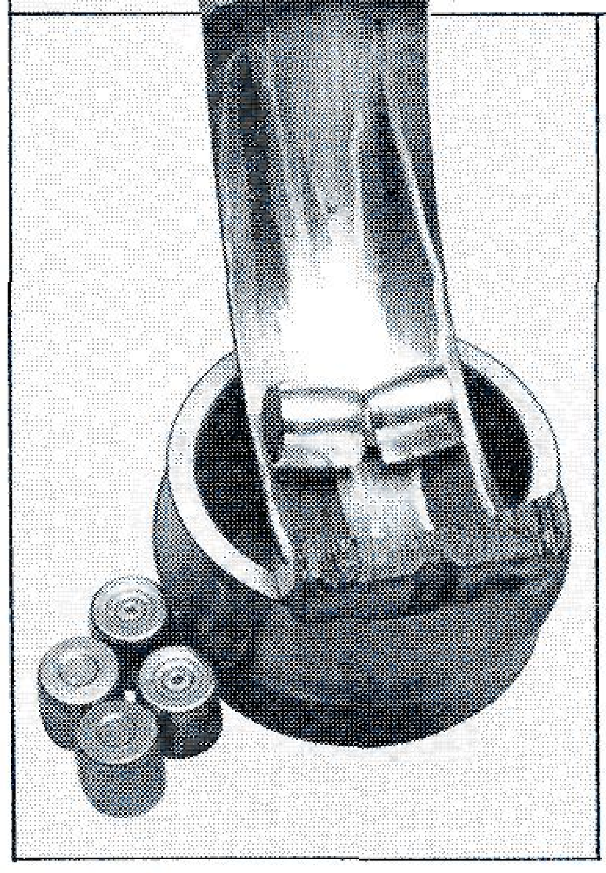
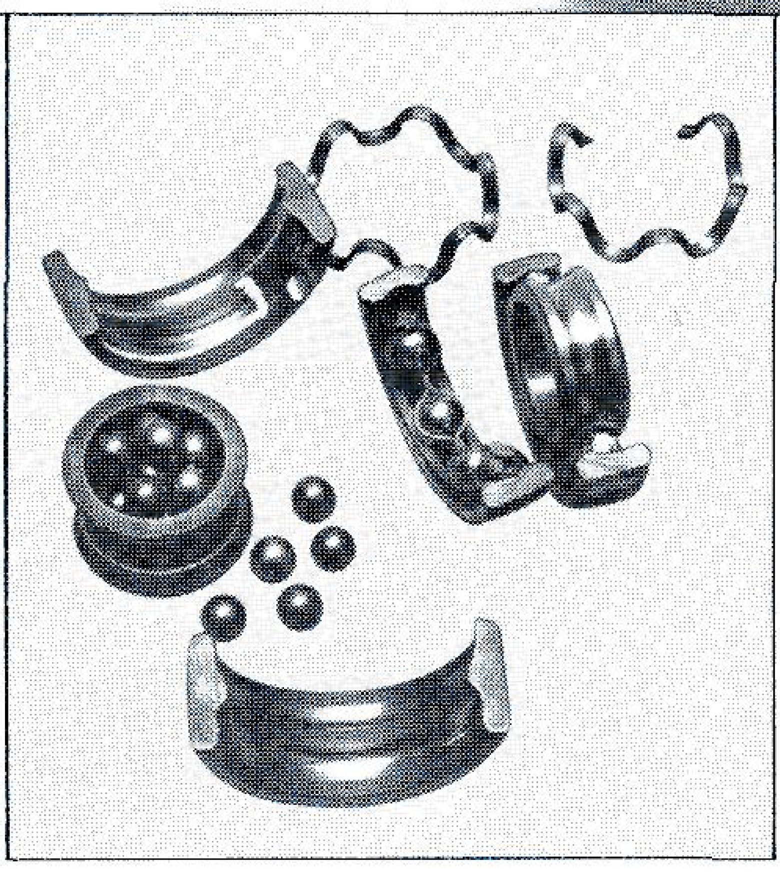
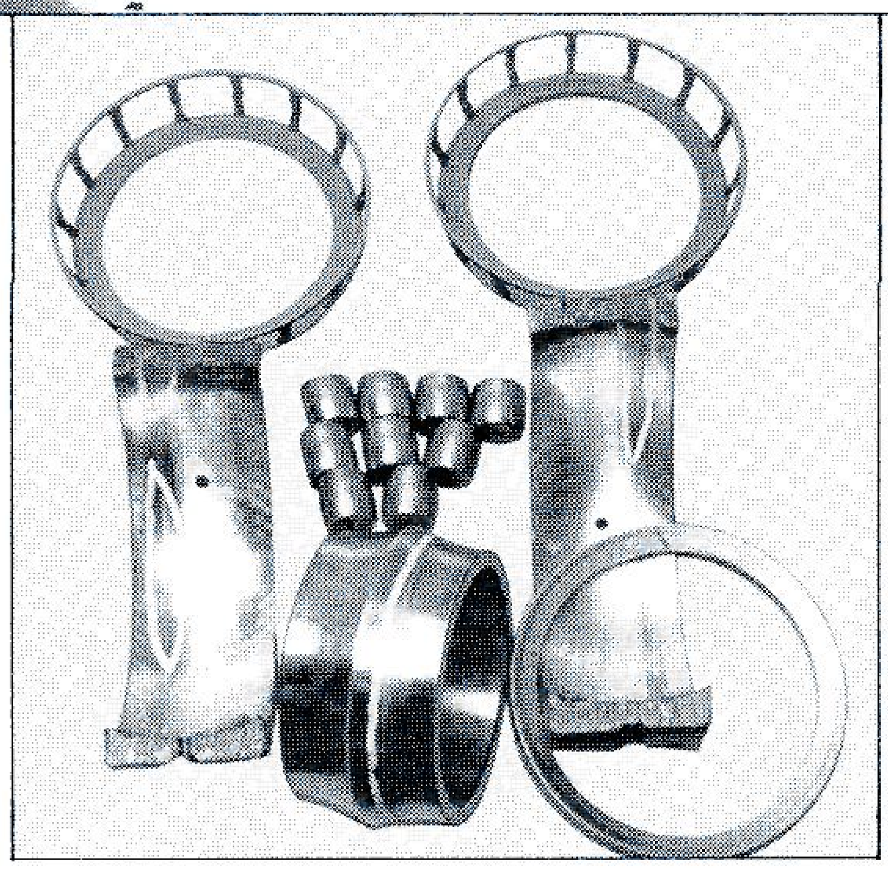
Brüel & Kjær application notes

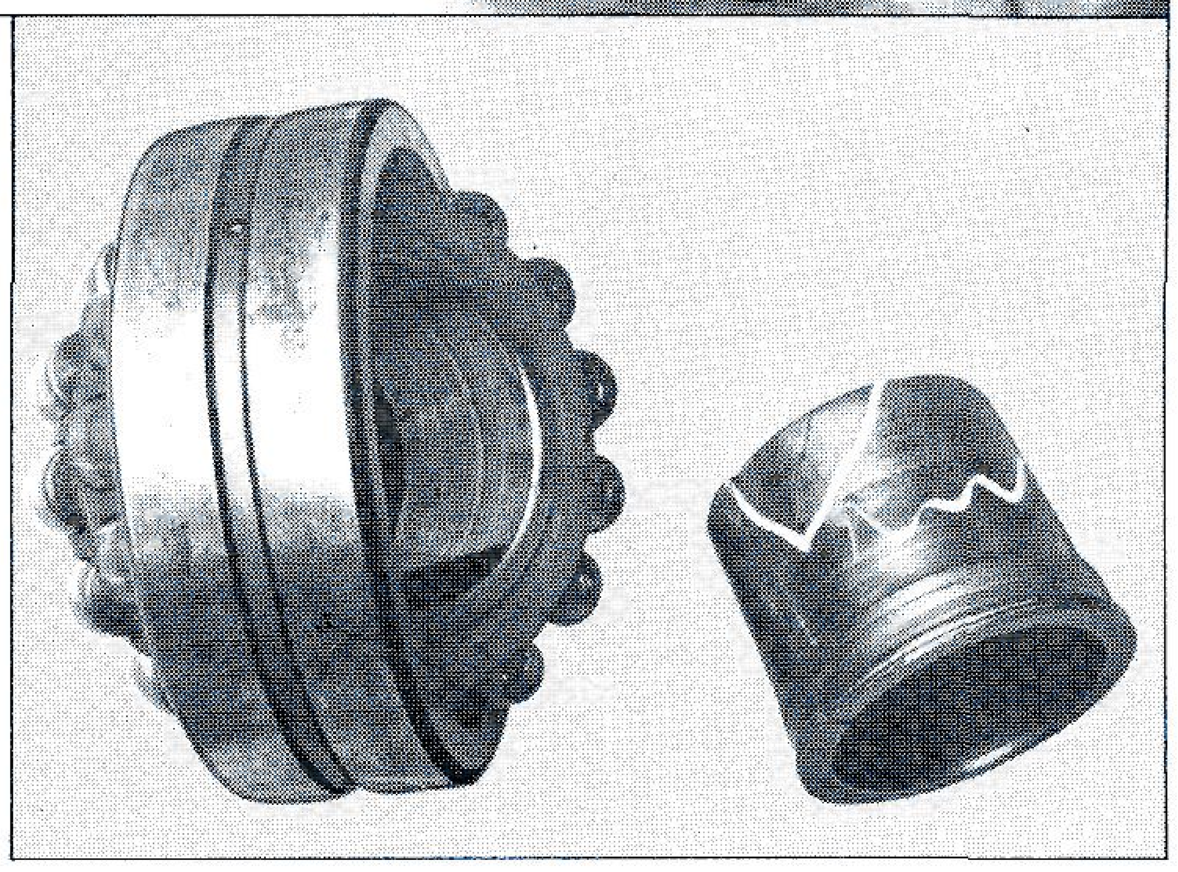
Machine-Condition Monitoring using Vibration Analysis

The use of Spectrum Comparison for Bearing Fault Detection – A Case Study from Alma Paper Mill, Quebec, Canada









BO 0253-11

The use of Spectrum Comparison for Bearing Fault Detection – A Case Study from Alma Paper Mill, Quebec, Canada

by *D.N.Brown & T.Jensen*
Brüel & Kjær

Introduction

This Application Note describes a vibration monitoring programme in operation at Abitibi Price's Alma Paper Mill, Quebec, Canada. It is one in a series of reports detailing the benefits of such a machine-monitoring system. A number of actual cases are described here of how faults have been detected on paper machines using vibration spectrum-comparison techniques. Faults have been detected long before they could become critical, enabling repair to be scheduled for planned production shutdowns.

The production of paper is a highly competitive industry and mills can ill afford costly downtime or unsaleable paper. To combat this problem and ensure profitable production, the mill's maintenance must bring in new ideas and equipment to tackle these old problems. The use of vibration monitoring to monitor and analyse the condition of vital rotating machinery in the plant is one such scheme.

In each of the examples described the consequences of not having detected the fault would have been an almost certain stop in production. The resulting savings due to the avoidance of lost production and expensive maintenance, means an extremely quick payback on the initial investment in monitoring equipment. In fact, the avoidance of just one unexpected stop in production could payback the outlay for equipment.

Since installation of the vibration-monitoring system at Alma Paper, there have been no unexpected breakdowns on monitored equipment. All problems have been detected by the system early enough to enable repair to be scheduled for a planned shutdown.

The Alma Paper Mill

The Alma Paper Mill is a part of the Abitibi Price concern, which is the world's leading producer of newsprint and uncoated groundwood papers, and one of the largest industrial companies in North America. The Alma Paper Mill operates three paper machines and produces newsprint and directory, which is reputed to be some of the best in the world.

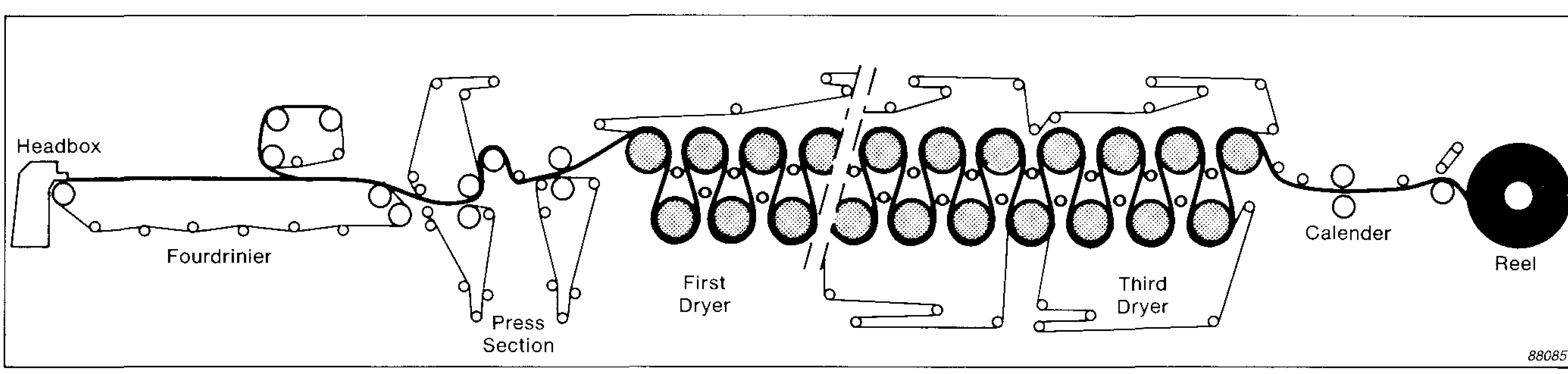


Fig. 1. Layout of a paper machine showing how the paper, which is formed as one long sheet, passes through the critical stages of production

The Paper Machine

Fig. 1 above shows the complex roll arrangement of a paper machine. The paper machine itself is one of the most critical sections in the round-the-clock paper-production process. A breakdown in any section of the paper machine would result in an immediate production stop, with all the detrimental losses in production.

Alma's paper machine no. 14 produces some 370 tonnes of paper per day. At a market price for newsprint of approximately 500 Cd$/tonne, a loss of just one day's production would be in the region of 215 000 Cd$ (1 Cd$ ≏ 0,8 US$). Add the cost of maintenance personnel, spare parts etc., and the total cost of a breakdown on, for example, a dryer roll which can take a good few hours to replace, becomes huge.

Abitibi Price have been in the paper production business for many years – the Alma mill produced its first roll of paper in 1925, and the age of some of their older paper machines can be as much as 40 years. With many of these machines running over design speed, the life expectancy of many parts is significantly reduced. The cause of a breakdown could transpire from, for example, excessive wear of machine parts, unbalance of rollers, misalignment of the paper machine, felt problems etc. Most of these faults will eventually cause damage to the paper machine's many bearings, and a large part of the mill's maintenance is involved with the changing of damaged rolling-element bearings.

Condition-based Maintenance in the Papermill

An effective solution to a mill's maintenance problems is to operate a programme where the condition of the machines is measured, and maintenance is carried out based on these measurements. Vibration monitoring of rotating machinery is considered as the best method of determining a machine's condition. This allows repair to be carried out only when the measurements indicate that the condition of the machine is deteriorating, and maintenance to be scheduled well ahead of time. In this way unexpected breakdowns are avoided and machine running time is maximized.

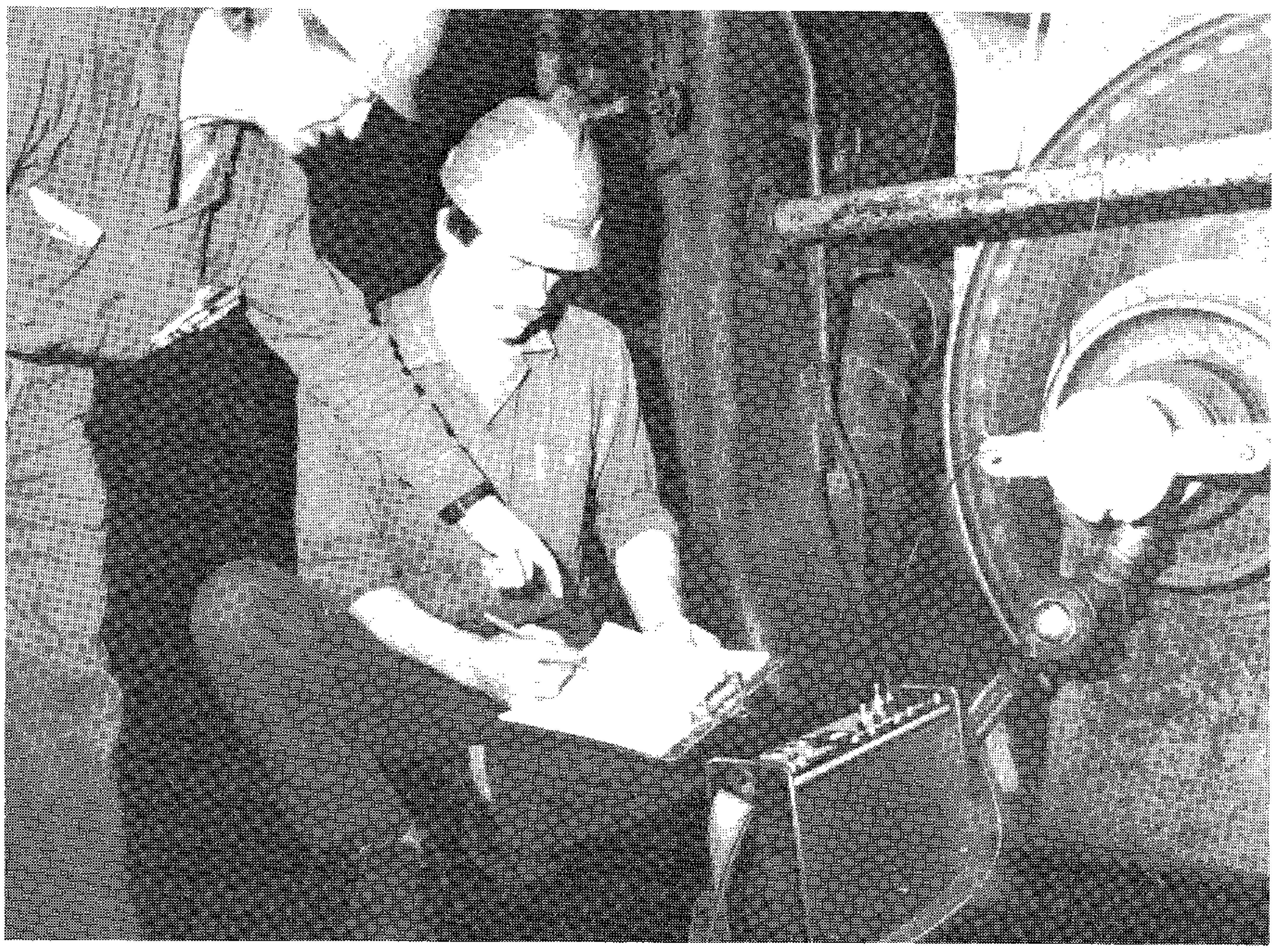


Fig. 2. Recording vibration signals from a dryer-can. Millwrights Regis Gaudreault and Sylvain Pedneault are responsible for collecting and analysing vibration data

Detecting Faults

Due to the large number of monitoring points on a paper machine, it is very important that the condition monitoring is carried out systematically. On the 3 paper machines in Alma the maintenance staff measure approximately 2900 monitoring points – 1100 on machine no.14, and 900 each on machines 9 and 10. To be able to control the large amount of data collected, the measuring programme is split up into 6 routes, each route being covered approximately twice per month.

Early Fault Detection

To be able to effectively *detect all types of faults at the earliest possible stage* in their development, it is necessary to perform **Spectrum Comparison.** This is a comparison of two frequency spectra recorded at different times from the same point on the machine. A *reference* spectrum is recorded on tape for later analysis and comparison with a *current* spectrum, looking for increases in individual frequencies or frequency ranges. Trending these increases allows the rate of fault deterioration to be studied.

To detect faults ranging from unbalance to gear and bearing problems, Constant Percentage Bandwidth (CPB) spectrum comparison is used. With CPB spectra, the frequency resolution is a constant percentage of the centre frequency (e.g. 6%) across the frequency range, which is displayed in logarithmic form.

Spot-checking Condition

For a quick spot-check of the condition of the mill's many hundreds of rollers, the **Broadband Vibration** levels are monitored using a hand-held vibration meter. Also, by measuring and trending the vibration signal's **Crest Factor** (ratio of peak to RMS value) a good indication of the condition of the many rolling-element bearings is given.

Fig. 3. Analyzing the recorded vibration signals on the office-based analysis system. Millwright Regis Gaudreault discusses the results with Project Engineer Richard Lefebvre

Diagnosing Condition

Having detected an increase in vibration, the source of the problem must be pin-pointed to enable quick, efficient repair. This can be done by analyzing the frequency content of the vibration signal using **Narrowband** and **Cepstrum Analysis**. It is important that a very high resolution (zoom) is used for this analysis. Paper machines are extremely complex machines containing a very large number of moving parts, many of which are rotating at similar frequencies, and vibration from one source can be transmitted over long distances. All this can make it difficult to accurately locate the source of an increase in vibration, and hence requires detailed analysis.

The following examples show how spectrum comparison and narrowband/cepstrum analysis have been used successfully to determine machine condition. Having detected and diagnosed a fault at an early stage, it is then possible to follow the fault development closely to maximize machine running time before repair.

Case Stories – Detecting Bearing Faults

Case 1. Bearing Defect – M/C 14 Dryer No. 4

This first example shows how a fault in a dryer-can bearing was found, saving at a conservative estimate 10 to 12 hrs lost production. The fault was discovered by detecting an increase in a frequency component corresponding to the bearing's BPFO[1] at 27,4 Hz, indicating a fault in the outer race.

Fig. 4 shows a Constant Percentage Bandwidth (CPB) spectrum measured from the bearing just before repair and illustrates how easy it can be to interpret the frequency spectrum. The frequency peaks corresponding to the roll rotation-frequency, the bearing fault and the roll's gear-drive are quite easily seen. The gearmesh frequency, located in the 200 to 500 Hz range, dominates the spectrum, being at a much higher vibration level than the bearing's BPFO. This would result in broadband detection techniques not picking up this particular fault until at a very late stage.

The fault was detected by using spectrum comparison. This showed the discrete-frequency increases at the bearing's BPFO at 27,4 Hz and its harmonics, see Fig. 5. Increases are also seen at the high frequencies, which is another indication of a bearing fault. The high frequency increases occur when impacts, which are produced every time the fault comes into contact with the bearing's rolling-element, excite the bearing's natural frequencies. Usually, this high frequency increase is a more sensitive indicator of a bearing fault than detecting discrete frequencies at the bearing's impact rates. However, with paper machines it is possible to mount the accelerometer very close to the bearing itself and thus pickup the bearing impacts above the background noise.

Having detected this fault, a decision was made to change the bearing at a scheduled shutdown. Had the fault not been detected and the bearing failed, the paper machine would have had to be shutdown without warning for 10 to 12 hrs. If the dryer-can itself had been damaged, then the enforced shutdown could easily have been 24 hrs.

1 BPFO is the fault repetition frequency for faults on the outer-race of a rolling-element bearing. For further information on bearing faults refer to Application Note BO0210.

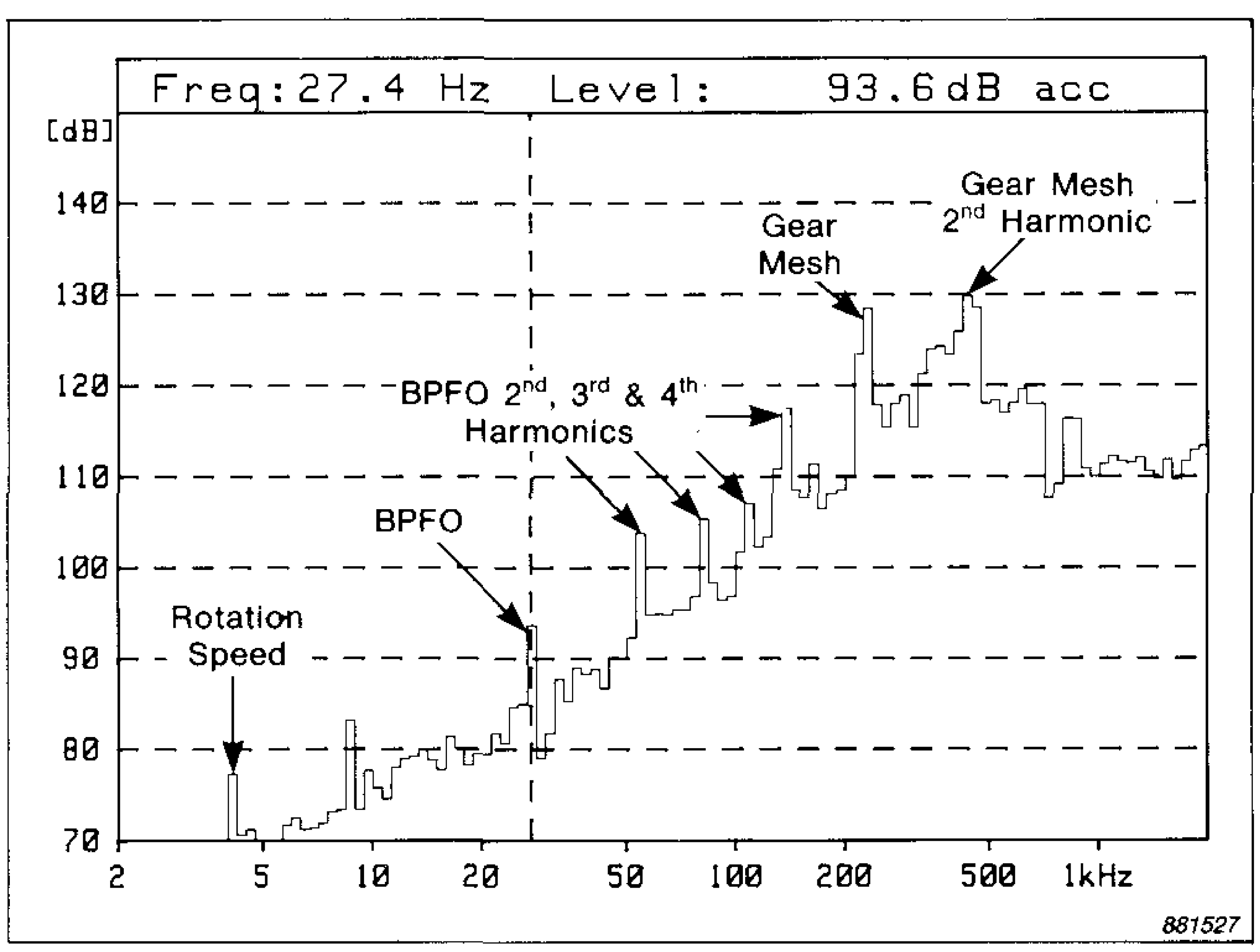


Fig. 4. The rotation speed, bearing fault frequencies and gearmesh frequencies are all presented clearly in the CPB spectrum

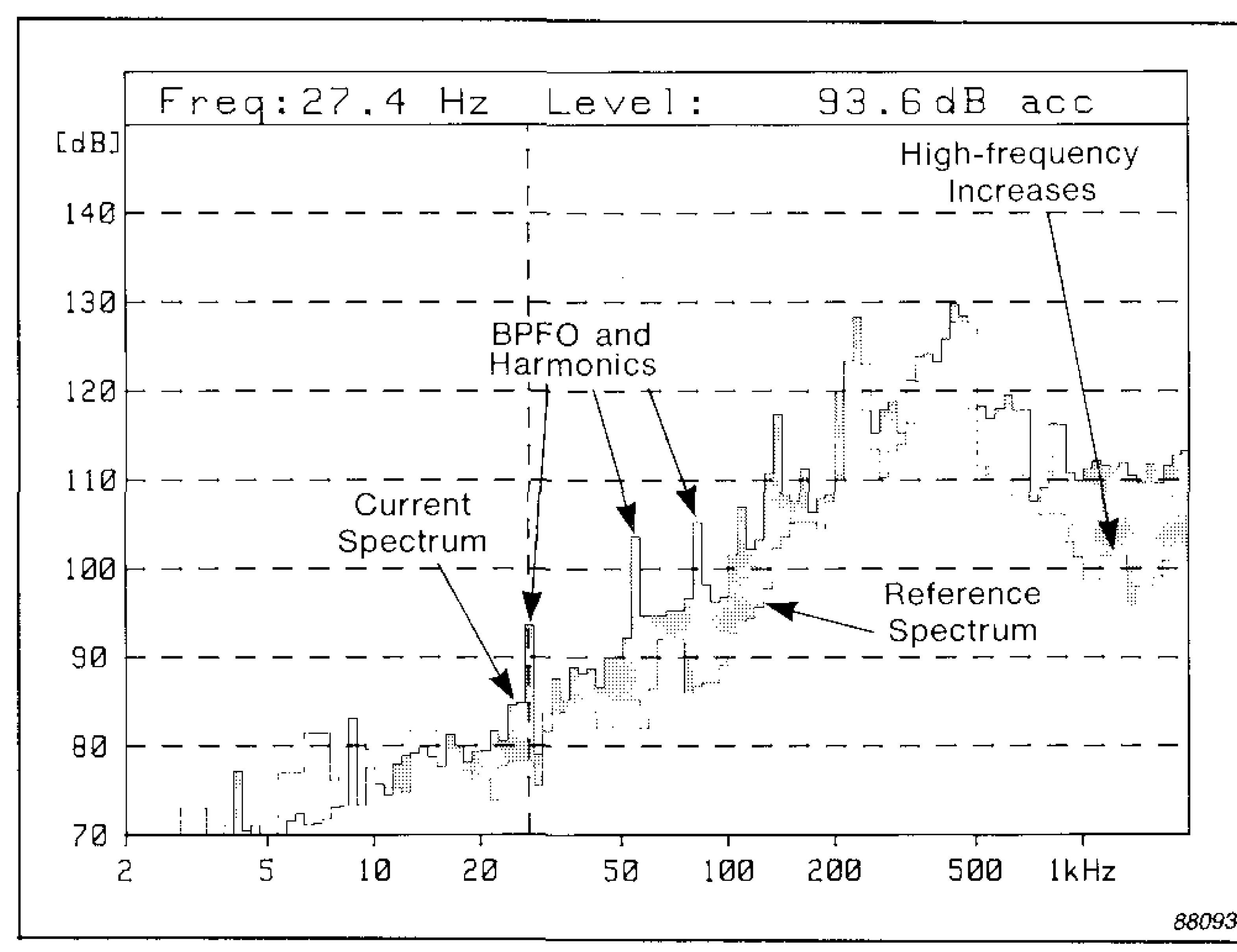


Fig. 5. Comparing the spectrum from Fig. 4 with its reference clearly shows increases (indicated by shading) at the bearing's BPFO, its harmonics and in the high frequency range

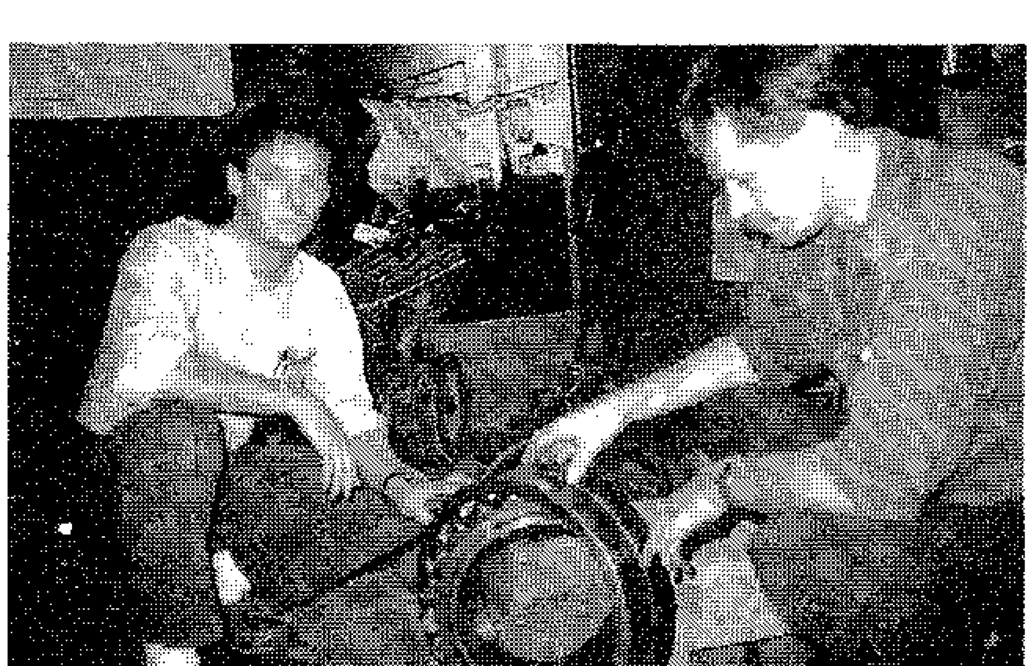


Fig. 6. The damaged bearing from Case 1. Damage to this type of bearing, which was taken from the rear-side of a dryer-can, can result in anything up to 12 hours of lost production due to its inaccessibility. In this particular case, had the bearing completely failed causing damage to the dryer-can itself, then production losses could have been as much as 24 hrs

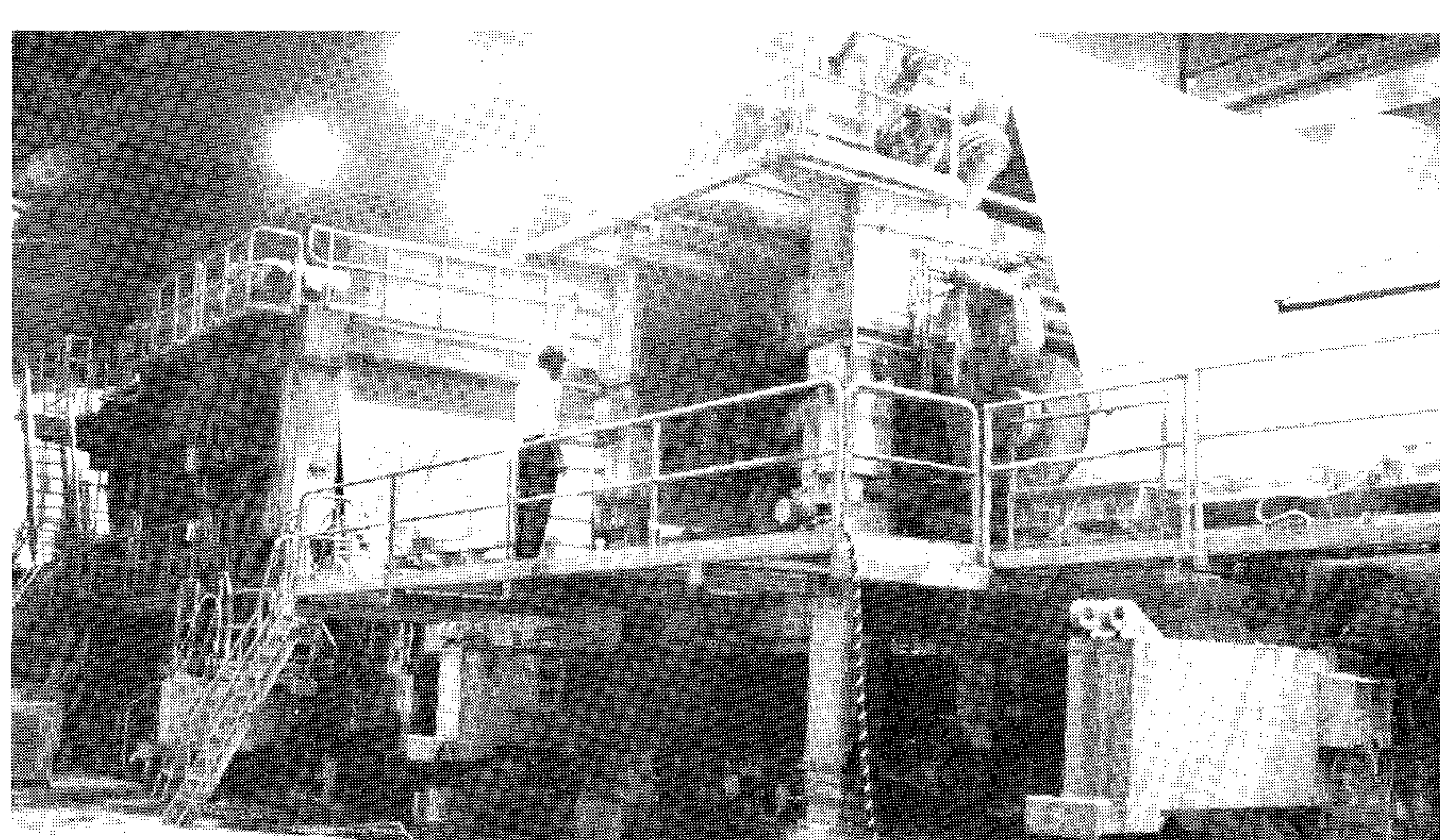


Fig. 7. Press section of the paper machine No. 14. Most of the problems described in this Application Note are from the dryer section, but problems in mill presses are not uncommon, especially with the high nip-loadings and high speeds experienced nowadays

Case 2. Bearing Defect – M/C 9 Felt Return Roll 1

This example shows how a bearing fault was detected and the 3–D Plot and Trend features used to follow the development of the fault. This allowed the condition of the bearing to be closely watched and paper production to be continued for as long as possible until the bearing could be changed at a scheduled production stop.

Fig. 9 shows how an outer-race fault was detected by spectrum comparison, indicating an increase in the bearing's BPFO at 27,5 Hz and its harmonics, and some increase at the higher frequencies. Also shown in this figure is the difference between the reference spectrum and the new spectrum which, for the purpose of clarity, only shows the increases.

It some cases it can be necessary to confirm the presence of a fault when, for example, background noise masks the bearing impact-frequencies. Fig. 10 shows how the Cepstrum can be used, and clearly shows the presence of the bearing's BPFO.

Fig. 11 shows a 3–D plot of the increases (as shown in Fig. 9), and it can be seen that the fault could best be followed by looking at increases in the 4th. harmonic of the BPFO. The fundamental 2nd., and 3rd. harmonics are too buried in noise to be useful.

Fig. 12 shows a Trend Plot made at the BPFO's 4th. harmonic. It can be seen that, after the initial increase, the vibration remained at a steady level. It was thus possible to maintain production and change the bearing at a scheduled production stop.

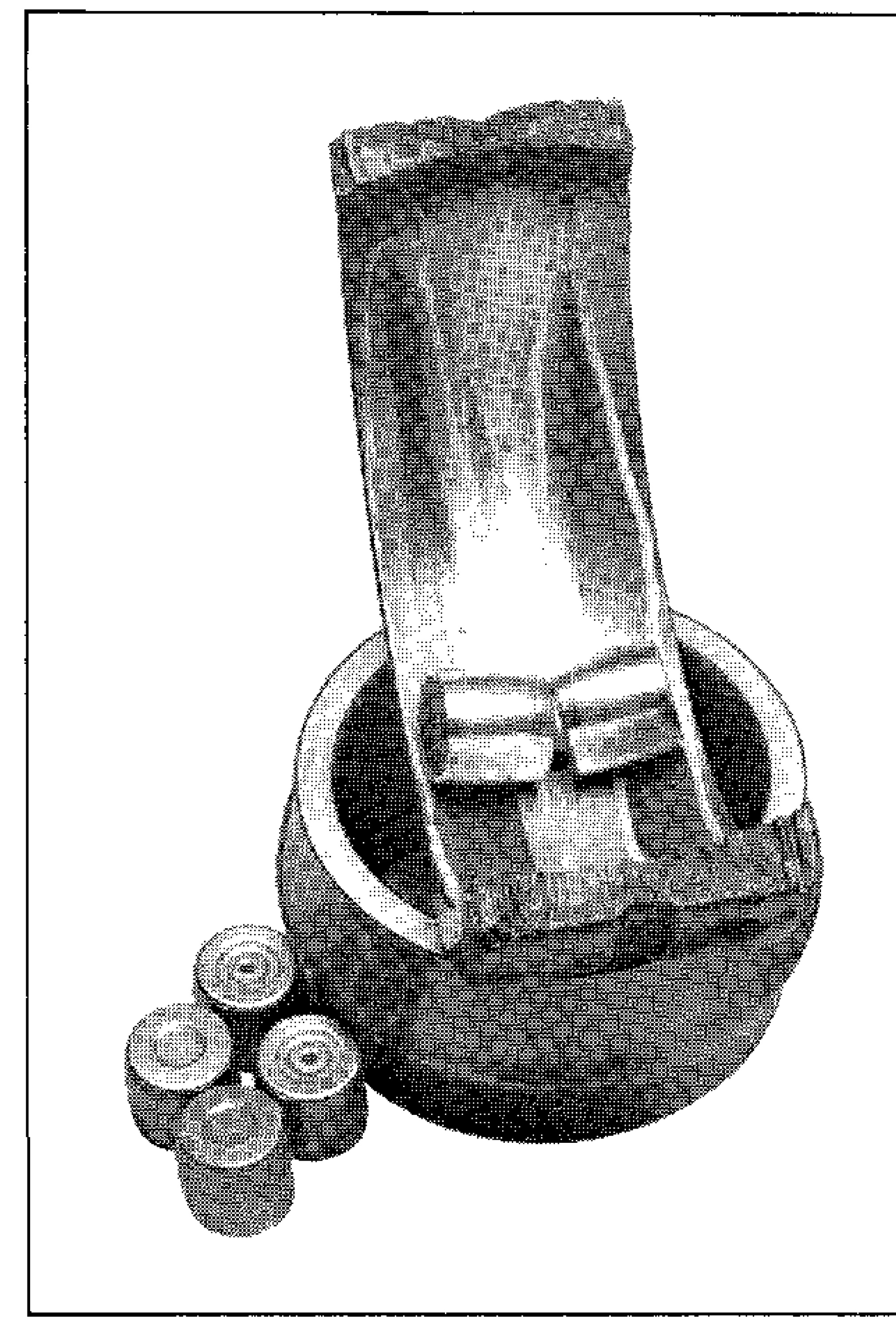


Fig. 8. The damaged bearing from Case 2

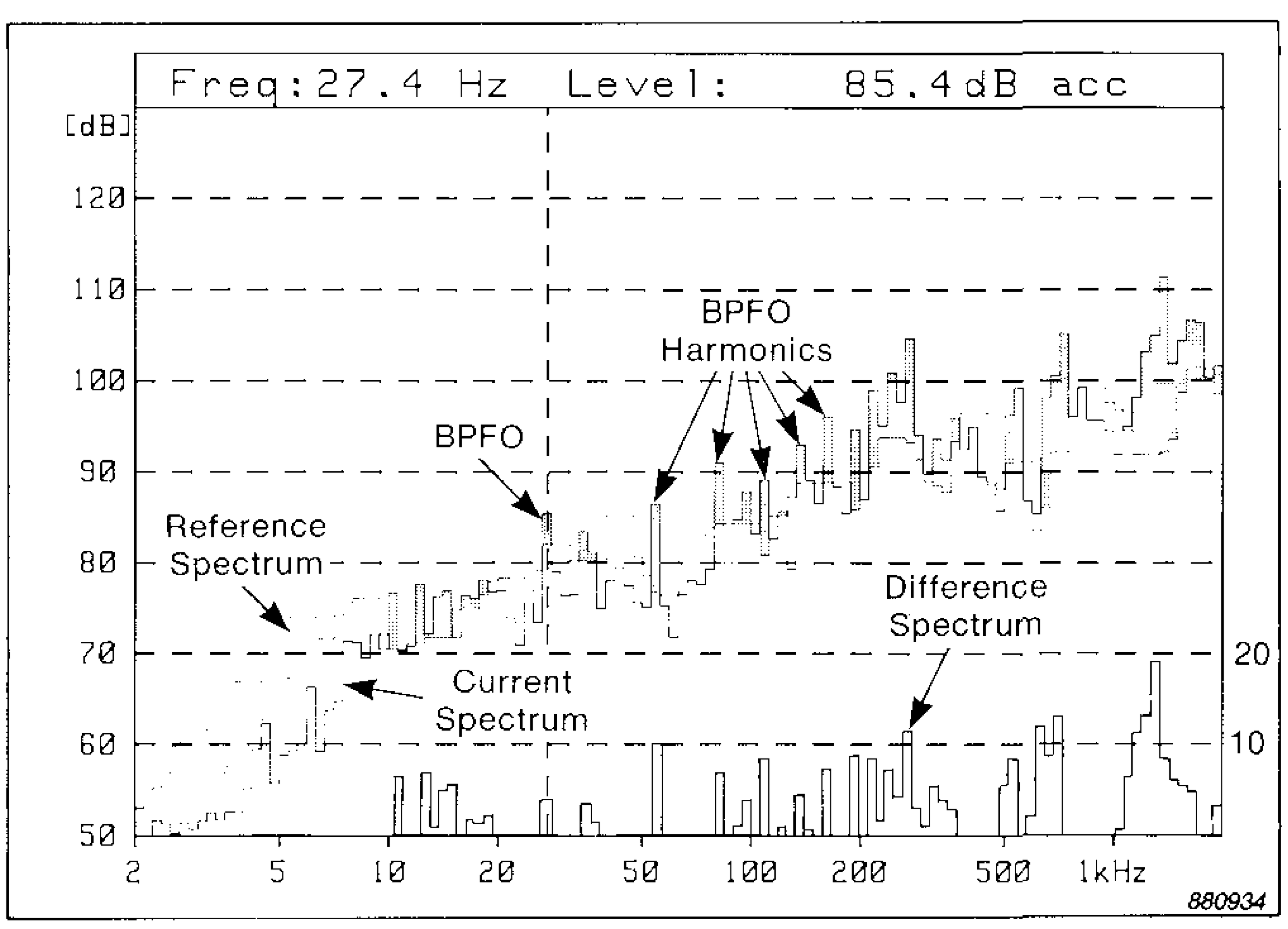


Fig. 9. Spectrum comparison between the current and reference spectra indicating the presence of a bearing fault. For clarity the difference between these two spectra is shown

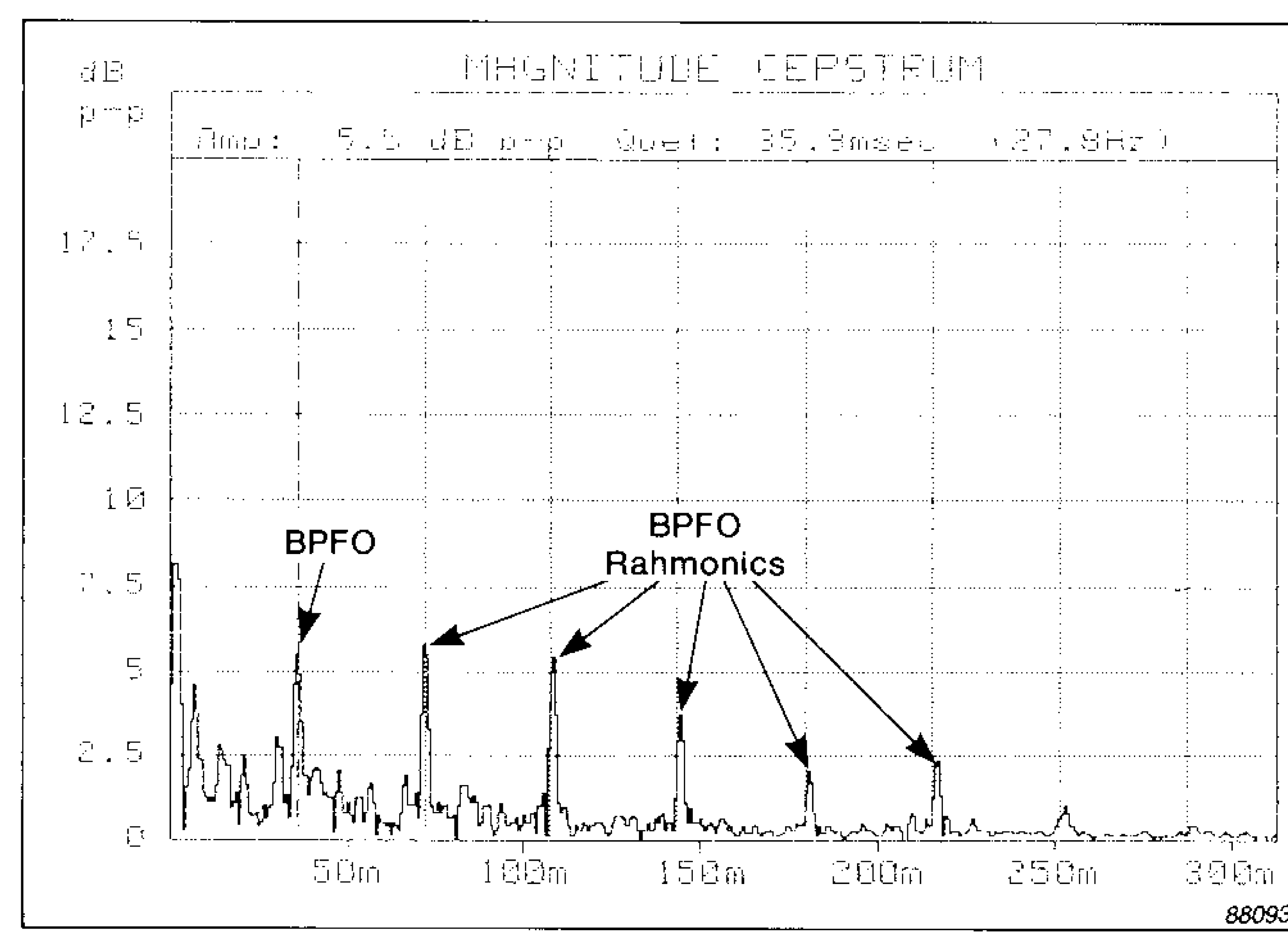


Fig. 10. Cepstrum clearly showing the bearing's BPFO and thus confirming the presence of a bearing fault

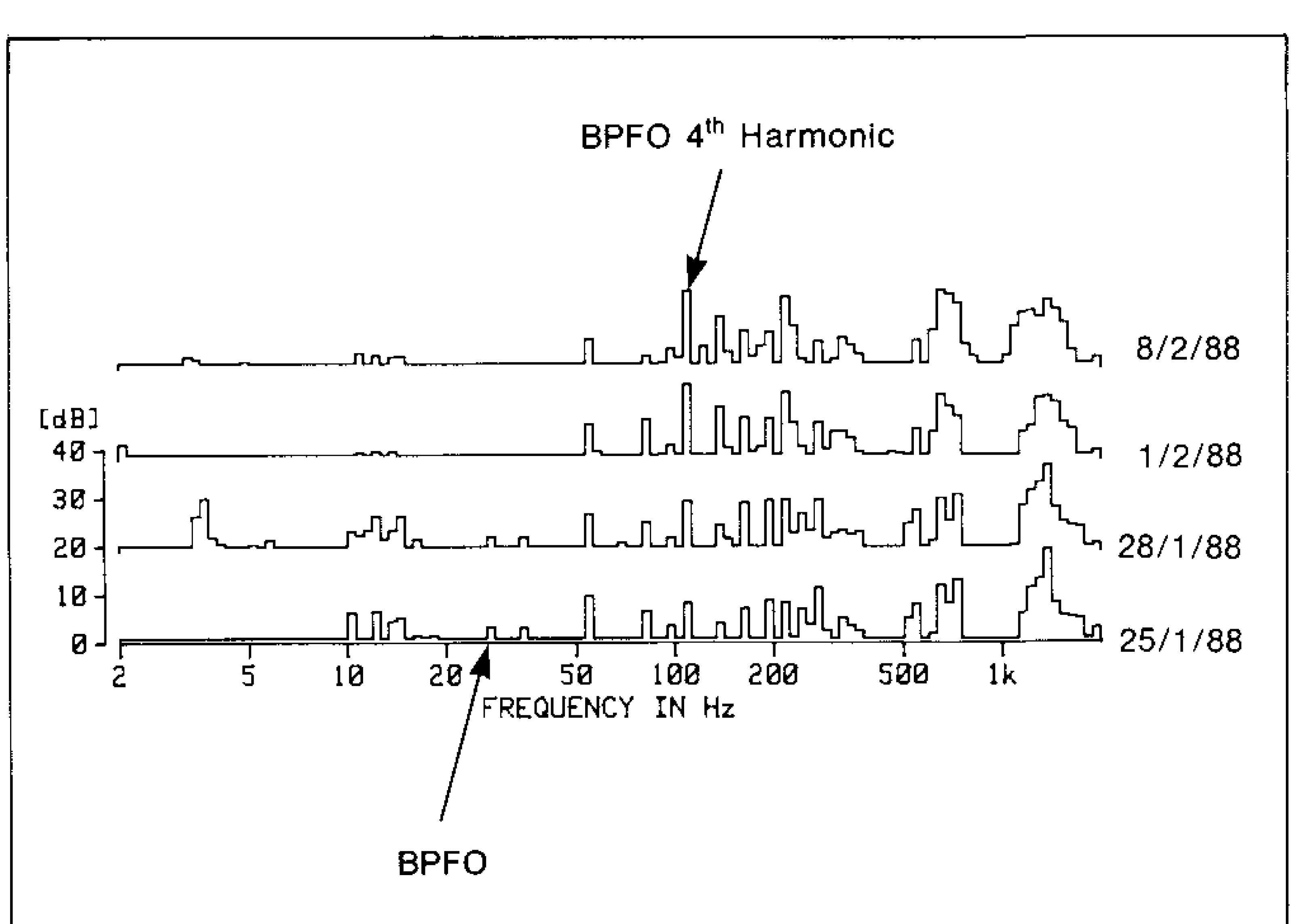


Fig. 11. 3–D Plot of increases in the vibration spectrum above the reference spectrum, showing over which frequency range to best perform the trend analysis

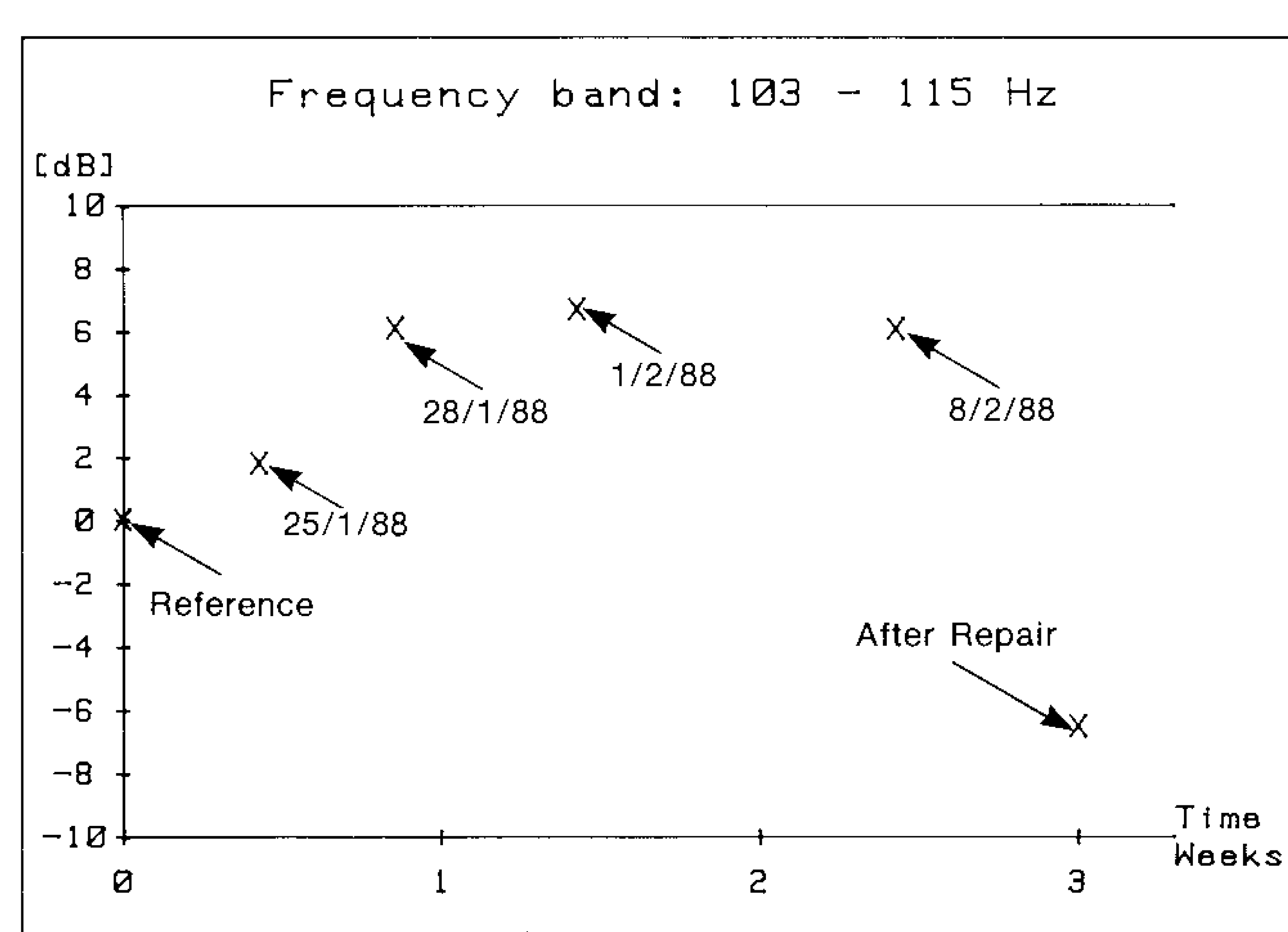


Fig. 12. Trend analysis at the BPFO's 4th harmonic. The bearing's condition stabilised after the initial increase and thus, by keeping track on the trend, production could be continued until a scheduled stop

Case 3. Bearing Seized – M/C 14 Dryer 13

This example is taken from the start of the monitoring programme, and shows measurements made just before a bearing seized. The example shows just how far the vibration levels can be allowed to develop before action is necessary. Fig. 13 shows a spectrum comparison, comparing spectra made just before a bearing seized and after being replaced with a new bearing. At the lower frequencies, it can be seen that increases of more than 20 dB were recorded before the bearing failed, and one peak in the mid-frequencies reached approximately 27 dB. Bearing in mind that conditions would be different for each machine type, it seems that increases of about 20 dB indicate an advanced state of wear, and should definitely signal immediate attention.

This breakdown happened during the introduction of the monitoring programme, and the bearing seized shortly after measurements were made, giving the operator no time to act on the measurements. From the spectra it can clearly be seen that the bearing was in an advanced state of wear.

Case 4. No Defect – M/C 14 Dryer 16

This example shows another case taken during the introduction of the monitoring programme, when a faulty bearing was suspected and the vibration monitoring equipment brought into use to confirm its presence.

A spectrum comparison was made, but showed no increases and thus no sign of a fault, see Fig. 14. However, to be on the safe side and to test the usefulness of the monitoring equipment, the bearing was changed during a scheduled shutdown. On inspection of the bearing it was found to be in perfect condition, as had been indicated by the measurements.

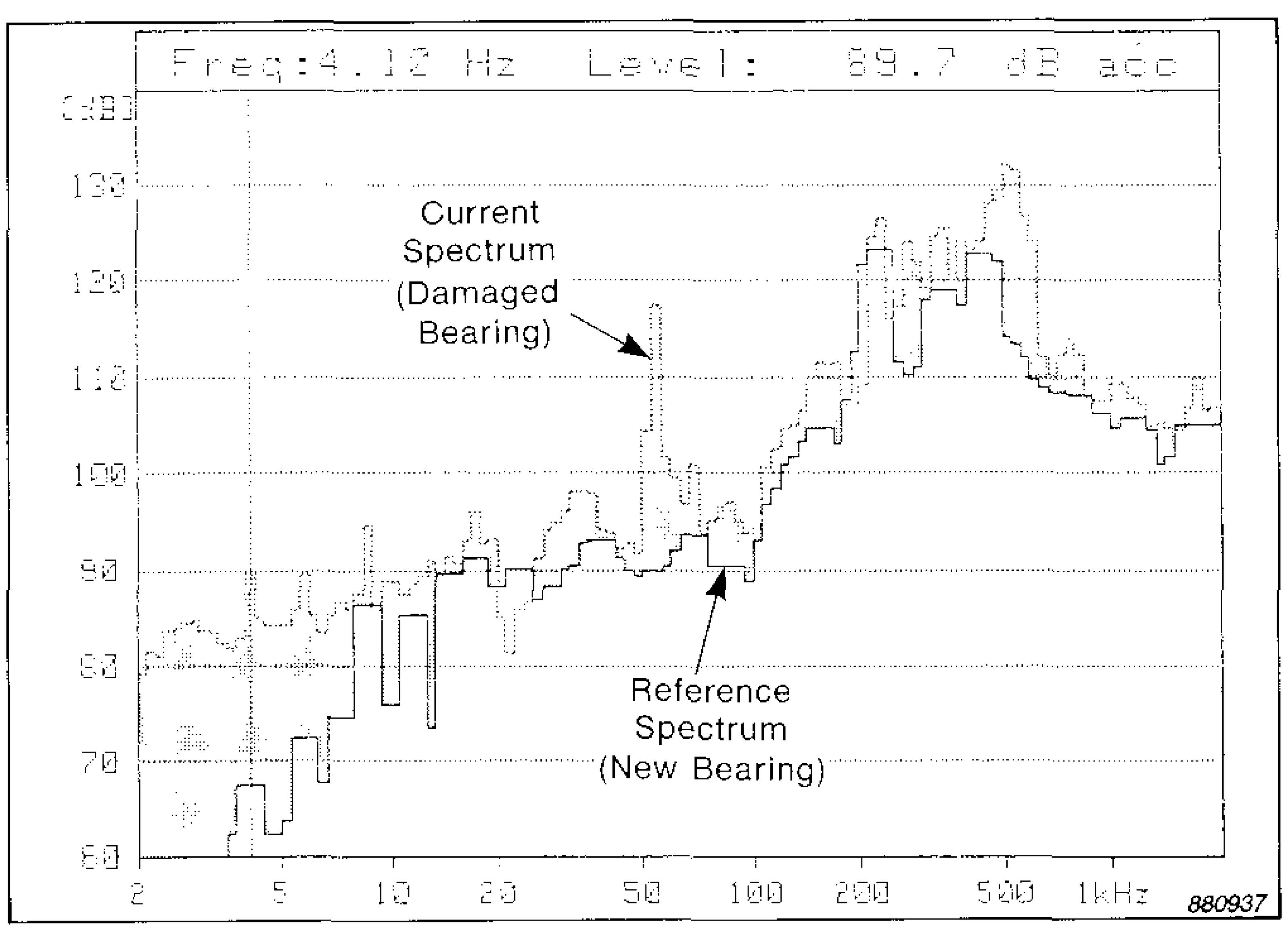


Fig. 13. Comparing spectra recorded just before a bearing seized and after being replaced with a new bearing (the shaded area indicates the decreases)

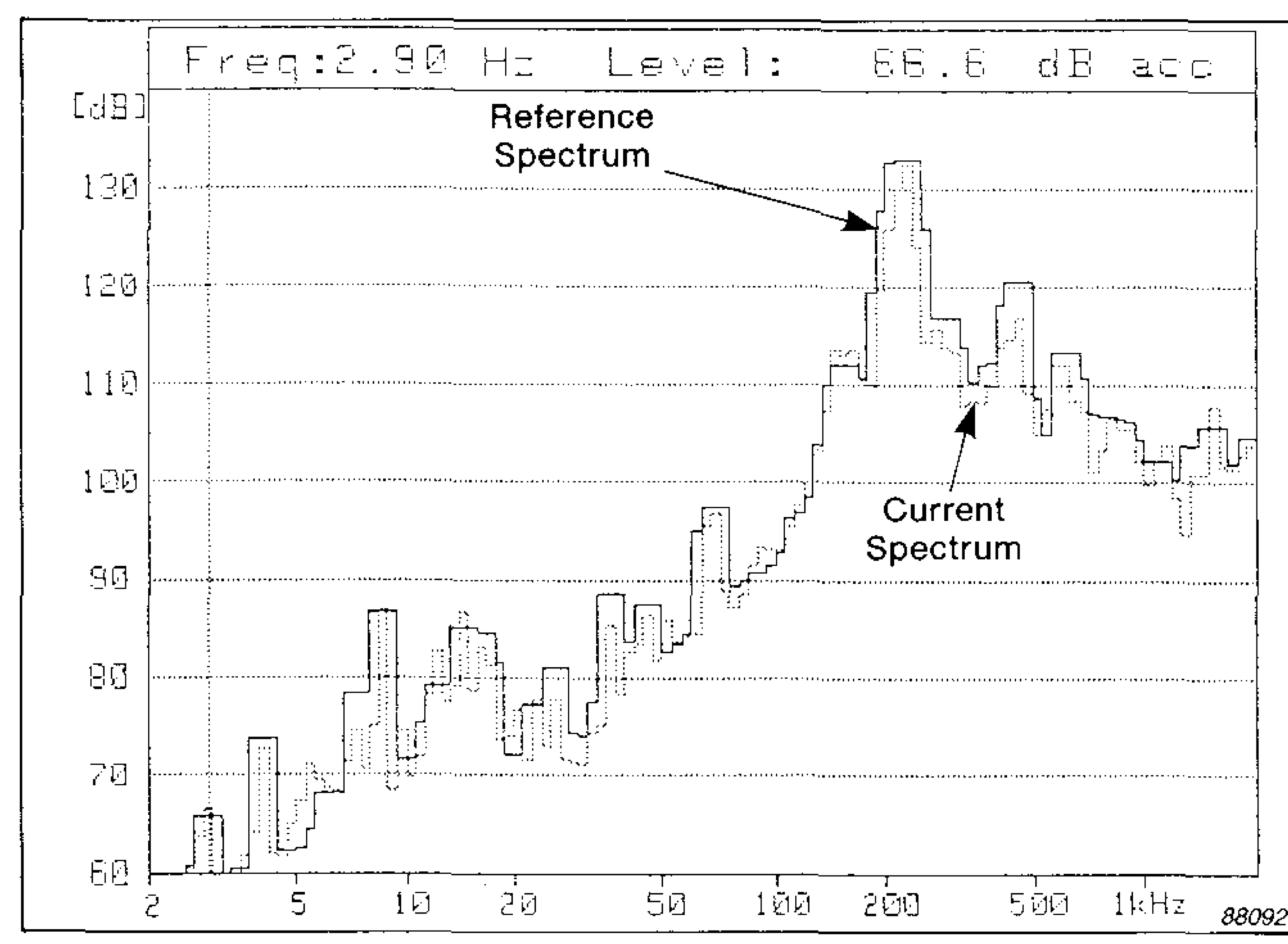
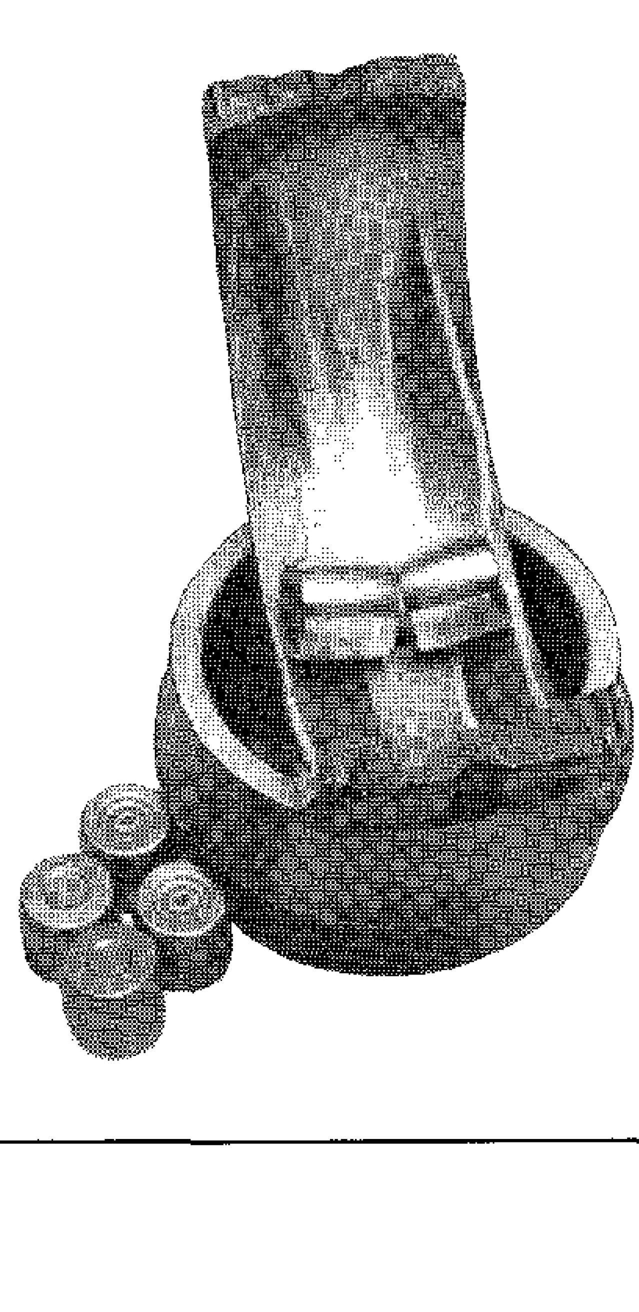
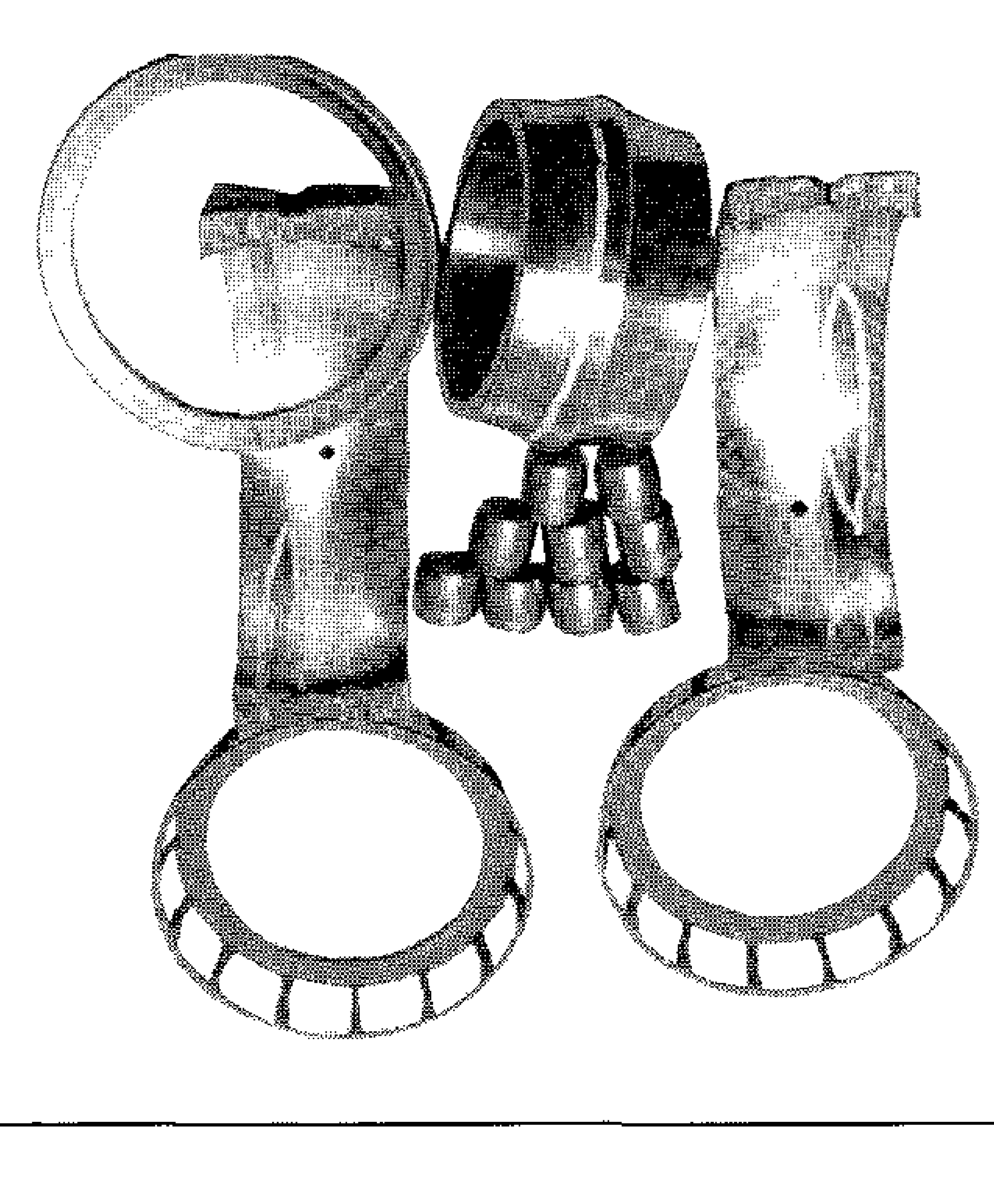
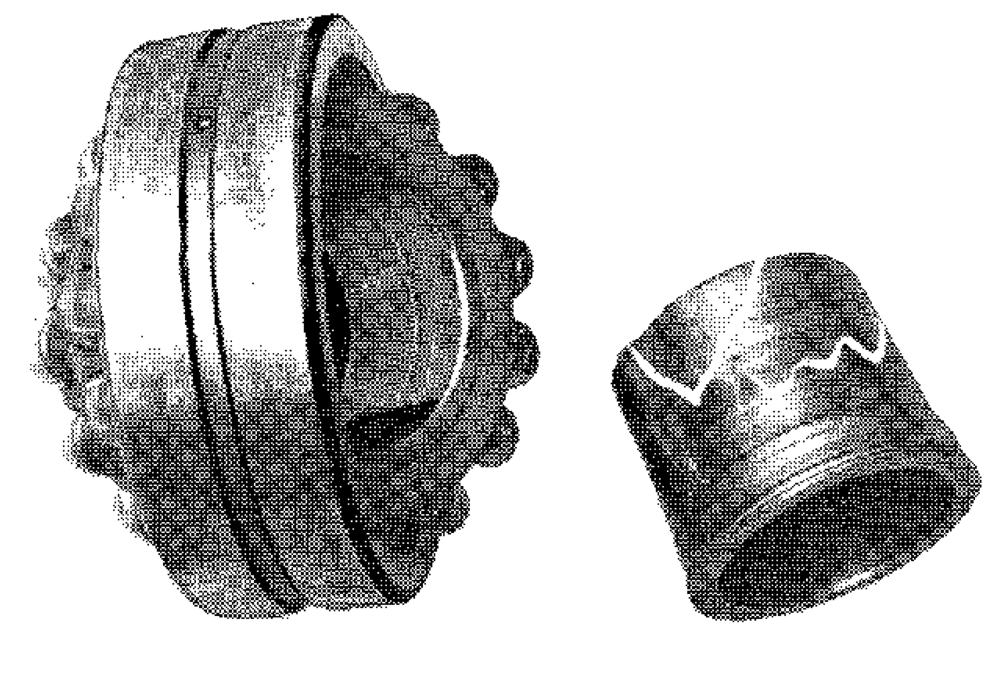


Fig. 14. Spectrum comparison showing no increases, indicating that the bearing is in good condition

Bearing failures are perhaps one of the most most common causes for concern in a paper machine, and therefore a maintenance department cannot afford to ignore technology which provides an effective method of determining bearing condition. The case stories described so far have shown that spectrum comparison is an effective means of detecting bearing faults and thus reducing paper-machine down time. The case stories that follow show how detailed vibration-analysis can be used to obtain a greater understanding of the type and location of a fault.







Case 5. Bearing Defect – M/C 10 Felt Return Roll 6

This example illustrates how a damaged bearing with a fault in its early stages was detected by using the zoom and cepstrum features of the Brüel & Kjær analyzers. It shows how a bearing fault was found by identifying peaks at the bearing's BPFO at 26,4 Hz and the bearing's cage rotational-frequency (FTF) at 1,7 Hz.

A bearing fault was first suspected after high-frequency level increases were detected by spectrum comparison, see Fig. 15. However, the increases were not particularly large and so it appeared that the fault was only in its initial stages.

To be completely sure of the presence of a fault, further analysis was then carried out to try and pin-point the exact cause of the increasing vibration level. Fig. 16 shows a narrowband zoomed-spectrum showing the bearing's BPFO at 26,4 Hz. The high resolution that the zoom spectrum provides allowed this frequency to be pin-pointed with extreme accuracy. However, the fault was obviously at a very early stage as the level of this peak was not very high, and hence not all that easy to detect.

Cepstrum analysis, however, confirmed the presence of a fault. It clearly indicated faults in both the bearing's outer race and its cage, by identifying the bearing's BPFO and its cage rotational-frequency (FTF). The cepstrum shown in Fig. 17 was made by performing a cepstrum analysis of the zoom spectrum shown in Fig. 16, and clearly shows the presence of the FTF at 1,7 Hz. The BPFO is also indicated but not easily seen as it is close to the bottom of the scale. It would be necessary to perform another cepstrum over a slightly wider frequency range to see the BPFO more clearly.

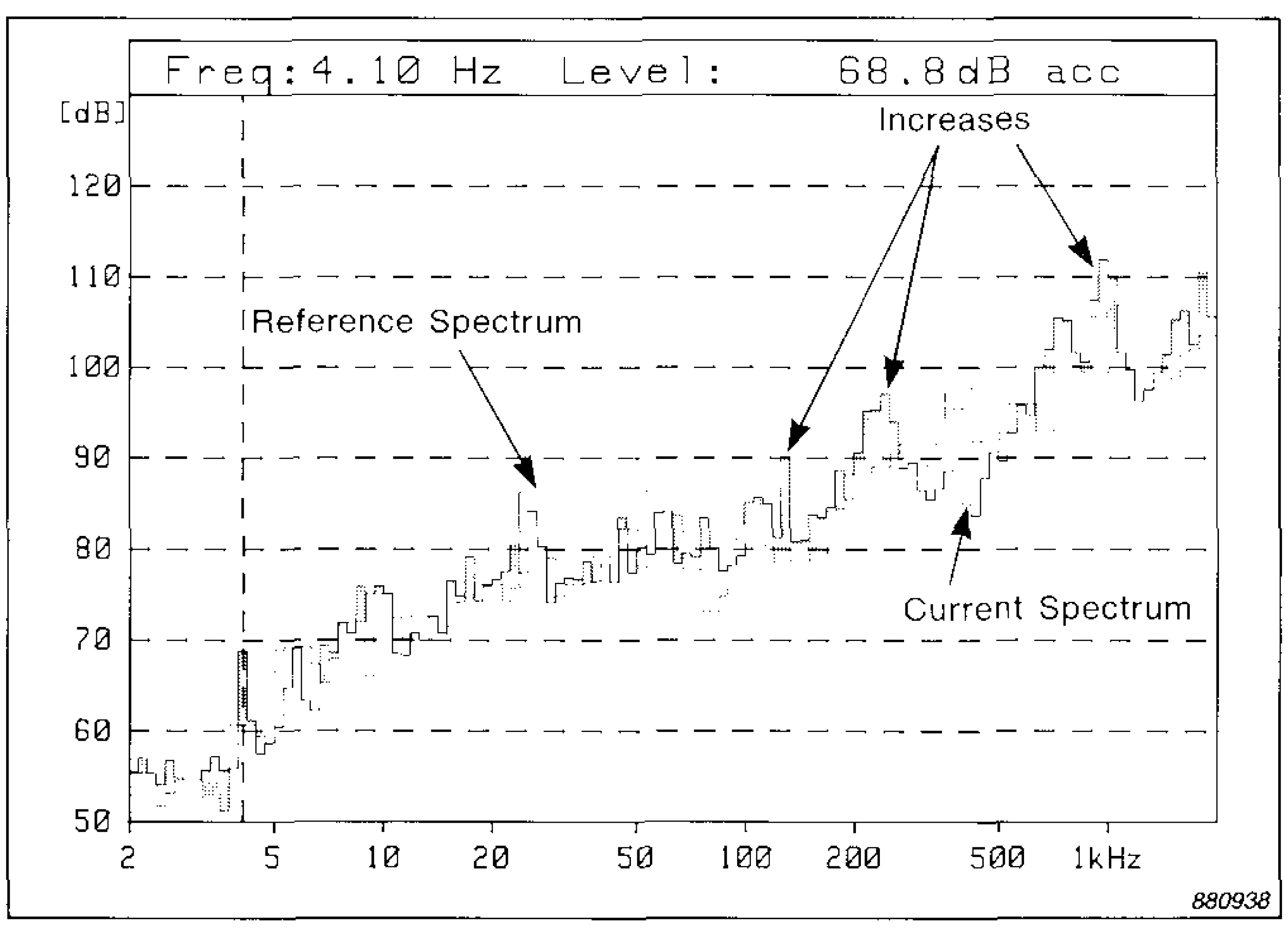


Fig. 15. Spectrum comparison showing slight increases in the high frequencies (indicated by the shaded area) indicating the possibility of a fault

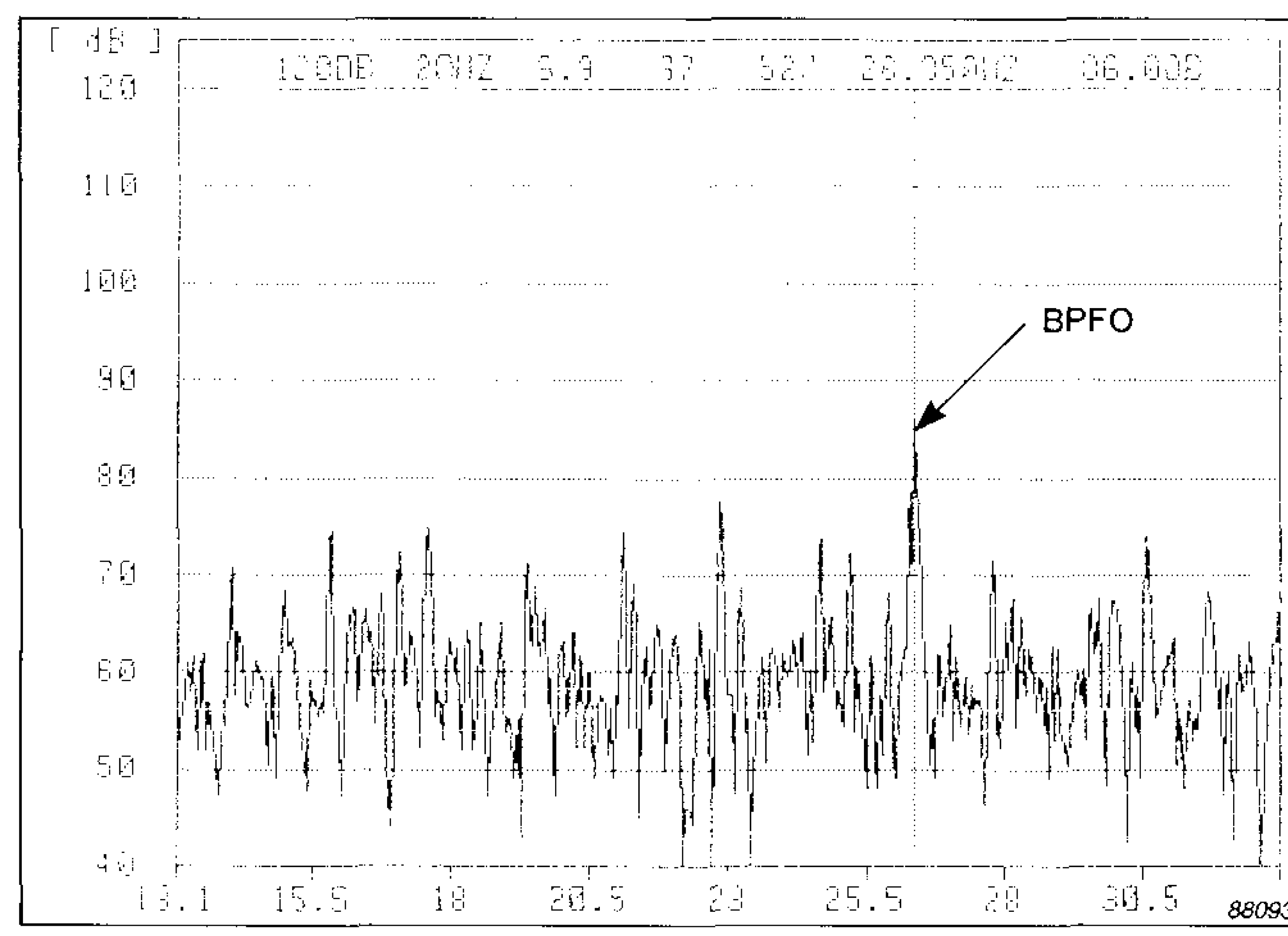


Fig. 16. Narrowband zoom spectrum showing the outer-race fault frequency (BPFO) at 26,4 Hz, indicating a fault in its early stages

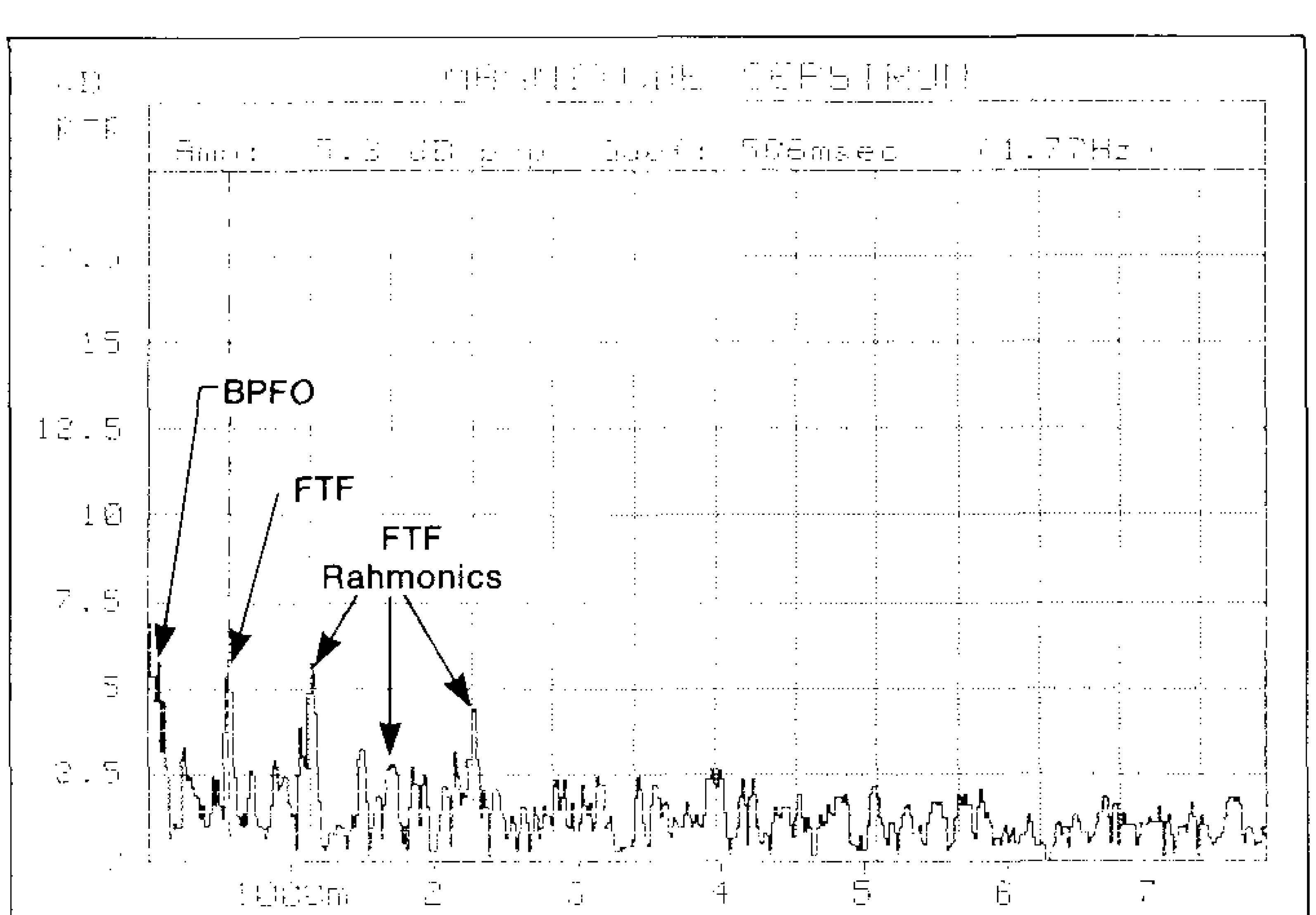


Fig. 17. The cepstrum confirms the presence of a fault. It shows the FTF and BPFO (which could also be shown as clearly as the FTF by performing the analysis over a different frequency range)

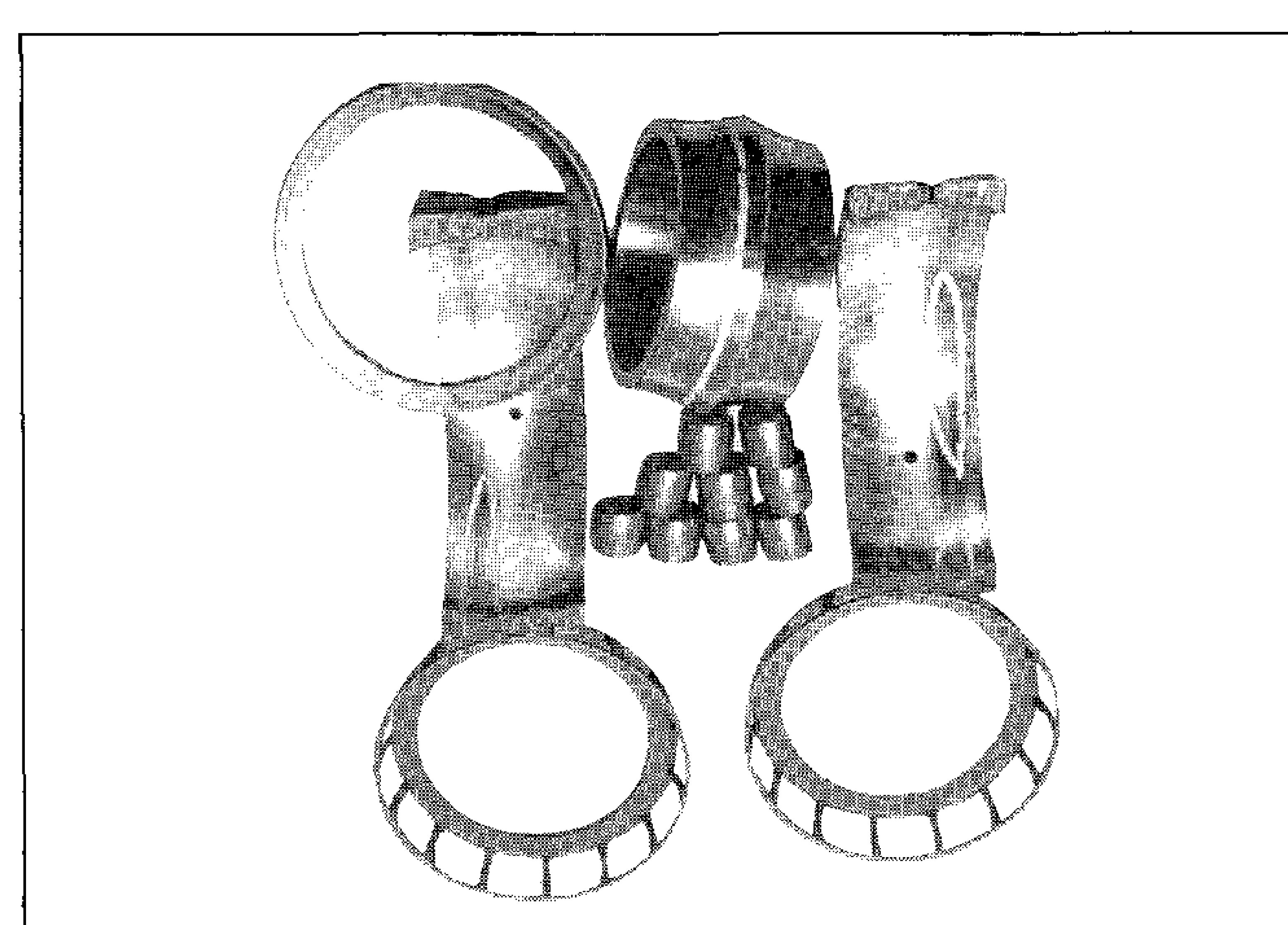


Fig. 18. The damaged bearing from Case 5

Case 6. Fault at Both Ends of Roll M/C 9 Felt Return Roll 40

This example highlights the problem of monitoring both ends of a roll, when it is only possible to measure at one end.

A spectrum comparison indicated the presence of a fault, but it was not sure at which end of the roll the fault was, as the same type of bearing was fitted front and back. Fig. 19 shows a spectrum comparison made just before and after changing the roll's front-side (tending) bearing. A reduction in the vibration levels at the higher frequencies was seen and, on inspection, a small amount of damage was found on the bearing's outer race. However, large vibration components at multiples of the rotational frequency were still quite evident, indicting a looseness problem.

The rear bearing was subsequently removed and the inner race found to be completely broken. Fig. 20 shows a spectrum comparison made just before and after repairing this rear bearing, and it can be seen that the harmonics and mid-range frequencies had dropped in level significantly. It was estimated that the bearing would only have lasted another 2 to 7 days before total failure. The monitoring programme, however, had allowed both bearings to be changed at the scheduled shutdown.

Measurements were only made on the front bearing due to the inaccessibility of the back bearing, which is a quite common problem on paper machines. However, this case shows the necessity of measuring on both ends of the roll. To overcome the problem of access to the back bearing, therefore, transducers could be permanently mounted on the bearing housings and cables routed to an easy point of access.

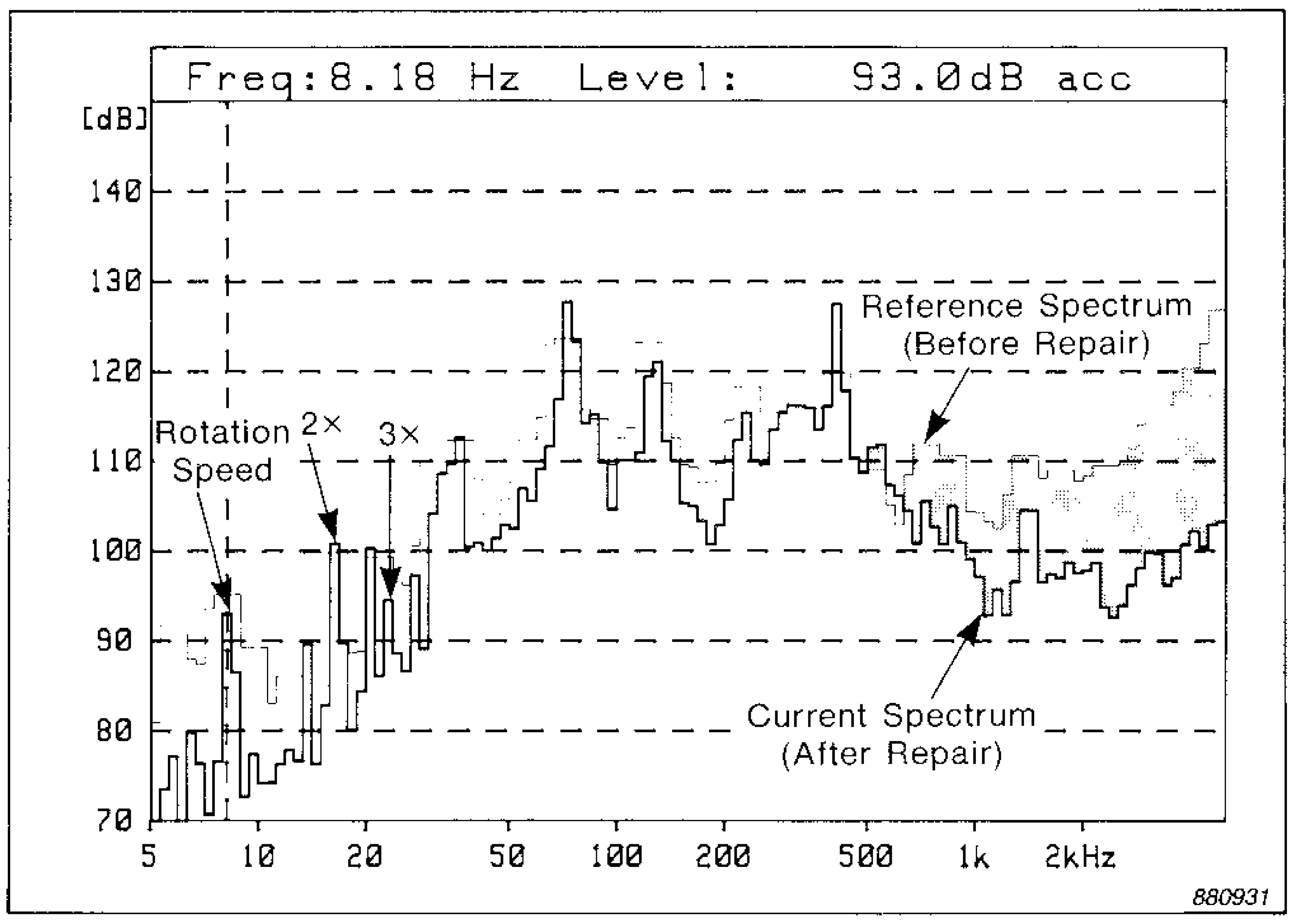


Fig. 19. Spectrum comparison made just before and after repairing the front bearing, the shaded area indicates the reduction in vibration level at the high frequencies. A problem still remained, indicating that it may be at the other end of the roll

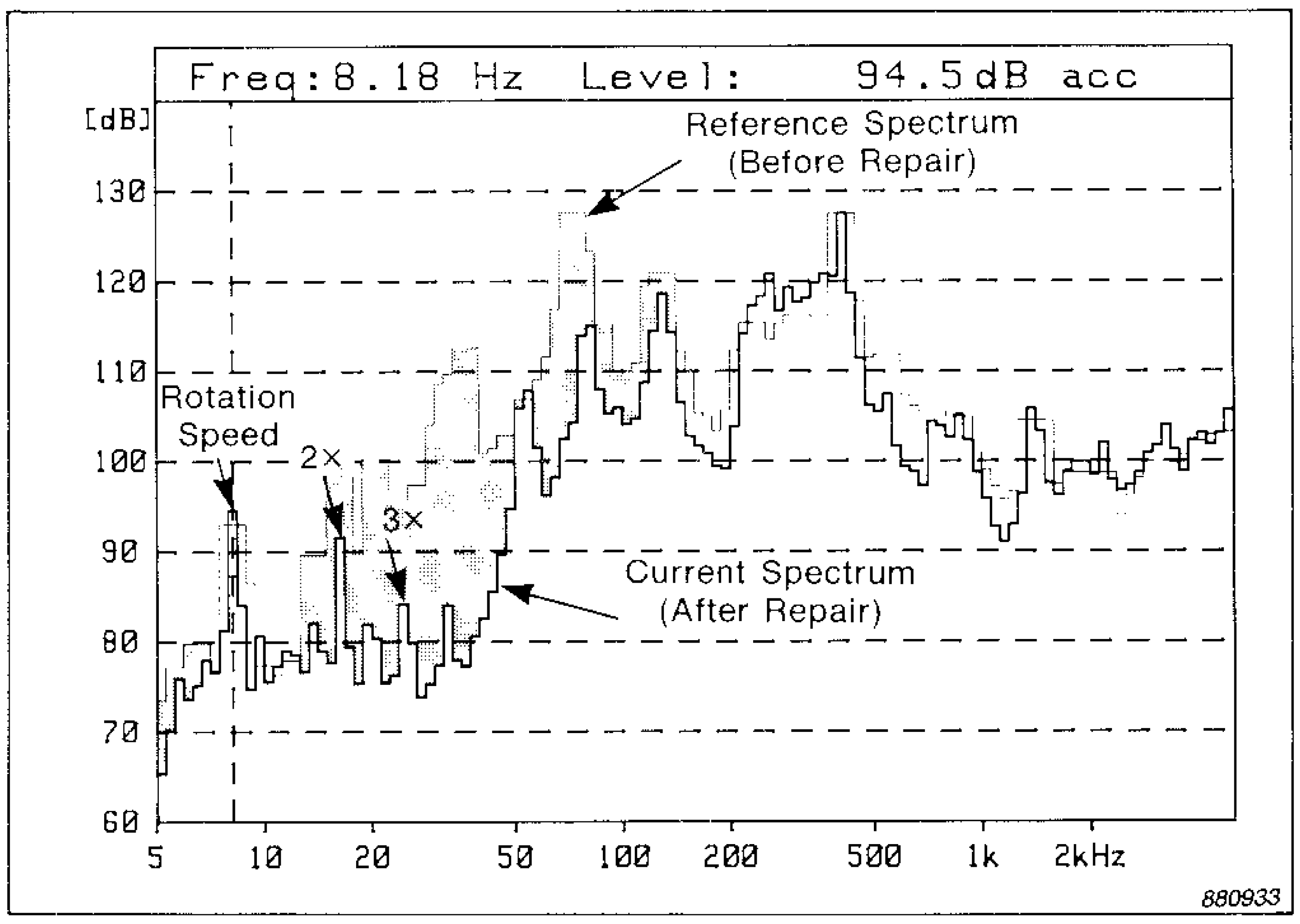


Fig. 20. Spectrum comparison made just before and after repairing the rear bearing which was found to have a broken inner-race. The shaded area indicates the reduction in vibration level

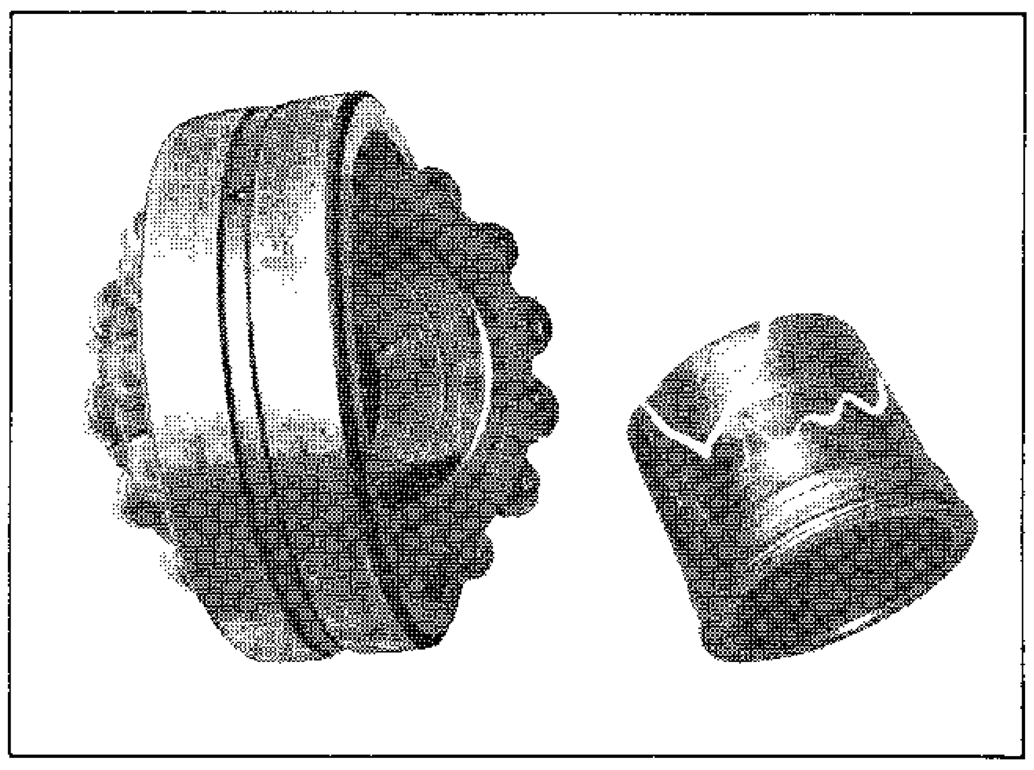


Fig. 21. The damaged rear bearing from Case 6. Detecting this fault had not been easy as measurements were only possible on the front-side bearing. To overcome this problem it would be necessary to permanently mount accelerometers on the rear-side bearing housing and route the cables out to an easy point of access

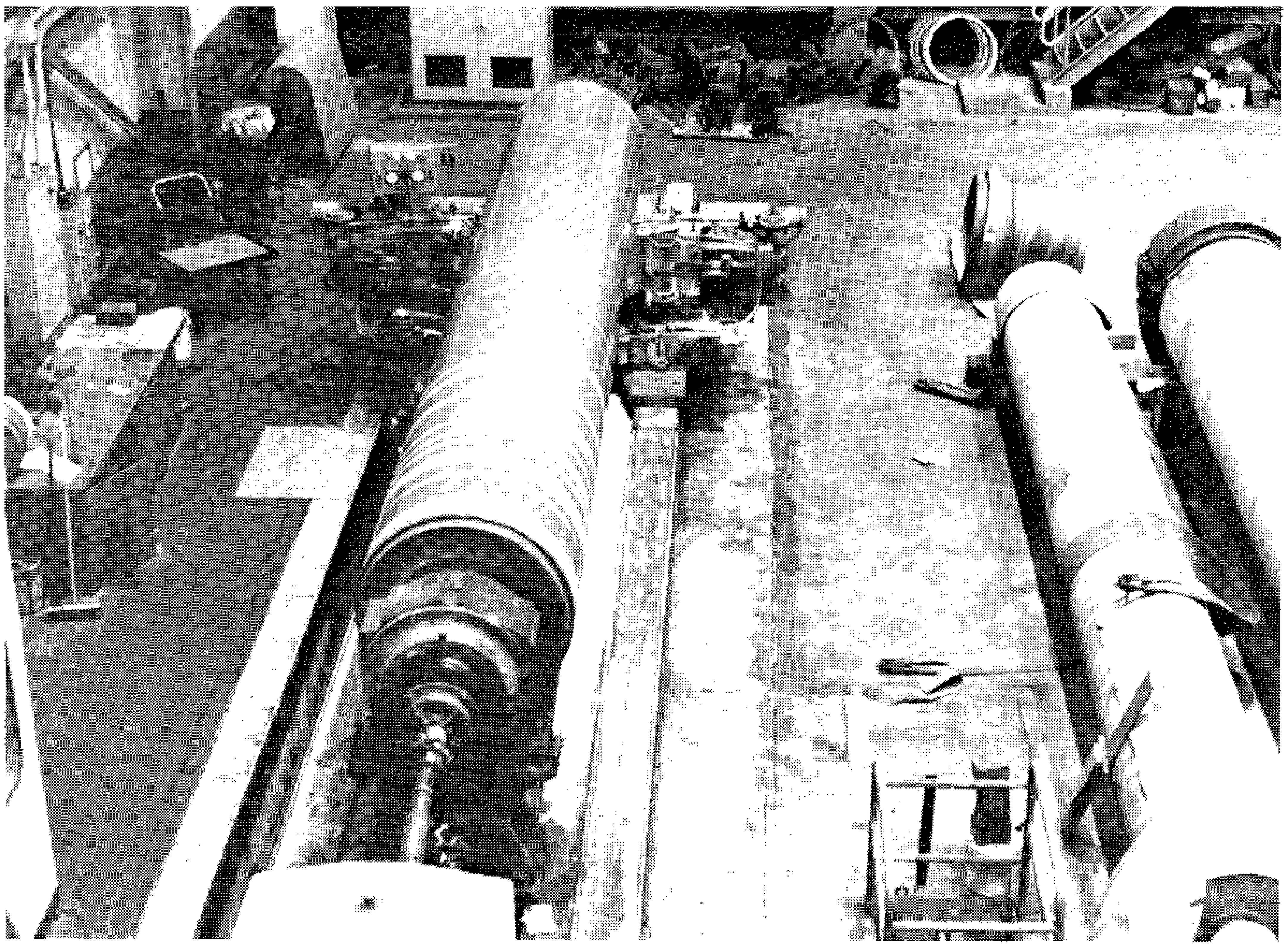


Fig. 22. Redressing a roll from machine 14

Case 7. Journal Bearing Defect– Water Feed Pump

It is not just the paper machine itself that can be monitored, as virtually all pulp and paper production processes contain a high degree of rotating equipment. This example shows how a fault was diagnosed on a steam-turbine driven water feed-pump.

Figs. 23 shows a problem with looseness in a journal bearing of the feed pump, shown in Fig. 24. The narrowband spectrum clearly shows the fundamental frequency and a large number of harmonics – the classic signs of looseness.

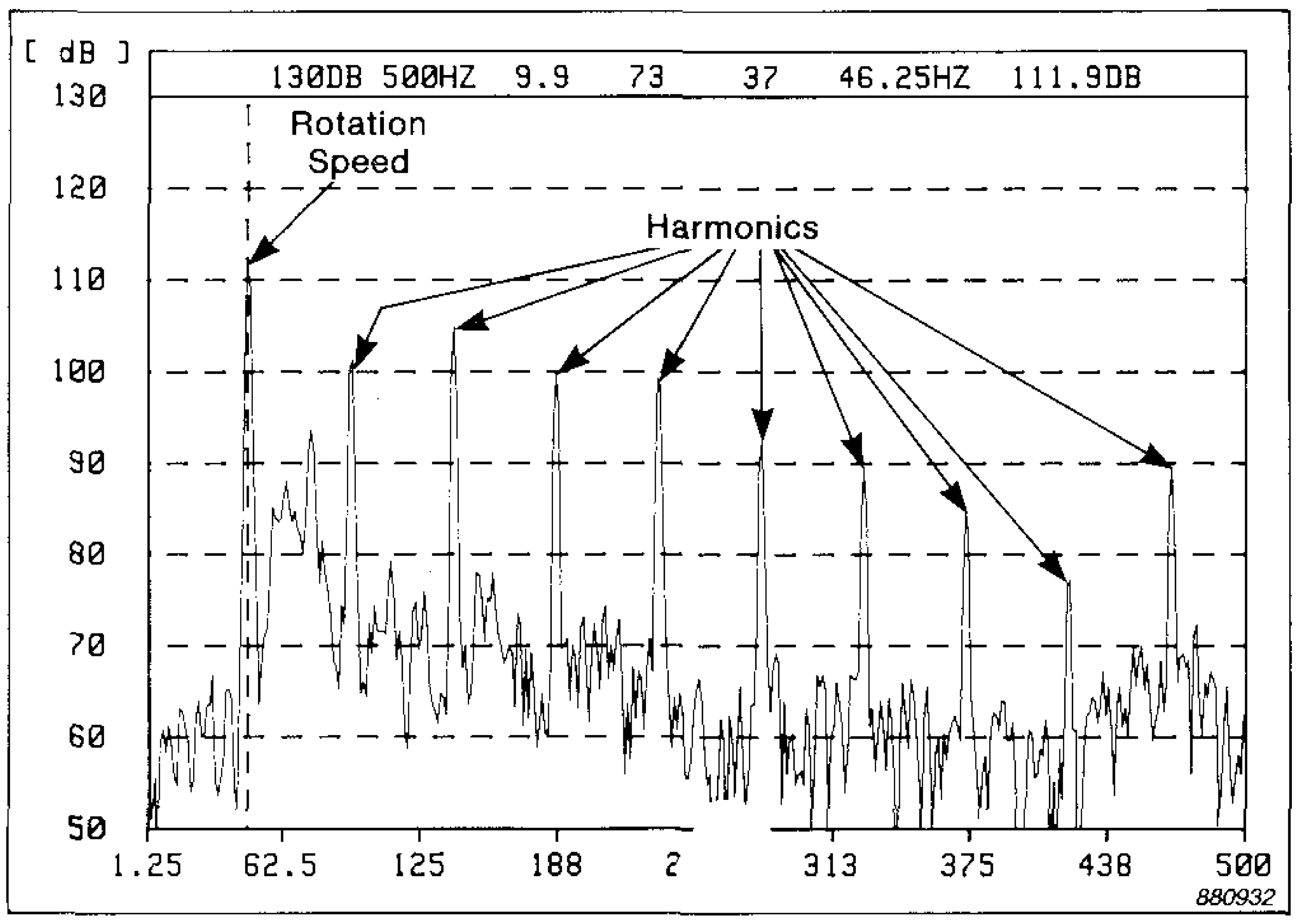


Fig. 23. Narrowband spectrum from the water feed pump, exhibiting the classic signs of a looseness problem

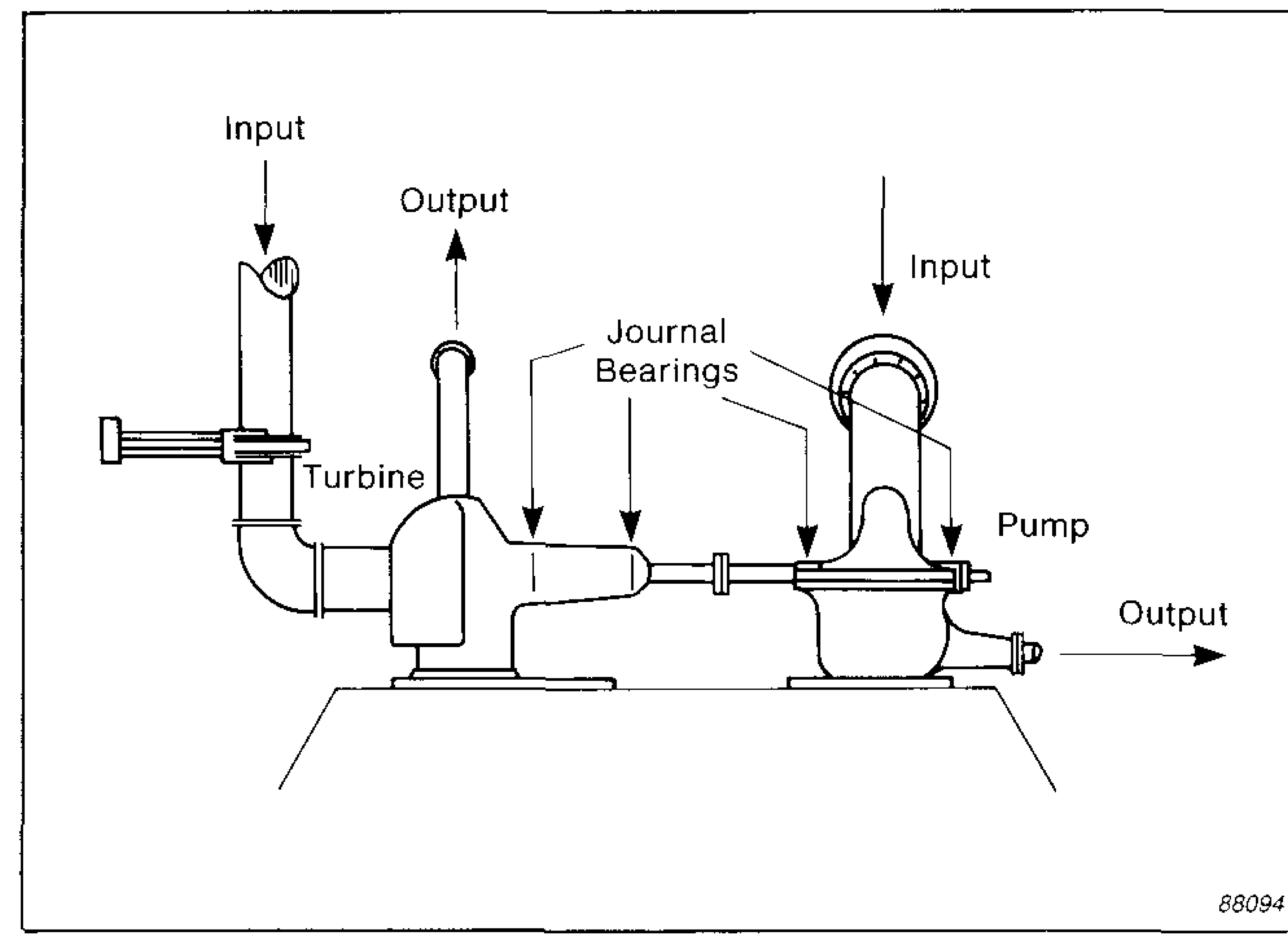


Fig. 24. The steam-turbine driven water feed-pump from Case 7

Success of the Monitoring System

The vibration monitoring programme at the Alma Paper Mill has shown itself to be a resounding success story. There have been no unexpected breakdowns on monitored equipment since installation of the system, apart from the single failure during introduction of the system (see case 3). All problems have been detected by the system early enough to enable repair to be scheduled for a planned shutdown. This record means that the initial investment in the monitoring equipment, training etc., has been paid back, and more!

To illustrate this point, just prior to installation of the monitoring system a bearing failed requiring 20 hrs to replace. The mill's maintenance team knew the bearing was in a bad condition but estimated that it would last until the next planned shutdown. This was not to be the case, and the bearing failed. Had the monitoring system been installed, this failure *would* have been detected at an early enough stage to allow its condition to be followed closely and repair to be planned well ahead of the scheduled shutdown.

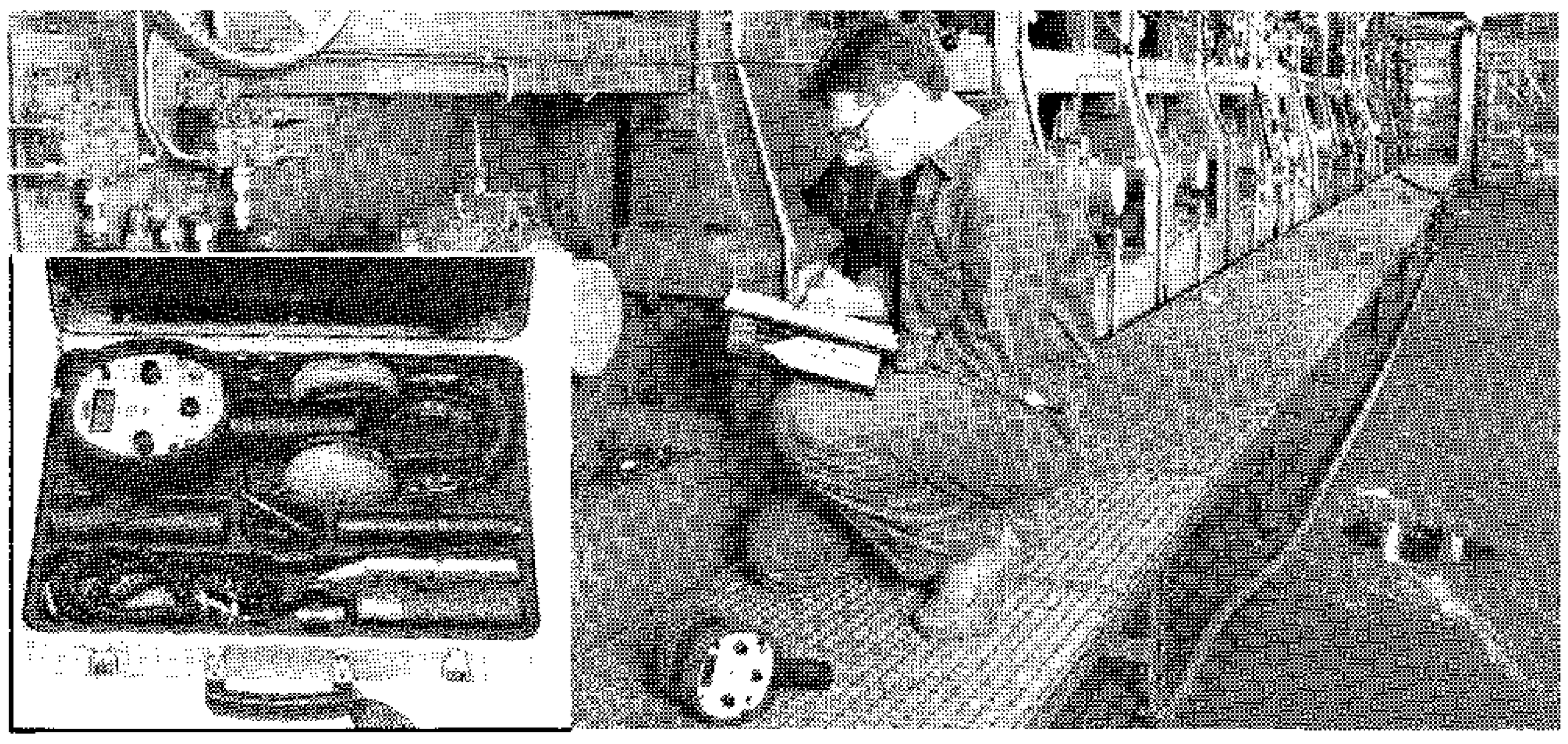
This Application Note has shown the power of spectrum comparison to detect faults at a very early stage in their development. This has allowed faulty bearings to be effectively detected and, with the help of 3-D plots and trend analysis, their condition to be closely followed to allow them to be replaced during scheduled shutdowns. The narrowband and cepstrum facilities of the analyzers have enabled the exact fault to be pin-pointed, removing any doubt as to the type of fault and allowing the correct spare parts to ready and waiting for the repair.

Acknowledgments

The authors wish to thank Abitibi Price for permission to visit and report on the vibration monitoring programme in operation at the Alma Paper Mill, and are indebted to Project Engineer Richard Lefebvre and Millwrights Regis Gaudreault and Sylvain Pedneault for their work in gathering information for this Application Note.

Vibration Monitoring of Pulp & Paper Machines

The following gives an overview of monitoring equipment available from Brüel & Kjær. The systems range from simple, hand-held vibration meters up to fully-automated permanent monitoring systems.

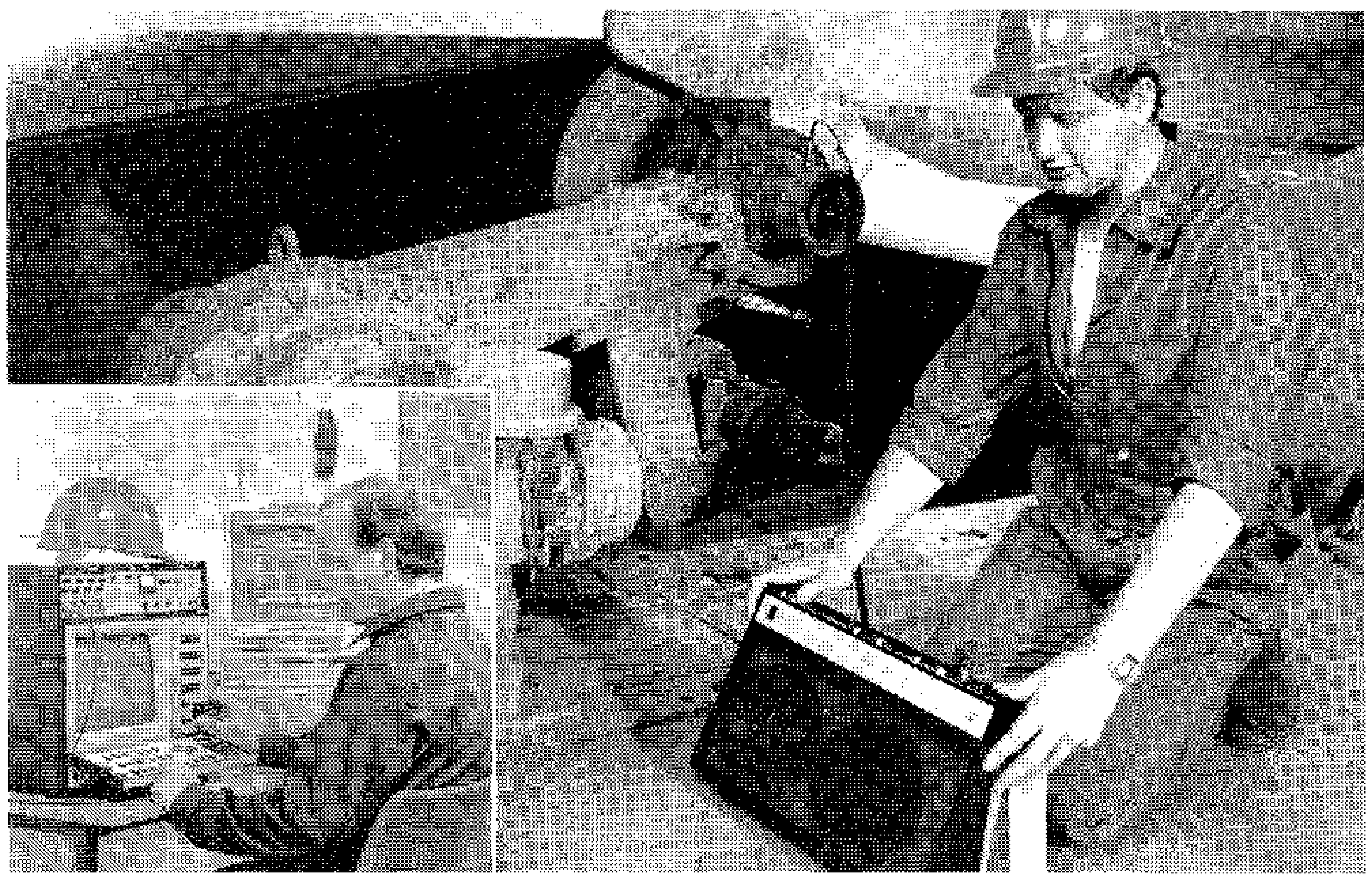


Spot-checking Machine Condition

The Type 9613 Vibration Monitoring Set, comprising Vibration Meter, Stroboscope and Headphones, provides the tools for a fast, easy check on machine condition. The Vibration Meter gives a one-figure reading of overall machine condition or the Crest Factor of bearing vibration. Connecting the Headphones to the Vibration Meter enables the vibration to be listened to, using the ear as an effective frequency analyzer. The Stroboscope allows movement to be "frozen" to study deflection shapes, and determine exact roll-rotation speed.

Portable Detection and Analysis

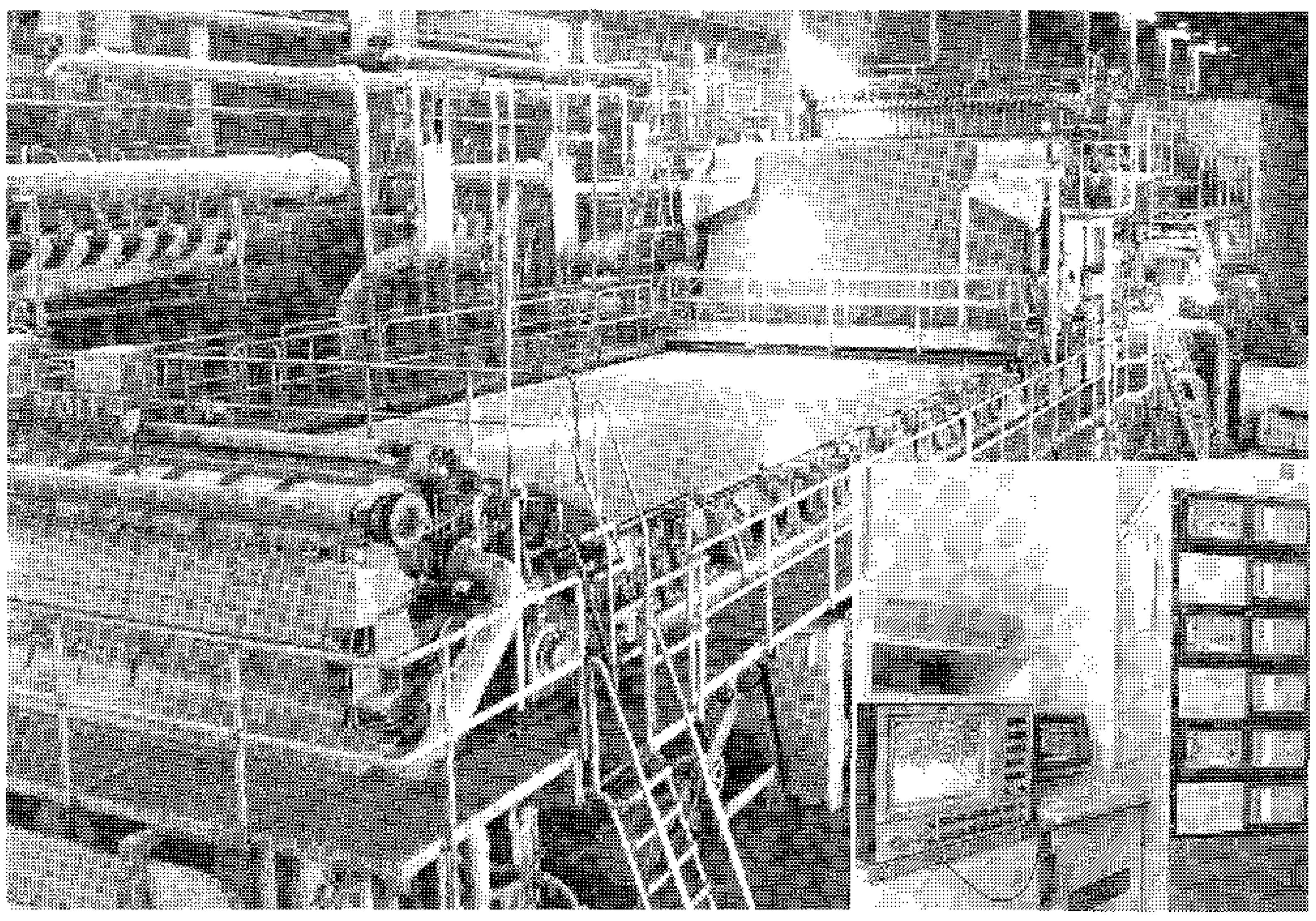
The portable Type 2515 Vibration Analyzer and Personal Computer with software Type 7616 provide a powerful combination for systematic machine-monitoring. A high level of data-base management allows easy access to relevant information, and measurement routes can be made up to help with the large number of measurements necessary on paper machines. The Analyzer is used firstly as an instrument for fault detection using spectrum comparison and then, having found a fault, it is used as an instrument for troubleshooting the fault using features such as zoom, harmonic cursors, cepstrum etc. All data can be down-loaded to the Computer where post-processing is carried out, including spectrum comparison, 3–D plotting and trend analysis.



Office-based Detection and Analysis

Vibration signals are first recorded on tape using Tape Recorder Type 7007 for later analysis in the office. Analysis is made with a Signal Analyzer Type 2033 (or 2-channel Types 2032/4) under control of a computer running the appropriate B & K software. Such a system combines the versatility of the Tape Recorder with the high-powered analysis functions of the Signal Analyzer. Spectrum comparison, zoom, cepstrum, 3–D plotting, trend analysis and much more can all be performed with the analyzer/computer combination.

It is such a system that is in use at the Alma Paper Mill.



Permanent Monitoring

Permanent monitoring provides the safety of knowing that critical machine parts are monitored around the clock. These systems are particularly useful in the paper industry where 24 hr production is maintained, and it is often awkward if not impossible to attach transducers to certain parts of the machine whilst it is running (e.g. the drive-end of a dryer-can). Transducers can be permanently attached to bearing housings, and high-quality cable used to route the signals to a Type 2505/2514 Monitor/Multiplexer system.

Alarms are automatically given if the vibration level exceeds preset limits. For spectrum comparison, high-resolution analysis, trending etc. the signals are run into a computer/analyzer setup in the control room. The whole process of broadband monitoring and spectrum comparison can be fully automated.

Brüel & Kjær

WORLD HEADQUARTERS: DK-2850 Nærum · Denmark · Telephone: +45 2 80 05 00 · Telex: 37316 bruka dk · Fax: +45 2 80 14 05

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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