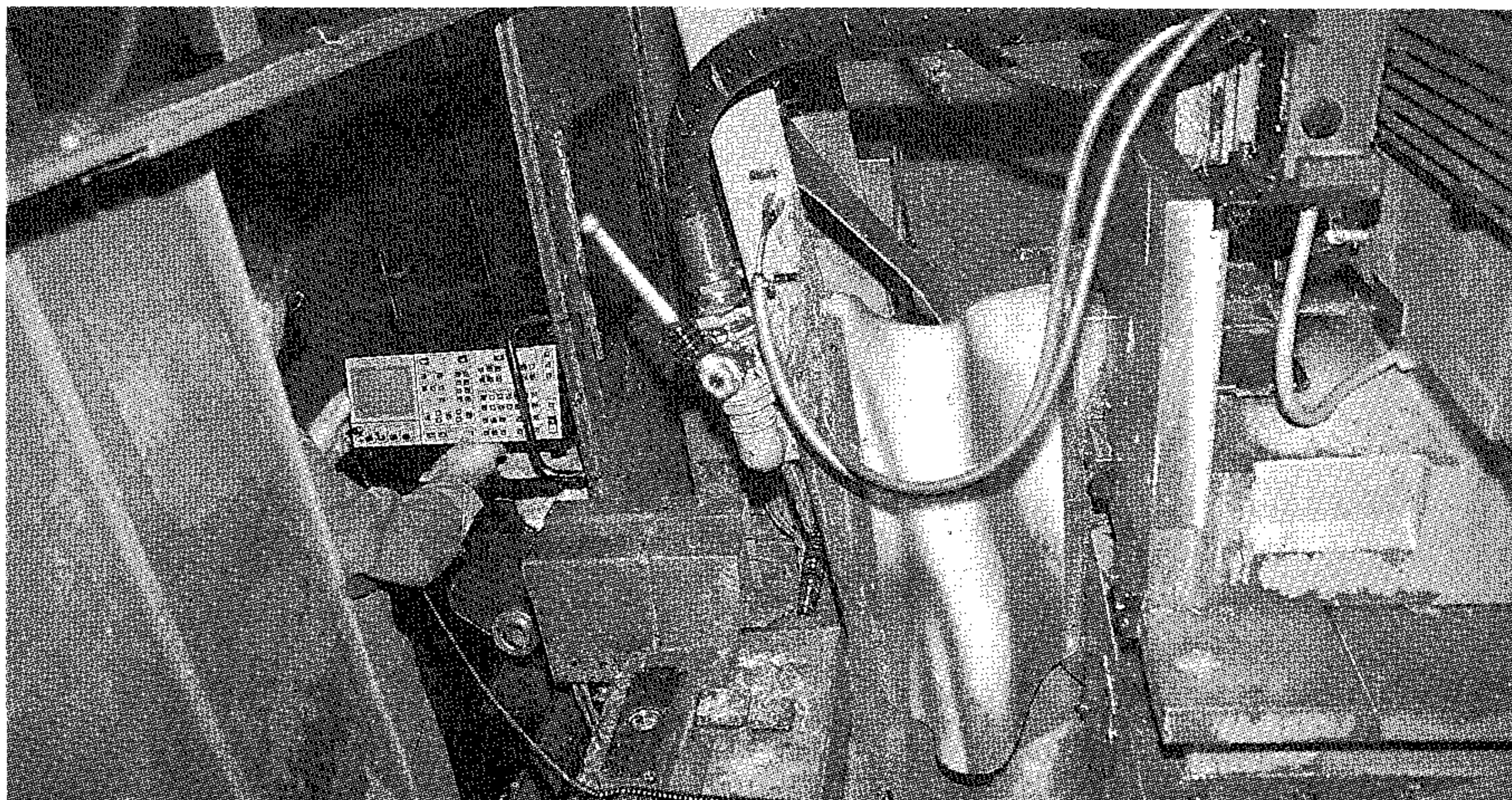


# Application Notes

## Condition Based Maintenance and Quality Assurance of Production Machinery

Production output and quality assurance are the key elements in any production facility. Techniques that help to maintain a high production throughput and provide a tool for both maintaining and monitoring finished quality are therefore of paramount importance.

This Application Note details the role that vibration monitoring plays at the Ford Motor CO's Düren plant, Germany. Considerable savings in maintenance costs and a high-level of output quality have been achieved.



Machine vibration levels reflect machine condition. Regular vibration measurements on production machinery can therefore be used for both quality assurance of the machined product, and maintenance checks on the machine itself. In this cover photograph the condition of a circular grinding machine is analyzed with the Brüel & Kjær Type 2515 Vibration Analyzer

### The Role of Machine Condition Monitoring in Production-line Facilities

The concept "Machine Condition Monitoring" involves measuring and monitoring some defined parameter that reflects the condition of a machine. Machine condition monitoring has, therefore, a vital role to play in any plant with today's demands for quality production and low downtime. In this Application Note we describe how condition monitoring can be used for both condition-based-maintenance and quality assurance in the batch production industry.

The use of *condition based maintenance* for the early detection of faults and consequent prevention of breakdowns has been well documented. The use now of condition monitoring for *quality assurance* is the next logical step, and is demanding increasing attention as production units compete for ever better product quality.

In the batch production industry, condition monitoring lends itself well to 24-hour operation, just-in-time maintenance and the ever increasing

automation. It can be used for a wide range of production line operations and unmanned machining processes.

This Application Note shows how the Ford Motor Co has successfully piloted such a monitoring programme with considerable success, and how they have been able to pin-point problem areas *well before* the product quality was reduced.

### What Benefits can be Achieved?

The condition monitoring of production machinery has widespread usage.

For **maintenance**, an early indication of machinery damage is obtained, thus enabling repair to be planned well ahead of time. A reduction in maintenance labour costs and spare parts results, and consequently a reduction in spare parts stocks. Reduced secondary damage and increased oper-

ator safety are also achieved.

For **production**, a reduction in machine downtime, assured productivity, improved machine throughput, and reduced levels of scrap can all be achieved.

For **quality assurance**, problem areas can be identified before the quality suffers. An early indication of deterioration in quality and identification

of the cause provide increased quality reliability. The machine condition measurements can then be used as a parameter for the appraisal of finish quality.

For **machinery planning**, condition monitoring can be used as a tool for use when commissioning machinery and for machine acceptance criteria.

## Using Vibration to Indicate Machine Condition

Experience has shown that most rotating equipment faults show up as changes in the vibration signatures of the machine long before ultimate breakdown. Vibration is thus a primary indicator of machine condition, as shown in Fig.1. Secondary indicators are bearing temperature, lubricant pressures and foreign particles in lubricants, but none of these can detect such a wide range of potential faults, and at such an early stage, as vibration measurements.

For the earliest detection of faults it is necessary, however, to use more than just the overall level of vibration. The vibration *frequency spectrum* must be used. Faults will show up as increases in specific frequency compo-

| Parameter                      | Temperature | Pressure | Flow | Oil analysis | Vibration |
|--------------------------------|-------------|----------|------|--------------|-----------|
| Machine Fault                  |             |          |      |              |           |
| Out of Balance                 |             |          |      |              | x         |
| Misalignment/Bent Shaft        | x           |          |      |              | x         |
| Damaged Rolling Elem. Bearings | x           |          |      | x            | x         |
| Damaged Journal Bearings       | x           | x        | x    | x            | x         |
| Damaged or worn Gears          |             |          |      | x            | x         |
| Mechanical Looseness           |             |          |      |              | x         |

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Fig. 1. The use of vibration as an indicator of machine condition covers the widest possible range of machine faults

nents in the spectrum. This not only leads to the fault being detected earlier but the increases also indicate what

the cause of the fault is, and the extent of the fault can be followed using trend analysis.

## Monitoring at Ford

Ford are recognised as being a leader in the application of Condition Monitoring in the batch manufacturing industry. Condition Monitoring has been successfully introduced into Ford at a number of locations.

At the Düren plant featured in this Application Note, a pilot programme was run for a year on a range of equipment. 12 machines were chosen to be monitored, all were critical to production – amongst others CNC Automatic Lathes, Multi-stage and Index Machines. At the Düren plant, Condition Monitoring is primarily seen as a means of improving quality, with in-

creased uptime and reduced maintenance costs as a secondary benefit.

The monitoring programme concentrates on monitoring machine condition, and not the condition of the machine tool. To realise this, the vibration measurements are always made with the monitored machine in the idling state, i.e. turning at operating speed but not machining. This gives two advantages; firstly it means that the technicians have enough time to make the vibration measurements, and they can be made without worry about the machining process; and secondly it means that the condition of

the machining tool does not effect the measured results.

Normally it is advised that vibration measurements are made under operating conditions as true to the “normal conditions” as possible. In this case, however, it is possible to measure in the idling state as the load applied by the machine tool does not effect the load on the machine — the energy used to run the machine is far greater than the energy used for the machining process. Test have shown that the vibration spectrum only varies slightly when changing from the machining to the idling state.

## Financial Results from the Monitoring Programme at Ford

The financial benefits of condition monitoring can be considerable. At the Düren plant, estimated savings from just one year of operation ran into the

hundreds of thousands of DEM (german marks).

On a pilot project at Ford England, a payback on initial equipment invest-

ment of just one year was experienced. After two years the savings had reached an outstanding 12 times the initial investment.

## Examples from the Monitoring Programme

### Index Machine Bearing Fault

This first example is from an Index Machine, and shows how the monitoring system was able to detect a rolling-element bearing fault.

First signs of the fault were seen as vibration increases in the high frequencies (2 kHz to 20 kHz range). The fault developed very quickly, as shown by the trend curve in Fig.2. At this point an estimated lead time until the critical limit was calculated as 5 days. The machine was allowed to continue

running and in fact broke down after 4 days.

There are always some uncertainties when calculating trend lead times, as it is often difficult to predict how a machine will behave when close to a failure. The measurement points in the trend curve in Fig.2 showed quite a spread (the correlation was only 0.89 — the closer to 1, the better the lead time prediction) giving some uncertainty in the trend calculation.

### Multi-Spindle Head Coupling Design Fault

In this example, the monitoring system was used to detect a faulty machine design, and the measurements used as evidence in supporting a compensation claim from the manufacturer.

When replacing a multi-spindle head coupling with a new design, a drop in machining quality was experienced. Vibration measurements were then made which showed a marked

increase in the vibration level. Suspecting the coupling to be the cause of the problem, the old one was replaced into the machine. The vibration dropped back to its original level, as shown in Fig.3.

This particular example saved an estimated 140000DEM, as a record of the vibration increase was sent to the coupling manufacturer as proof of where the cause of the problem lay. The manufacturer assumed responsi-

bility and paid for the necessary maintenance.

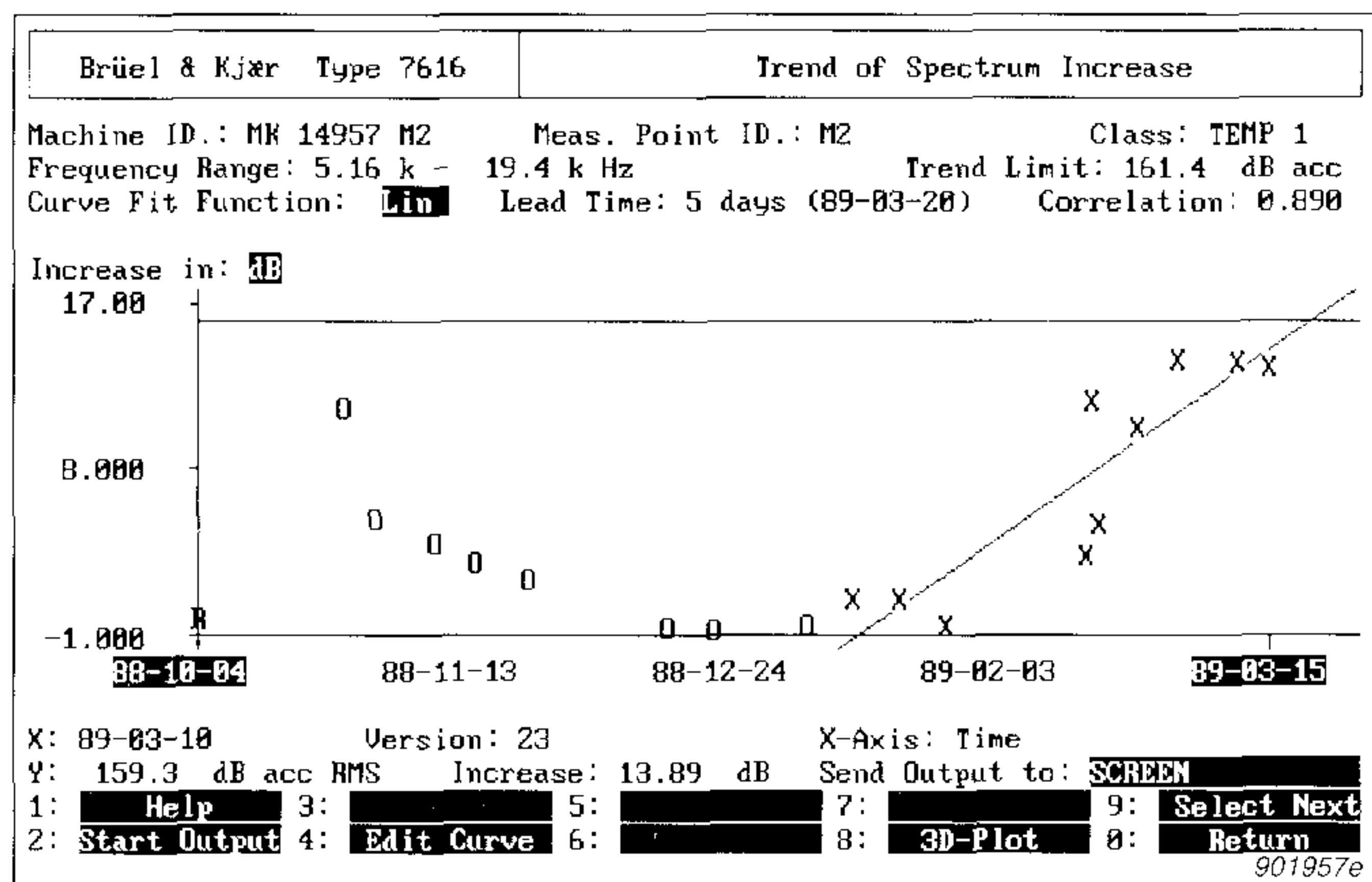


Fig. 2. The trend curve from the Index Machine showed a bearing fault to be developing very quickly

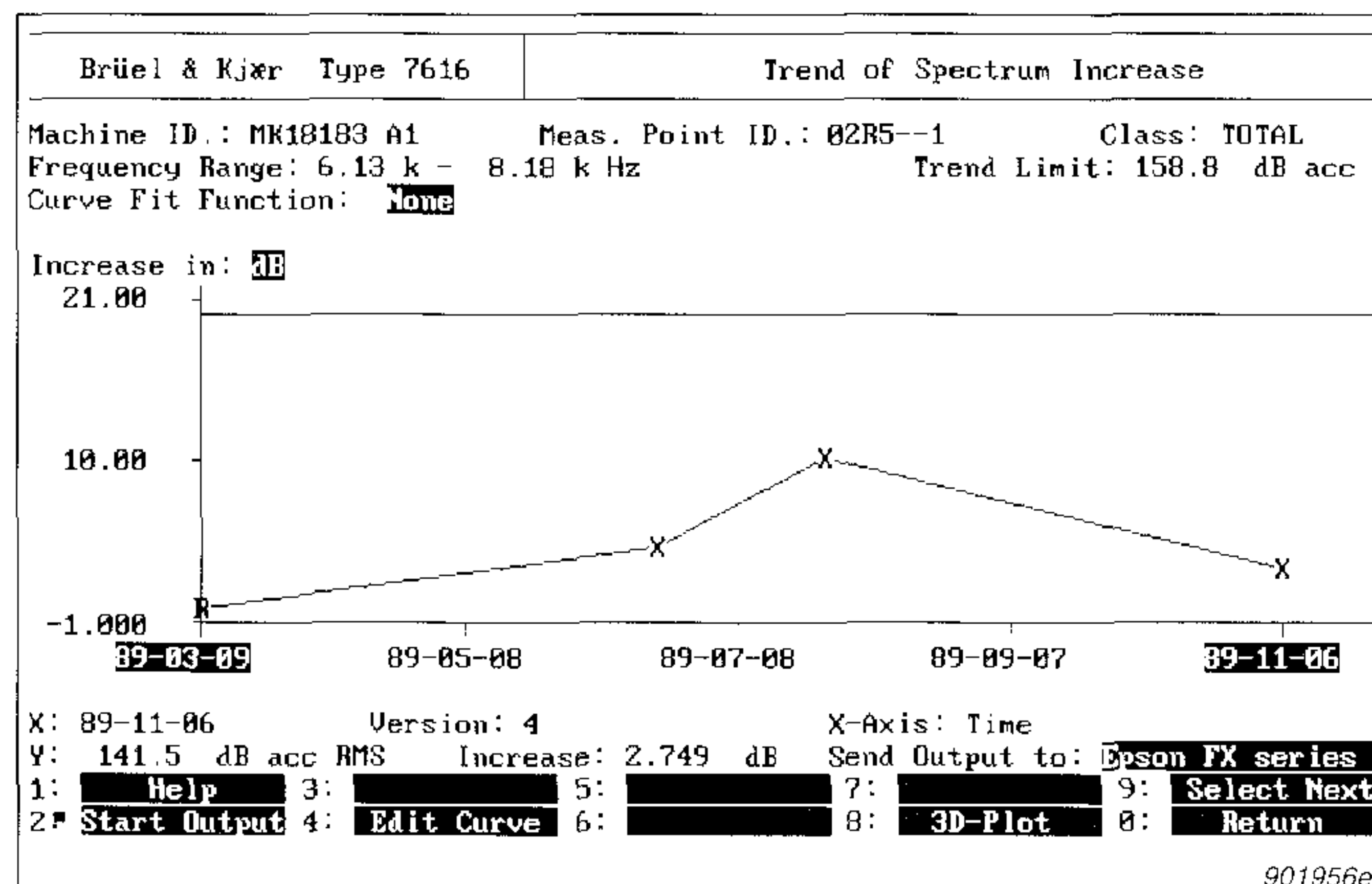


Fig. 3. The vibration increase due to the new coupling was very evident

### Bell Housing Resonance Problem

In this example, the monitoring system was used to improve the tolerances of a particular machining process.

Poor tolerances were being obtained when drilling gear-box bell housings. Fearing that the drilling operation was exciting one of the structural resonances of the housing, the Vibration Analyzer was used to record the housings natural frequencies. This was done using a

so called *hammer test* – the housing was excited by light blows with a hammer and the resultant vibration response measured.

Fig.4 shows the response of the housing. The peak at 1320 Hz corresponds to a multiple of the drill rotation frequency, which was obviously exciting a structural resonance. One solution to the problem was to damp the housing resonances during the machining process. Fig.5 shows the re-

sponse from a damped housing. However, this solution proved to be too expensive to carry out, and therefore it was necessary to move the drill harmonic frequency away from the bell housing resonance. As it was not possible to change the drill speed, a redesign of the drill bits was made to change of the number of cutting edges. This resulted in the machining tolerances being kept well within specifications.

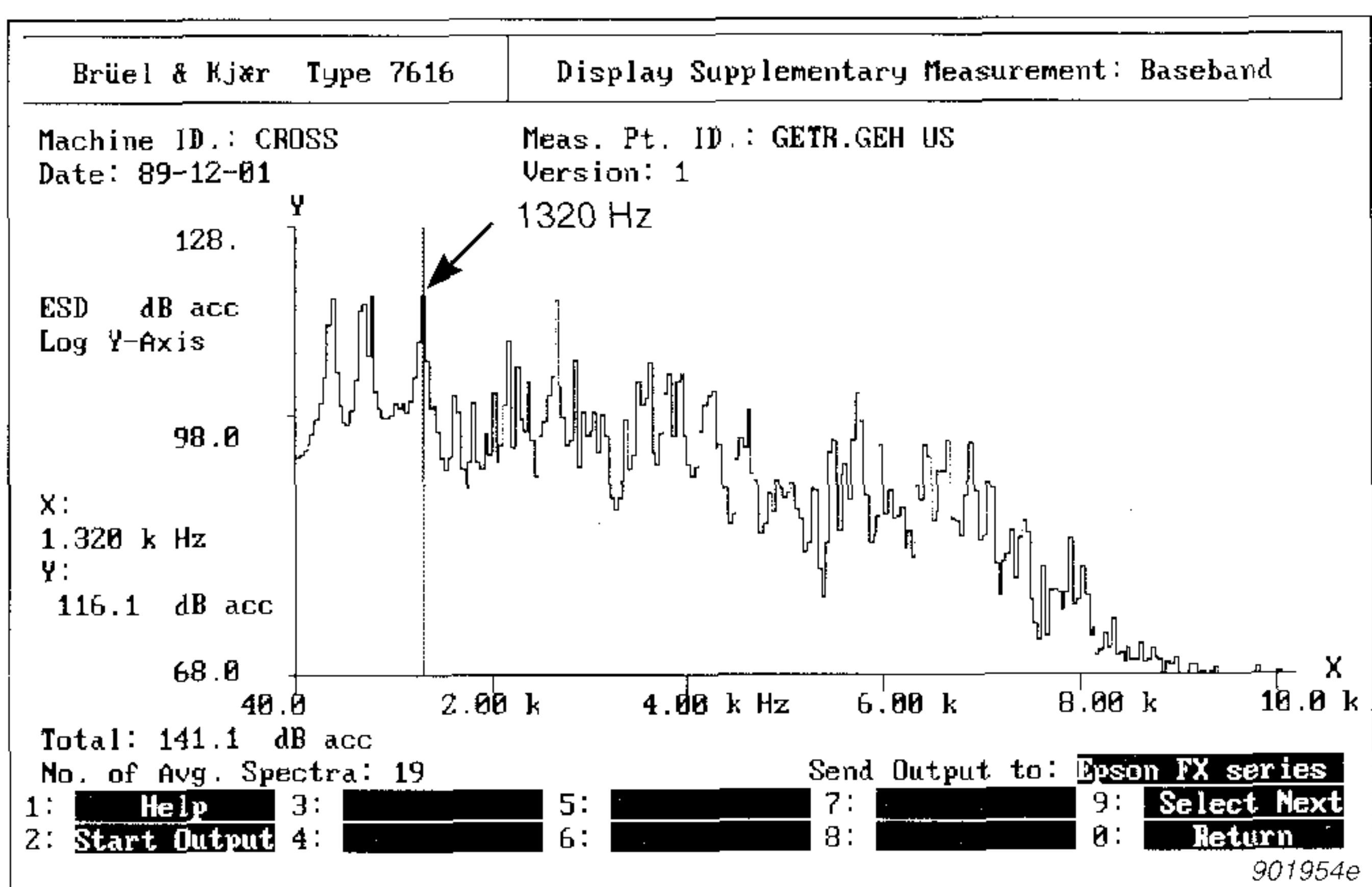


Fig. 4. The frequency spectrum from a hammer-test on the gearbox housing shows some natural frequencies to be in the area of the drill speed and harmonics

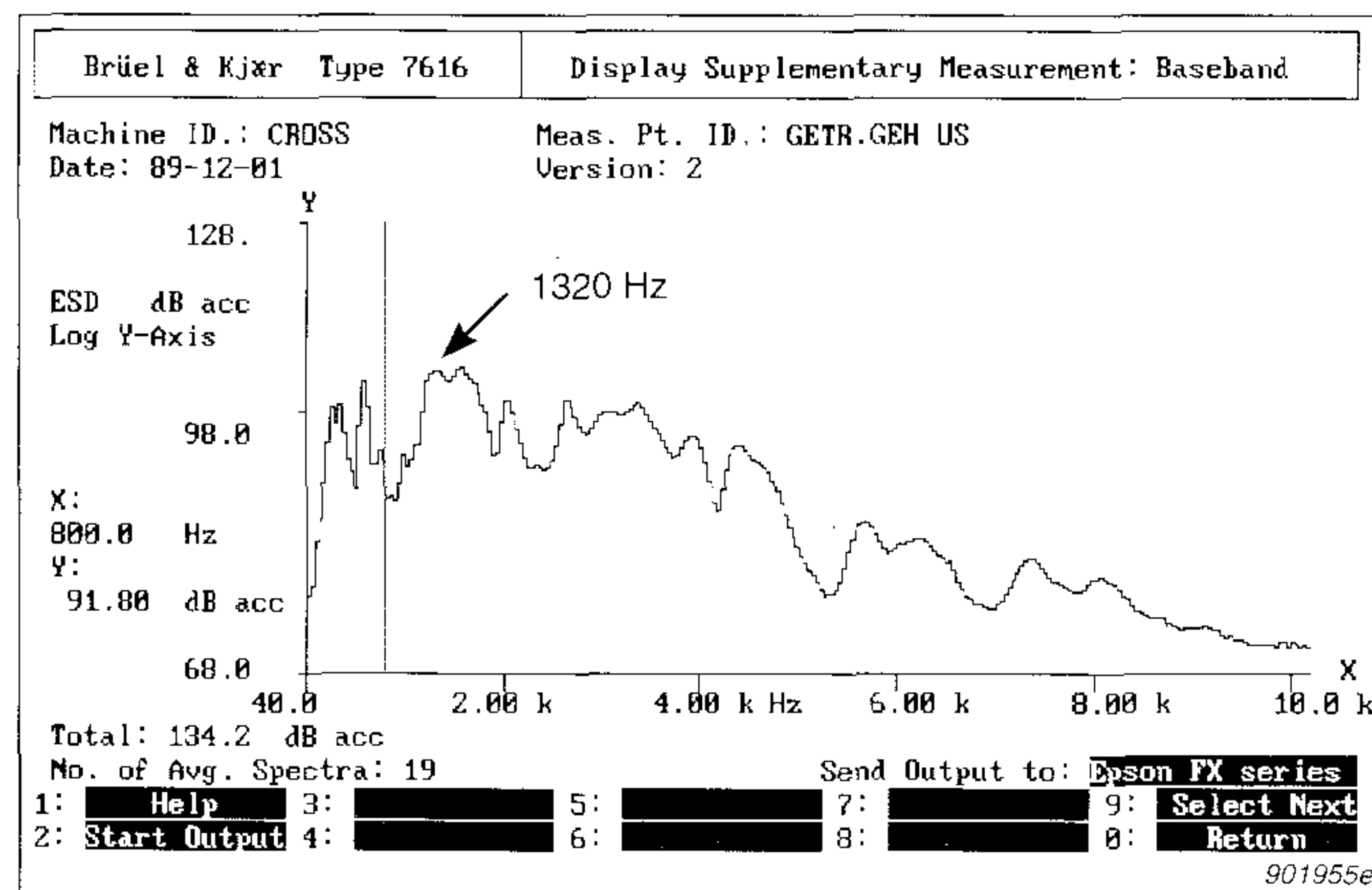


Fig. 5. A hammer-test on a damped housing shows the natural frequencies to be considerably damped

### Grinding Machine Fault-diagnosis Problem

In this example, the use of the monitoring system averted unnecessary maintenance work.

A decrease in quality was noticed in the output from a grinding machine. The maintenance team thought that

worn journal bearings were the problem. However, measurements with the Vibration Analyzer clearly showed that there was no problem with the bearings but indicated an unbalance problem. On further investigation it was discovered that the grinding machine's automatic balancing system

was inoperative. This was corrected and the quality problem resolved.

The vibration measurements, therefore, had saved an unnecessary strip down of the grinding machine and replacement of "healthy" parts.

## The Monitoring System

A portable, battery-powered **Vibration Analyzer Type 2515** was chosen for making the routine vibration measurements. The analyzer utilizes frequency spectrum comparison for detecting significant increases in vibration. Having detected such an increase, the analyzer has features such as narrowband analysis, zoom, phase and cepstrum analysis to thoroughly analyze the machine's vibration to determine exactly what the fault is.

The Vibration Analyzer is interfaced with a Personal Computer running **Application Software Type 7616**. This coordinates data collection and carries out extensive data-management and post-processing of vibration data. In this way, the extent of the fault can be determined and an estimate made as to when it would become critical, thus allowing maintenance to be scheduled well ahead of time. Examples of output plots from the software are shown in Figs. 2 to 5.

### The Measurement Programme

At the beginning of each measurement operation a route map is issued by the computer. This contains detailed information on the machines to be measured. Reference data for the machines on the route are then loaded from the computer into the analyzer. The analyzer is then taken out into

## Conclusions

The pilot project run at Düren has been extremely successful. The monitoring system has shown itself capable of detecting a wide range of machine problems, and a clear improvement in component quality has been achieved. The resultant financial benefits have been considerable.

### Future Considerations

The use of Condition Monitoring is expanding. A wish for the future

## Acknowledgment

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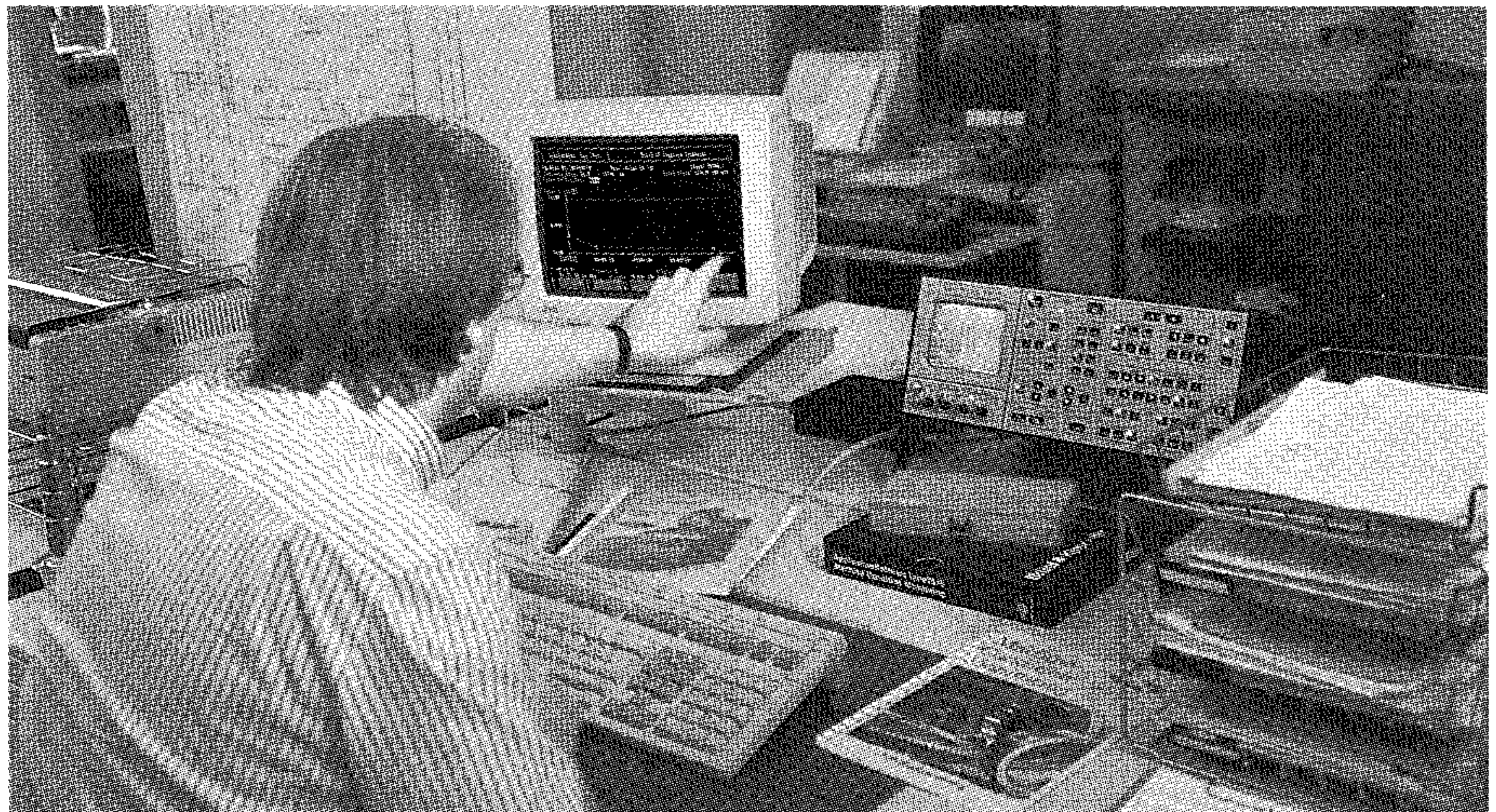


Fig. 6. Analyzing machine condition in the comfort of the office. Measurement data recorded by the portable Vibration Analyzer is down loaded to a computer for storage and further analysis

the plant and the current vibration data from these machines is measured. If required, this data can be compared on-the-spot with the reference data to give a quick overview of the machine's condition. Otherwise the measurement is stored for later analysis in the plant office.

When all measurements are finished, the analyzer is returned to the office and data is reloaded back into the computer where spectrum comparison takes place. This determines if the current spectrum has changed relative to the reference spectrum, indicating a fault. Reference data can be

would be that all machine manufacturers designed-in monitoring points, and supplied baseline frequency spectra for later comparison.

As technology moves on and the knowledge of fault mechanisms increases, so expert systems can be used for fault diagnosis. Hardwired transducers and computer control can remove the need for making manual measurements. Continuous tool-monitoring can be used for adaptive control

stored for various machine running conditions, known as *measurement classes*, to ensure that the spectrum comparison is made under similar operating conditions. Likewise any slight change in machine speed can be compensated, and process variables such as temperature and load can be stored to determine their relationship with machine condition.

In the event of a fault being found, the analyzer's analysis functions can be used to accurately diagnose the nature of the fault. 3-D plotting and trend analysis can be carried out to help with maintenance scheduling.

to help insure product quality and tool performance, and the machine monitoring system can become a key element in process control systems.

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