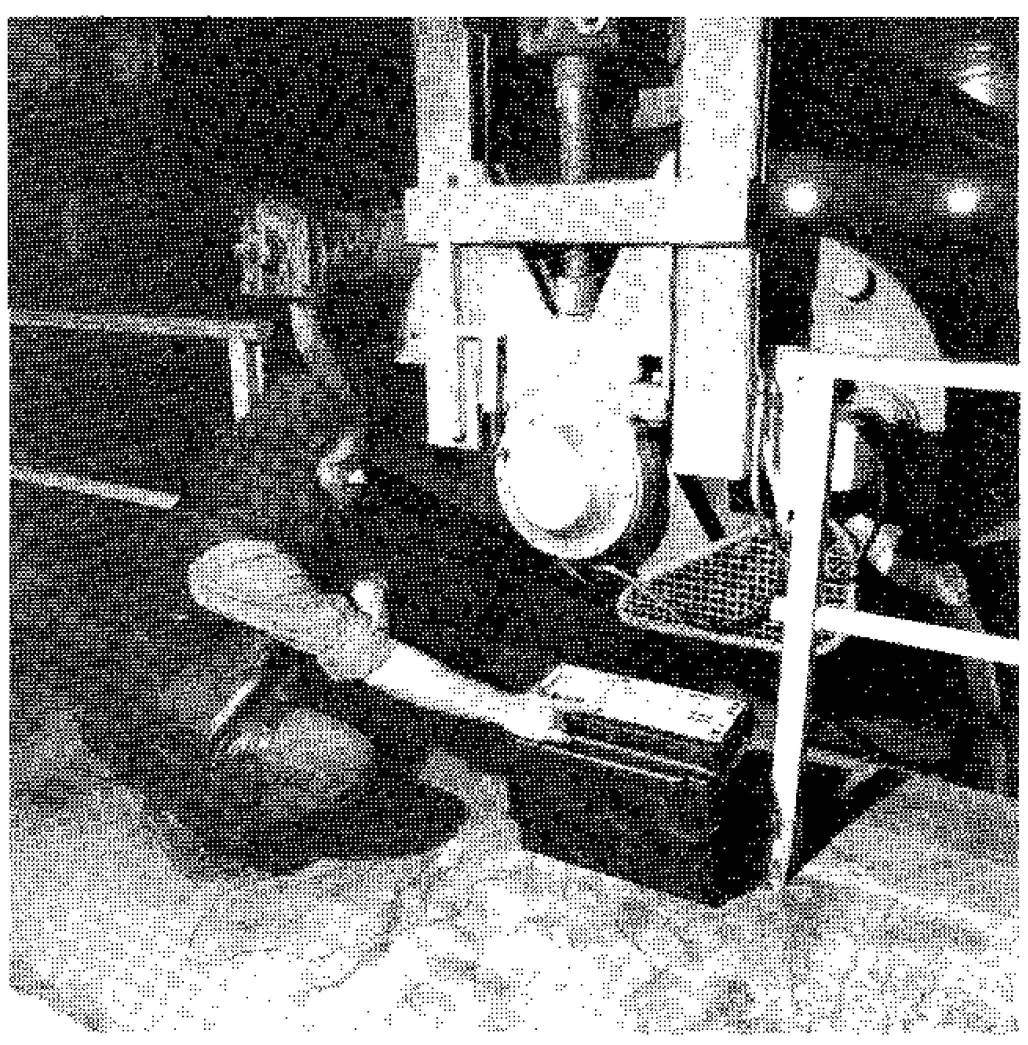
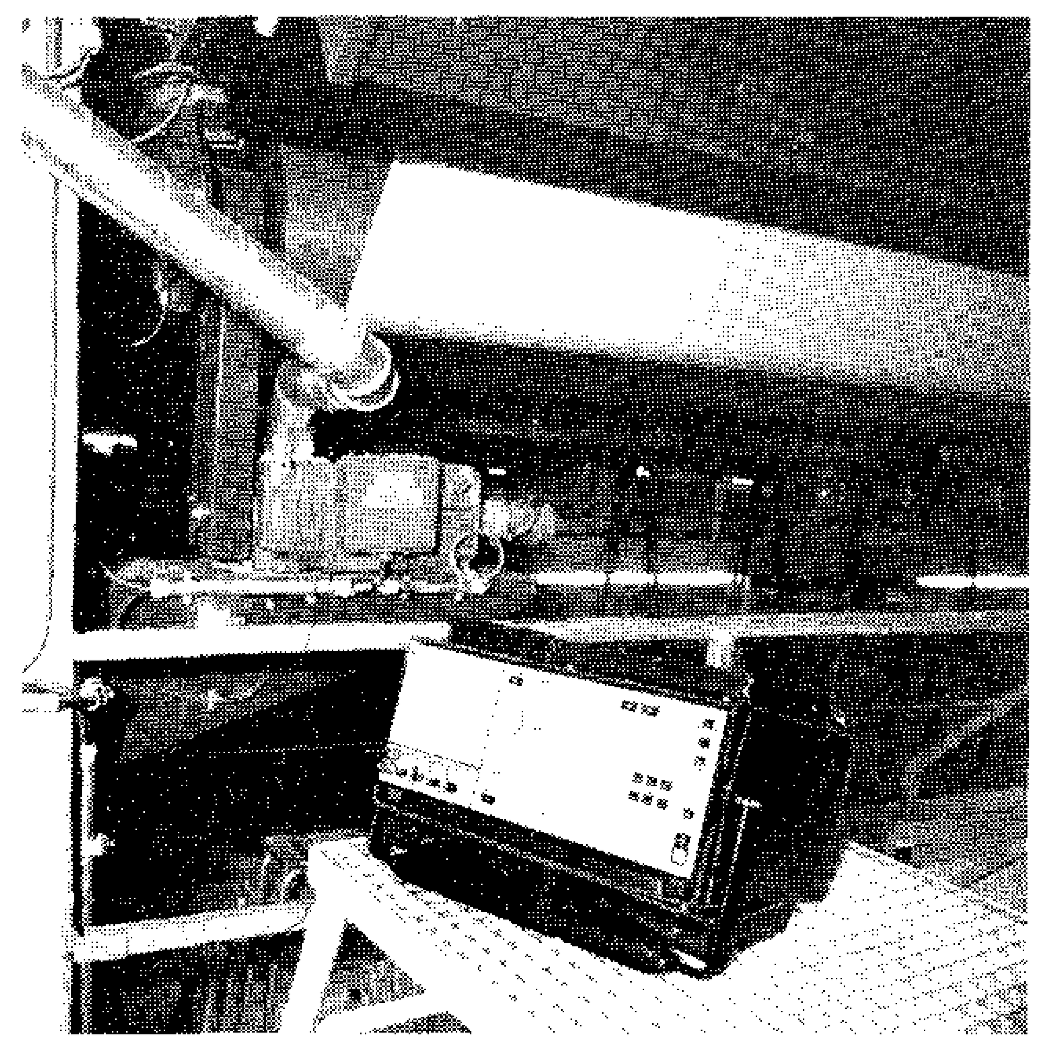
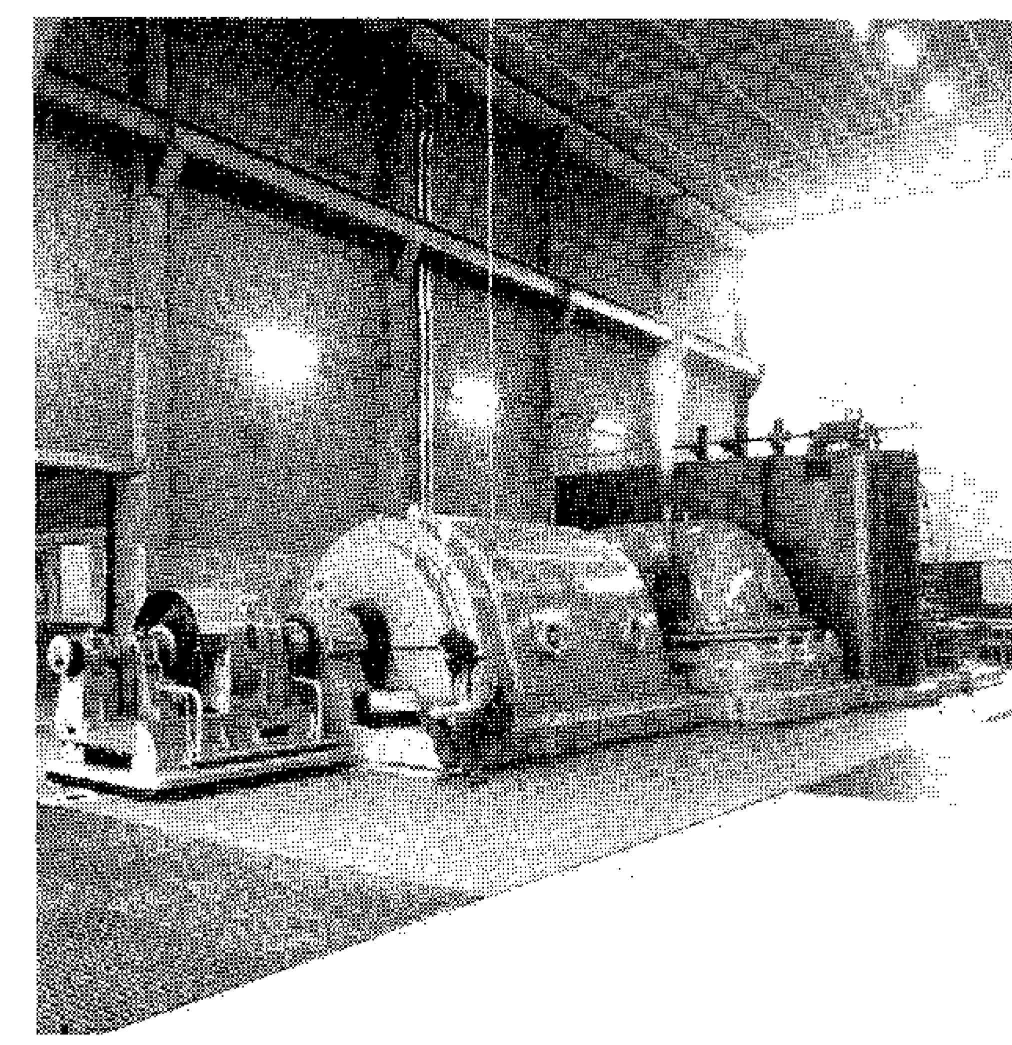
Application Notes

Systematic Machine-Condition Monitoring

A Case Study from Parenco Paper Mill in Holland



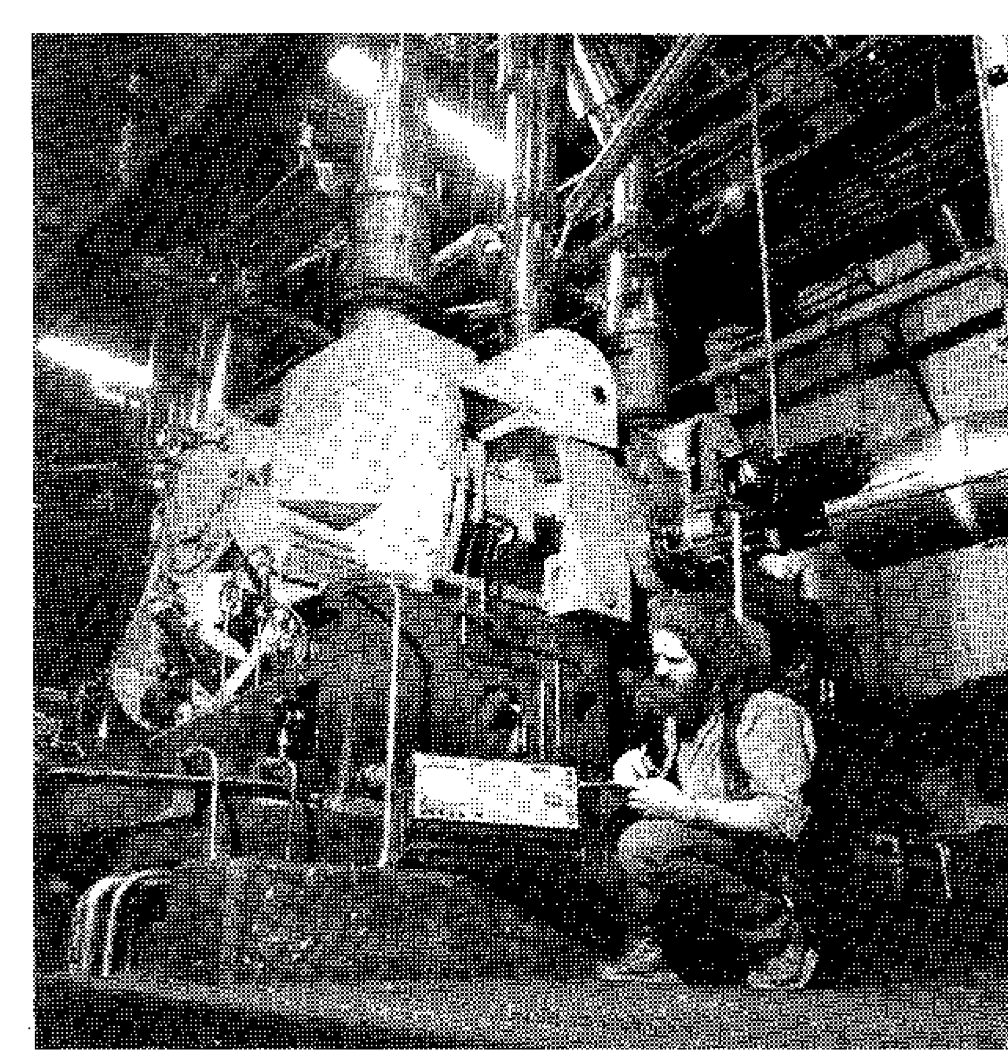


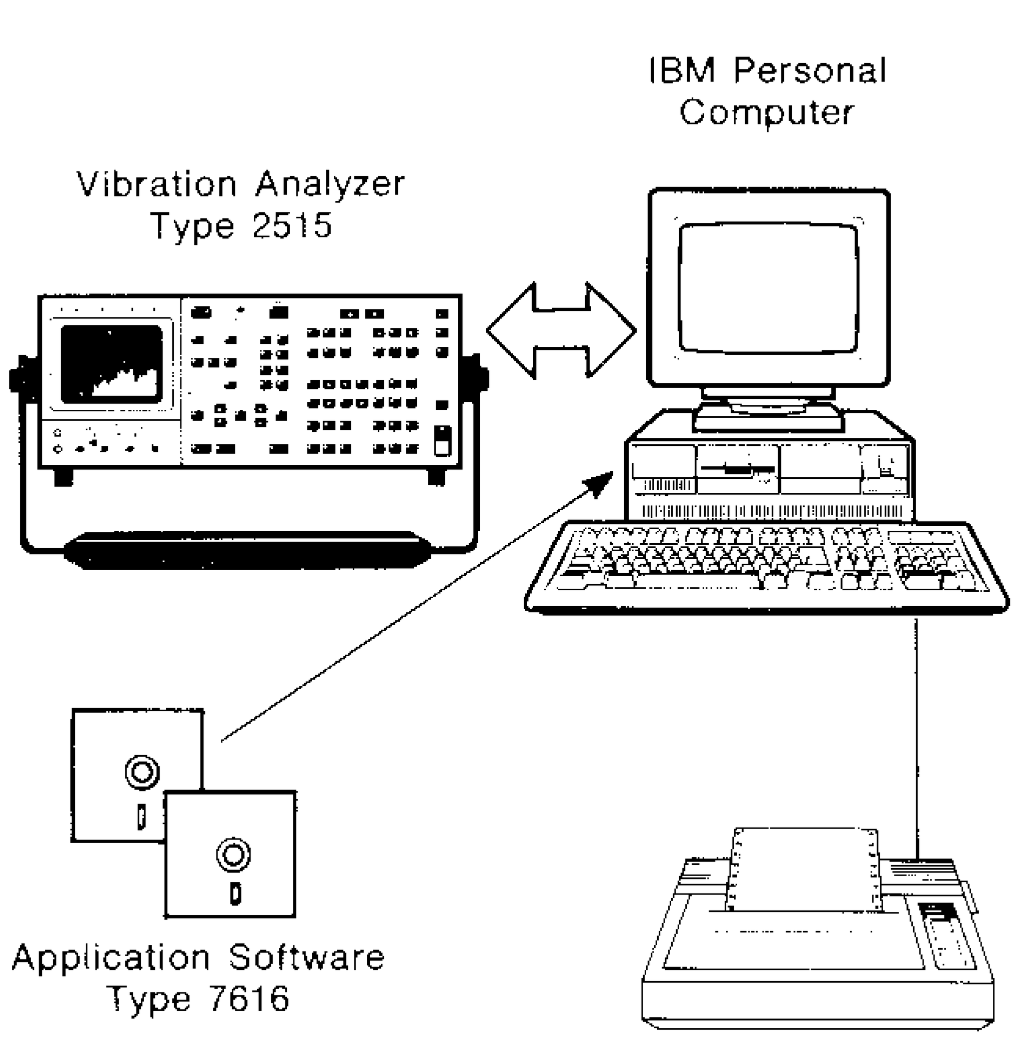


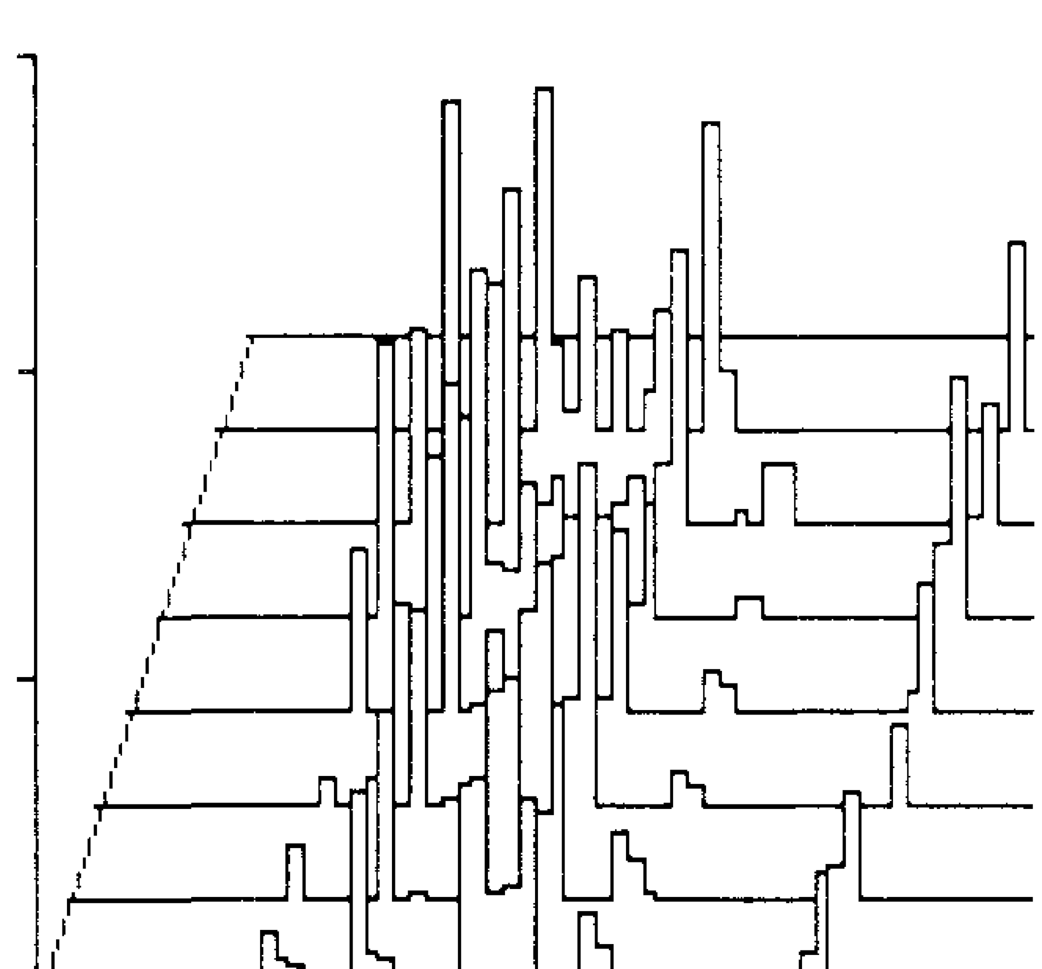
Parenco produces high-quality newsprint for several well-known European daily newspapers. To maintain their proud reputation, they must maintain both quality and quantity of production.

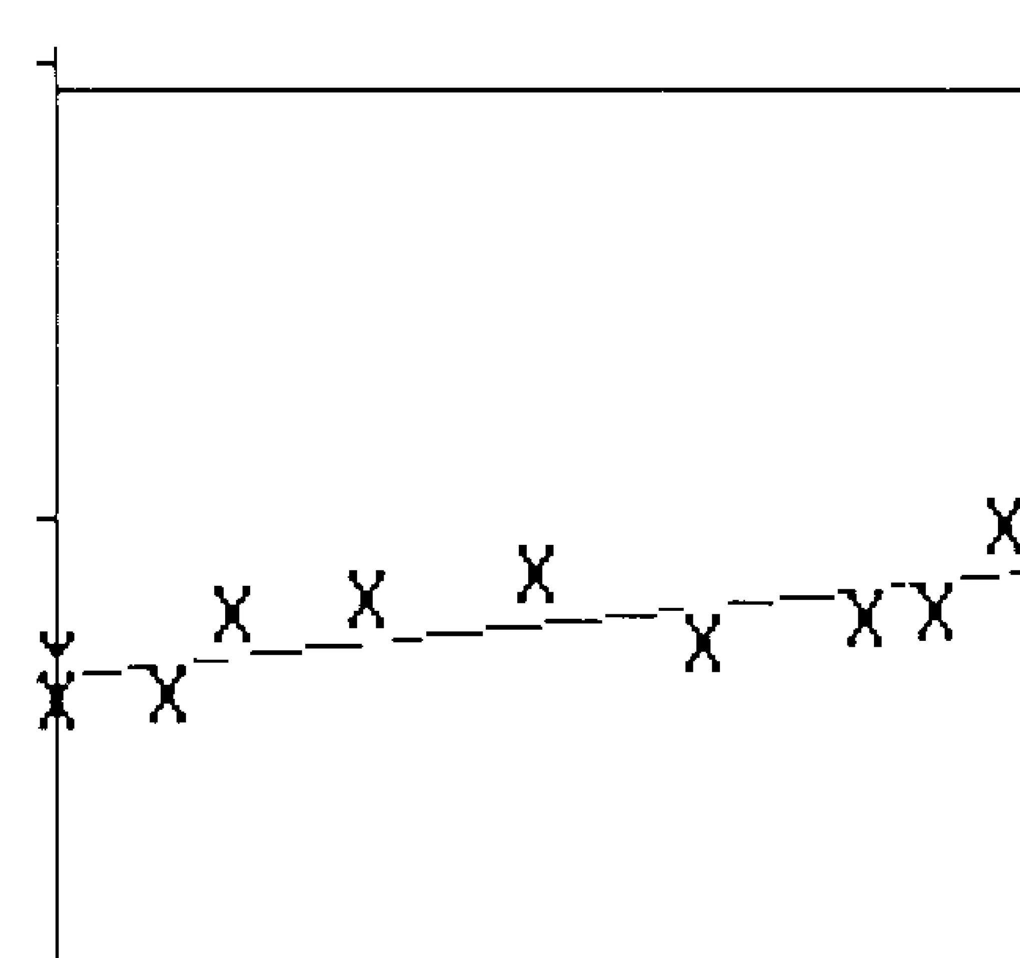
They use the Brüel and Kjær Systematic Machine Condition Monitoring concept to monitor the vibration spectrum at 6000 measurement points on their paper machines and power plant. The system features early fault detection, powerful fault diagnosis, and trend analysis to predict the lead time to breakdown.

This application note describes the use of this Brüel and Kjær system at the Parenco paper mill.









Brüel & Kjær

Systematic Machine-Condition Monitoring

A Case Study from Parenco Paper Mill in Holland

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Introduction

A Distinguished History
The Parenco story begins in 1720, when a wind-powered paper mill was established in Renkum, Holland, on a tributary near the river Rhine. In 1853 a steam-powered mill was built on the same site and in 1912 the owners built another factory nearby and installed two paper machines for newsprint.

After 67 years of loyal service, the old machines were replaced in 1979 by a modern newsprint machine. Continued success led to the purchase of a second new paper machine in 1987, and an increase in production from 180000 to 400000 tonnes per year.

The Product: Newsprint
The annual global consumption of newsprint is about 29 million tonnes. The EC accounts for about half of this and the Parenco factory is strategically situated at the centre of the largest consumer markets in the EC. Parenco produces high quality newsprint for many well-known British, Dutch, French and German daily newspapers.

The Monitored Machines
Parenco monitors vibration spectra on all the important machines normally found in a paper mill i.e. paper machines, pulp mills, wrapping lines, pumps, compressors etc. They also monitor their steam turbine, gas turbine and electric generators. The main machine categories are listed below.

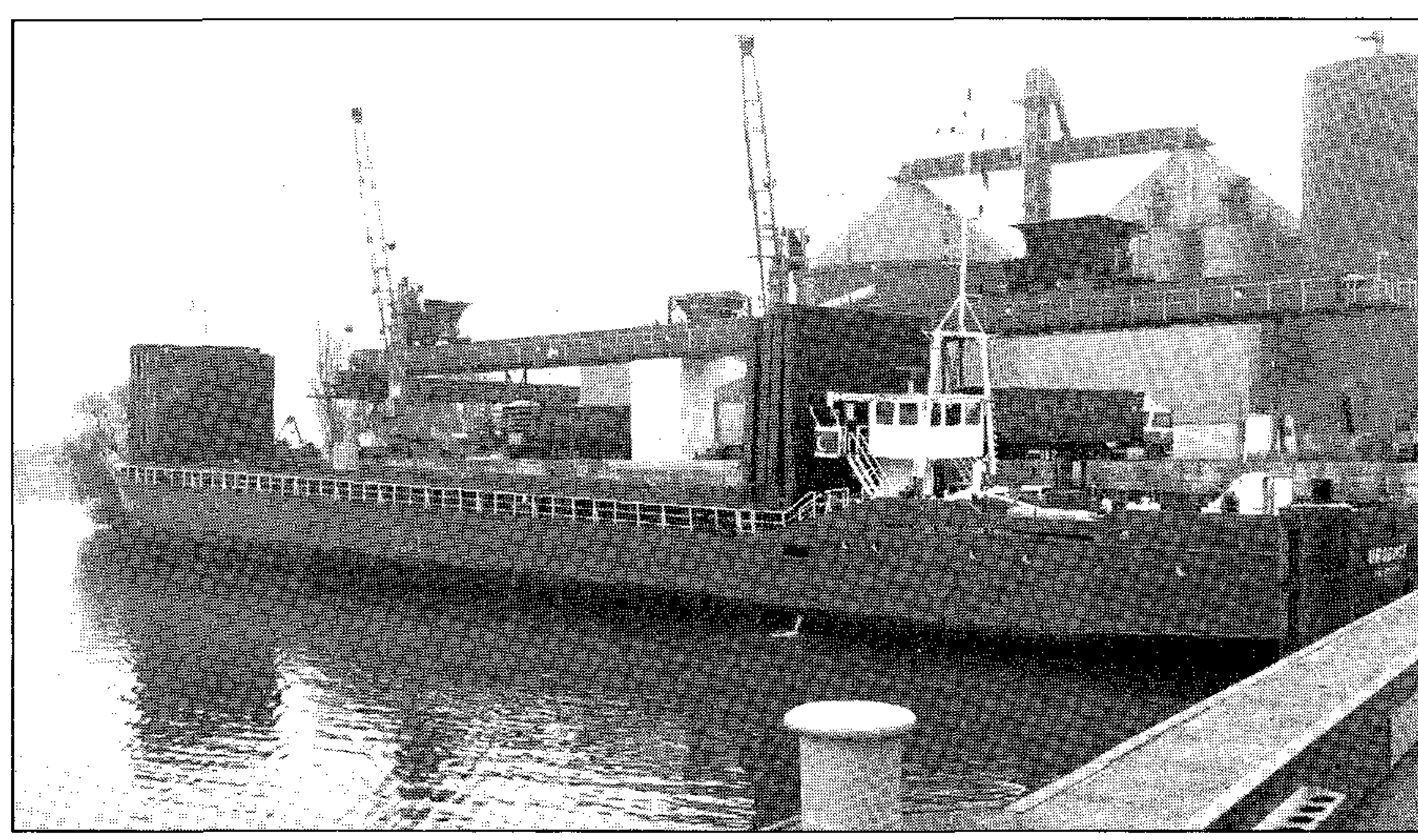

Fig. 1. The plant is located on a tributary of the river Rhine, where there is good access to the forests and printing industries of Europe

■ Paper Machine PM1, 1987
Manufacturer: Valmet
Type: Symformer 8,50 m
Capacity: 220000 T/year

This machine uses two 8,50 m soft compact calenders manufactured by Kleinwefers and two 8,50 m Vari-top winders manufactured by Jagenberg.

■ Paper Machine PM2, 1979
Manufacturer: Valmet
Type: Symformer/N 8,50 m
Capacity: 180000 T/year

This machine has a built-on calender and it uses 8,5 m Vari-dur and Vari-top winders manufactured by Jagenberg.

■ Thermo-mechanical Pulp Mill
Manufacturer: Sprout Bauer
Type: 7 MW and 15,5 MW refiners
Number: 7
Capacity: 360 T/day

■ Groundwood Pulp Mill
Manufacturer: Voith
Type: Chain grinders
Number: 9
Capacity: 200 T/day

■ Automatic Wrapping Line
Manufacturer: Lamb
Capacity: 400000 T/year

■ Power Plant
Gas turbine and electric generator
Exhaust gas boiler

Steam turbine and electric generator
Fluid bed boiler

■ Vacuum Pumps

■ Auxiliary Pumps

The Vibration Monitoring System

The Vibration Staff

The vibration staff consists of two vibration analysts and an experienced mechanic. The two analysts take care of fault diagnosis, while the mechanic does the routine work of fault detection. Together they systematically monitor the vibration spectrum at 6000 measurement points, spread over the 417000 m^2 premises, using the Type 2515 Vibration Analyzer and its associated Type 7616 Application Software.

Type 2515 Vibration Analyzer and Type 7616 Application Software

The portable vibration analyzer is a powerful FFT and CPB frequency analyzer, designed to detect and diagnose even the most complex machine faults at a very early stage. Fault detection features include memory space for up to 100 measurements and on-the-spot spectrum comparison; diagnostic features include cepstrum and envelope analysis, which are useful in connection with gearbox and bearing faults.

The application software, running on a PC, complements the vibration analyzer: the software package has a comprehensive database to store measurements downloaded from the vibration analyzer, and routines to warn about significant increases in the vibration spectrum and predict lead times to breakdown. The combination forms a complete systematic machine condition monitoring system.

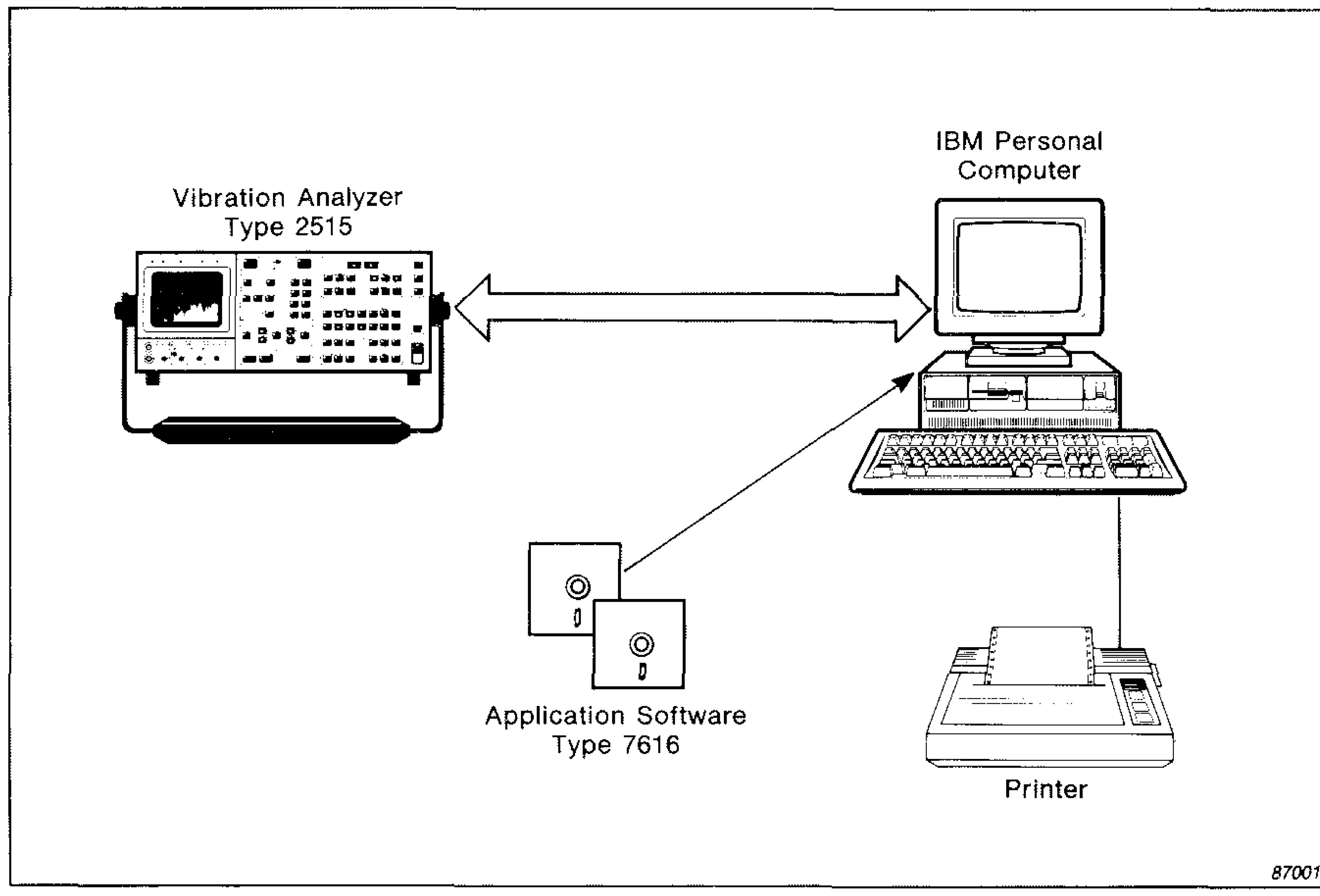

Fig. 2. The portable vibration analyzer can be used for on-the-spot fault detection and diagnosis. For data management and processing, it can be interfaced with an office-based PC

Spectrum Comparison for Fault Detection

Vibration Spectrum

A vibration spectrum from a point on a machine casing contains information about the condition of the machine. The spectrum components correspond to various machine elements and their faults as shown in Fig. 3. When regular spectrum measurements reveal an increase in vibration level at a particular component, this indicates that a fault is developing at the machine element which corresponds to that component.

Constant Percentage Bandwidth (CPB)

This systematic machine condition monitoring system compares constant percentage bandwidth spectra plotted on a logarithmic frequency scale, as shown in Fig. 3. These spectra are best for systematic fault detection as they contain the optimum (minimum) amount of information necessary for detection of a very wide range of faults.

The Vibration Spectrum

Frequency Range	Low	Medium	High
Fault to be detected	Unbalance Misalignment Bent shaft Oil whirl Eccentricity	Wear Faults in gears	Faults in rolling element bearings

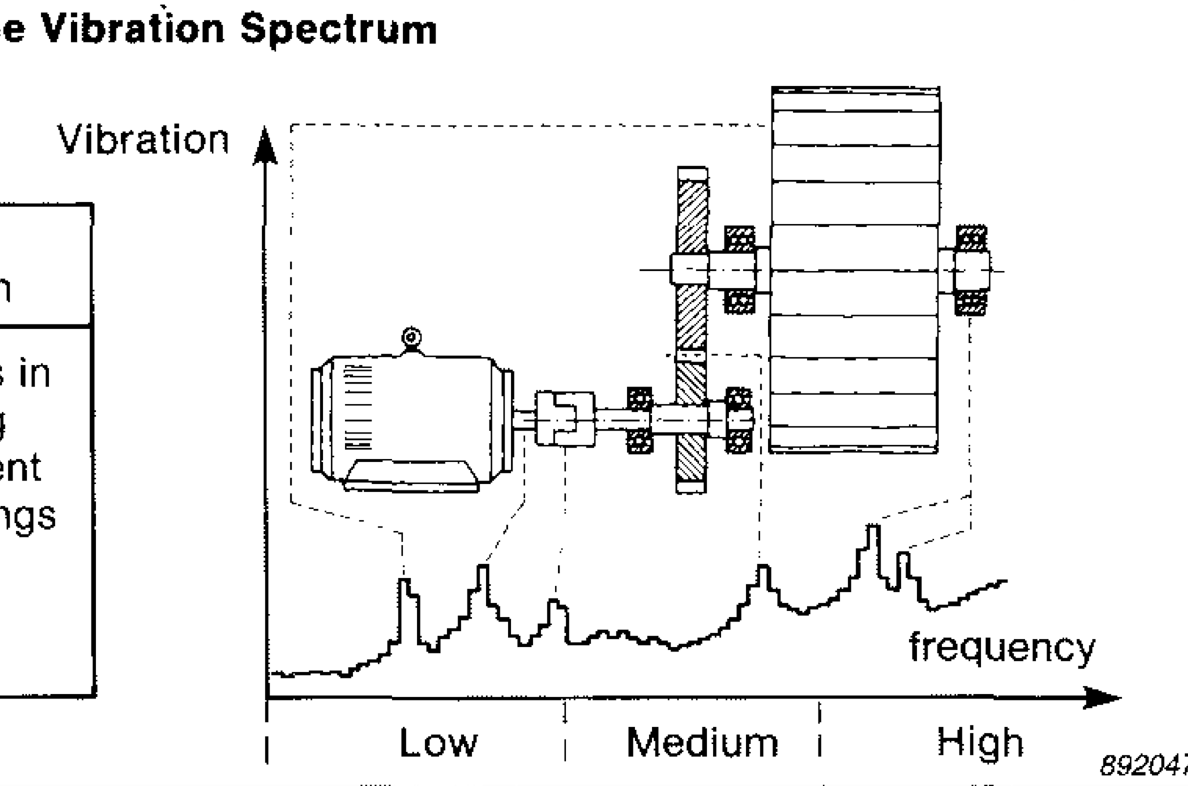

Fig. 3. The peaks in the spectrum correspond to the vibration from various components in the machine. Constant percentage bandwidth (CPB) spectra plotted on a logarithmic frequency axis are best for detection of a very wide range of faults

Organising Routes, Machines, and Measurement Points in the Database

Grouping Machines and Measurement Points into Routes
Since all 6000 measurement points could not possibly be covered in one measurement session, Parenco divided them into groups. They classified the machines according to their overall importance and associated a measurement interval with each one (shortest intervals for most important machines). Then they grouped machines with equal measurement intervals together so that finally all 6000 measurement points were distributed into groups of up to 100 measurement points. Fig. 4 shows part of a printout of their route directory.

Route ID.	Date	Machine ID.	Meas Pt ID.	Data Type
ELECTR.M.PM-1 (1)	88-01-24	CALIBRATE	1	Log 23%
		PM1-03	1-A	Log 6%
		PM1-03	1-H	Log 6%
		PM1-03	1-V	Log 6%
		PM1-03	2-A	Log 6%
		PM1-03	2-H	Log 6%
		PM1-03	2-V	Log 6%
		PM1-01	1-A	Log 6%
		PM1-01	1-H	Log 6%
		PM1-01	1-V	Log 6%
		PM1-01	2-A	Log 6%
		PM1-01	2-H	Log 6%
		PM1-01	2-V	Log 6%
		PM1-04	1-A	Log 6%
Continues		PM1-04	1-H	Log 6%

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Fig. 4. Part of a directory of measurement points in a route. It is also possible to get directories which list either routes, machines or measurement points

Identifying Routes, Machines and Measurement Points
Fig. 5 illustrates the idea of a route. The route is *Electr.M.PM-1 (1)*. This is at the wet section, driving side of paper machine no. 1. The machines in the route are *PM1-01* to *PM1-15*. These are the first 15 motors at the wet section. The measurement points are *1-A, 1-H, 1-V etc.* These are axial, horizontal, and vertical measurement points at the non-driving end of each motor. When the mechanic selects this route for a measurement routine, all the measurement points are automatically included.

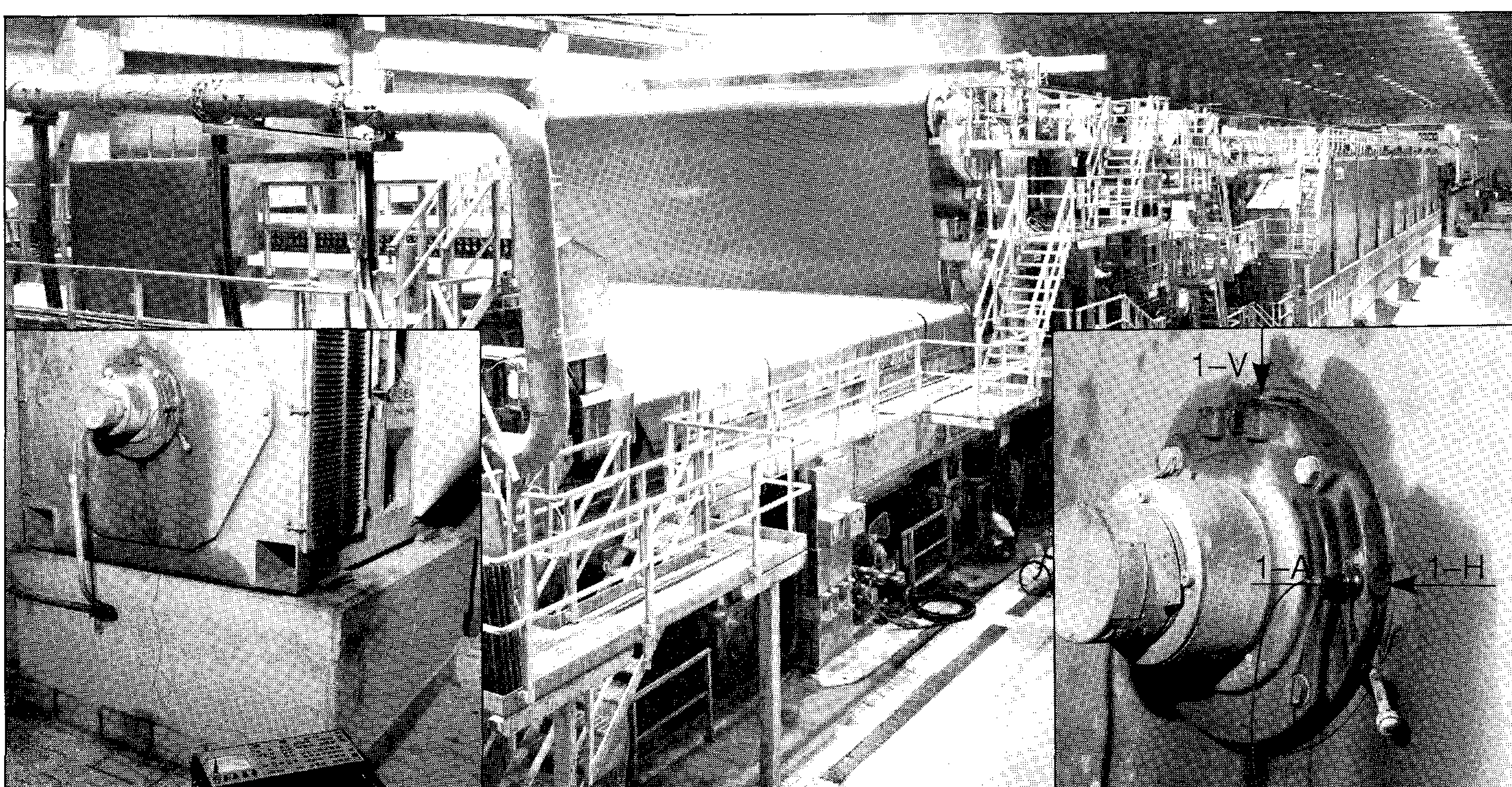

Fig. 5. An example of a route (PM1), a machine (PM1-05), and measurement points (1-A, 1-H and 1-V). The route is at paper machine no. 1, the machines are the electric motors at the driving side, and the measurement points are vertical, horizontal and axial on the outer bearing housing

Choosing and Setting Pre-defined Vibration Limits

Criterion for Vibration Limits?
There is no absolute criterion for defining vibration limits because no two machines behave similarly. The only sure way is to have a reference measurement for each individual measurement point and define the vibration limit relative to this reference. This is the principle used in the application software:

For each measurement point a reference spectrum is recorded, using the vibration analyzer, and transferred to the computer. The application software automatically sets two limits for the vibration spectrum, one for tolerable increases (tolerance limit) and one for unacceptable increases (trend limit).

Measuring a Reference Spectrum

For a given measurement point, the measurement set-up of the analyzer used for the reference measurement will be used for all subsequent measurements at this measurement point. One important parameter of the set-up is the number of spectrum averages. This must be large enough to get reproducible spectra, but small enough in order to minimize the measurement time. The correct number depends partly on the machine cycle speed, and it is determined during the reference measurement as follows:

The user selects measurement start and average start on the analyzer. Each time a new spectrum is measured it is included in the averaged spectrum and the updated average-spectrum is displayed on the analyzer screen. When the level changes in the average spectrum fall to less than 1 dB, the number of averages is correct and the user selects average stop.

The analyzer takes only a few seconds to measure a single spectrum and typically 1,5 to 2 minutes to measure a reproducible average spectrum. The measurement time required is normally less than this for high speed machines.

A Typical Reference Spectrum and its Profiles

For each measurement point, the vibration limits are represented by three profiles: reference mask, tolerance profile, and trend limit profile. An example for point 5-V of the gas turbine (Fig. 6) is described below.

The program creates the reference mask by broadening the peaks of the reference spectrum, see Fig. 7. This prevents small speed changes from indicating vibration increases.

The tolerance profile is a copy of the reference mask, raised vertically to the vibration level the user wants to tolerate before beginning to trend (discussed later), see Fig. 8. It is usually raised to 2× reference mask. The trend-limit profile is also a copy of the reference mask, raised vertically to the maximum vibration level the user wants to allow before the machine is shut down, see Fig. 8. It is usually raised to 10× reference mask.

If the current spectrum exceeds the tolerance profile, the program gives a *warning*; if it exceeds the trend-limit profile, the program gives an *alarm*, see Fig. 9.

Learning from Experience

The 2× and 10× levels mentioned above are only guidelines. The vibration staff will adjust the limits for some measurement points as they learn from experience with the system.

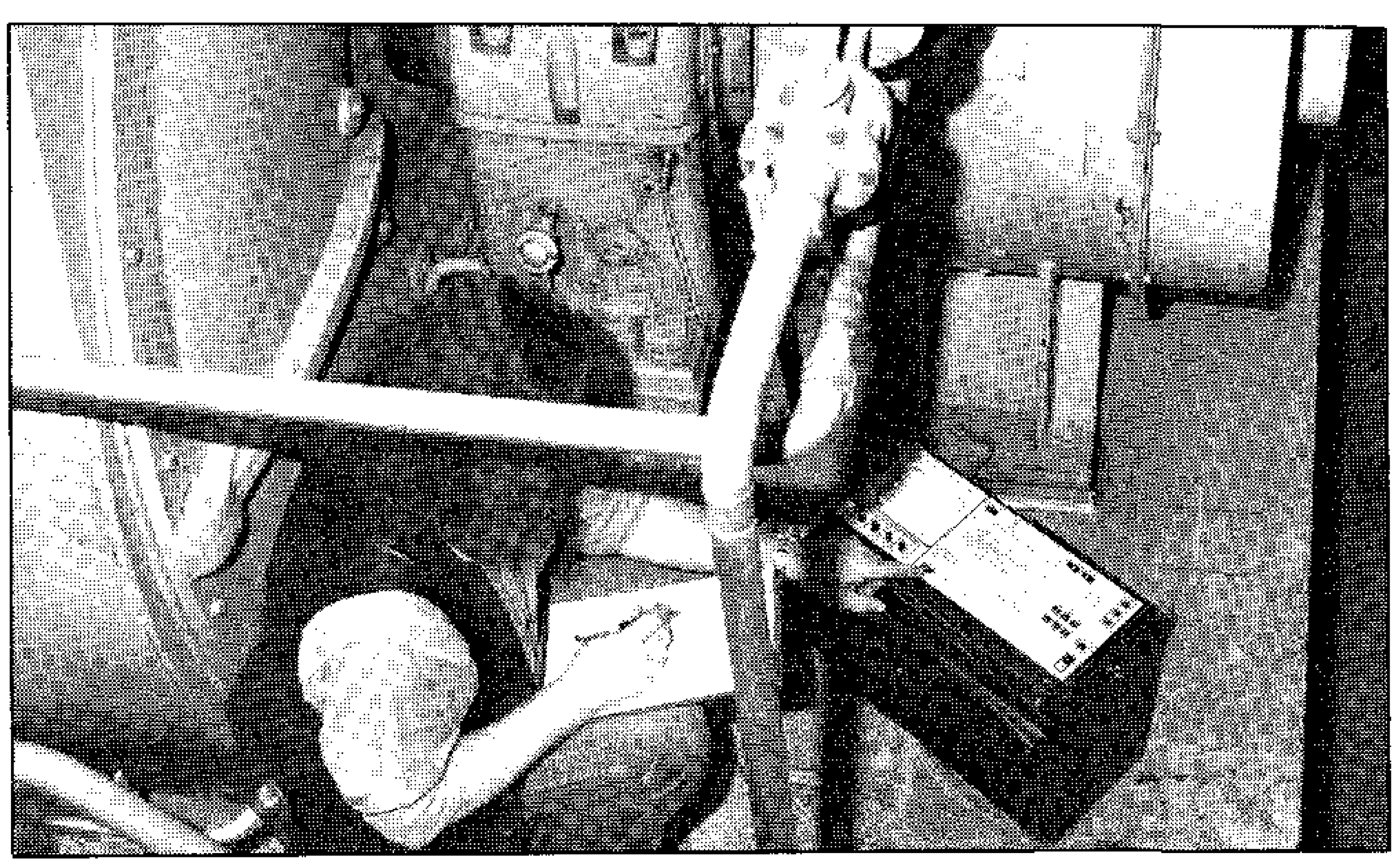

Fig. 6. The mechanic measuring at the generator end of the gas turbine. The vibration limits (profiles) for measurement point 5-V are shown in figures 7 to 9

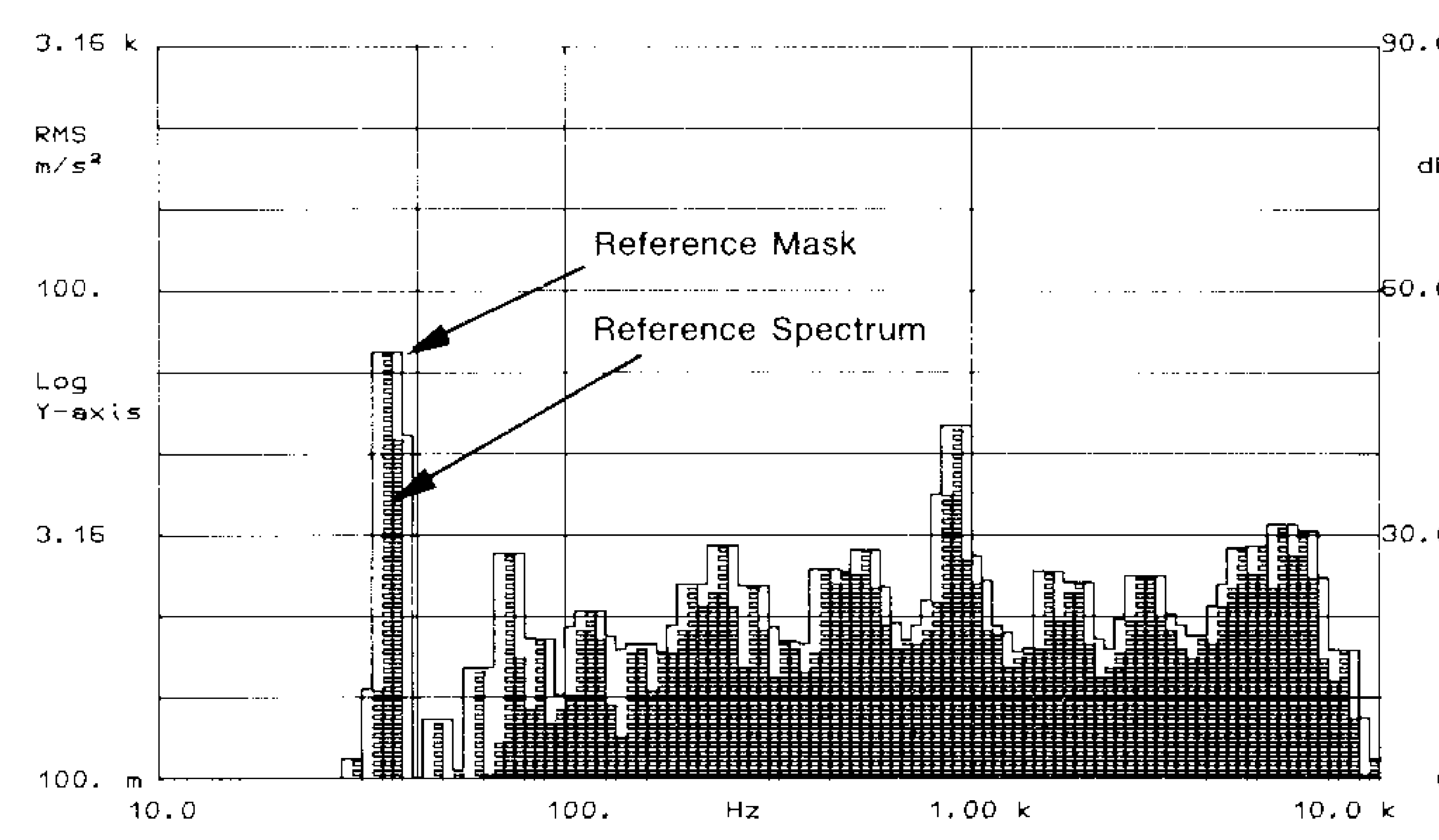

Fig. 7. The reference spectrum and the reference mask. The reference mask is a broadened reference spectrum. The broadening effect prevents small speed-changes from causing false alarms

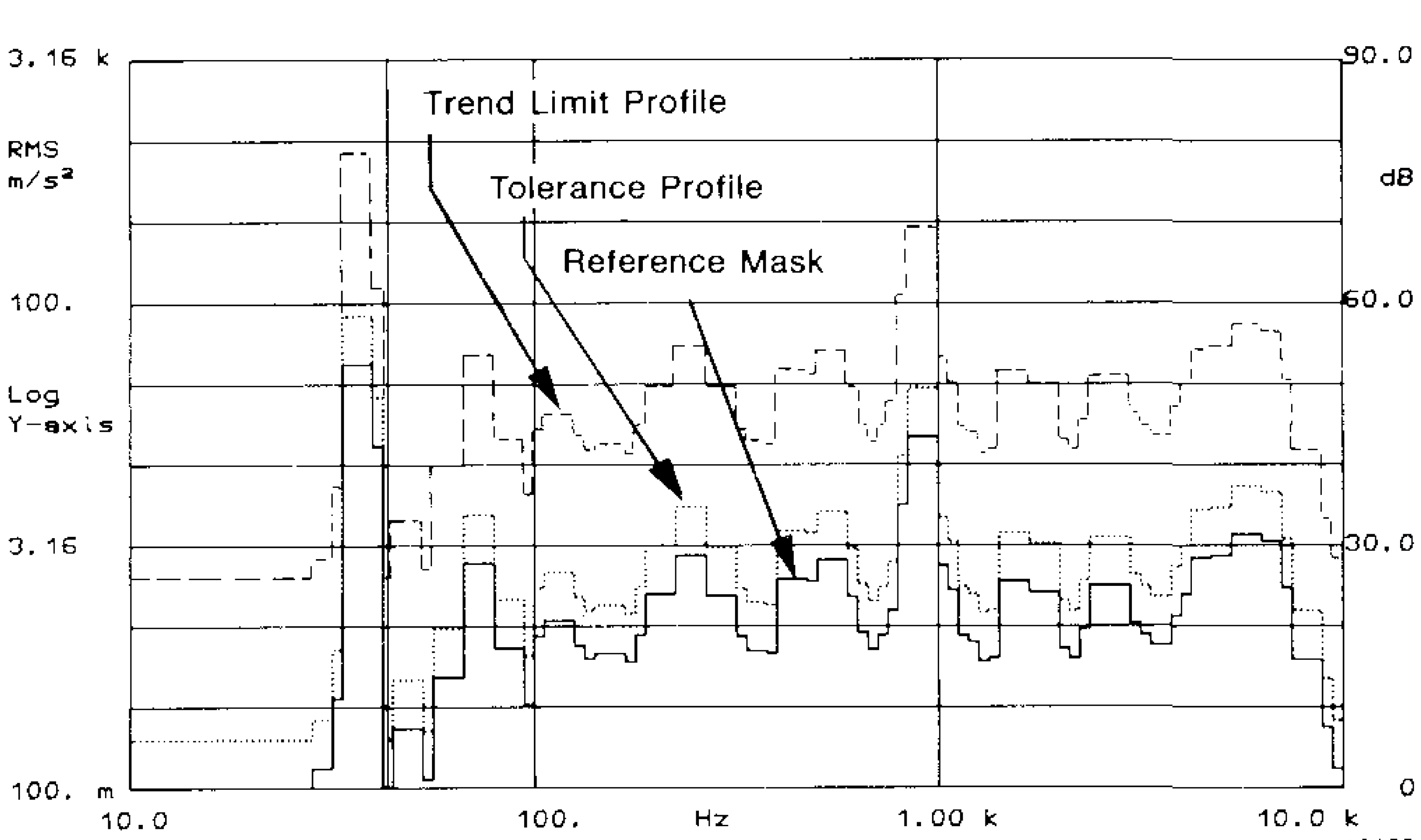

Fig. 8. The reference mask, tolerance profile, and trend-limit profile. These two profiles are raised versions of the reference mask. Their heights are normally 2× and 10× reference mask respectively

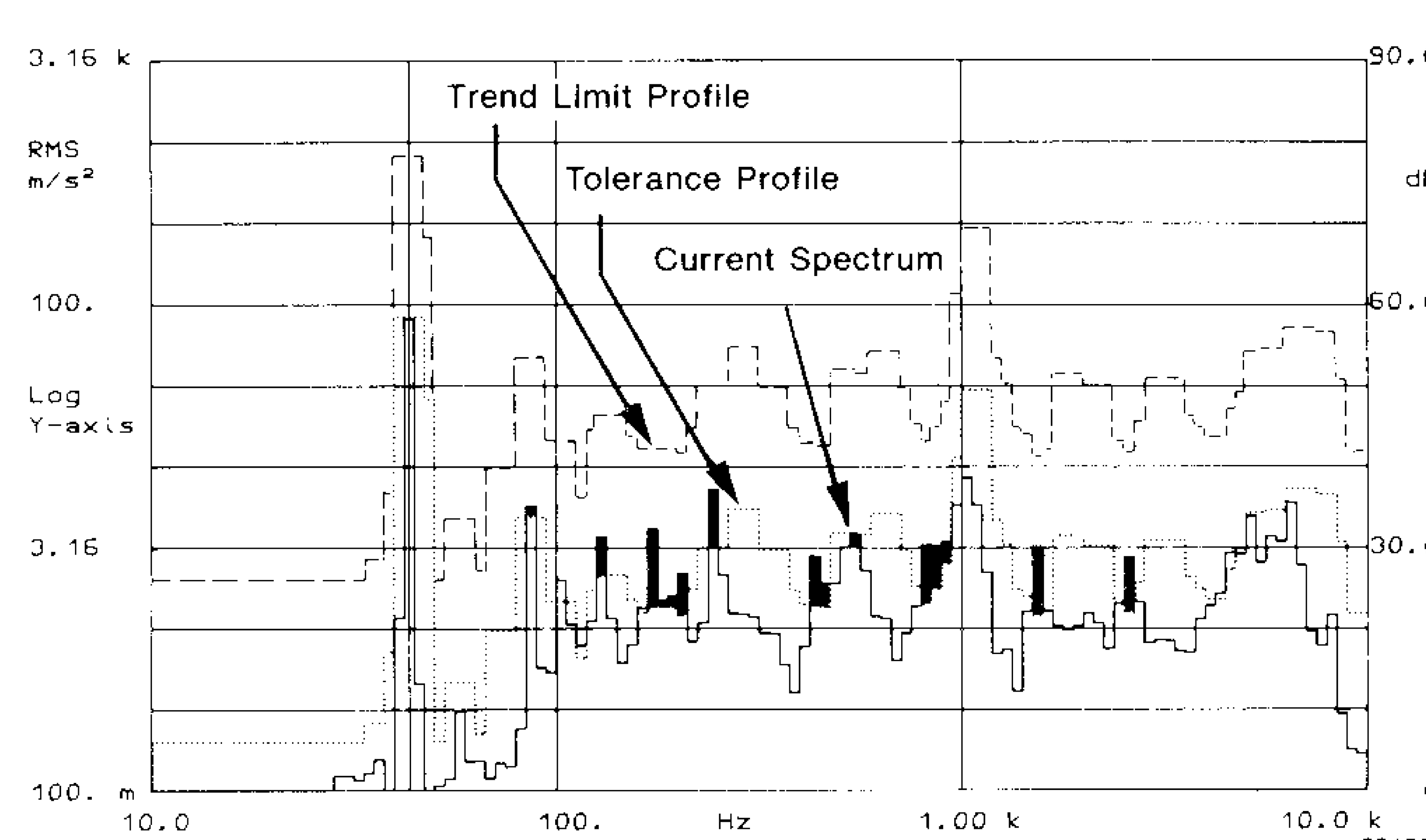

Fig. 9. The tolerance profile, trend-limit profile and a current spectrum. If the current spectrum exceeds the tolerance profile (as indicated by shading) there is a warning; if it exceeds the trend-limit profile, there is an alarm

Measurement Point Preparation

Magnetic Mounting on Special Discs
The accuracy and reproducibility of the measurements, which are crucial to the reliability of the whole monitoring system, depend partly on the measurement points. At each measurement point there is a stainless steel disc which is specially machined and attached with glue. When one of the accelerometers 4370, 4384, 4390 or 4391 is mounted at the measurement point using the magnet UA 0642, the measurement is accurate and reproducible within the frequency range 10 Hz to 10 kHz. This frequency range covers all the speed ranges which Parenco need to monitor i.e. 600 RPM to 600 000 RPM.

Added Advantages
Other advantages of this mounting method include easy use, freedom of hands, absence of human interference, flat frequency response over a wide frequency range, easy cleaning and reproducibility of measurement position.

Routine Data Collection

Loading the Analyzer
Once the database is prepared, the work involved in collecting, storing and evaluating new data is systematic. On a measurement day, the mechanic uses a quick routine in the software program to select the measurement points he wants to visit. Because the factory is so large, the measurement points are grouped by area into measurement routes; when the mechanic selects a route, all the measurement points in the route are automatically included in his routemap, see Fig. 11. The computer loads the analyzer with a reference spectrum and a measurement set-up for each measurement point in the routemap (up to 100 possible), and the printer produces a hard copy of the routemap, see Fig. 12.

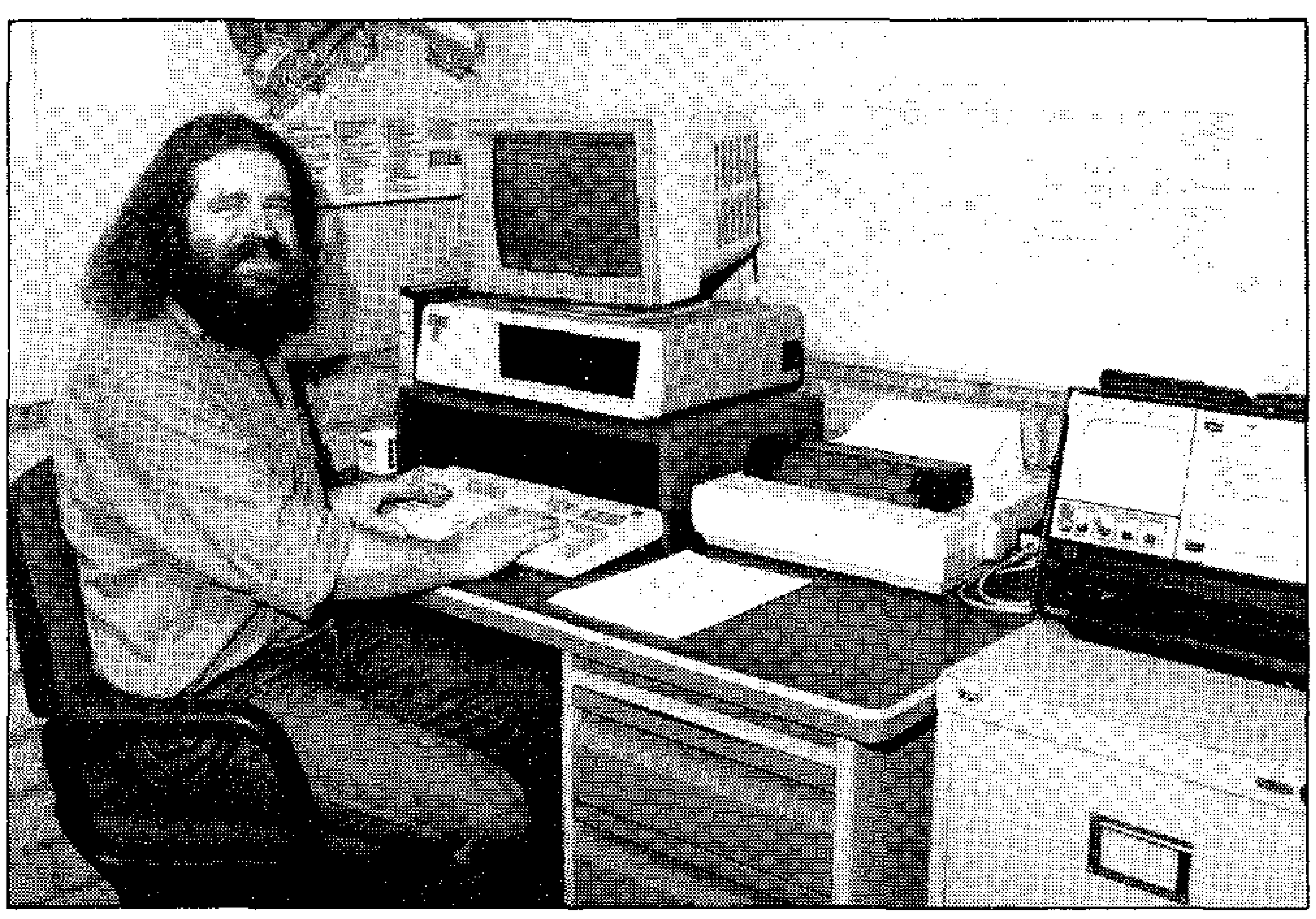

Fig. 10. The mechanic preparing the analyzer for today's route. The computer unloads a reference spectrum and measurement set-up to the analyzer for each measurement point he selects and the printer produces a routemap

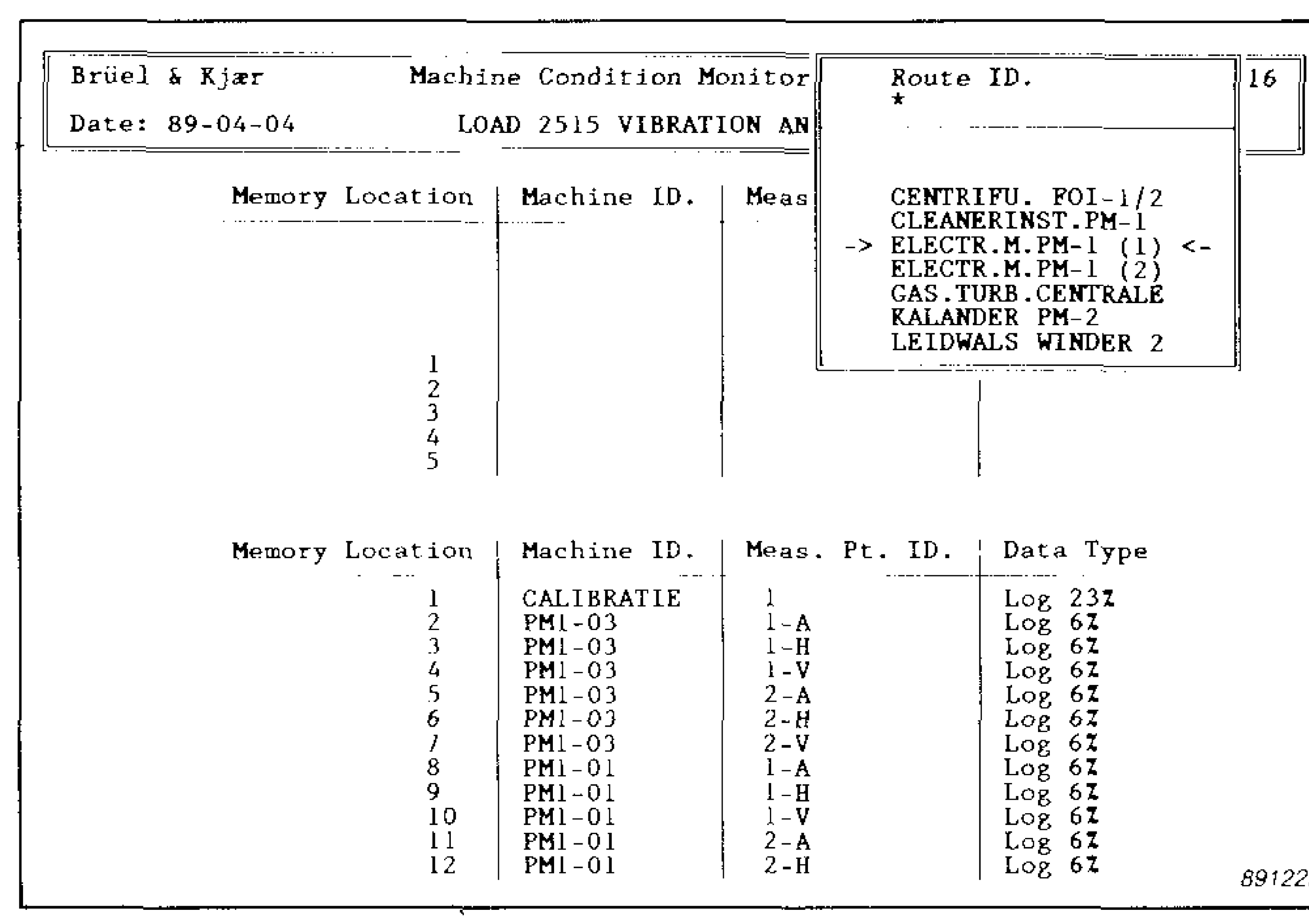

Fig. 11. To simplify the job of routine data collection, measurements can be grouped into convenient measurement routes. When the mechanic selects a route from the window as shown, all the measurement points in the route are automatically included in his routemap

Measurement Routine
Now the mechanic is ready to take the analyzer along the route and measure at the measurement points as indicated on the routemap. To make the measurement routine more simple, he places an overlay over the front panel of the vibration analyzer, see Fig. 13. The overlay hides the un-used push-buttons and displays the measurement procedure, which is as follows:

1. Attach the accelerometer to the mounting plate at the measurement point
2. Recall the reference set-up and spectrum from the memory location specified on the routemap
3. Adjust (a) the input-module settings if requested by the analyzer, and (b) the gain
4. Start the measurement, which will be done exactly like the reference measurement
5. Move the cursor to the reference frequency — this is necessary if the machine speed has changed since the reference spectrum was measured. (See the description of Speed Compensation on page 9.)
6. Quickly compare the new spectrum with the reference spectrum to check for increases
7. Enter comments and values of machine process parameters (if any) on the routemap
8. Store the new spectrum and tick on the routemap to indicate measurement done

During the measurement, the vibration analyzer stands on the ground, or on the mechanic's customised tricycle, and the accelerometer sits on the measurement point disc. The mechanic inspects the machine visually and cleans the next measurement point. (Since the disc has a very smooth surface, cleaning is very easy and quick, even at the wet sections of the paper mill.)

After the correct number of averages, the measurement stops automatically. A quick check of the difference spectrum shows immediately whether the machine has a serious fault.

Brüel & Kjær	Machine Condition Monitoring System		Type 7616
	PARENCO B.V. RENKUM CONTACTPERS:R.HOEDEMAKER tst.432		
Date: 89-04-04	ROUTEMAP		Page: 2

Machine ID.	Proc. Par. / Meas. Pt. ID.	2515 Memory	PP. Value/ Meas. Done	Range: min - max / Data Type and Alarm Status
CALIBRATIE	1	1	____	Log 23%
PM1-03	1-A	2	____	Log 6%
	1-H	3	____	Log 6%
	1-V	4	____	Log 6%
	2-A	5	____	Log 6%
	2-H	6	____	Log 6%
	2-V	7	____	Log 6%
PM1-01	1-A	8	____	Log 6%
	1-H	9	____	Log 6%
	1-V	10	____	Log 6%
	2-A	11	____	Log 6%
	2-H	12	____	Log 6%
	2-V	13	____	Log 6%
PM1-04	1-A	14	____	Log 6%
	1-H	15	____	Log 6%
	1-V	16	____	Log 6%
	2-A	17	____	Log 6%
	2-H	18	____	Log 6%
	2-V	19	____	Log 6%

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Fig. 12. A Routemap. This is printed out automatically when the analyzer is loaded with a job. It tells the mechanic where to measure and it has columns for recording process parameters (not shown here) and for ticking to confirm that the measurement is stored

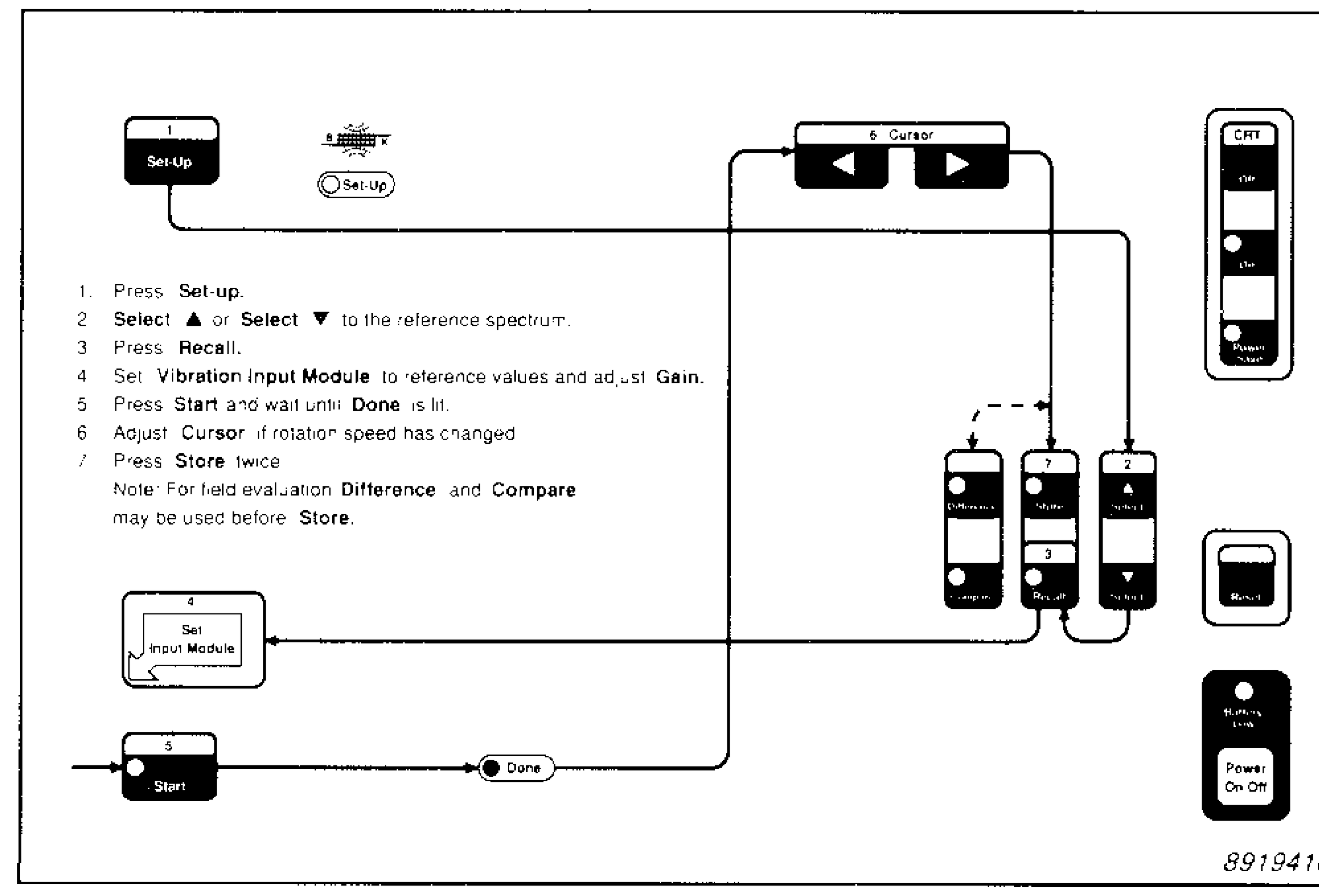

Fig. 13. The overlay which covers the front panel of the vibration analyzer during routine measurements. It hides the un-used pushbuttons and displays clearly the measurement procedure

Unloading the Collected Data

Unloading the Analyzer

The non-volatile memory of the vibration analyzer can store 100 measurements. When the job is complete, the mechanic returns to the computer, connects the IEEE interface, and selects the routine which automatically unloads the new spectra into the database. On request, he manually enters the comments and machine process parameters (listed on the routemap) via the keyboard. The computer sends a spectrum comparison report to the printer (the report can also be viewed on the screen).

Spectrum Comparison Report

The spectrum comparison report (SCR) is shown in Fig. 14. For each point, any significant increases (fault indications) are included in a list of warnings. Apart from this list, the amount of information in the SCR is defined by the user in the system configuration part of the program, see Fig. 15.

The routine SCR will include neither text nor plots for a measurement point unless there is a warning. When there is a warning, it includes the text and plot(s) requested. In this example, the text describes the measurement point and lists the warnings; the plot shows the current spectrum, the tolerance profile, and the diference between these. The difference indicates any significant vibration increases (warnings).

It is good practise to have a second plot which shows the current spectrum and the reference spectrum together. This plot is useful to reassure the user that the spectrum is reproducible.

The summary report simply lists the measurement points which give warnings and alarms, see Fig. 16.

Brüel & Kjær	Machine Condition Monitoring System			Type 7616
	PARENCO B.V. RENKUM CONTACTPERS:R.HOEDEMAKER tst.432			
Date: 89-04-04	SPECTRUM COMPARISON REPORT.			Page: 1
	Machine ID	Measurement Point ID	Date	Version
Current	PM1-05	1-H	88-04-18	24
Reference	PM1-05	1-H	88-03-29	1

LIST OF WARNINGS: (Speed Compensation: 0 %)

Frequency in Current	Frequency in Reference	Increase Above Reference	Increase Above Profile	Absolute Level	Alarm
3.68 kCPM	3.68 kCPM	7.1 dB	1.1 dB	1.588 mm/s	
5.50 kCPM	5.50 kCPM	16.6 dB	10.6 dB	2.176 mm/s	
7.32 kCPM	7.32 kCPM	11.2 dB	5.2 dB	661.5 µm/s	
7.80 kCPM	7.80 kCPM	7.9 dB	1.9 dB	486.2 µm/s	
9.24 kCPM	9.24 kCPM	8.8 dB	2.8 dB	614.3 µm/s	

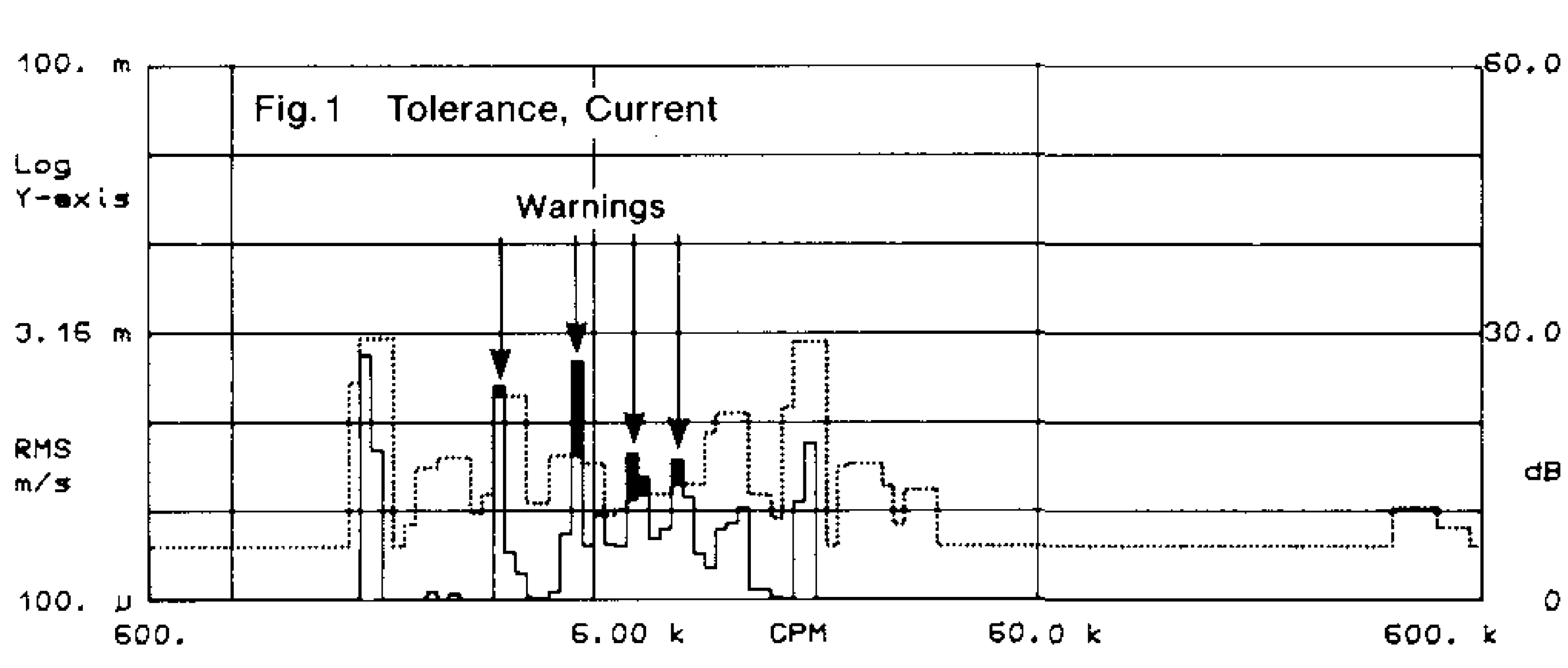

Fig. 14. A routine Spectrum Comparison Report. This is printed out automatically when the analyzer is unloaded after a job. It always gives a warning if there is a significant increase. Other information in the report is decided as shown in Fig. 15

Brüel & Kjær	Machine Condition Monitoring System	Type 7616
Date: 89-04-04	MEASUREMENT POINT REPORT PARAMETERS	User: 7616

Machine ID. : PM1-05
Measurement Point ID.: 1-H

Print Texts		Print / Plot Curves		
Description Fields	No	Reference Spectrum	No	
Process Parameters	No	Current Spectrum	If Warning	Fig 1
Total Level	No	Cur. - Ref. Mask	No	
Comments	No	Cur. - Tol. Profile	No	
Units of Increase	dB	Reference Mask	No	
		Tolerance Profile	If Warning	Fig 1
		Supplementary Measm	No	

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Fig. 15. This screen is used to design a routine Spectrum Comparison Report for a single measurement point. It is normally set when the measurement point is created, but it can be reset any time. In this case, the information is requested only when there is a warning

Brüel & Kjær	Machine Condition Monitoring System	Type 7616
	PARENCO B.V. RENKUM CONTACTPERS:R.HOEDEMAKER tst.432	
Date: 89-04-05	SPECTRUM COMPARISON REPORT.	Page: 1

Summary Report:

Machine ID.	Meas.Pt.ID./ Proc.Par.	Alarm/ Warning	Status	2515 Mem.
PM1-05	1-H	Alarm		1

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Fig. 16. The summary report, which simply lists the measurement points giving warnings or alarms

Trend Analysis

When the routine data collection reveals a fault, the analysts examine the troublesome measurement point in the analysis section of the program. As an example, consider the measurement point at the non-drive end of the motor shown in Fig. 22. The spectrum comparison report indicated a fault at this point, which was diagnosed as a bearing fault using the vibration analyzer. This type of fault can be trended in order to predict a suitable maintenance date. The procedure is explained below.

The 3D plot in Fig 17 shows how the increases above the tolerance profile develop with time, and Fig. 18 shows a trend of the overall level of these increases. This trend gives a lead time of 81 days to the trend limit.

A better lead time estimation is found by isolating and trending only the increases which are directly related to the fault. This is done by moving the cursor around the 3D plot to find the frequency range where the components are growing steadily with time, i.e. the frequency range where the developing fault is most obvious, see Fig. 19. A trend of this critical section, as shown in Fig. 20, produces a more correct (shorter) lead time of 21 days to the trend limit.

Different sections of the 3D plot should be trended to get the shortest possible lead time. And finally, there are two curve fit functions, linear and exponential. Either one can be selected; the best one is the one with the highest correlation coefficient. The value is between 0 and 1, and it is displayed at the top, right hand corner of the screen. The values in Fig. 20 and Fig. 21 (0,854 for linear and 0,812 for exponential) indicate that the linear option is the best in this case.

After Trending, What Action?

This is where big decisions based on the following considerations must be made. How close is the vibration level to the alarm limit? How important is the machine to the process? What is the cost of an unexpected breakdown? When is the next scheduled shutdown? Is the damaged part so expensive to replace that it should be run until breakdown?

In this case, the fault in a motor at the drier section of the paper machine was a bearing fault, developing gradually. The motor is a critical machine; if it breaks down, the paper machine must be shut down. Consequently, the analysts' aim was to schedule the repair work (bearing replacement) to take place during a systematic shutdown, before the vibration reached the trend limit. In the meantime, he continued to monitor the fault: he reduced the measurement interval to get more closely-spaced data points in the trend, and to get updated, more accurate estimates of the lead time. As planned, they did manage to run the machine until the next systematic shutdown.

After replacing the bearing, they measured a new spectrum and compared it with the original reference spectrum. The increases had disappeared, which confirmed that their action was correct.

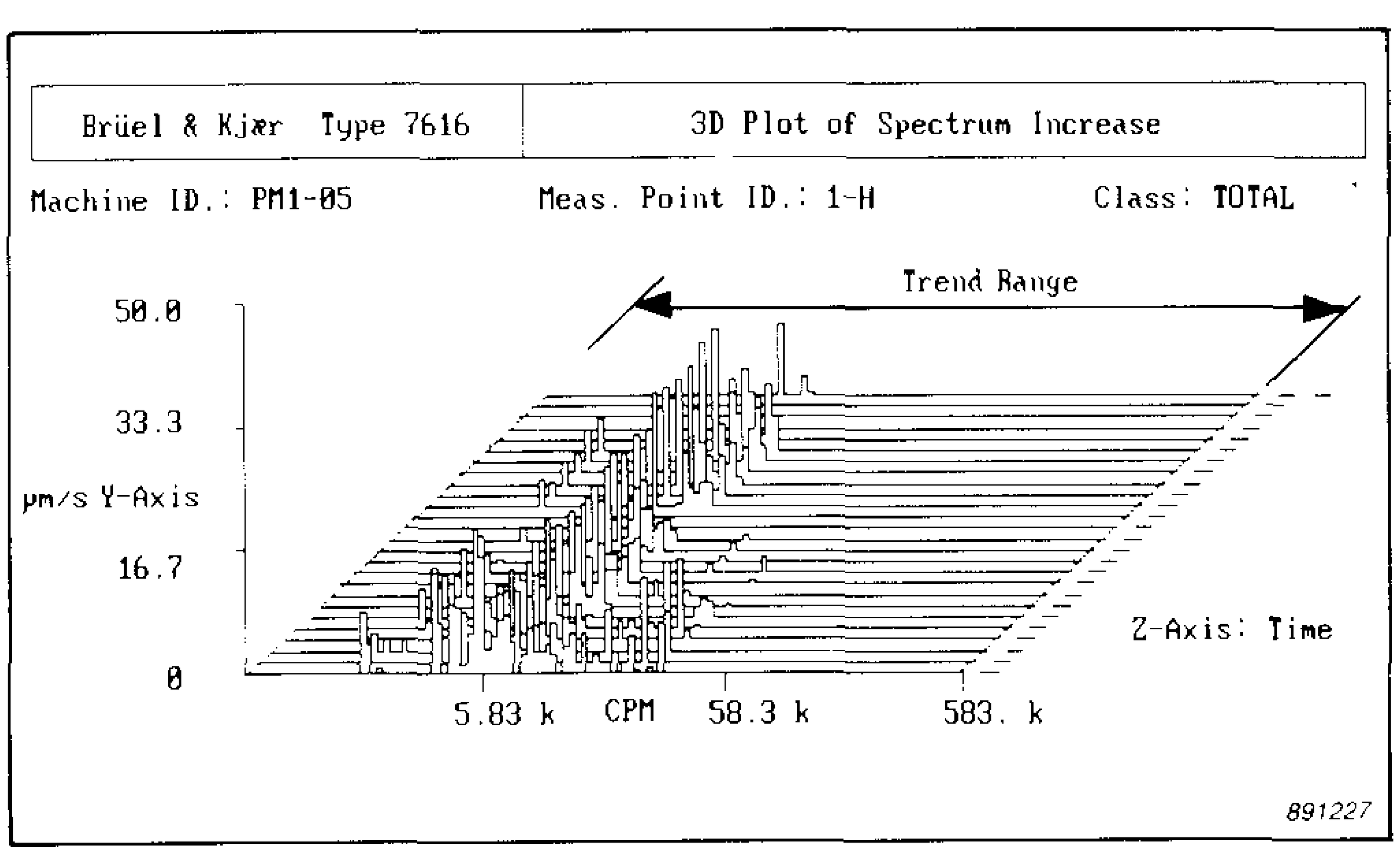

Fig. 17. A 3D Plot showing how the fault is developing with time. The peaks in the plot are increases of the current spectra above the tolerance profile

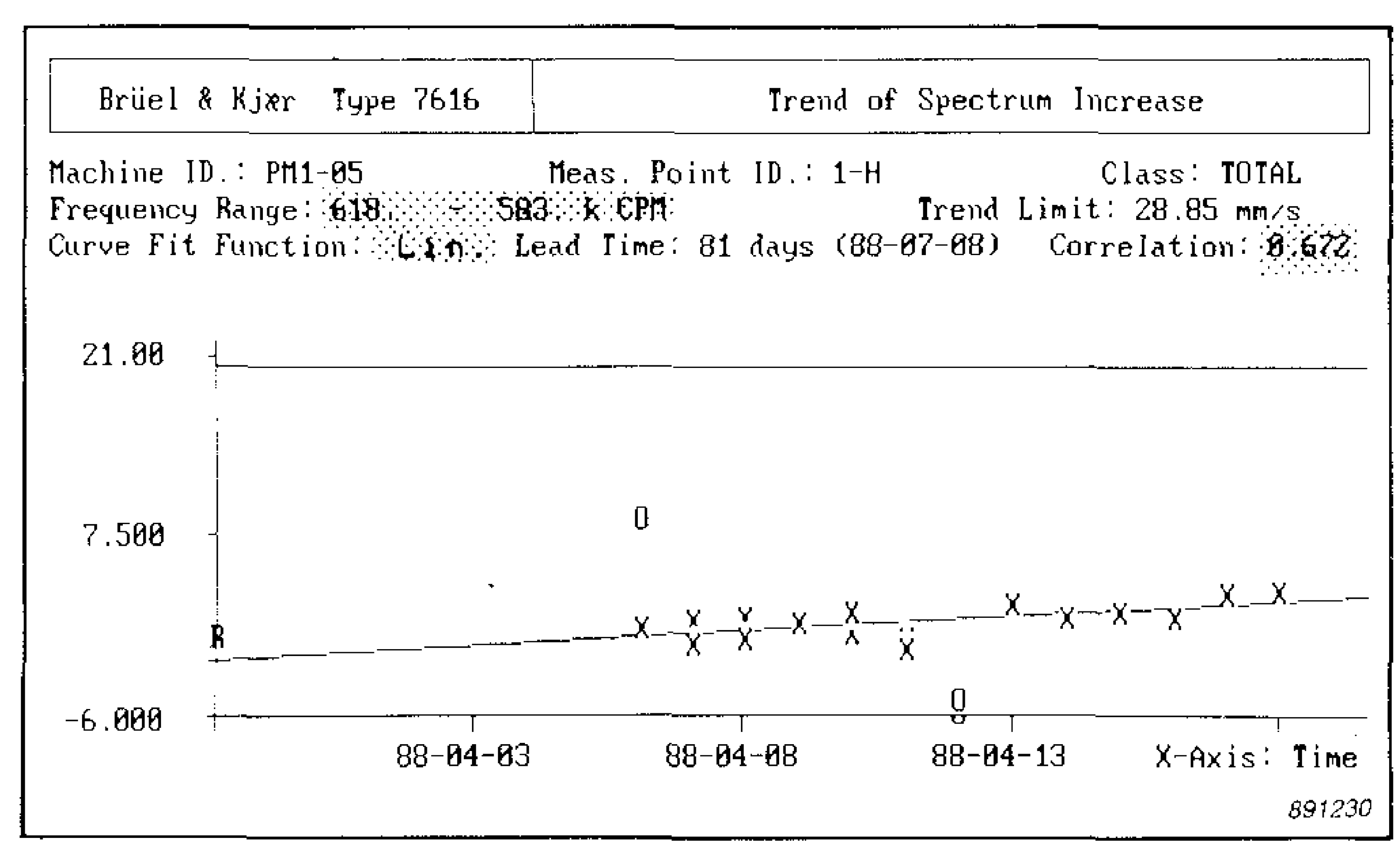

Fig. 18. A trend of the overall vibration level. The o points are measurements which have been temporarily excluded from the trend. Note the lead time of 81 days and the corelation coefficient of 0,672

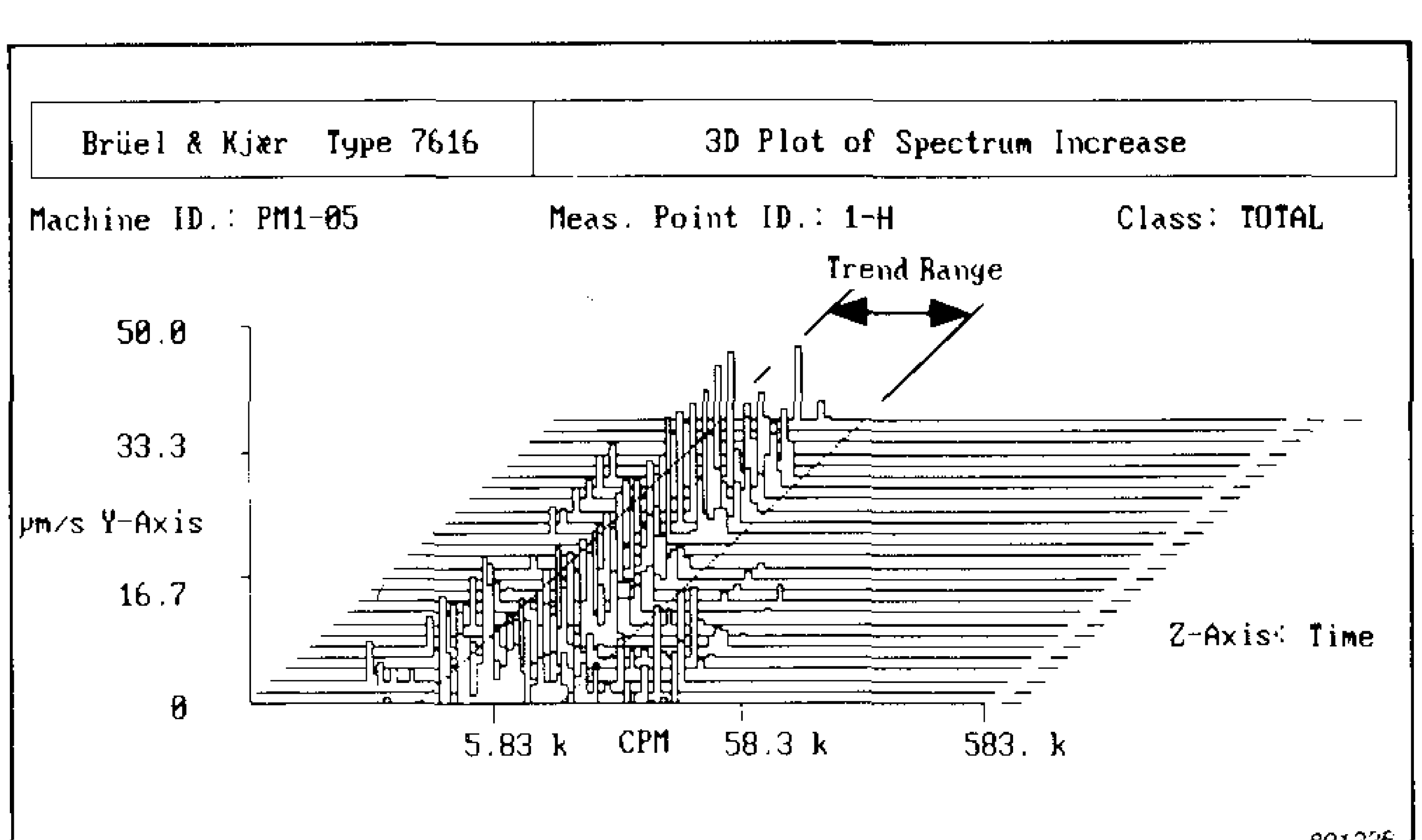

Fig. 19. Trend Range Markers marking the critical section of the plot. They can mark any section of the plot

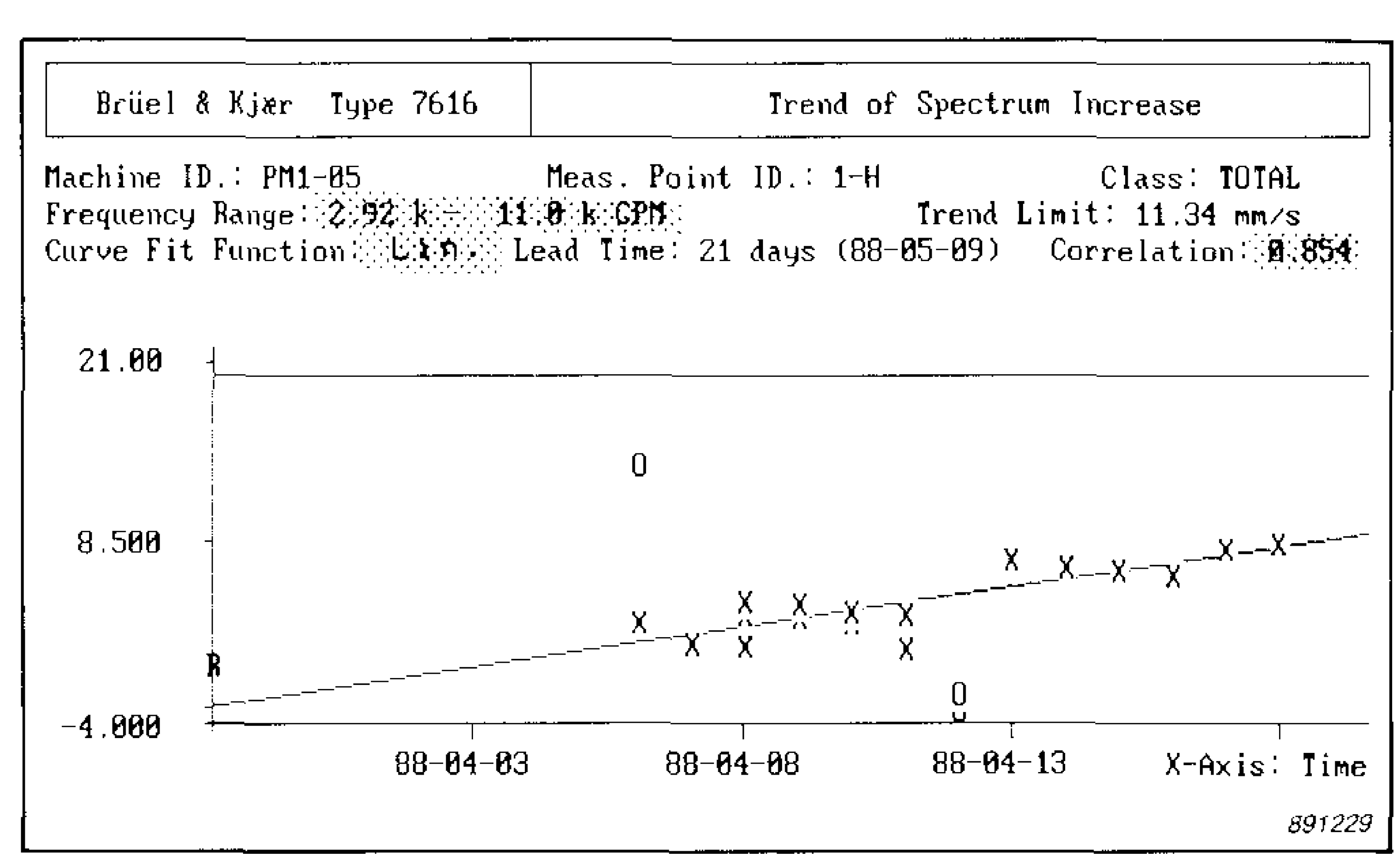

Fig. 20. A trend of the critical section of Fig. 19. Note that the lead time has been reduced from 81 days to 21 days. Note also the correlation coefficient of 0,854

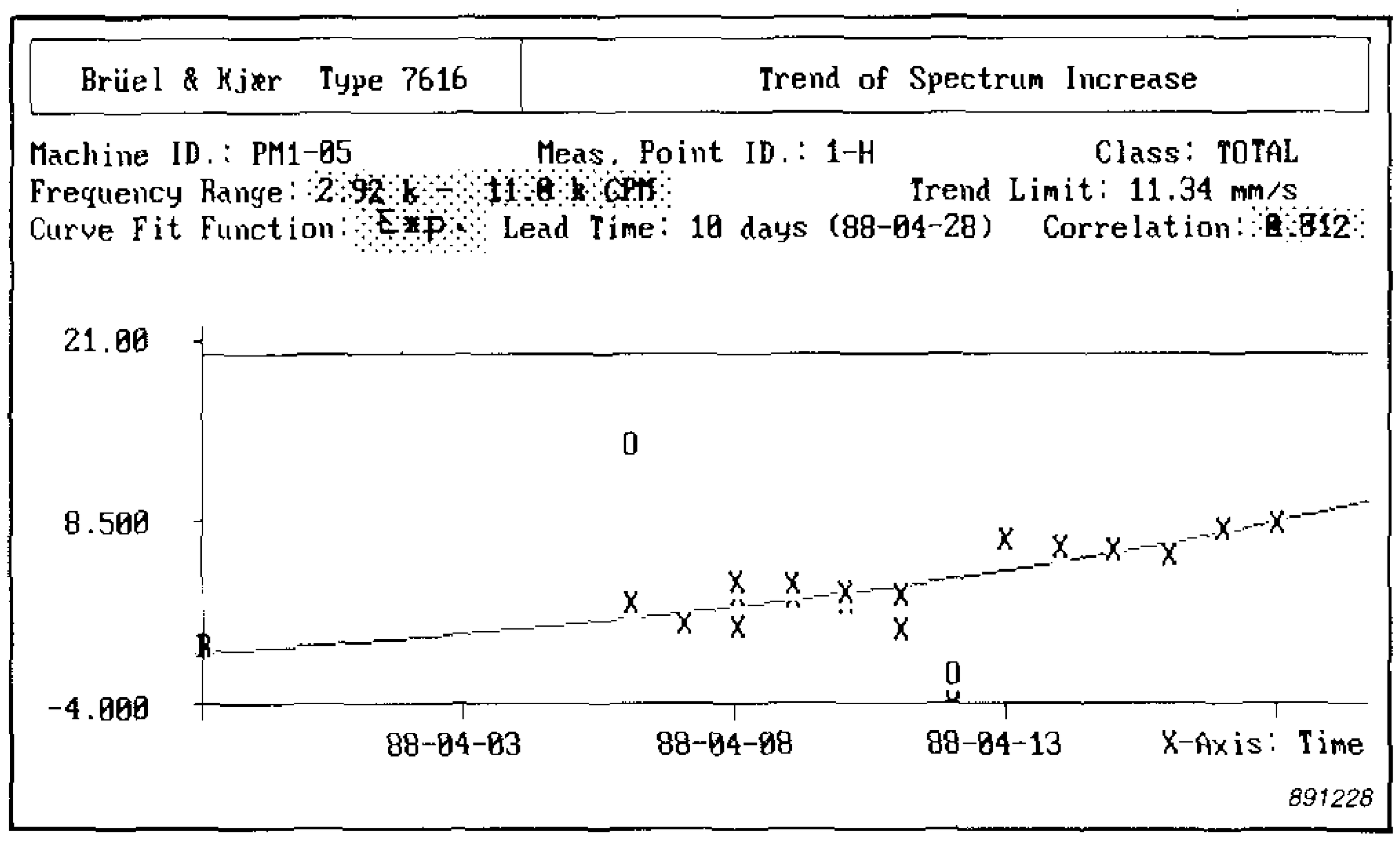

Fig. 21. An exponential curve fit function on the same data as Fig. 20. The correlation coefficient of 0,812 indicates that the linear fit is best in this case

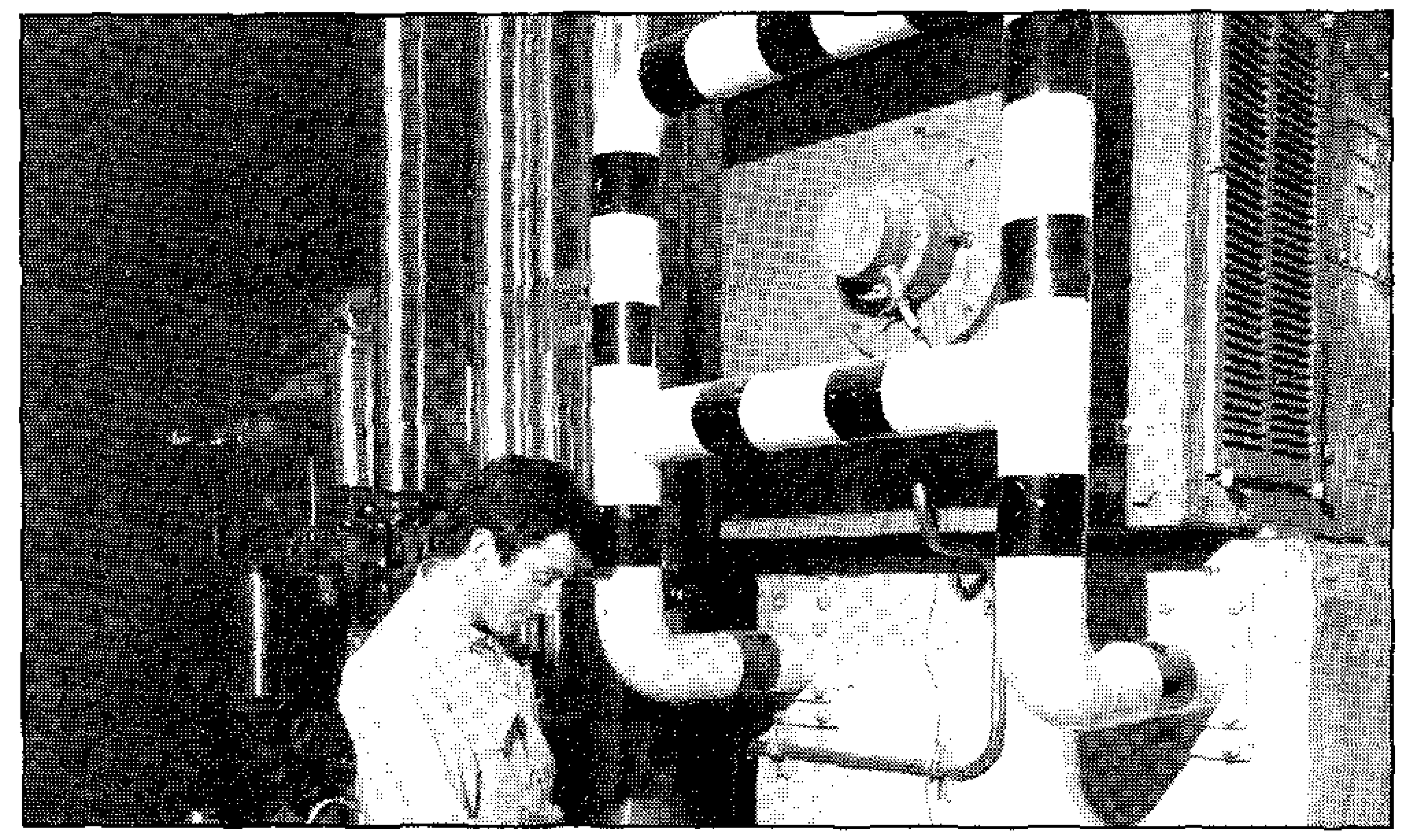

Fig. 22. The motor in the drier section of PM1 where the fault was found. If the motor failed without warning, the complete paper machine would have to be shut down

Case Study of a Roller-Bearing Fault

Detection and Diagnosis

This is another example of a predicted roller-bearing failure at a paper-machine motor, PM1-20. When a spectrum comparison indicated warnings for the measurement points at both ends of the motor, the analysts reduced the measurement interval in order to monitor the fault closely—the measurement point locations are shown in Fig. 23. The 3-D Plot in Fig. 24 shows the increases above the tolerance profile of the subsequent measurements at measurement point 1-H.

The frequencies of the increasing components are 61,3 Hz, 86,6 Hz and 173,2 Hz. As these are not harmonics of shaft speed, the problem is neither unbalance nor misalignment. The next most likely fault is bearing damage, which would cause increases at the characteristic ball-passing frequencies.

The roller bearings in the motor are SKF 6326 at the non-driving end and SKF 6330 at the driving end. By entering the input rotation speed (13,66 Hz) and the bearing type (SKF 6326) as data in a typical bearing program, Parenco got a printout of the characteristic ball-passing frequencies, i.e. fundamental train frequency (FTF), ball spinning frequency (BSF), ball-passing frequency, inner (BPFI), bal-passing frequency, outer (BPFO), and their harmonics. See Fig. 25. A quick examination of the data revealed that the second harmonics of the BSF and the BPFO were 60 Hz and 86 Hz respectively i.e. they corresponded to the increasing components in the spectrum.

Trending the Critical Component

The most rapidly-developing increase was at 2×BPFO. The trend of this component in Fig. 26 shows that the increase will reach 20 dB within three days. Parenco reacted quickly and replaced the bearing soon afterwards. (As predicted, there was clear evidence of damage to the outer race.)

Characteristic Ball-passing Frequency Components

Normally the signal from a bearing fault is so weak that the characteristic ball-passing frequencies cannot be identified in the vibration spectrum. (This is an application for envelope analysis.) However, for the big motors which drive big paper-machine rollers, the signal from the bearing fault is strong because (1) the accelerometer is located on the bearing housing, close to the bearing, and (2) the big rollers exert large forces on the motor shaft and roller bearings. This explains the prominence of the characteristic ball-passing frequency components in this case.

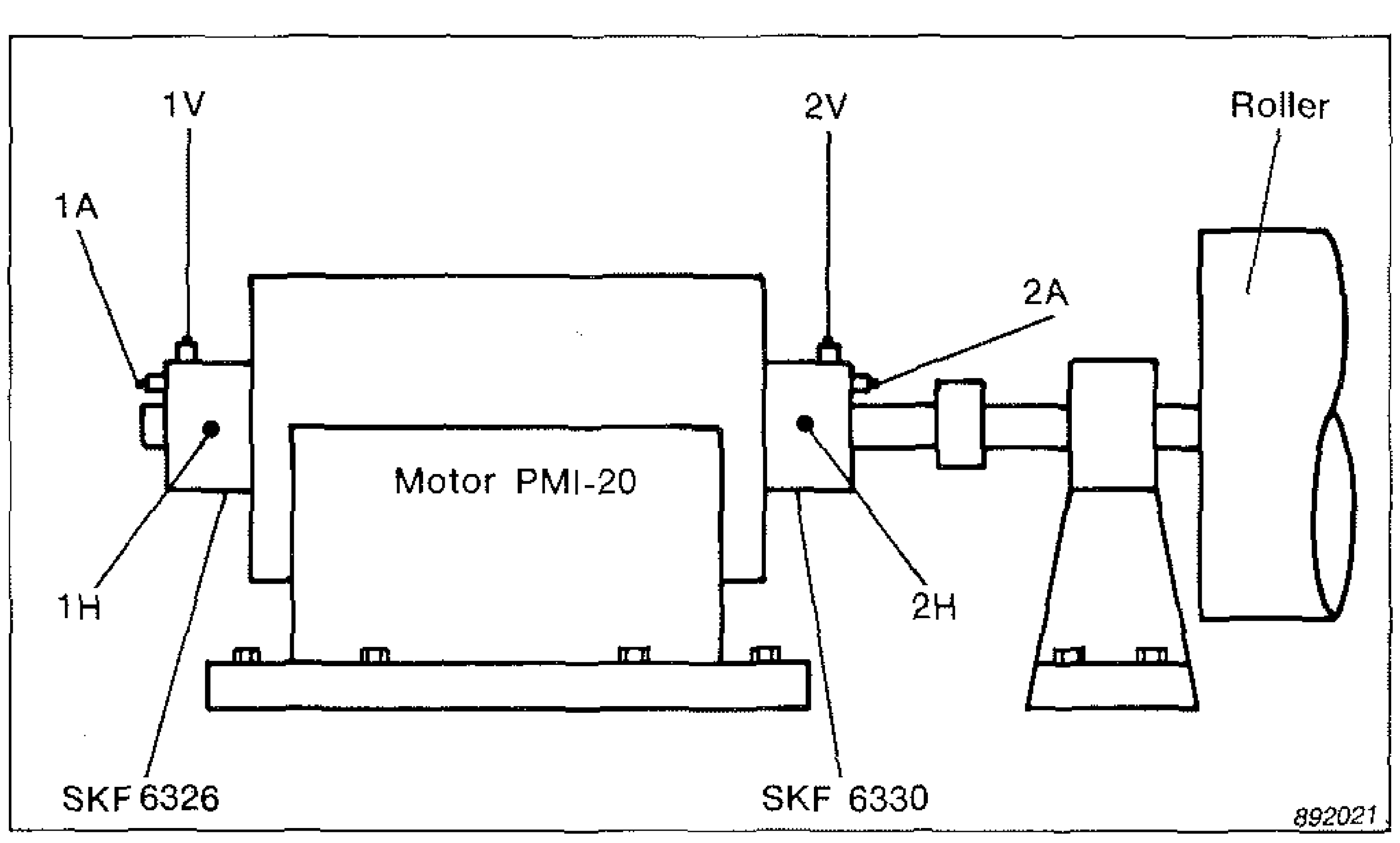

Fig. 23. The identifications and locations of the measurement points and roller bearings on motor PM1-20

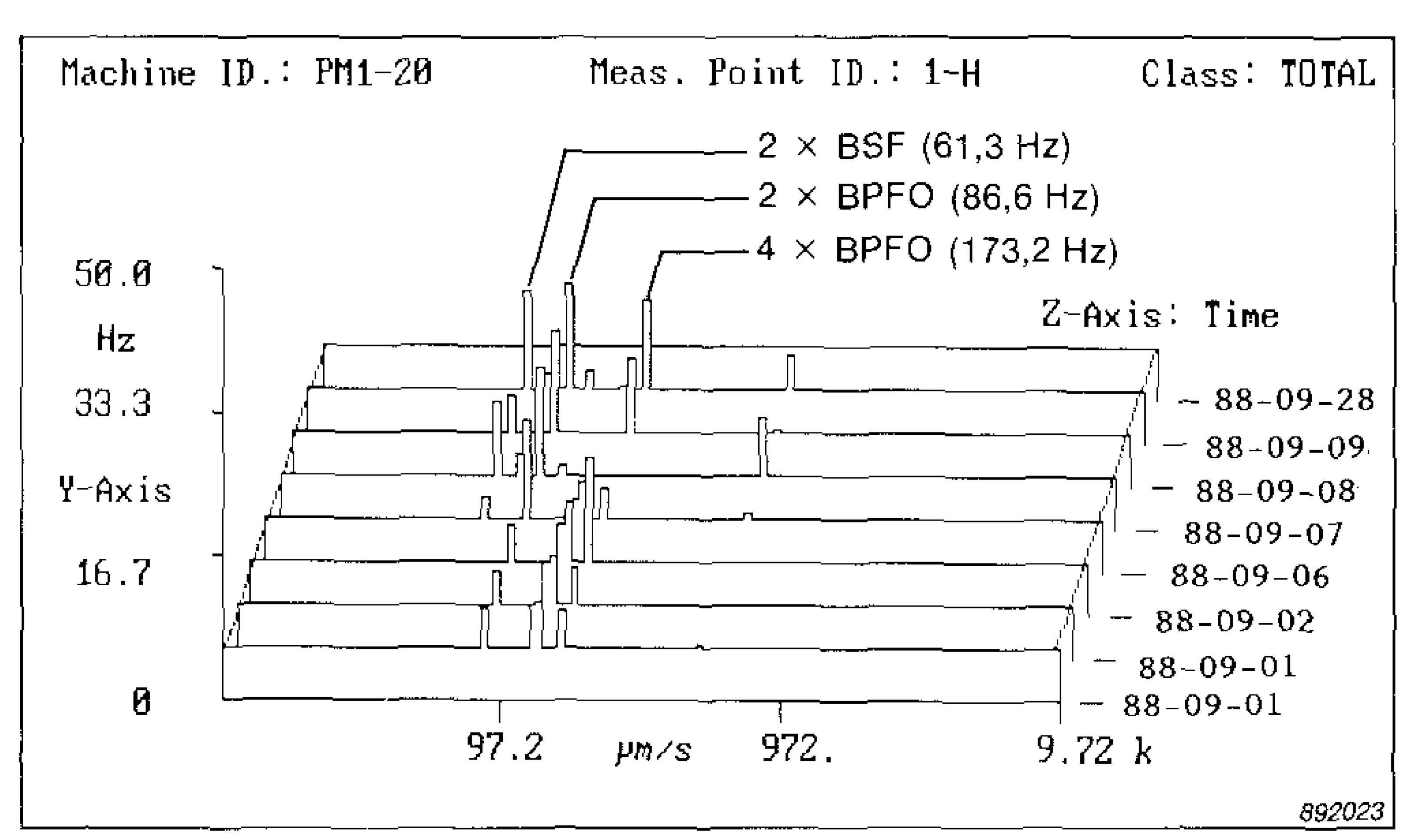

Fig. 24. A 3-D Plot of the increases above the tolerance profile for measurement point 1-H. The increasing components are not harmonics of the rotation speed. They could be characteristic ball-passing frequencies

Frequencies displayed in Hz Bearing: SKF 6326			Speed: 819 in RPM	
R/S	FTF	RSF	BPFO	BPFI
1x 14	5	30	43	66
2x 27	11	60	86	133
3x 41	16	90	128	199
4x 55	21	120	171	266
5x 68	27	150	214	332
6x 82	32	180	257	399
7x 96	37	210	299	465
8x 109	43	240	342	532
9x 123	48	270	385	598
10x 136	53	300	428	664

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Fig. 25. A list of the characteristic ball-passing frequencies for roller-bearing SKF 6326 with shaft rotation-speed 819 RPM. The 60 Hz BSF and 86 Hz BPFO correspond to the increasing 61,3 Hz and 86,6 Hz spectrum components

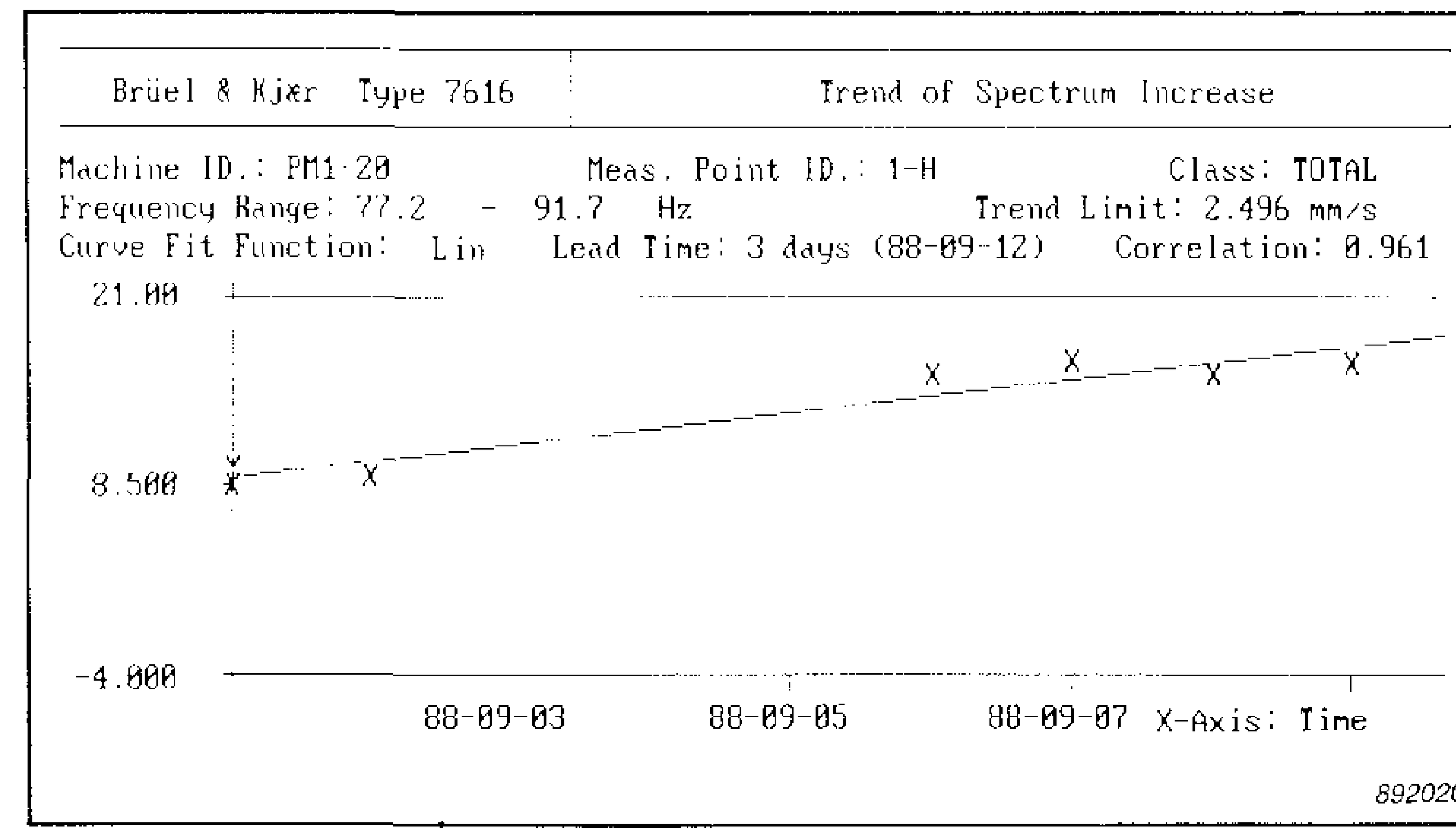

Fig. 26. A trend of the 2×BPFO (86,6 Hz) component. This is the most rapidly-developing component from the 3-D plot. The fault has developed very rapidly since the first warning and the lead time is only 3 days

Special Features to Prevent False Alarms

Speed Compensation

Spectra measured at different machine running-speeds cannot be compared because corresponding components do not line up. However, the Type 7616 system allows them to be compared because it incorporates speed compensation. When the mechanic measures a reference spectrum at a machine which has a variable running speed, e.g. the wet-section roller in Fig. 27, he moves the cursor of the vibration analyzer to one speed-related component (the reference frequency) in the spectrum; during all subsequent measurements at this machine, he moves the cursor to this speed-related component. As a result, when the spectra are compared with the reference spectrum (or with the profiles), all corresponding speed-related components line up as illustrated by Fig. 28.

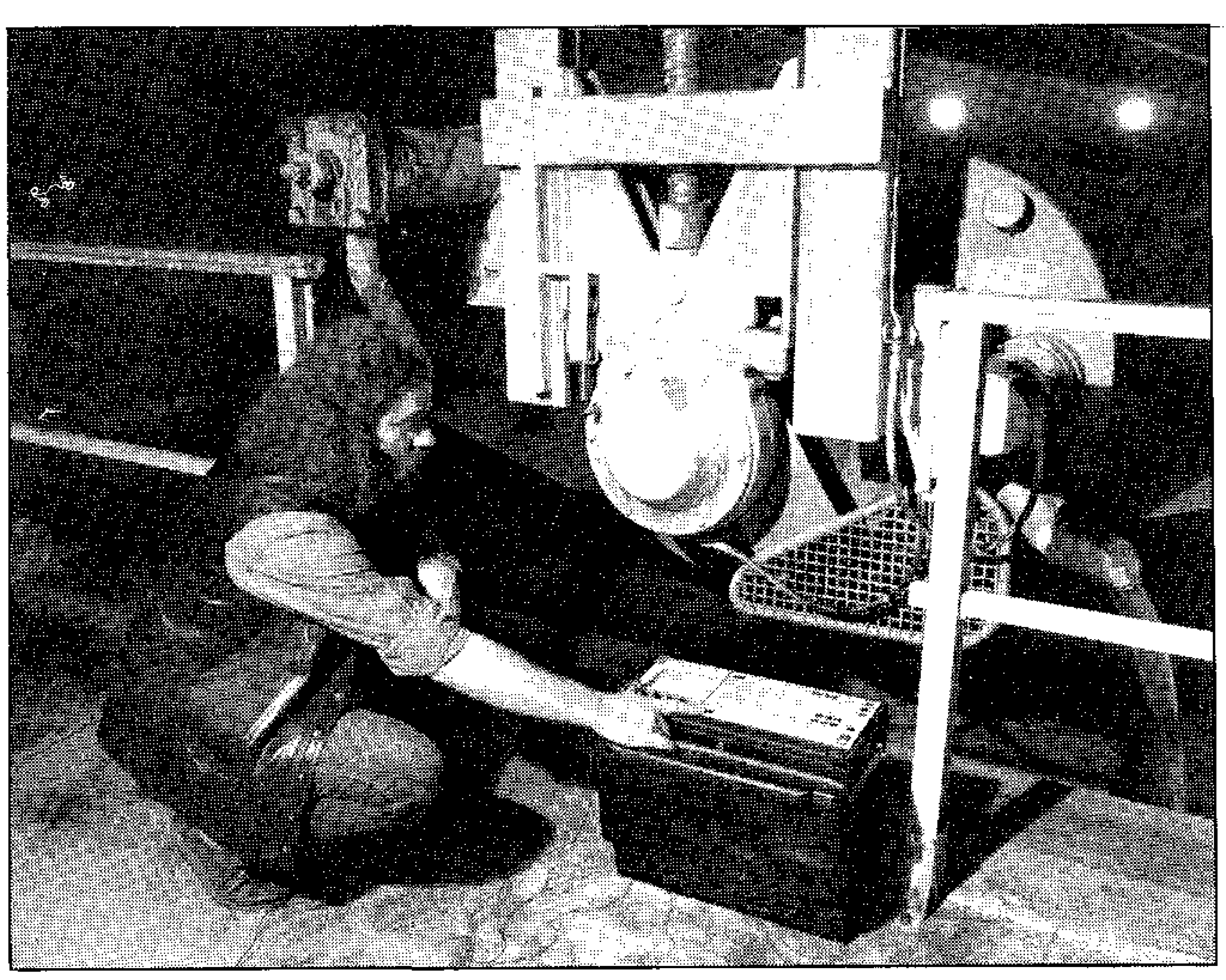

Fig. 27. A motor in the wet section of PM1. What if its speed changes between measurements? Use speed compensation!

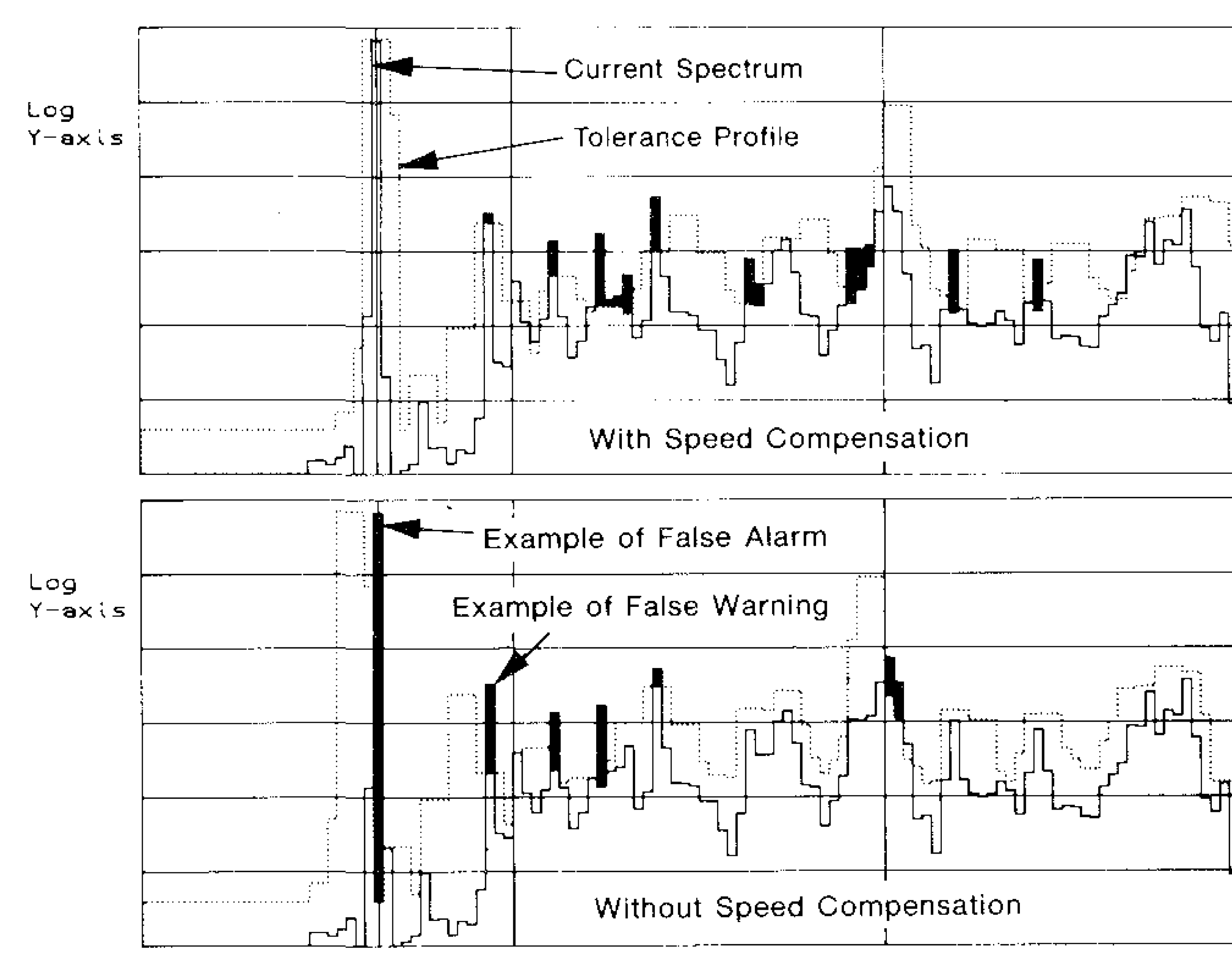

Fig. 28. Speed compensation is used for machines with varying running speed. The plots show a current spectrum and its corresponding tolerance profile. In the upper plot, with speed compensation, there are no false warnings. In the lower plot, without speed compensation, there are some large false warnings.

Measurement Classes

When a machine has changing process parameters, these can cause vibration increases which can give the false impression of a developing fault. For example, the grade (weight) of the paper being produced on a paper machine affects the vibration spectrum. In the Type 7616 program, the measurements can be grouped in process classes, according to the values of the process parameters, in order to prevent false alarms. See Fig. 29. During each measurement, the mechanic records the values of the process parameters on the routemap, see Fig. 30. Later, when he unloads the measurements, they will be grouped automatically according to the recorded values. The program will only compare measurements which are in the same class, thus eliminating the chance of false warnings.

Brüel & Kjær Machine Condition Monitoring System Type 7616

Date: 89-04-04 CREATE/UPDATE MEASUREMENT CLASSES User: 7616

Machine ID.: 07-21-000 Measurement Point ID.: 1-A

Class No	Name	OIL TEMP. °C Min	-	Max	Min	-	Max	No of Meas.	Date of Ref.
1	OIL-LOW	50.00	-	70.00		-		1	
2	OIL-HIGH	70.00	-	90.00		-		0	
3			-			-			
4			-			-			
5			-			-			
6			-			-			
7			-			-			
8			-			-			
9			-			-			

891232

Fig. 29. Creating measurement classes according to the values of machine process parameters. There can be several process parameters and a class is defined using either one or two of them. In this case there are two classes, one for low oil temperature (50° - 70°C) and one for high oil temperature (70° - 90°C)

Machine ID.	Proc. Par. / Meas. Pt. ID.	2515 Memory	PP. Value/ Meas. Done	Range: min - max / Data Type and Alarm Status
07-21-000	OIL TEMP.		60°C	50.00 - 90.00 °C
	1-A	1	✓	Log 6%
	1-H	2	✓	Log 6%
	1-V	3	✓	Log 6%
	2-A	4	✓	Log 6%
	2-H	5	✓	Log 6%
	2-V	6	✓	Log 6%
	3-A	7	✓	Log 6%
	3-H	8	✓	Log 6%
	3-V	9		Log 6%
	4-A	10		Log 6%
	4-H	11		Log 6%
	4-V	12		Log 6%
	5-A	13		Log 6%
	5-H	14		Log 6%
	5-V	15		Log 6%

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Fig. 30. A routemap with recorded process parameter values. As the mechanic unloads his measurements, the program asks for the values. After these are entered, the measurements are automatically assigned to their appropriate classes. In this case the recorded temperature is 60°C, so the measurements will be placed in the oil-low class

Conclusions

Using this systematic machine condition monitoring system, three men monitor 6000 measurement points successfully. Basically, the system works as follows.

Each measurement point in the database has an ID, a reference spectrum, and associated process parameters. The routine work is data collection with the portable vibration analyzer. As part of the routine, the program compares the new vibration spectra with their references (in the corresponding process classes) and gives warnings of significant increases. A warning prompts the user to diagnose the fault at the measurement point using the special diagnostic features of the vibration analyzer; if it is a developing fault (eg. a bearing fault) the user trends the data and the program predicts a lead time to breakdown.

Two noteworthy features of the system are the use of CPB spectra and process parameters. With CPB spectra there is optimum use of spectrum data for detection of a very wide range of faults. The process parameters are used to prevent harmless vibration increases associated with a machine process from causing false alarms.

As the bearing examples showed, *early warning, early trend,* and *early lead-time prediction* are features which give the user confidence in the system. These enabled Parenco to confidently delay the repair work until a scheduled shutdown, instead of fearing an unexpected shutdown of the complete paper machine. As a result of their confidence in the system Parenco recently increased the vibration team from two to three members and purchased a second portable vibration analyzer.

Acknowledgement

The author would like to thank the Parenco vibration staff and Brüel and Kjær engineer Mr. Henk Smith for their co-operation in preparing this application note.

Brüel & Kjær

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