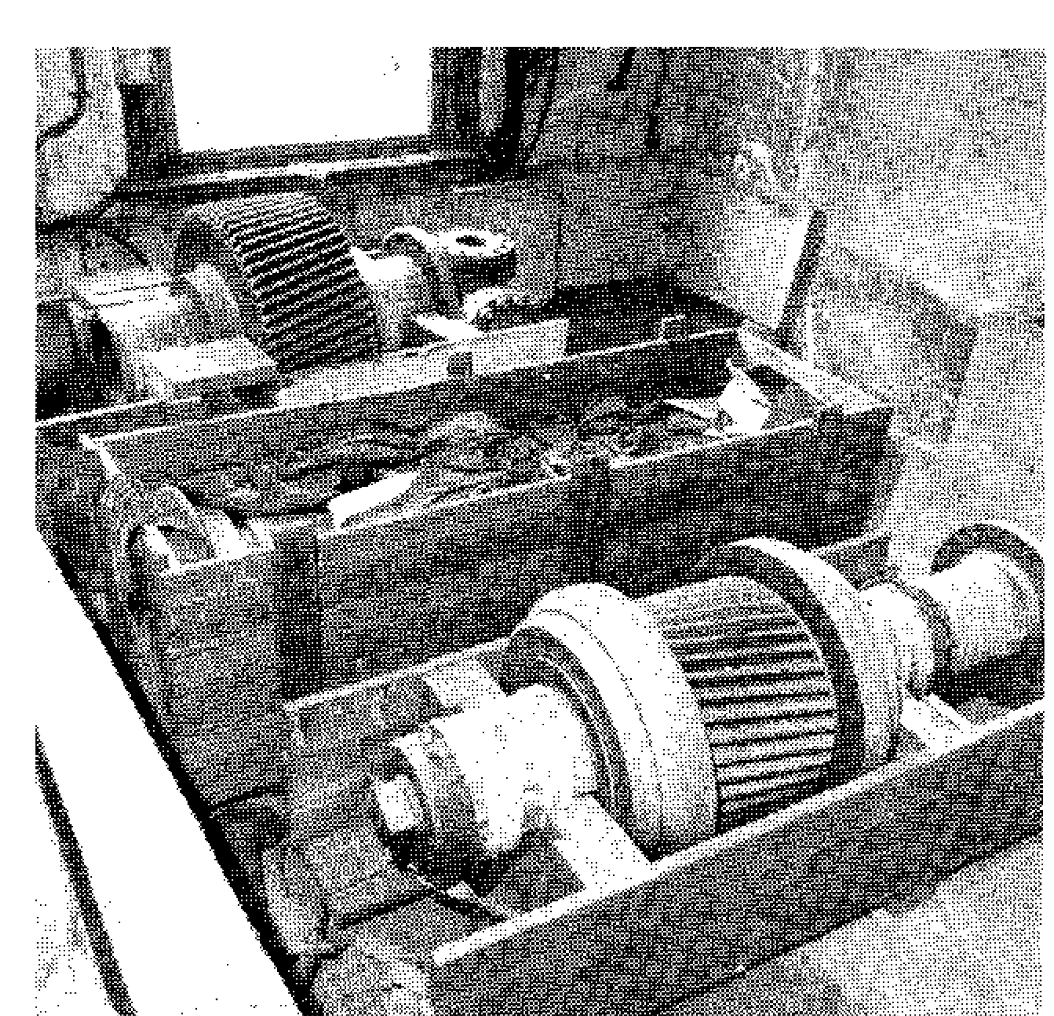




Groenpol Industrie Amsterdam BV is an industrial service company with 42 offices located throughout Holland. The headquarters in Amsterdam has 170 employees who service, repair and modify various types of equipment for process and power industries. Their vibration consultancy group uses Brüel and Kjær analyzers and instruments to diagnose vibration faults in rotating machines. This application note describes some of their experiences.







Diagnosis of Vibration Problems in Holland

Case Studies from the Groenpol Vibration Consultancy

Matt o'Sullivan
Mechanical Engineer
Brüel and Kjær, Denmark

Introduction

The Groenpol Services

The Groenpol vibration staff monitor machine condition for various industrial and military customers, based mostly in Holland, but also in West Germany. They offer various services, including long-term maintenance contracts, advice on implementing monitoring systems, intermittent fault diagnosis, and accelerometer calibration. They use a lot of Brüel and Kjær equipment, including Portable Vibration Analyzer Type 2515 and PC-based Application Software Type 7616 for monitoring and in-situ balancing, and Dual Channel Signal Analyzer Type 2032 for accelerometer calibration.

Portable Vibration Analyzer

A vibration spectrum measured on a machine represents the operating condition of the machine. By measuring a vibration spectrum, Groenpol can judge a machine's condition; furthermore, by measuring vibration spectra regularly and comparing with a reference spectrum, they are improving their detection rate and detecting faults much earlier. Groenpol practise this philosophy using the vibration analyzer. They use it in their maintenance contracts and recommend it to customers who want to set up their own monitoring systems. To file and process the collected spectra they use PC-based software, which is mentioned later.

Together with machine specifications, Groenpol use the diagnostic features of the portable analyzer to pinpoint faults in a wide range of machines. These features include Zoom for use with electrical machines, Cepstrum for gear faults, and Envelope analysis for roller bearing faults.

In their work, Groenpol find that structural faults are the root causes of many component failures. They use the portable vibration analyzer to find the resonance frequencies and to measure phase on the vibrating structure. With the results they plot the operation deflection shapes, which they use to plan the structural modifications.

Finally, the vibration analyzer, which is capable of measuring phase to an accuracy better than 2°, is used for 1 and 2-plane, in-situ dynamic balancing.

Application Software

For systematic machine condition monitoring, the portable vibration analyzer is used together with a Brüel and Kjær PC-based software program. The program has a database for management and storage of data from many machines, and procedures to warn about spectrum increases and to recommend maintenance dates. Its special features include (a) constant percentage bandwidth (CPB) spectrum comparison for detection of the widest possible range of faults, and (b) consideration of the effect of process parameters on vibration spectra, for reliable results.

Acknowledgement

The author would like to thank the Groenpol vibration engineers Mr. K. Brüske and Mr. G. van Nimwegen, and Brüel and Kjær engineer Mr. Henk Smith, for their co-operation in preparing this application note.

Case 1 – Piston-compressor Loose on Foundation

The Machines

A company which manufactures Aluminium from Bauxite wanted to systematically monitor the condition of three critical piston compressors using vibration measurements. Groenpol was contracted to set up the monitoring system.

The compressors are double acting, with two pistons, one vertical and one horizontal. They are mounted on separate concrete islands, which are isolated from the floor by strong steel springs. They are driven at 500 RPM (8,3 Hz) with vee belts by a 1500 RPM (25,0 Hz), 250 kW motor. Fig. 1 shows a top view of the machinery set-up and the measurement point locations.

The Measurements

Before they install a monitoring system on a machine, Groenpol always ensure that the machine is *properly secured to a sound foundation.* This condition is necessary because the first (reference) measurement must represent the machine in a good condition. To check the condition, they measure the overall vibration level in vertical, horizontal and axial directions; if the vertical level is lower than each of the other two levels, they are satisfied.

They measured the overall vibration levels, on all three compressors, at the points shown in Fig. 1. For one machine the vertical (12,8 mms^{-1}) was much higher than the horizontal (4,4 mms^{-1}). This result suggested a foundation problem.

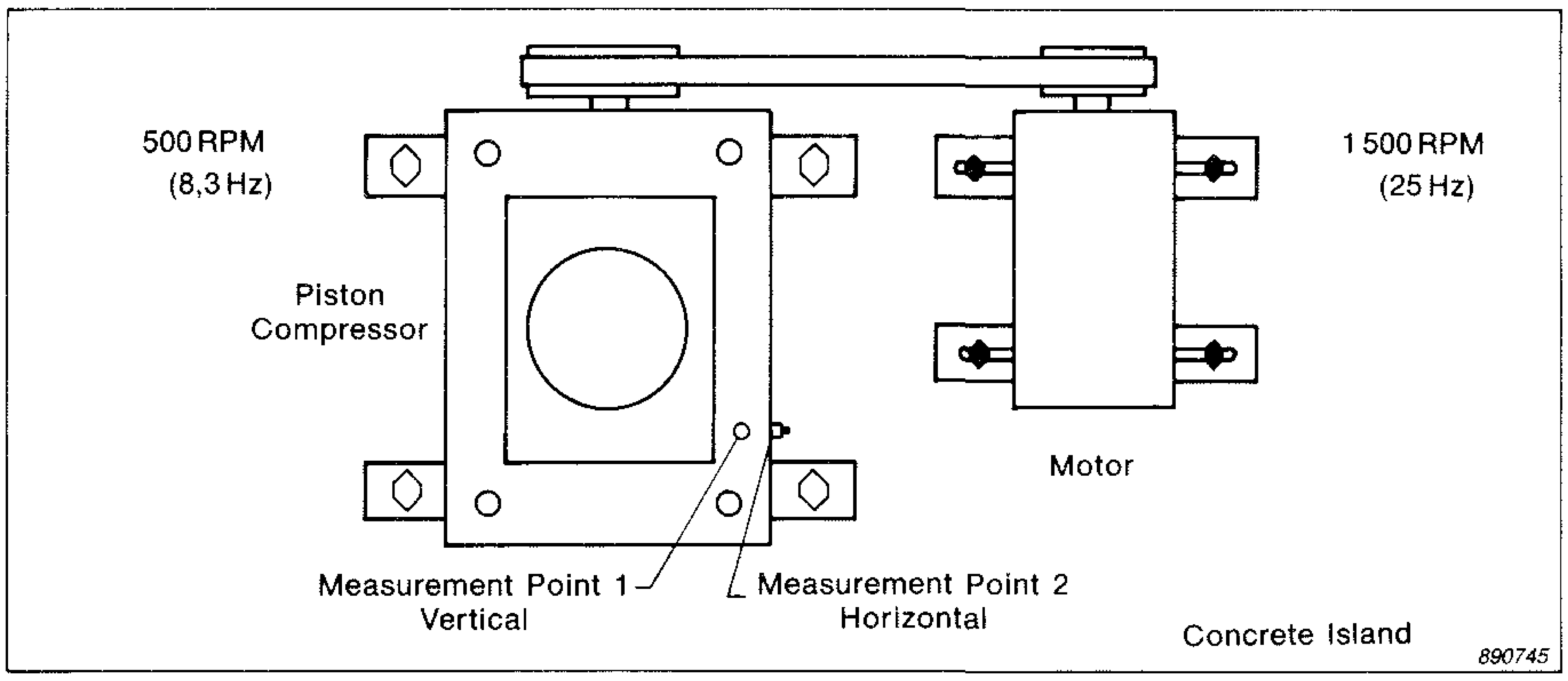


Fig. 1. A top view of the motor and compressor on the concrete island. The locations of the vertical and horizontal measurement points are indicated

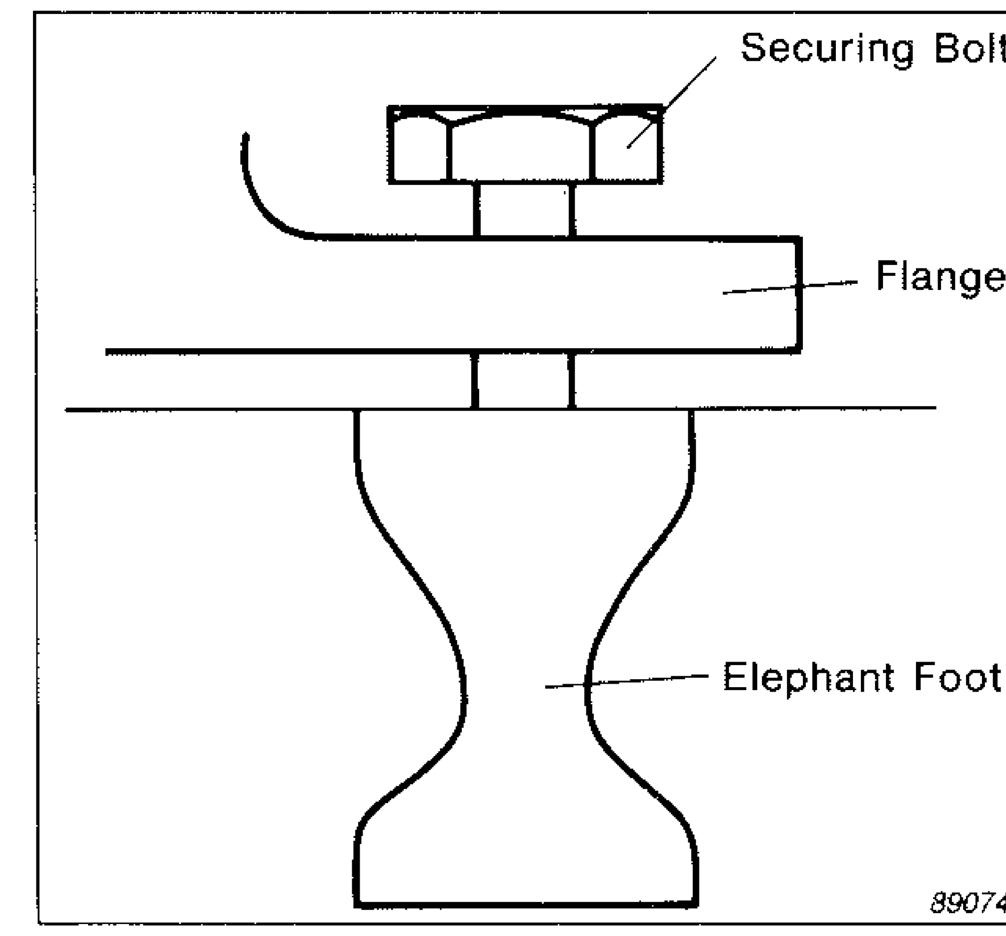


Fig. 2. A loose bolt, in its elephant foot, at the base of the non-driven end of the compressor. The casing is excited at the shaft rotation speed, causing a harmonic family of the shaft speed in the spectrum

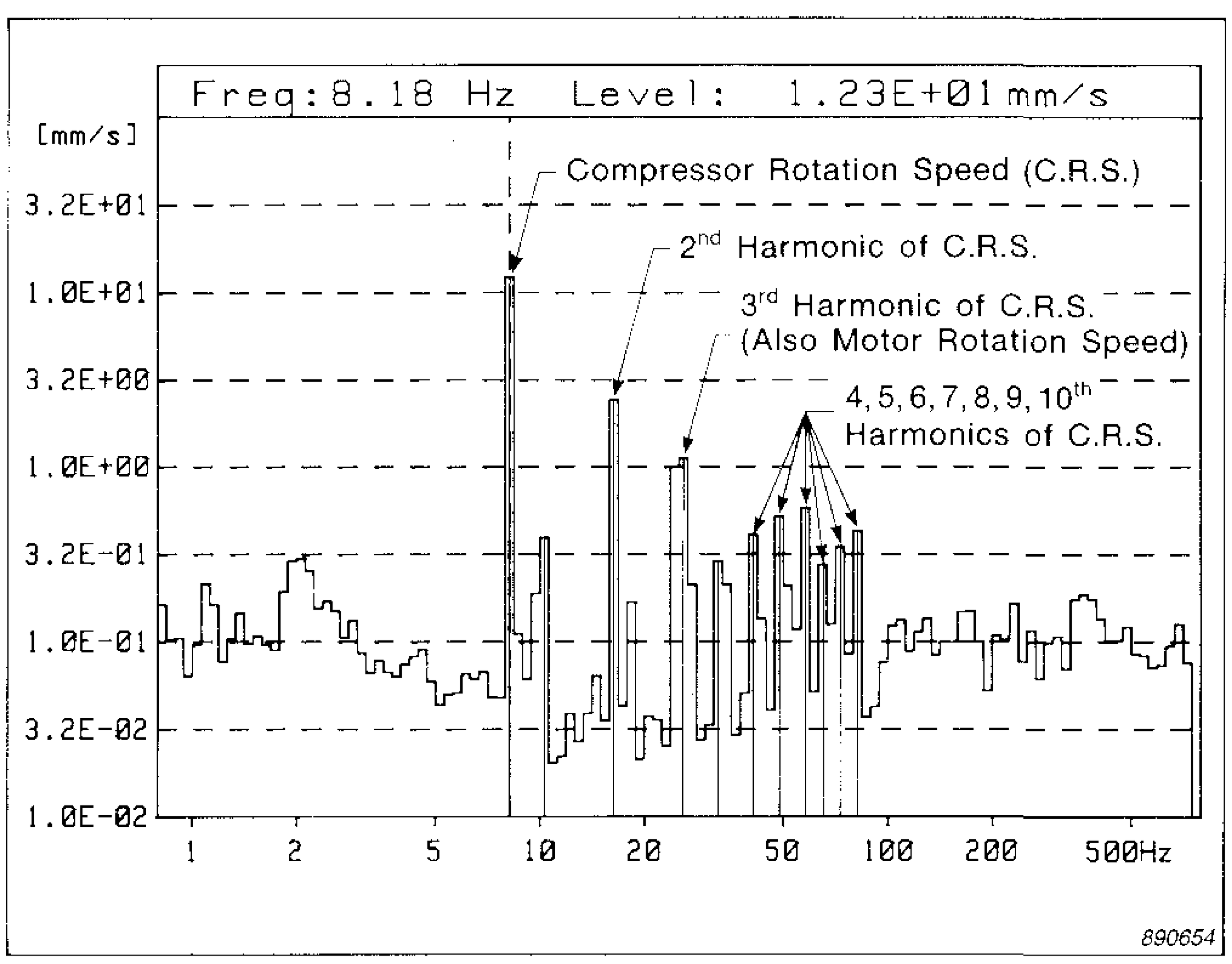


Fig. 3. A vertical measurement (500 Hz, CPB spectrum) from the compressor casing. The prominent harmonic family of the compressor rotation speed indicates looseness

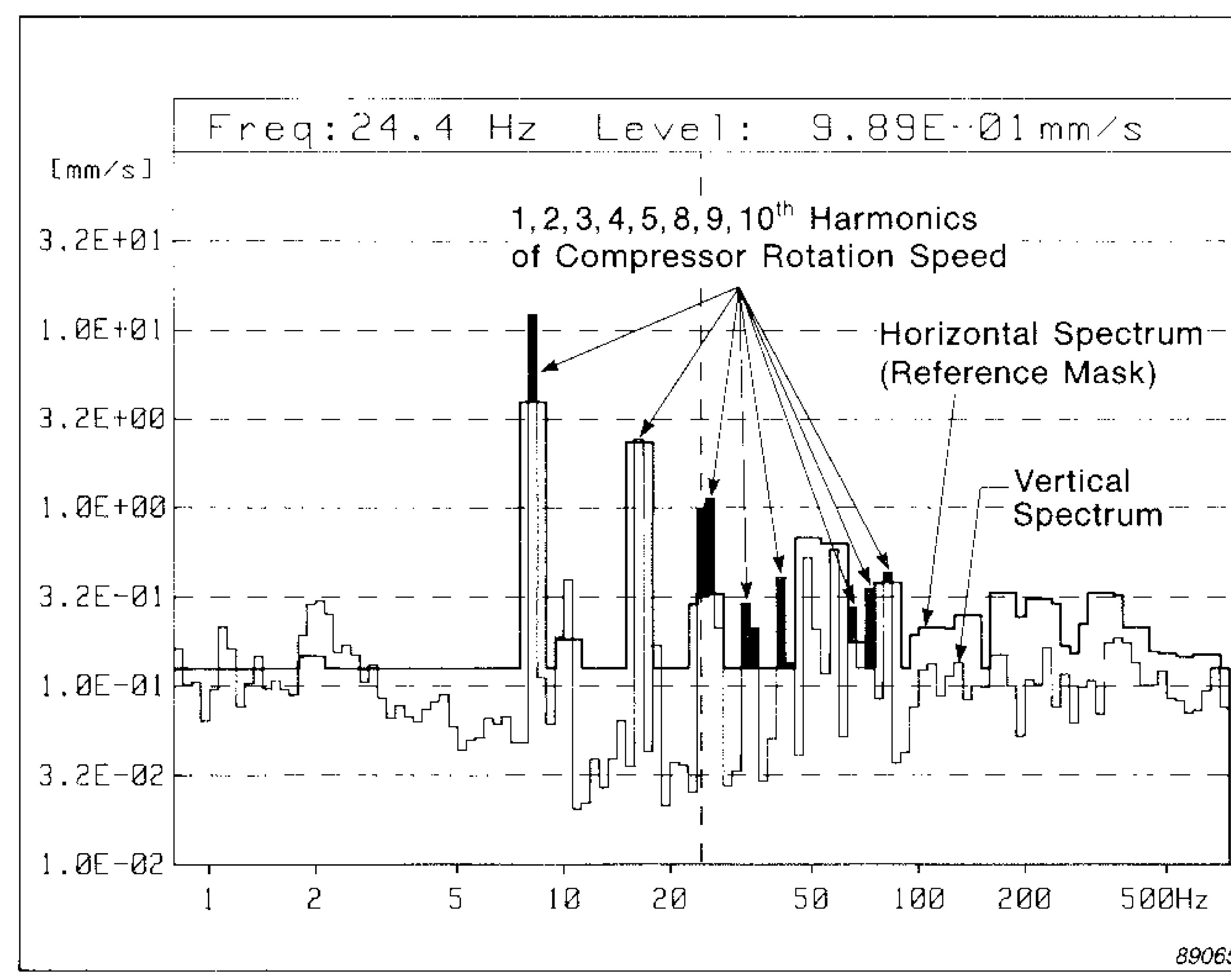


Fig. 4. A comparison of vertical and horizontal measurements (500 Hz, CPB spectra) from the compressor casing. The horizontal measurement is the reference. Note that the vertical exceeds the horizontal at harmonics of the compressor rotation speed

The spectrum from the vertical measurement point is shown in Fig. 3. It contains a harmonic family of the rotation speed. They compared the vertical and horizontal spectra as shown in Fig. 4. The harmonic family in the vertical spectrum exceeds that in the horizontal spectrum, a result which indicates that the excessive vertical vibration is caused by mechanical looseness. Groenpol decided to check the bolts securing the compressor to its foundation.

The Fault

They found two loose, worn bolts on the elephant feet at the non-driven end of the compressor, see Fig. 2. The company decided to wait until the next scheduled stop before replacing the bolts. After that, the machines would be ready for systematic monitoring.

Conclusion

For machine condition monitoring based on spectrum comparison, the first (reference) spectrum must represent the machine in a good condition. Groenpol measure vibration spectra in vertical, horizontal and axial directions to check the machine condition. When the vertical level is higher than each of the other two levels, they suspect a foundation problem.

Mechanical looseness is often indicated in the vibration spectrum by a prominent harmonic family of the rotation speed.

Case 2 – Loose Rotor in an Electric Motor

Quality-control Vibration-tests on Electrical Machines

Groenpol has its own workshop for repairing electrical machines of various types and sizes. After repair, each machine is taken to a test area where the overall vibration level is measured in vertical, horizontal and axial directions. Here it must satisfy two test criteria:

The first criterion is the German recommendation for vibration severity, VDI 2056. Here the machines are grouped according to rated power and their condition is classified according to overall RMS velocity level. In this case the machine is a 14 kW lift motor and it belongs to group K (<15 kW). In this group, the overall RMS velocity level must be less than 0,7 mms^{-1} in all directions for a 'good condition' classification.

The second criterion (Groenpol's own criterion) specifies that the axial vibration level must be less than the vertical and the horizontal levels, with the machine uncoupled.

Diagnosis with the Type 2515

The lift motor had a vibration level of 1,67 mms^{-1} in the horizontal direction, so it failed to satisfy VDI 2056. The Type 2515 Vibration Analyzer was used to help diagnose the problem. A linear-baseband spectrum revealed a large family of harmonics of the rotation speed, see Fig. 6. This is the classic symptom of mechanical looseness and in the case of an electrical machine, it usually indicates worn rotor bearings. Groenpol secured the rotor and, as expected, the motor passed the subsequent vibration test.

Conclusions

Groenpol has a go/nogo quality control test for *uncoupled* electric machines repaired in the workshop. The test specifies the following two requirements of the overall vibration level:

1. Must satisfy VDI 2056 in all directions
2. Axial < vertical, horizontal

Rotor looseness is a typical fault in lift motors. It is caused by continuous braking and change of direction over many years. The fault is indicated in the spectrum by a harmonic family of the rotation speed.

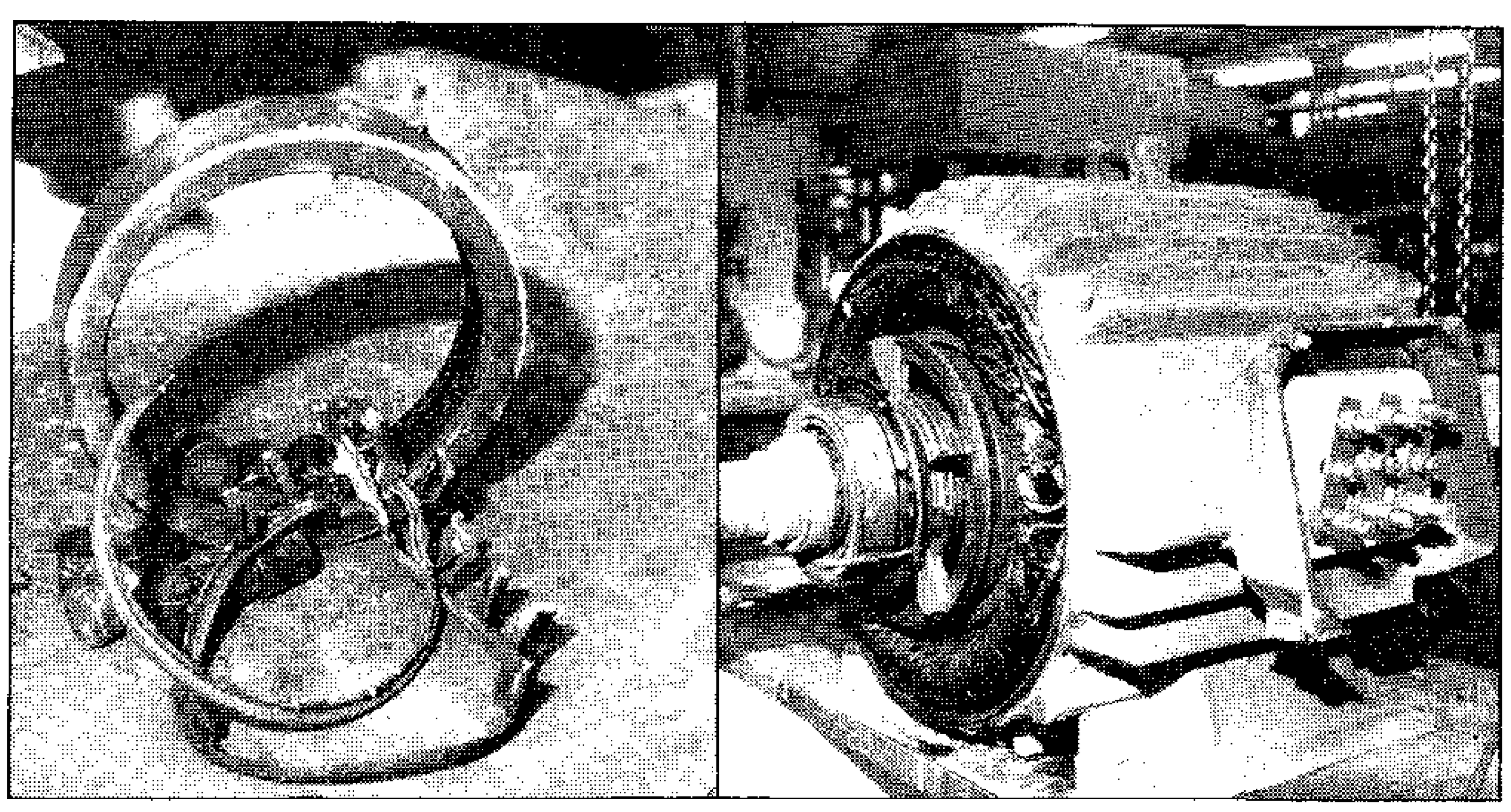


Fig. 5. Groenpol have a workshop where they service and repair various types of machines. Here is a damaged roller bearing from a dismantled electric motor

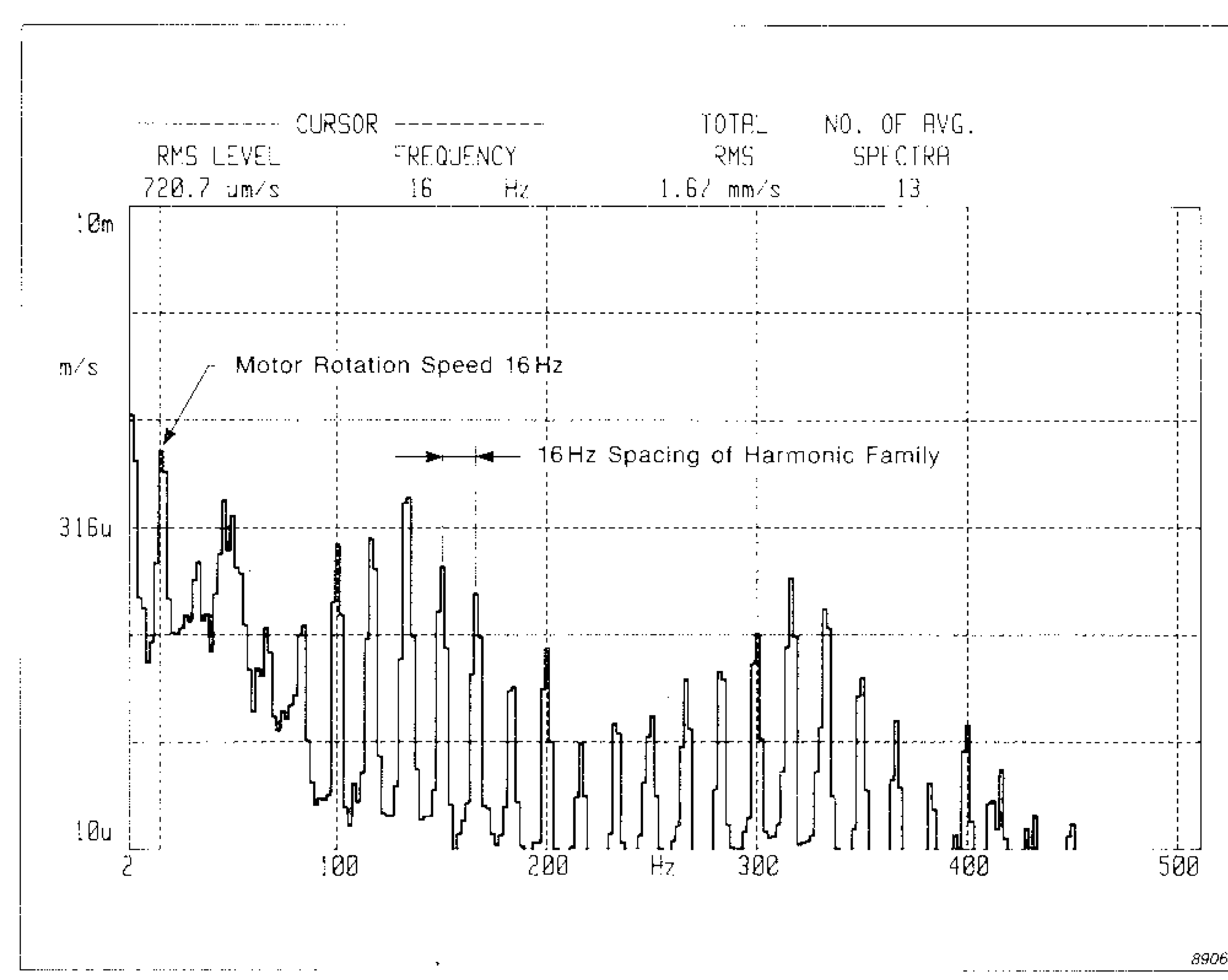


Fig. 6. The spectrum from the lift motor, measured at the drive side, horizontal direction. The harmonic family of the rotation speed is the classic symptom of a loose rotor

Case 3 – Motor Problems at a Paper Mill

The Machine

The motor concerned is a 1 MW, 900 RPM (15 Hz) unit, located high up in an awkward position. It drives flat-belt pulleys at both ends, see Fig. 7. When the maintenance staff noticed that the vibration level was relatively high compared to vibration severity criteria VDI 2056, they called Groenpol and asked them to do the repairs in-situ.

Diagnosis with the Type 2515

To diagnose the fault, Groenpol measured with the vibration analyzer at the two horizontal measurement points shown in Fig. 7. At measurement point 1 they noticed a high vibration level at the motor rotation speed. The spectrum from measurement point 2 is shown in Fig. 8. It shows that most of the vibration occurs at the rotation speed; from this Groenpol concluded that the main problem was unbalance.

The 2^{nd}, 4^{th} and 6^{th} harmonics of rotation speed are prominent but their level is much lower; from this Groenpol suspected a misalignment problem at the coupling near measurement point 2.

Correcting the Faults

Groenpol balanced the two pulleys in-situ. Next they uncoupled the pulleys from the motor and balanced the motor in-situ. Finally they examined the coupling and they found it was stiff and worn due to lack of grease. After it was cleaned and greased, and the shafts re-coupled, the machine operated normally. An overall RMS measurement confirmed that the vibration level was now acceptable.

Conclusions

A high component at rotation speed usually indicates unbalance, and a prominent harmonic family of 2×rotation speed suggests misalignment or a coupling fault. The positions of the measurement points sometimes help to reveal the location of the fault, as in the case of the coupling fault.

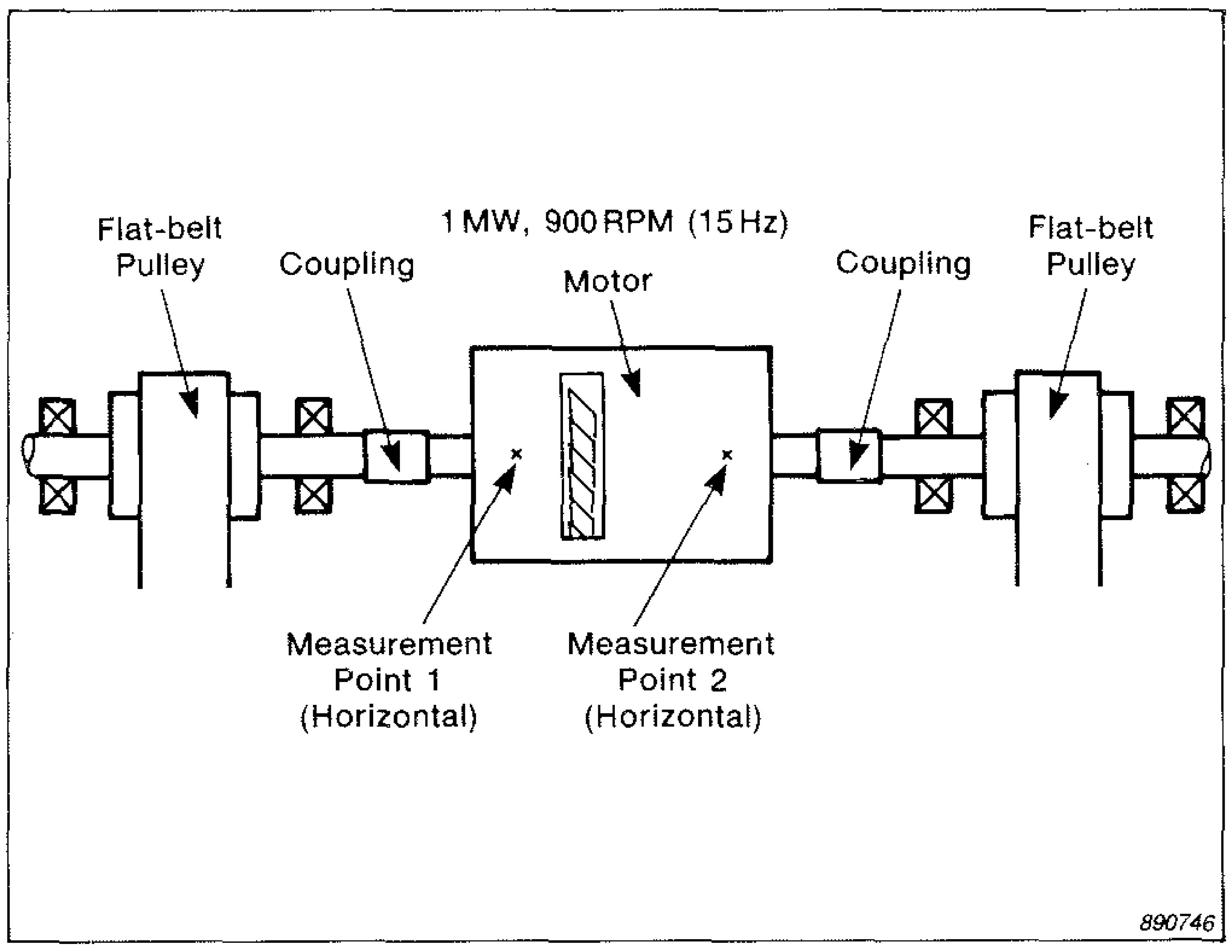


Fig. 7. The 1 MW motor drives two flat-belt pulleys as shown. Since it is very large and located high up in an awkward place, the maintenance staff wanted the repairs done in-situ

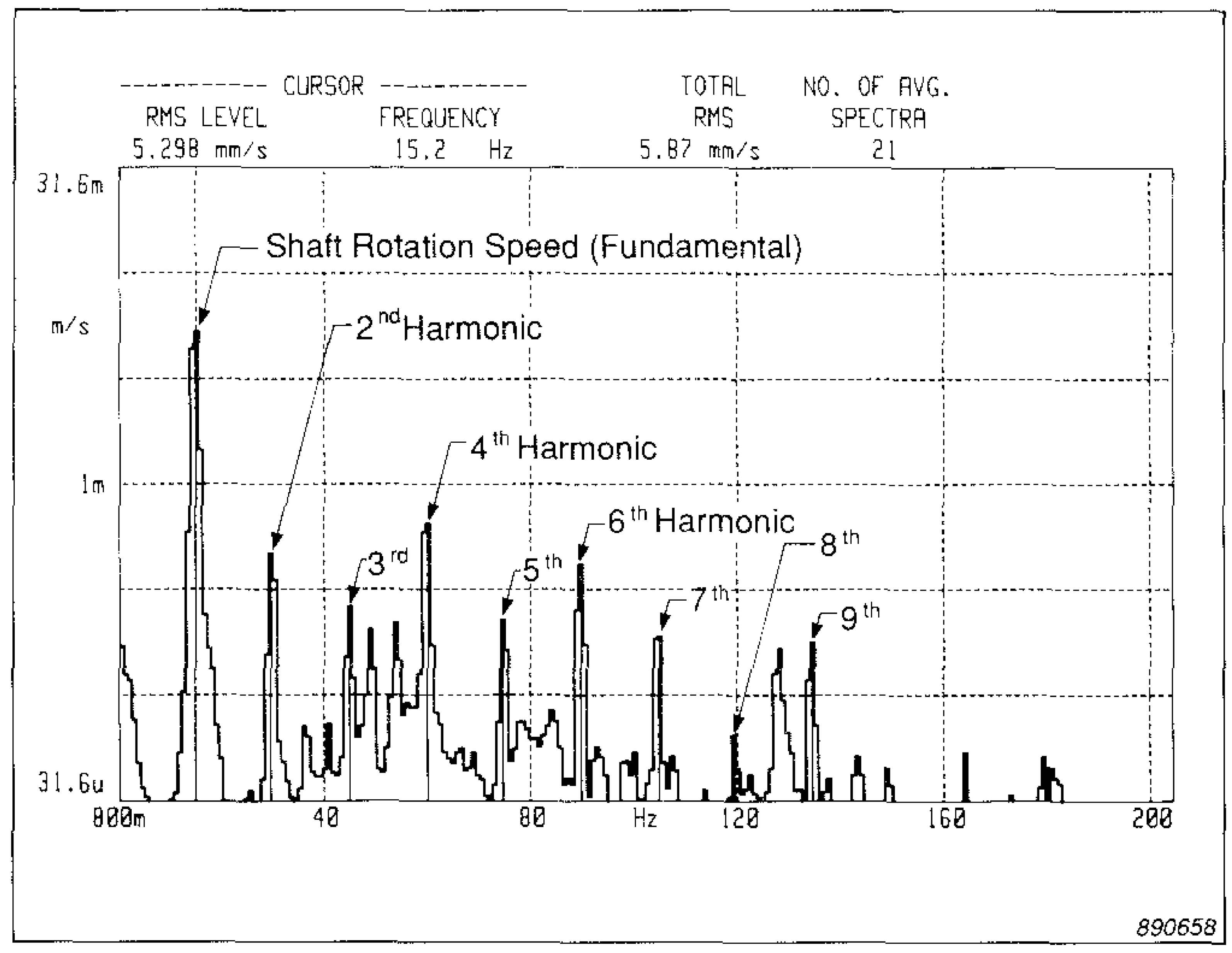


Fig. 8. A horizonal, linear-baseband spectrum from measurement point 2. The high level at the motor speed indicates that the main problem is unbalance. The prominent 2 × rotation speed harmonic family suggsts a misalignment or coupling problem

Case 4 – Structural Problems with a Fan

The Fan

The company in this case manufactures Tarmacadam for road surfacing. The faulty fan is used to extract dust from the manufacturing area. It was located about 1,5 m from ground level, on top of a steel frame which stood unbolted to the floor, see Fig. 9.

Balancing Problems

When the vibration level became excessive, the company asked Groenpol to balance the fan. A typical instrumentation set-up for 2-plane, in-situ dynamic balancing is shown in Fig. 10.

During the balancing procedure, Groenpol found that the problem was more difficult than first expected. For a fan like this with a diameter of 1.5 m, they normally use a trial mass of about 150 g. When they mounted this mass and did a trial run, the vibration level became so high that the structure was unsafe. They repeated the trial run with a reduced mass of 20 g and, despite some problems with phase stability, they managed to complete the measurements and reduce the unbalance.

A Faulty Frame

Soon afterwards the vibration level became intolerable again. Groenpol suspected a structural problem and decided to inspect the frame closely, see Fig. 11. On sand-blasting, they found a large crack at the top. This had caused a low-frequency resonance in the frame, near the fan rotation frequency. They advised the company to weld the crack, add stiffeners, and fill the frame with concrete.

The company stiffened the frame as shown in Fig. 11 and this increased the frequency of the resonance. During subsequent balancing jobs, the 150 g trial mass did not cause dangerous vibration levels and the phase was much more stable.

Spectrum Interpretation

After the repairs were finished, Groenpol measured a horizontal, 2 kHz, 6% CPB spectrum at the bearing casing, at the driven end of the fan, see Fig. 12. The overall RMS level of 4,3 mms^{-1} was acceptably low. The origin of the main peaks in the spectrum is as follows:

Peak 1 is the fan rotation speed. This indicates residual unbalance in the fan.

Peaks 2, 3 and 4 are harmonics of the motor rotation speed. They are probably caused by the motor exciting the loose frame.

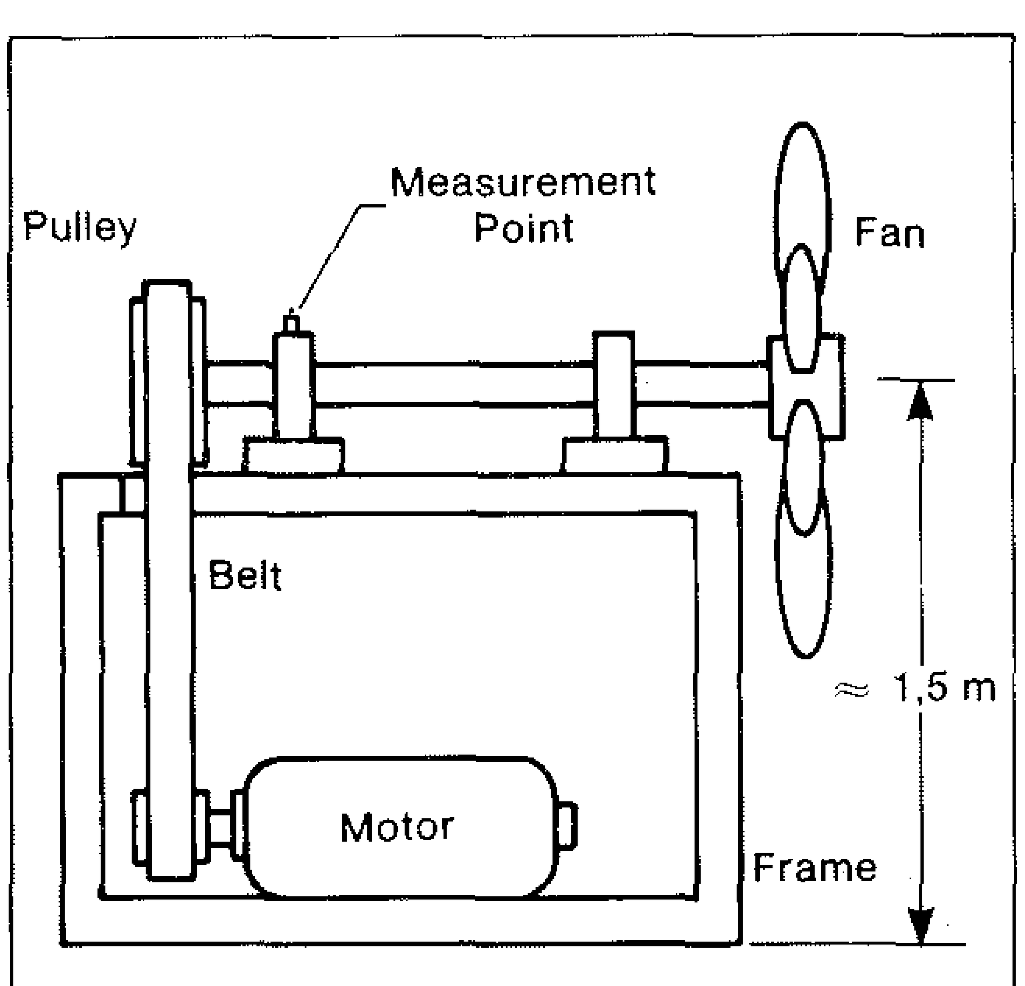


Fig. 9. The motor drives the fan through a belt drive as shown. The frame sits loose on the floor

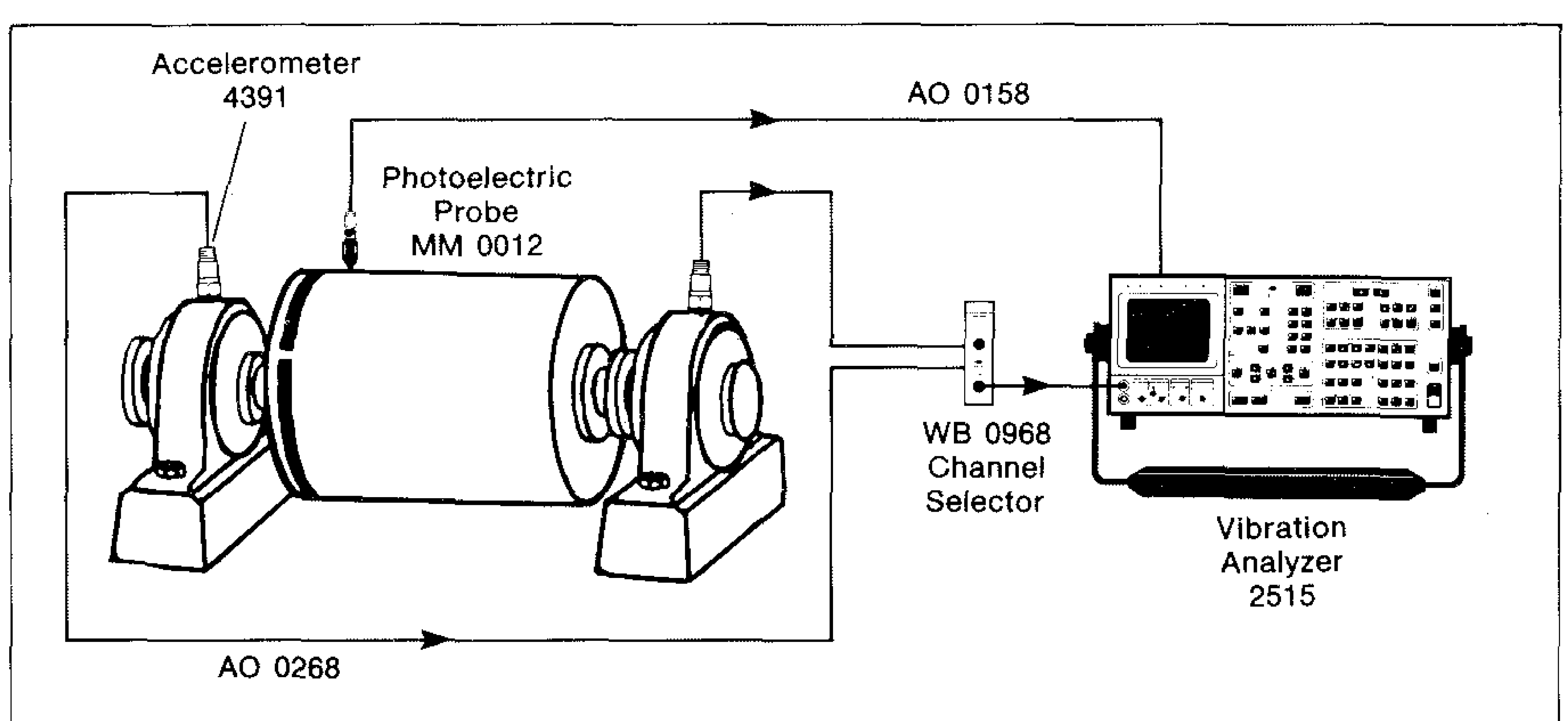


Fig. 10. A typical instrumentation set-up for in-situ balancing with a portable vibration analyzer

Peaks 5 to 11 are also members of a harmonic family. Peak 5 is the fundamental with a frequency of 183 Hz. This does not correspond to any shaft rotation speeds. Instead it is probably a characteristic ball-passing frequency of a roller element bearing, which indicates bearing fault. The harmonic family is prominent because it is amplified by resonances in the machine.

Conclusions

Cracks in machine frames can give rise to very high vibration levels. The spectra from loosely mounted machines normally contain harmonic families of shaft rotation speed.

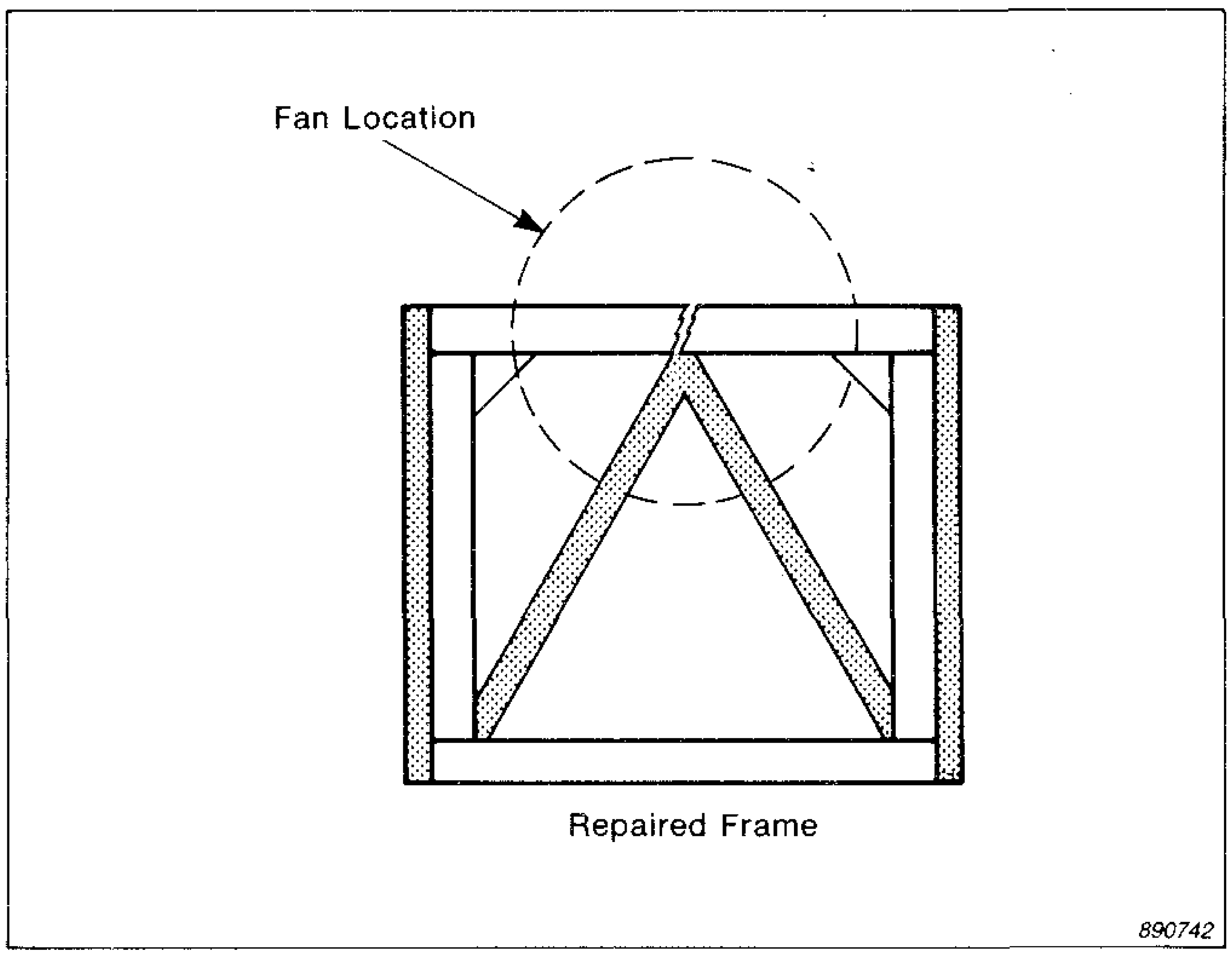


Fig. 11. The original frame had a crack near the top. This was welded and stiffeners (shaded sections) were added

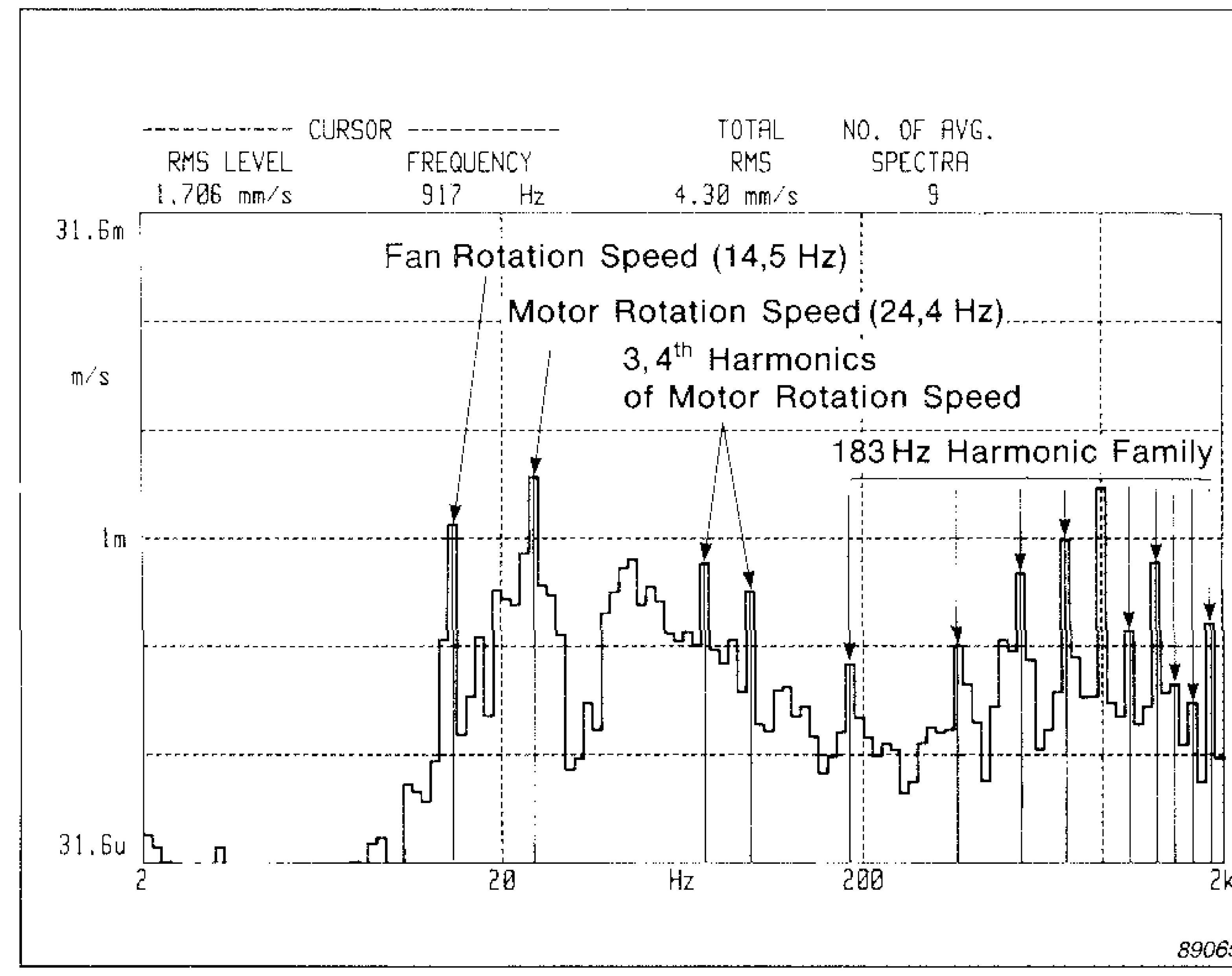


Fig. 12. Horizontal, 2 kHz, 6% CPB spectrum. This was measured at the bearing casing, at the driven end of the fan shaft, after the frame was repaired. Note the two harmonic families

Case 5 – Structure/Foundation Problems in a Screw Compressor

Structural Vibration

Most of the cases Groenpol investigates involve faulty structures or foundations. A common symptom of structural faults is the occurrence of repeated, unexplained component failures, e.g. bearing failures. These occur because the machine structure vibrates excessively, upsetting and fatigue cycling bearings, shafts, bolts, hoses, etc.

This case concerns a structural problem with a screw comressor.

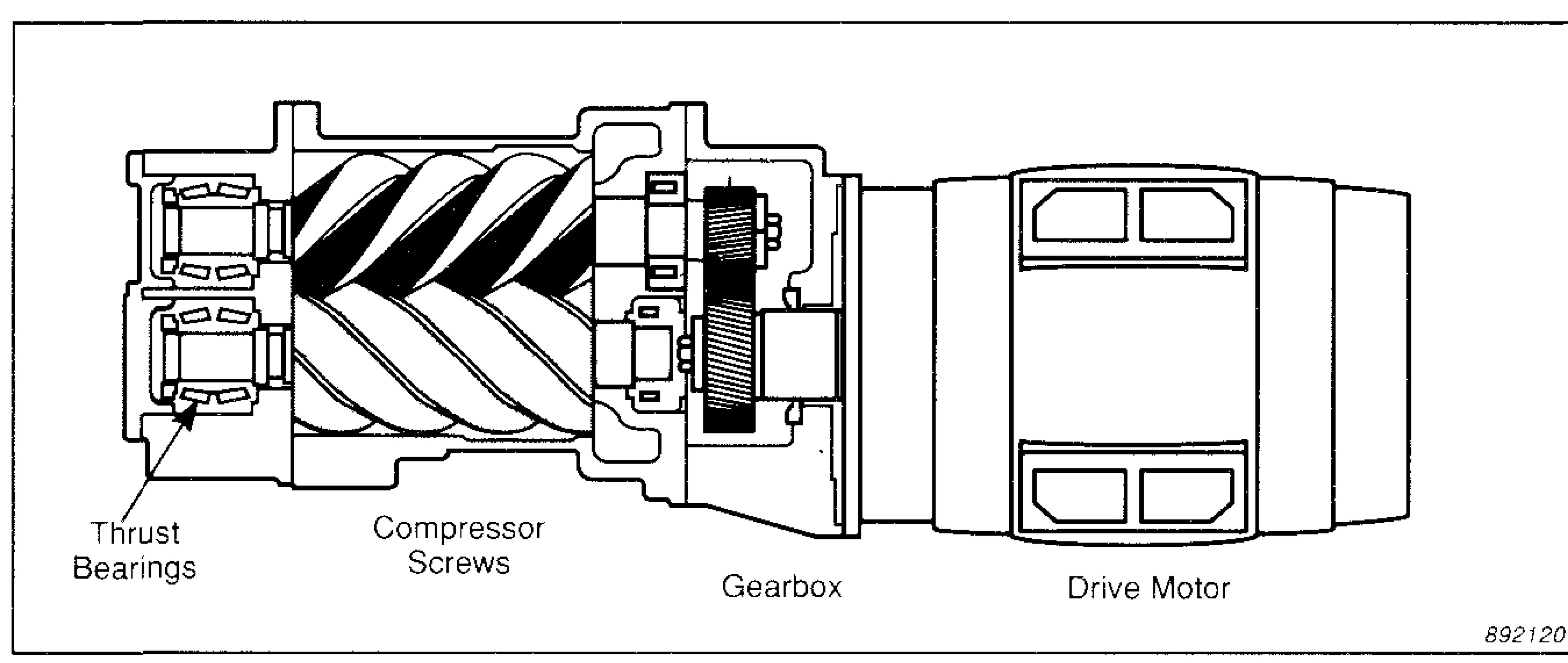


Fig. 13. A typical, small screw compressor, in which the top screw drives the bottom screw. The spiral profiles on the screws are called lobes; normally one screw has 4 lobes and the other has 6 lobes. The lobemeshing frequency is the product of the number of lobes and the screw rotation-frequency

Screw Compressors

Screw compressors are used for high-pressure compression. Two adjacent, rotating spiral screws trap the gas at one end and force it out the other, see Fig. 13. In small compressors, as in this case, an electric motor drives one screw, which in turn drives the other screw. The speed ratio of the screws depends on the numbers of lobes. These are normally 4 and 6, which means a speed ratio of 6:4.

Diagnosis Using the Type 2515 Vibration Analyzer

The compressor in question is mounted as shown in Fig. 14. When the company noticed high noise and vibration levels, they asked Groenpol to correct the problem. Groenpol found the spectrum shown in Fig. 15 when they measured with the Type 2515 Vibration Analyzer. The following peaks are visible:

Fan motor speed: 25 Hz
Compressor motor speed: 48,7 Hz
Screw 1 rotation speed: 57,9 Hz
Screw 2 rotation speed: 86,6 Hz
Lobemeshing frequency: 345 Hz
Lobemeshing frequency harmonics

The lobemeshing frequency harmonics are the highest peaks in the spectrum. According to manufacturers of screw compressors, this indicates thrust-bearing damage. When the mechanics removed the thrust bearing they found the suspected damage.

Persisting Problems

When the bearing failed again soon afterwards, Groenpol began to suspect a structural problem. They measured on the frame and found excessive vibration at 25 Hz i.e. at the rotation speed of the cooling fan. They concluded that the fan was exciting a resonance frequency of the frame and they advised the company to modify the frame. The company ignored this advice and subsequently they paid the price when a seal failed in the compressor and oil entered the air system. All operations had to be stopped until the system was cleaned out.

The company continued to monitor

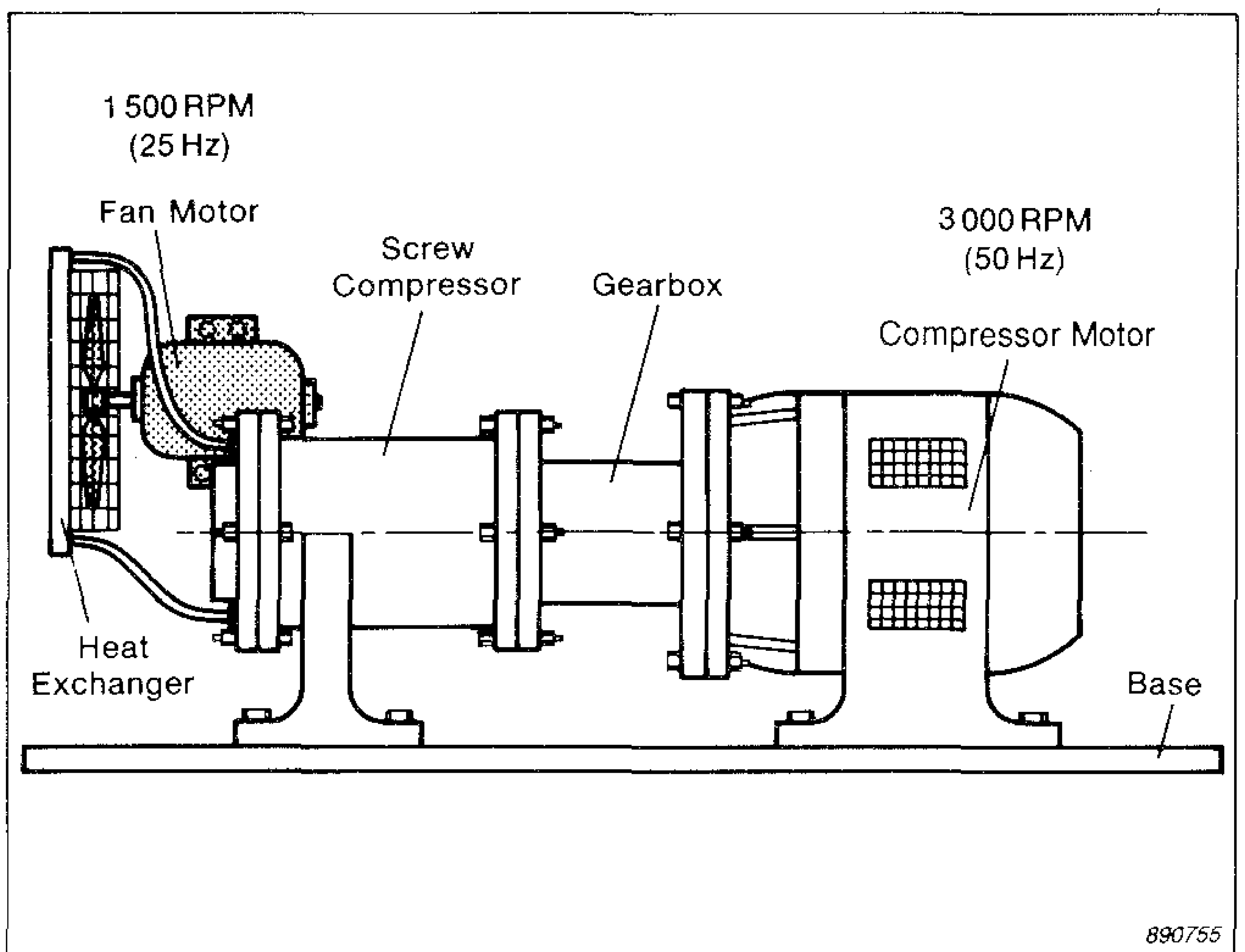


Fig. 14. The compressor unit which consists of the compressor motor, gearbox and screw compressor, and a smaller motor which drives a cooling fan

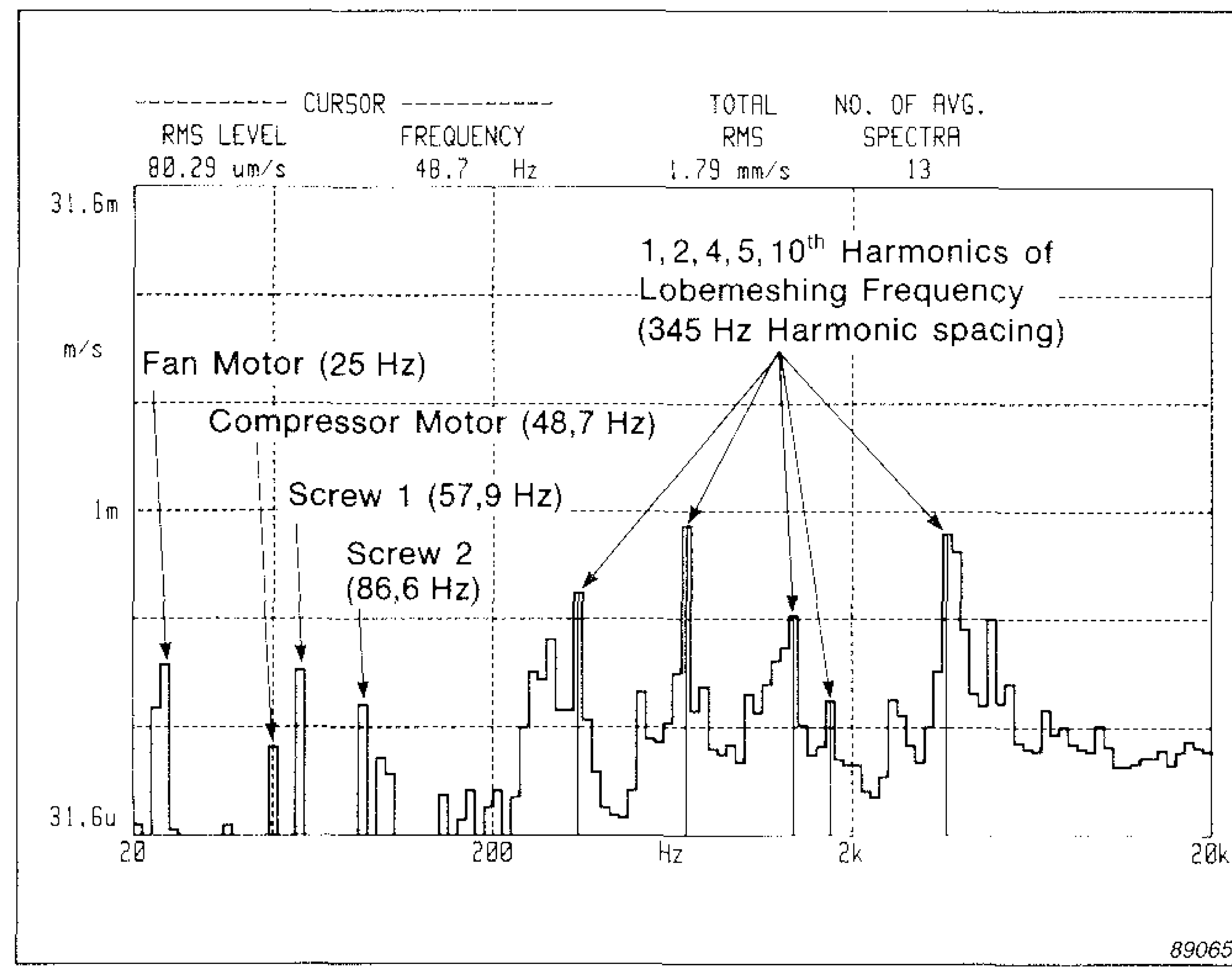


Fig. 15. Axial, 20 KHz, 6% CPB spectrum. Measured at the non-drive end of the compressor motor. Note the harmonic family of the lobemeshing frequency. This is a symptom of thrust-bearing damage

the overall vibration levels and found that these exceeded the acceptable limits. Before the warranty period ended, they returned the compressors to the manufacturer for overhaul. The manufacturer stiffened the frame in order to move the resonance frequency away from the fan excitation frequency. However, when the compressor was started again the vibration was worse than before.

Groenpol decided to investigate the vibration modes of the frame. They used a vibration exciter to shake it sinusoidally and found resonance frequencies at 18 Hz and 50 Hz. They measured the phase with their balancing instrumentation and used the results to plot the mode shapes, see Fig. 16. These show that the frame bent in the middle at the gearbox.

By an unlucky coincidence, the compressor motor speed of 48,7 Hz was exciting the 50 Hz resonance frequency of the frame.

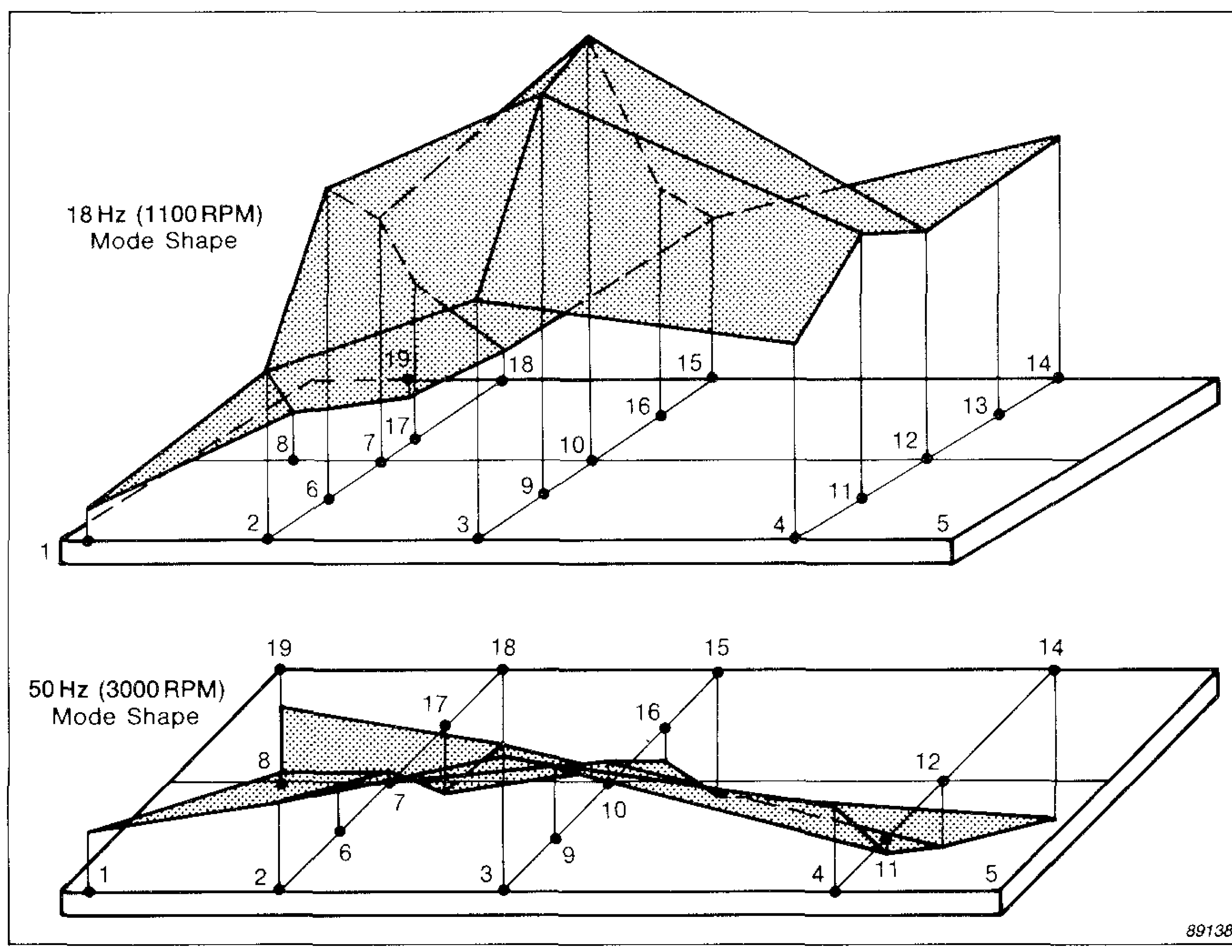


Fig. 16. The 18 Hz and 50 Hz mode shapes of the compressor frame. The 50 Hz mode is excited by the 48,7 Hz rotation speed of the compressor motor

Dampers instead of Stiffeners

The company could not afford to modify the frame further, so Groenpol decided to insert vibration dampers between the motor and the frame in an attempt to dissipate the 48,7 Hz vibration being transmitted from the motor to the frame. This was successful. The vibration of the frame dropped to an acceptable level and the machine functioned normally.

Two similar compressors had the original frame types and similar problems. Groenpol tested these and found resonance frequencies at 10 Hz and 25 Hz. The 25 Hz fan rotation speed was exciting the frame. They inserted vibration dampers between the fan motors and the frames to damp the 25 Hz vibration. Again, the operation was successful.

Conclusions

A small excitation signal (from the cooling fan in this case) can cause a large vibration level in the structure if its frequency coincides with a structural resonance frequency. Vibration dampers can be used to reduce the force transmitted from the excitation source to the structure. They are often the simplest, cheapest solution.

Brüel & Kjær

WORLD HEADQUARTERS: DK-2850 Nærum · Denmark · Telephone: +45 42 80 05 00 · Telex: 37316 bruka dk · Fax: +45 42 80 14 05 / +45 42 80 21 63

Australia (02) 450-2066 · Austria 02235/7550*0 · Belgium 02·242-97 45 · Brazil (011) 246-8149/246-8166 · Canada (514) 695-8225 · Finland (90) 80 17 044
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