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MACHINERY VIBRATION MONITORING PROGRAM AT THE SAVANNAH RIVER SITE (U)

By

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ABSTRACT

The Reactor Maintenance's Machinery Vibration Monitoring Program (MVMP) plays an essential role in ensuring the safe operation of the three Production Reactors at the Westinghouse Savannah River Company (WSRC) Savannah River Site (SRS). This program has increased machinery availability and reduced maintenance cost by the early detection and determination of machinery problems.

This paper presents the Reactor Maintenance's Machinery Vibration Monitoring Program, which has been documented based on Electric Power Research Institute's (EPRI) NP-5311, Utility Machinery Monitoring Guide, and some examples of the successes that it has enjoyed.

Introduction

The Reactor Areas at the Savannah River Site consist of three heavy-water moderated, nuclear reactors; and various support facilities. The reactors are production reactors and operate at lower pressures and temperatures than commercial power generating reactors.

The Machinery Vibration Monitoring Program has been in existence for many years in one form or another. In 1986 it assumed the responsibility for regularly monitoring reactor area equipment for vibration levels. The program is now monitoring 209 machines on a biweekly basis, this represents 1848 monitoring points. The program also provides vibration surveys as requested for Start-Up Testing, procedures, and Post Maintenance Testing. Balancing of equipment and calibration of accelerometers is also performed.

Objectives

The objectives of Reactor Maintenance's MVMP are the following:

- Increase availability of equipment through monitoring vibration levels, a measurement of the machinery operating condition.
- Reduce maintenance cost by:

  - identification of machinery faults
  - minimizing damage by detecting faults early
  - allowing time to plan commitments of manpower, parts and equipment

- Assist Reactor Maintenance to become a proactive, rather than reactive, organization.

Goals

The goals of Reactor Maintenance's MVMP are the following:

- To detect abnormal machinery operating conditions prior to the immediate need for maintenance or equipment failure - with no false alarms.
- To accurately diagnosis the cause of excessive vibrations on machinery.
- To collect baseline vibration data on all equipment following repairs and overhauls.
- To follow up on all vibration reports issued in order to confirm the diagnosis and to associate vibration signatures with the cause of the vibration.
- To perform balancing of rotating equipment as required.
- To provide sensitivity checks of Vibration and Acoustic Monitoring (VAM) system accelerometers.
- To provide vibration analysis acceptance testing of new equipment and designs.
- To determine the benefits and cost savings provided by the detection of vibration problems.
- To provide input in determining if scheduled maintenance on a machine needs to be performed earlier than scheduled or if it can be postponed to a later date.

Machinery Classification

For the purposes of the MVMP, a machinery classification scheme has been adopted. The following classification, based on EPRI Utility Machinery Monitoring Guide, is used to catergorize the machinery.

Class I (Critical, not-spared) - this classification refers to a machine that is not spared in the field and that will result in immediate total or partial loss of reactor power level when the machine is shutdown. The term "immediate" is used to indicate that another adverse event or equipment failure need not occur before the reactor power level is affected.

Class II (Critical, spared) - this classification refers to a machine that will result in a complete or partial but not immediate, loss of reactor power level when the machine is shutdown. The term "not immediate" is used to indicate that another adverse event or equipment failure must occur before the reactor power level is affected.

Class III (Noncritical) - this classification refers to a machine that will not immediately affect reactor power level. Repairs to the machine can be made without affecting the reactor power level.

Class IV (Problem Units) - this classification refers to a machine that is identified as requiring maintenance or that has a recurring maintenance problem. This is a catch-all for machines that should receive special attention for some reason, but that are not necessary critical for reactor operation.

Each monitored machine in the Reactor Areas has been classified according to the above scheme. This information is contained the Monitored Machinery Database (A sample data sheet will be presented later.)

Program Information

This section provides information on the type, timing, and format of the information that will be provided by the Machinery Vibration Monitoring Program. It also specifies who will receive this information. The information required by the MVMP and who shall provide it is also listed.

Four types of reports are generated as part of the MVMP plan. They are as follows:

Vibration Report - This report is issued when an abnormal vibration condition is detected while monitoring a machine on a scheduled route (Appendix II, MVMP Vibration Routes contains the various vibration routes) This report will also be issued when a vibration survey is requested on a machine, other than for post maintenance testing. The information reported and format of this report is shown in the following report for a cooling water pump. This report is issued by the MVMP Specialist or Coordinator (the Coordinator will review and initial the report prior to issue).

Post Maintenance Testing Report - This report is issued when a vibration survey is performed on a machine following maintenance. This report shall be attached to the Procedure or Work Package by the Maintenance organization if the Procedure or Work Package requires the post maintenance vibration survey. The information reported and format of this report is similar to The Vibration report with minor changes. This report is issued by the MVMP Specialist or Coordinator (the Coordinator will review and initial the report prior to issue).

Monthly Report - This report summarizes the efforts of the MVMP over the past month. The information reported includes the number of points surveyed, a listing of equipment surveyed, the number of exceptions (points exceeding the evaluation criteria), the number of unscheduled surveys and the number of these which were for post maintenance testing. A summary of the vibration reports and case studies for machinery problems detected by the MVMP are attached to this report. This report is issued by the MVMP Coordinator.

Monthly Route Schedule - This report will provide the tentative route survey schedule for the month. The purpose of this report is to allow personnel to know when the vibration surveys will be performed so that equipment, especially standby equipment, on which a survey is desired can be on line. This report will be issued by the MVMP Specialist.

The timing for issuance of the various reports and to whom they are issued is listed below:

Vibration Report - Is issued within two working days of the vibration survey. The report is issued through plant mail (via special messenger for reports that require maintenance action). If immediate action is required, the Reactor or Power Shift Manager and the Reactor Maintenance Area Manager are notified of the condition by phone. The report is issued to the following personnel:

Area Reactor Maintenance Managers
Manager 100 Area Reactor or Power
Area Outage Manager
Reactor or Power Shift Manager
Manager Reactor Maintenance Central Maintenance
Manager Reactor Maintenance Engineering Services
Manager Reactor Maintenance PM
Files (Vibration and Central)

Post Maintenance Testing Report - Is issued within two working days of the vibration survey. The report is issued through plant mail. If immediate action is required, the Reactor or Power Shift Manager and the Reactor Maintenance Area Mananger is notified of the condition by phone. The report is issued to the following personnel:

Area Reactor Maintenance Managers
Manager 100 Area Reactor or Power
Area Outage Manager
Reactor or Power Shift Manager
Manager Reactor Maintenance Central Maintenance
Manager Reactor Maintenance Engineering Services
Manager Reactor Maintenance PM
Work Package File
Files (Vibration and Central)

> ***Note: When an abnormal vibration condition is detected that requires maintenance attention, A Reactor Work Request will be attached to the Shift Manager's copy of the Vibration or Post Maintenance Testing Report. A Condition Tag will also be hung on or near the affected equipment.***

Monthly Report - Is issued within one week of the end of the month. The report is issued through plant mail. It is distributed to the following personnel:

Manager Reactor
Manager Reactor Maintenance
Managers 100 Areas Reactor and Power
Area Reactor Maintenance Managers
Managers Reactor Engineering
Area Managers Reactor and Power
Area Outage Managers
Manager Reactor Maintenance Engineering Services

Manager Reactor Maintenance Central Maintenance
Manager Reactor Maintenance PM
Files (Vibration and Central)

Monthly Route Schedule - Is issued prior to the beginning of the month for which the schedule has been arranged. It is issued to the following personnel:

All Area Reactor Maintenance Managers
All Area Managers Reactor and Power
Managers 100 Areas Reactor and Power
All Area Outage Managers
Manager Reactor Maintenance Central Maintenance
Manager Reactor Maintenance Engineering Services
Manager Reactor Maintenance PM
Vibration Files

Request for vibration surveys shall be made to MVMP personnel. The request is entered into the Vibration Request Logbook. The following information will be provided to the MVMP personnel by the person making the request:

- Equipment to be surveyed
- Location of equipment
- Reason for the survey - if a survey is for post maintenance testing, provide the Procedure or Work Package number and the Reactor Work Request number under which the work was performed and a brief description of the work performed and conditions found
- Desired time of the survey

Data Analysis

This section deals with the translation of the raw vibration data into useful information. The following procedure from the Electric Power Research Institute (EPRI) Utility Machinery Vibration Monitoring Guide has been used to aid in defining the frequency of monitoring, the analysis techniques that will be used, the data evaluation methods, and the data that will be stored for future diagnostics.

Step 1. Define the potential machinery faults and vibration characteristics that would be produced by those faults for each monitored machine.

Step 2. Establish the frequency of monitoring needed to detect an acceptable percentage of failures.

Step 3. Determine the analysis techniques that are most sensitive to the vibration characteristics produced by the most common machinery faults.

Step 4. Define the evaluation criteria that will be used for each machine.

Step 5. Determine the data comparison methods that will detect deviations from the defined evaluation criteria.

Step 6. Define the diagnostic data to be stored for future use.

The information derived from using this procedure is contained on the individual data sheets for each monitored machine in the monitored Machinery Database. For equipment that is not regularly monitored, a data sheet will be created prior to performing a vibration survey. The following is the data sheet for a cooling water pump.

The intervals for monitoring vibration levels and comparing them to their acceptance criteria have been established as the following:

* <u>Trouble Shooting</u> - Vibration readings are taken only when high vibrations are suspected by personnel.

* <u>Event Triggered</u> - Vibration readings are taken according to a particular event, such as an overhaul or a load test. If a machine is scheduled for an overhaul, a vibration survey should be performed both prior to and following the overhaul. The post maintenance survey is especially important since most equipment failures occur after maintenance.

* <u>Periodic</u> - Vibration readings are taken at intervals of weekly, biweekly, or on a monthly basis. This monitoring provides for the detectiion of deteriorating operating conditions over time.

* <u>Continuously</u> - Vibration readings are collected continuously. This allows constant protection to the machine being monitored. The Vibration and Acoustic Monitoring (VAM) system provides continuous monitoring of the main Process Pumps and Process Piping.

Three analysis techniques are employed to monitor the machinery operating condition. The simplest is the overall vibration analysis technique. This involves the measuring of the root mean square (rms) or the peak amplitude of the vibration signal. Its primary purpose is to detect a change in the machinery vibration that could indicate the onset of a problem. The second analysis techique is employed to diagnose the nature of the machinery distress. This complex technique utilizes fast Fourier transforms (FFT). The time domain vibration signal, which is a complex mixture of various waves of different amplitudes and frequency, through Fourier transform, is translated into the frequency domain. The resulting vibration signature is a plot of the vibration amplitude versus its frequency of occurrence. The third analysis technique is primarily used on machinery that have rolling element bearings. This analysis technique is high frequency detection (HFD). It can detect rolling element faults earlier than any overall measurement can.

The vibration data is compared to the vibration criteria in several ways. The primary methods are amplitude limit checking and trending. Amplitude limit checking involves comparing the unfiltered vibration levels to predetermined limits. This is performed by the vibration monitoring software via an exception report. To determine the overall vibration level evaluation criteria, heavy emphasis was placed on the machine's past vibration and maintenance history. From examining records on the machinery's past vibration levels, "normal" operating levels were determined. The first evaluation value is set slightly higher than the machine's normal vibration level, and the second evaluation value is set .05 to .10 ips-rms higher than the first. These values appear as Alarm values on the portable data collector. This enables the person collecting the data to know immediately if the equipment is vibrating abnormally and that it needs special attention. It should be noted that severity criteria should serve as guidelines and not strict rules. (For equipment on which a data sheet does not exist, the evaluation criteria will generally be 0.20 ips-rms for overall levels and 1 g-rms for the high frequency detection mode.)

Trending of the overall vibration level will also be monitored. Trending is used to see if the vibration level on the machine is remaining steady or is changing. An increase or sometimes a decrease in the vibration levels can indicate the onset of a problem. The doubling of vibration levels often indicates a problem; and the tripling of levels indicates that the equipment needs to be shutdown. Trending also aids in reducing the effects process variations have on the vibration information. The percentage increase over the previous reading is generated by the vibration monitoring software. The portable data collector also displays the previous reading collected on a particular point. Thus while in the field, it is possible to see if the vibration level has changed dramatically. The comparison against the evaluation criteria will be manually performed. If either of these methods indicate an evaluation criteria has been exceeded, further data comparison is performed.

The cover sheet of the report containing the exceptions, overall levels, and percentage increases, will be initialed and dated by the personnel performing the review.

The comparison of the vibration signatures with the baseline signatures of the machine is the next process in the vibration analysis process. The appearance of new vibration peaks or the increase in amplitude of existing peaks could indicate that a problem is developing. Baseline vibration data is the overall vibration levels and vibration signatures of a machine when it is free of faults and operating under normal conditions. Baseline signatures are stamped in red with the word "BASELINE" and placed in a plastic folder in the equipments's history file. The vibration signatures contains two important pieces of information, the amplitude of the vibration and the frequency of occurrence. The amplitude is associated with the severity of the problem and the frequency is associated with the nature of the problem. For example, misalignment often results in a 2X running speed vibration being generated and defects on a rolling element bearing often generate very high frequency vibrations.

Examination of trend plots of both the overall level and vibration signatures (waterfalls) are also used. This information is available through the vibration monitoring software. Comparison with the vibration information on similar equipment is also utilized. In comparing the vibration data, it is necessary to be aware that the vibration characteristics of a machine can be influenced by the process conditions under which it runs, such as power supply or loading. Most equipment when in service operates under the same or similar process conditions. Some equipment, however, is operated in different configurations and with different process conditions which can affect the vibration levels. For this equipment, relevant process information, such as discharge pressure, is gathered along with the vibration data. This is used to establish whether the change in vibration levels is machine condition or process related. This knowledge of known process affects on the machinery vibration allows the collection of vibration data on a periodic basis, and removes the need to have the unit's operation changed in order to collect the information.

The overall vibration levels and vibration signatures are stored in the vibration monitoring software. This software is "backed up" on a three month frequency. These computer files are stored in a separate building from the originals. This information is retained for a minimum period of two years. Hard copies of the baseline vibration signatures are stored in the MVMP Equipment History Files until new baseline signatures are obtained. The hard copy vibration reports generated by the monitoring software are maintained for a minimum of two years. All vibration reports issued by MVMP personnel are retained permanently. A copy of these will be sent to Central Files for permanent retention.

Measurement and Transducer Selection

This section will provide information on the units in which the vibration levels will be expressed and what transducers will be used to measure the vibration levels.

Vibration can be measured and expressed in three major units; these being acceleration (g's), velocity (inch per second - ips), and displacement (mils). Velocity is the unit used most frequently. It allows for the detection of a variety of machinery defects over a wide frequency range. Velocity also has a flat vibration severity specification over a wide frequency range. This characteristic allows the severity to be determined without the need to know the frequency that the vibration is occurring. In piping vibration, the stress in the piping is directly proportional to the velocity of the vibration. Velocity can be expressed in units of ips-peak and ips-rms (root mean square). For a sinusoidal wave, the rms value equals .707 X the peak value. The rms value is used since it provides a better meaurement of the destructive energy contained in the vibration.Measurements taken on rolling element bearings also utilize a special unit of measurement. This unit is expressed in acceleration, g's-rms. This particular unit is a result of using the High Frequency Detection mode of the Microlog. The defects present when a bearing or gear tooth begin to fail are used to excite the natural frequency of the accelerometer. The level of excitation is measured; the higher the level, the greater the possibility of the bearing being defective.

Transducers are used to convert the vibration of the machinery into an electric signal that can be processed and analyzed. There are three basic types of transducers; the accelerometers, the velocity or seismic probe, and the eddy current or proximity probe. The Wilcoxon 793 accelerometer is used for the bulk of the vibration data collection. This transducer provides a nominal signal of 100 mv/g. The actual sensitivity of the accelerometer that is used on a survey is entered into the software prior to the collection of the vibration data. The Microlog contains the necessary circuitry to integrate this signal so that it can be expressed in either acceleration, velocity or displacement.

Data Collection

This section defines the location on the monitored machines from which the vibration data is collected; the method that is used to mount the vibration transducer; the method used to move the data from the monitored machine to the individual and system that analyzes the data; and the data gathering routes used to manually acquire the vibration data from the machines.

The vibration measurements are collected on the machinery bearings casing. This position is monitored because bearings are the component most likely to fail in rotating equipment. They also provide the the location for which forces experienced by the rotating element of the machine are transmitted to the stationary machine element. Readings are taken in the horizontal, vertical and axial directions when possible. In the Monitored Machinery Database, the points being monitored for each machine are listed on the machine's data sheet. These monitoring points are identified in the field by either a paint dot or a aluminum sticker with "VMP Vibration Monitoring Point" stamped on it. The points are marked so that meaningful trend information can be obtained.

There are many methods to attach velocity transducers and accelerometers to the machines being monitored: stud mount, bees wax, glue, adhesive disk, magnet, spring loaded quick disconnect, and hand-held. The method used to mount the transducer can significantly affect the repeatability of vibration measurements and the reliable frequency response range. Two methods are used, the magnet and hand-held. A magnet is attached to the base of the accelerometer or velocity probe by means of a threaded stud. This is the preferred method. In cases where there is insufficient space to mount the magnet, the transducer is hand-held. An extension stringer is used. It is screwed into the transducer and then it is pressed against the bearing with the tranducer.

The Palomar Microlog is used to transport the vibration information from the field to the office. It is a portable vibration analyzer that has the capabilities of collecting and then digitally storing the vibration information, both overall levels and vibration signatures, that are collected on a vibration survey route. The Microlog interfaces with a personal computer via the vibration monitoring software. Automatic reports are generated listing exceptions to the vibration acceptance criteria and the measurement levels for the points monitored. Other means of transporting this vibration data include the use of other dynamic signal analyzers and a scientific tape recorder.

The equipment surveyed is organized into various. A route is the way or path that the mechanic takes as he goes from machine to machine collecting vibration data. In most cases the routes are organized by area and then the building. The routes are performed on a biweekly frequency.

Instrumentation

The Palomar Micrologwith a Wilcoxon Model 793 accelerometer is the primary equipment used in the MVMP. The Microlog interfaces with an IBM or Compaq computer system via Emonitor, a vibration monitoring software package by Entek.

The Microlog and Wilcoxon accelerometers are calibrated such that traceability to the National Institute of Standard and Technology is maintained. Purchase specifications are written for each piece of equipment that is to be calibrated. These contains the calibration requirements. As a minimum for the accelerometers, the sensitivity is checked at a specified frequency and amplitude. This point is then used as the basis, as the linearity of the accelerometer both in frequency response and amplitude response is checked. The transverse sensitivity of the accelerometer and its natural frequency are also determined. The accelerometers are then functionally tested with their respective analyzers. The analyzers, prior to this, are tested separately to insure compliance with their manufacturer's specifications. They are treated as Category 1 MTE's. A log sheet will be maintained for the use of the Microlog and the Wilcoxon accelerometers. As a minimum the Microlog and Wilcoxon serial numbers, their calibration expiration dates, the date of use and the equipment or route on which they were used will be recorded. A Instrument Tool Report (ITR) will be completed and filed for each job performed to provide reverse traceability.

A total of six Wilcoxon Model 793 Accelerometers are required for the program. Two accelerometers will be used with each of the three Micrologs.

Personnel

The MVMP personnel report through line management within the Reactor Maintenance. This organization provides maintenance assistance to the 100 Area Reactor and Power Departments. There are currently three full time positions within the MVMP; the MVMP Coordinator, the MVMP Specialist, and The MVMP Mechanic. Appendix V, MVMP Personnel, contains a listing of different skill levels as defined in EPRI Utility Machinery Monitoring Guide. The responsibilities of each position and the current skill level of the personnel assigned to these positions are listed below.

Responsibilities of the MVMP Coordinator - Skill level IV

1). Oversee the MVMP program and update as necessary.

2). Assist the Vibration Specialist with the analysis of equipment with excessive vibration.

3). Assist the Vibration Specialist with software and hardware problems with the vibration program.

4). Perform balancing of equipment as necessary.

5). Assist with the calibration of vibration monitoring equipment.

6). Publish monthly MVMP report.

7). Assist in the performance of vibration surveys.

Responsibility of the MVMP Specialist - Skill level III

1). Provide analysis on equipment with excessive vibration and make repair recommendations. Issue Vibration and Post Maintenance Testing reports.

2). Coordinate the periodic collection of vibration data. Issue the Monthly Route Schedule.

3). Coordinate requested vibration surveys on equipment that is new, repaired or being returned to service after an outage.

4). Train maintenance mechanic in vibration monitoring.

5). Maintain a current listing of equipment covered by the PM/Vibration Monitoring program.

6). Insure that vibration monitoring equipment is calibrated as required.

7). Back up the Bernoulli Cartridges containing the vibration monitoring programs and information. The back up cartridges will be stored in a separate location than the master.

8). Assist in the performance of vibration surveys.

Responsibility of MVMP Mechanic - Skill level II

1). Provide periodic vibration monitoring of the equipment covered by the PM program.

2). Perform unscheduled vibration surveys as requested.

3). Insure that the monitoring locations are properly marked.

Training for personnel involved in the MVMP comes from attendance of seminars and on the job training. Experience is a valuable asset in performing vibration analysis. It is not only important to know the vibration collection instrumentation works, but also, how the piece of equipment that is being monitored works.

Examples

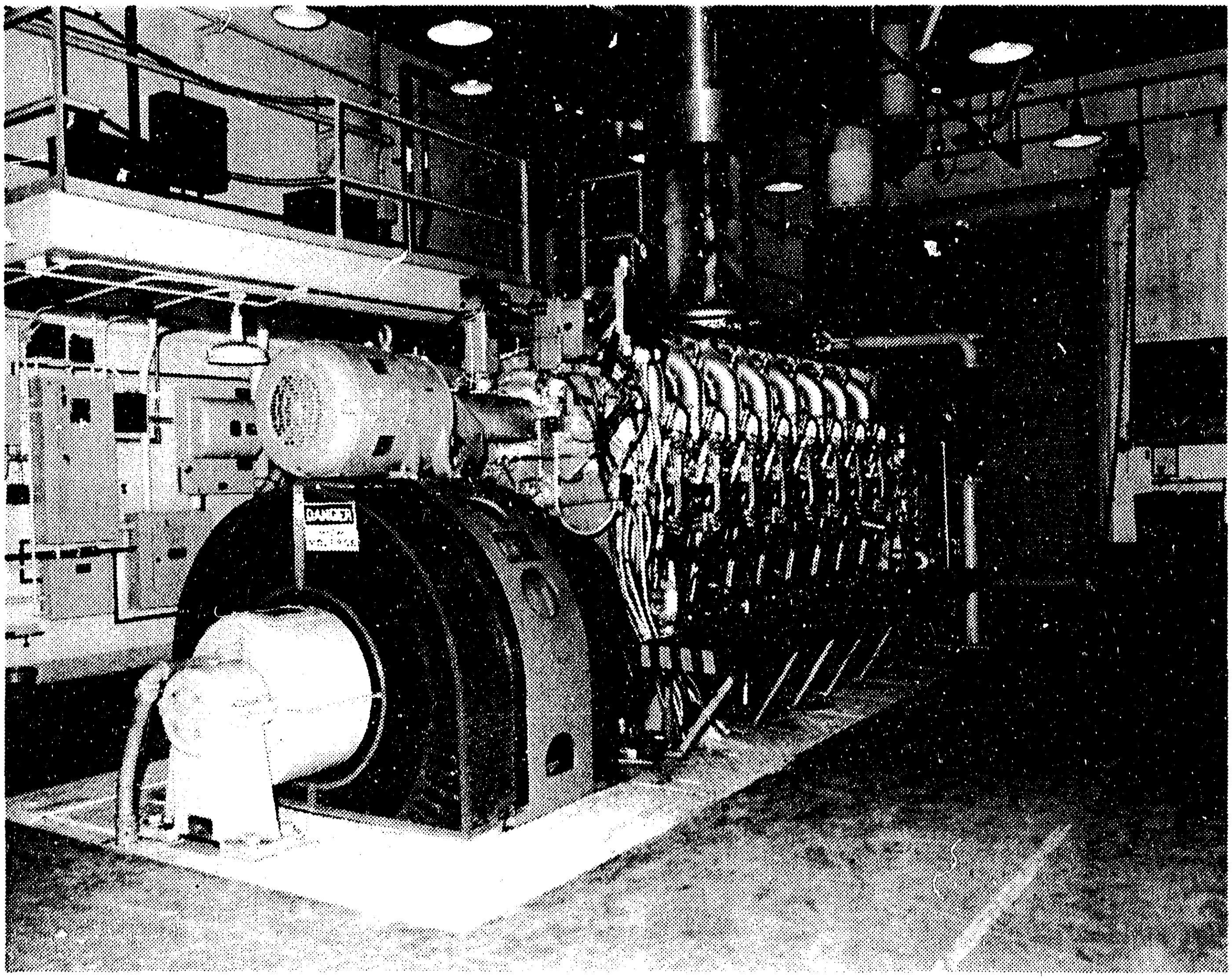
Following are examples of machinery defects or problems detected as a result of the MVMP. These examples are presented to both illustrate some of the successes a vibration analysis program can have and also to educate by presenting some classic vibration problems and their characteristic signatures.

EXAMPLE 1

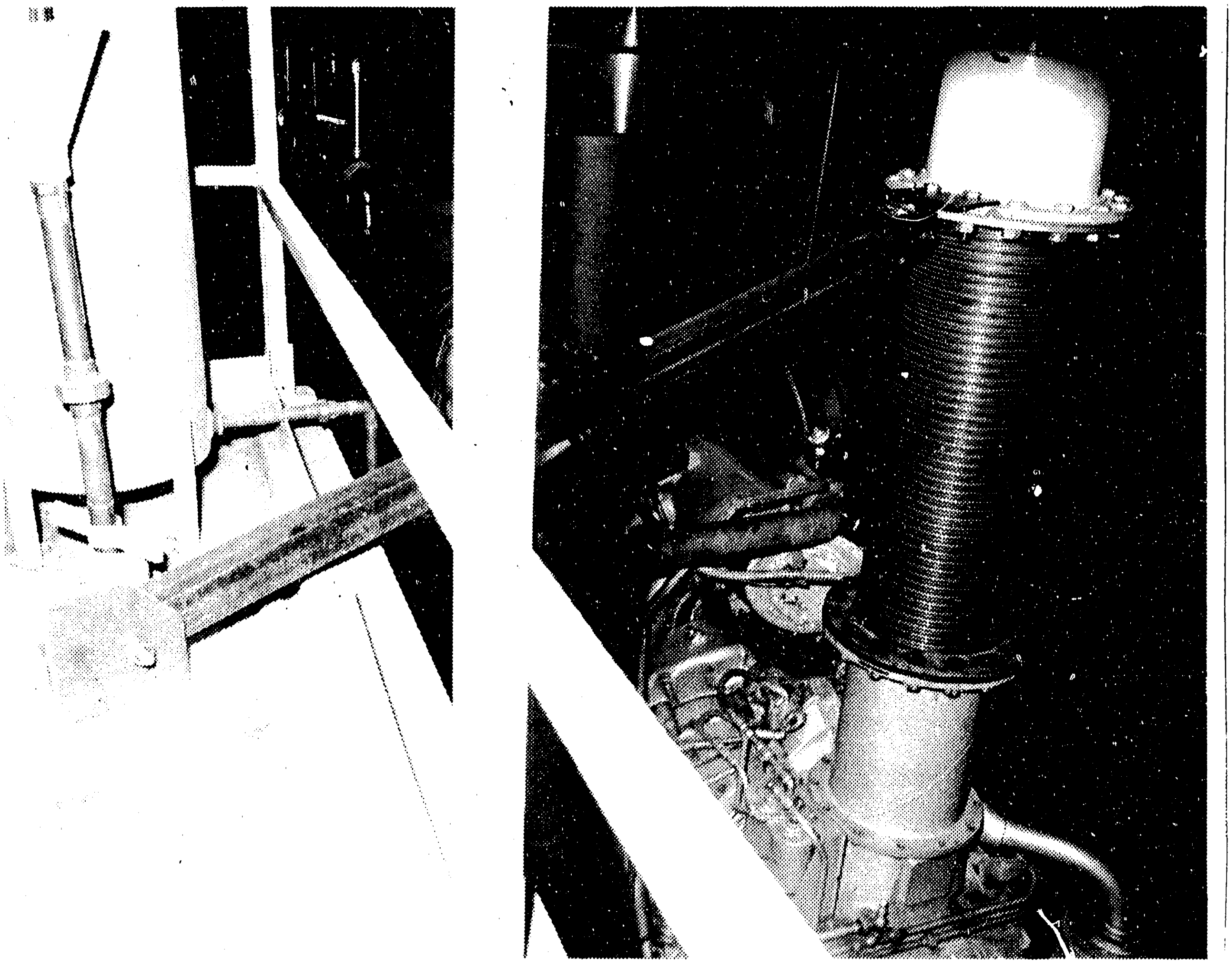
The vibration signatures in figure 3 and 4 are from the outboard bearing of two Ingersol Rand cooling water pumps (Picture 3) in the axial direction. The first peak in both signatures is at 3060 rpm. This corresponds to the vane pass frequency which is equal to the number of pump vanes times the speed of the pump. The similarity between the two signatures ends with this peak. In figure one, the signatures contains a very large peak at the third harmonic of the vane pass frequency and a large peak at 10,600 rpm. (The third harmonic of a frequency can be generated by a wobbling motion.) These are not present on the other pump's signature. The difference between these two signatures was the basis for the decision to pull the pump casing and inspect the pump which had just been overhauled. Baseline vibration signatures were not available.

The inspection of the pump revealed that the set screws used to hold the impeller wear rings in place had backed out. Picture 4 is one of these set screws. Repairs were made and the set screws were peened to prevent a reoccurrence. The vibration signature in figure 5 was taken at the same location as figure 1 following these repairs. A reduction in vibration levels from 0.30 ips-rms to 0.05 ips-rms was achieved.

This example illustrates two points. The first being the importance of post maintenance testing and the role that a Machinery Vibration Monitoring Program can have. And secondly, the usefulness of using comparison between similar pieces of equipment to aid in evaluating machinery condition.



Picture 1. Diesel Generator



Picture 2. Brace for piping

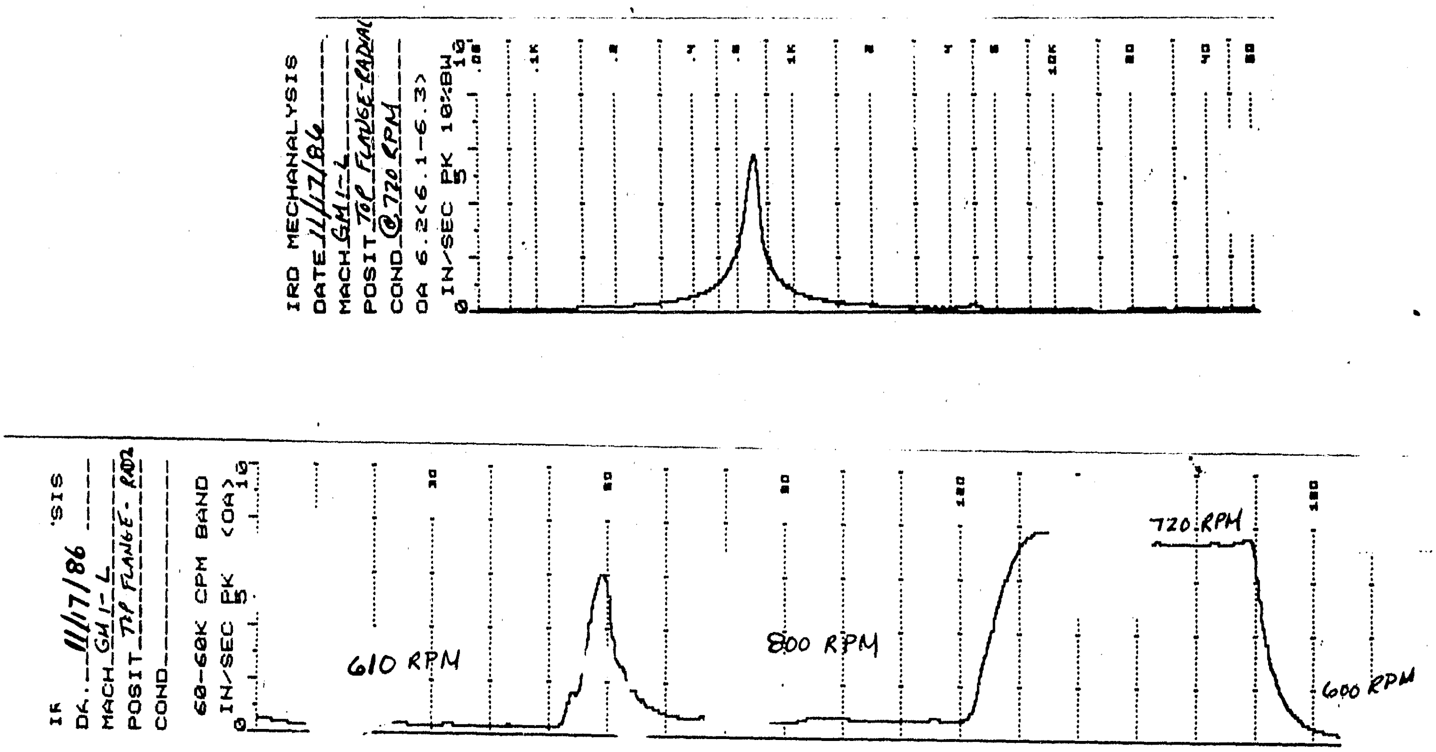


Figure 1. Piping vibration response to changes in operating speed

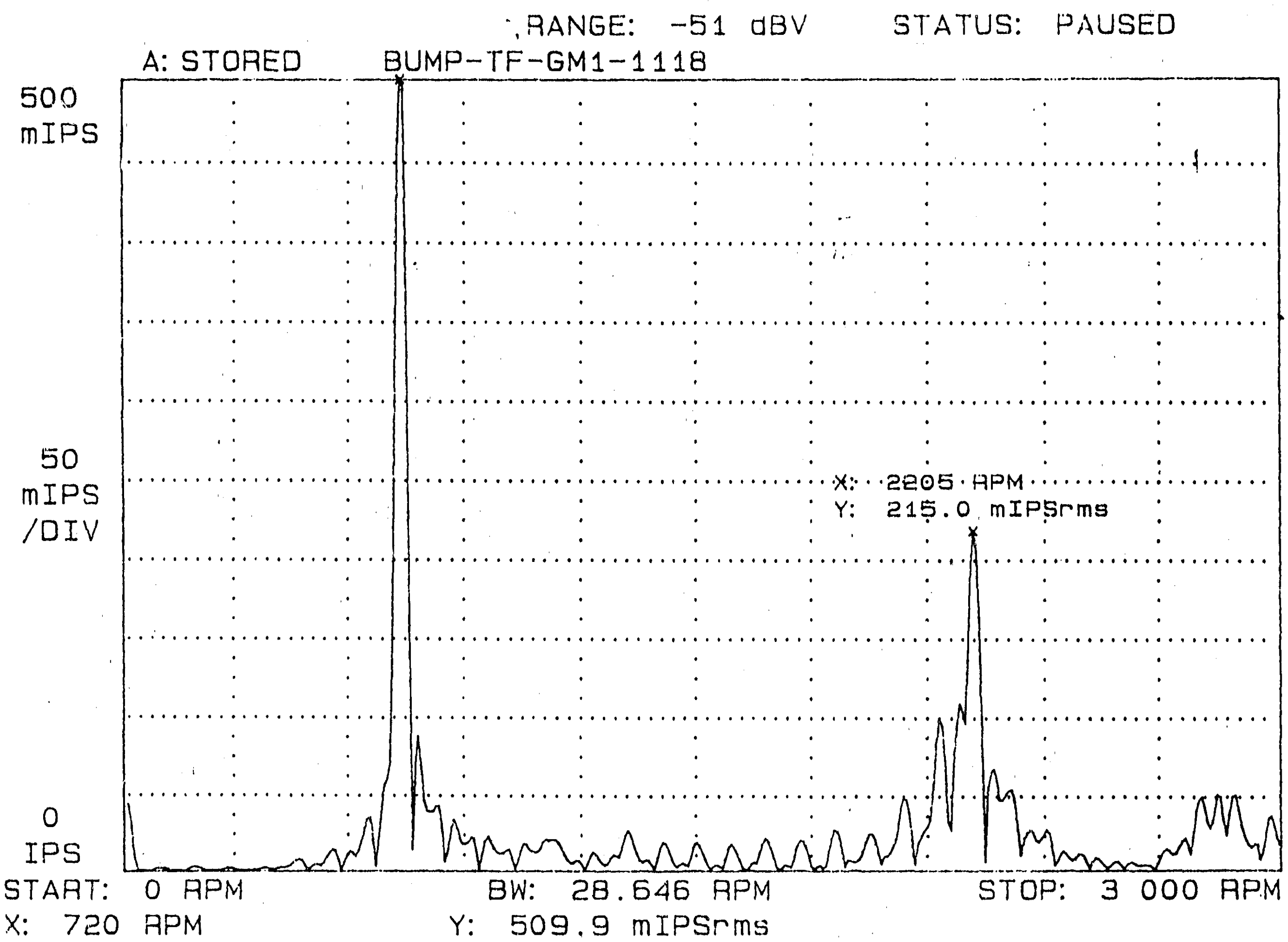


Figure 2. Bump test on piping flange, natural frequency 720 rpm

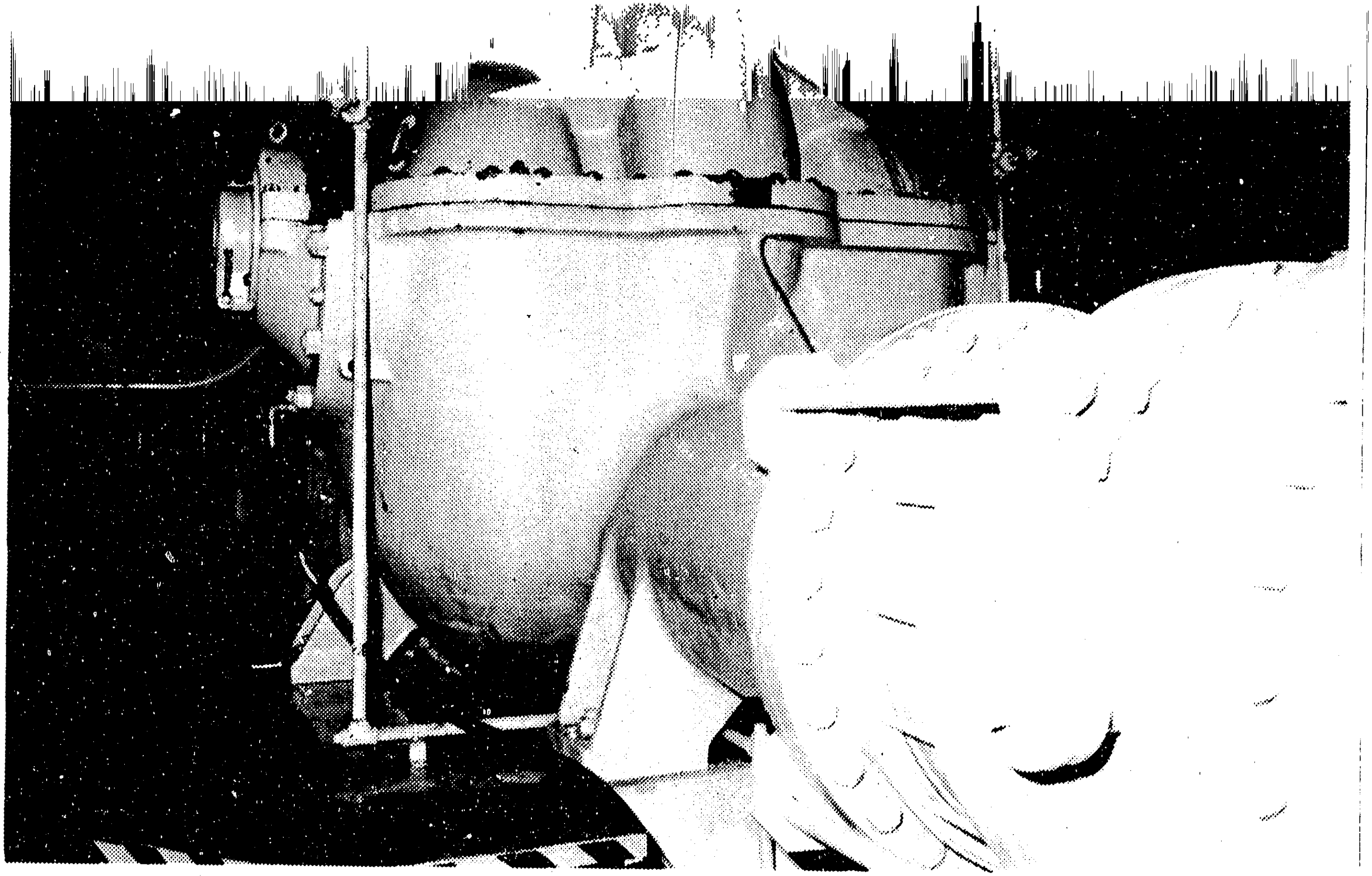
EXAMPLE 2

During the load test of an diesel generator (Picture 1), concern was expressed over the vibration at the blower end of the diesel. A vibration survey was performed on the unit. While collecting the vibration data, it was noticed that the pipe flange immediately above the blower and bellow section of piping, was vibrating excessively. The vibration was measured at an amplitude of 6 ips-peak, occurring at 720 rpm, the running speed of the diesel. This was of concern since stress in the piping is directly proportional to the amplitude of the vibration. The running speed of the diesel was varied to see what effect this would have on the vibration. The strip chart in figure1 indicates a speed dependence. At 610 rpm, the amplitude was only 0.4 ips-peak. As the speed was increased to 800 rpm, a spike occurred as the speed passed through 720 rpm. At 800 rpm, the vibration level was 1 ips-peak. When the diesel returned to 720 rpm, the amplitude once again increased. An amplitude of nearly 8 ips-peak was recorded.

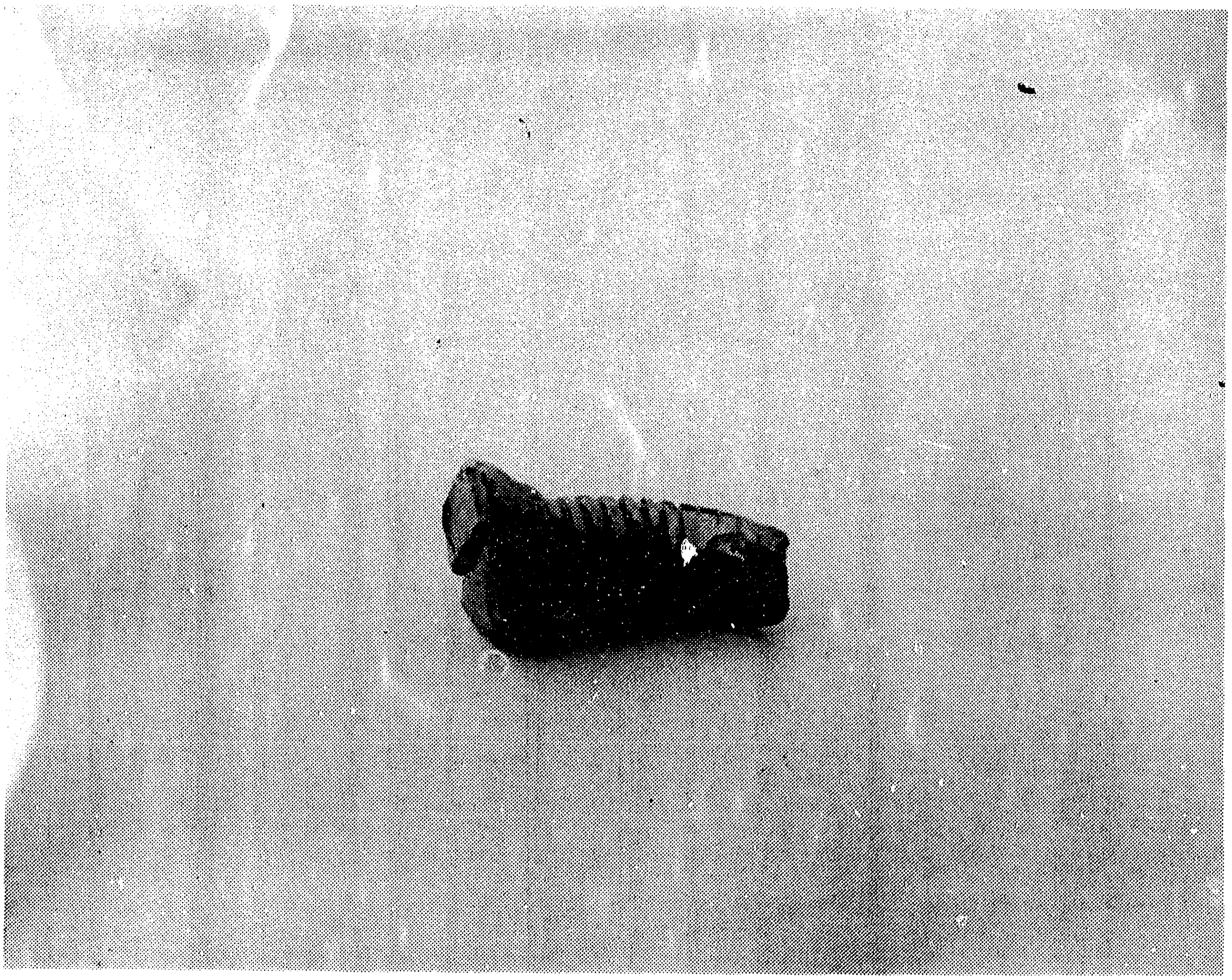
This indicated that resonance was the culprit for the high vibration levels. Resonance occurs when the natural frequency of an object, which is proportional to the objects stiffness divided by its weight, is at or close to the frequency of the exciting force. Resonance has the effect of magnifying the vibration level.

A bump test was performed on the flange to determine its natural frequency. A hammer was used to hit the piping ' excite the piping's natural frequency. Figure 2 is the resulting vibration signature. It confirmed that the natural frequency was indeed 720 rpm.

One method to correct a resonance problem, is to change the natural frequency of the object. The additional of weight will cause the natural frequency to decrease and increasing the stiffness will drive the natural frequency higher. Both methods were tried. A 70 lb piece of lead was wrapped around the piping just above the flange. This had the effect of reducing the natural frequency to 645 rpm and the vibration levels to 0.3 ips-peak. Due to seismic concerns, this method was rejected and a brace (Picture 2) was added. This effectively raised the natural frequency to 990 rpm and reduced the vibration levels to 0.5 ips-peak. Recall that the initial vibration was in excess of 6 ips-peak.



Picture 3. Ingersol Rand Pump



Picture 4. Impeller wear ring set screw

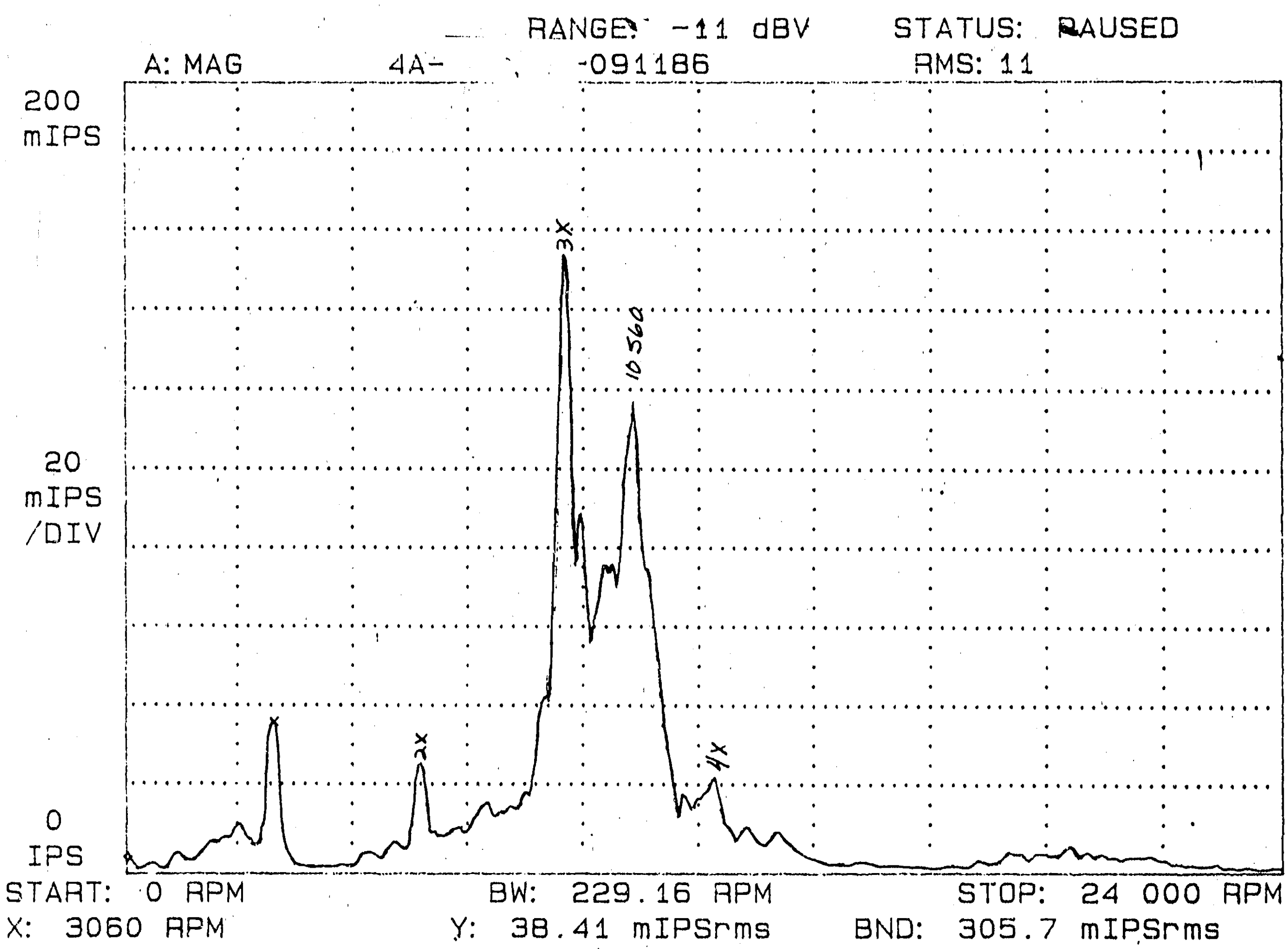


Figure 3. Axial vibration on outboard bearing prior to repair

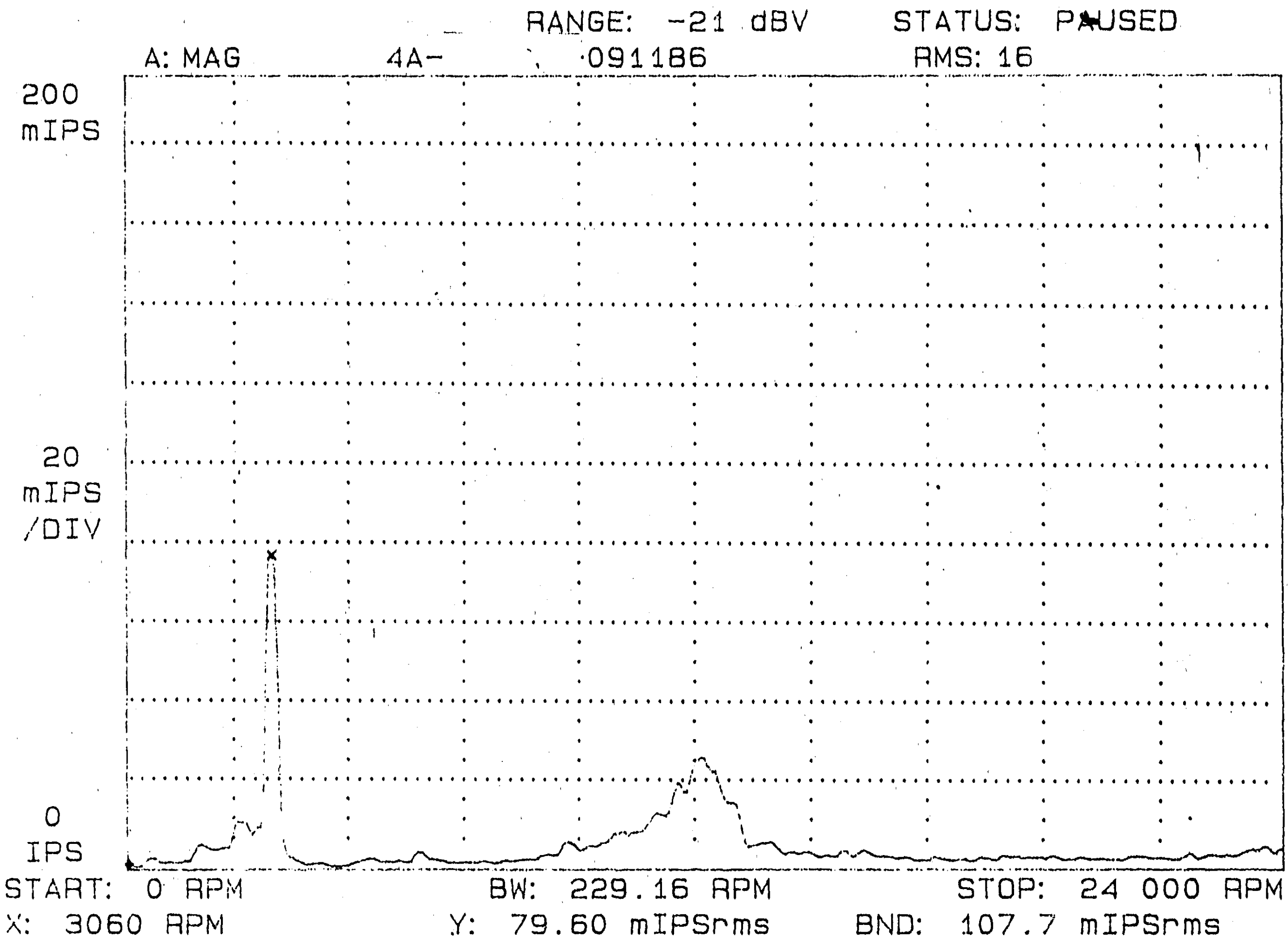


Figure 4. Axial vibration on outboard bearing of comparison pump

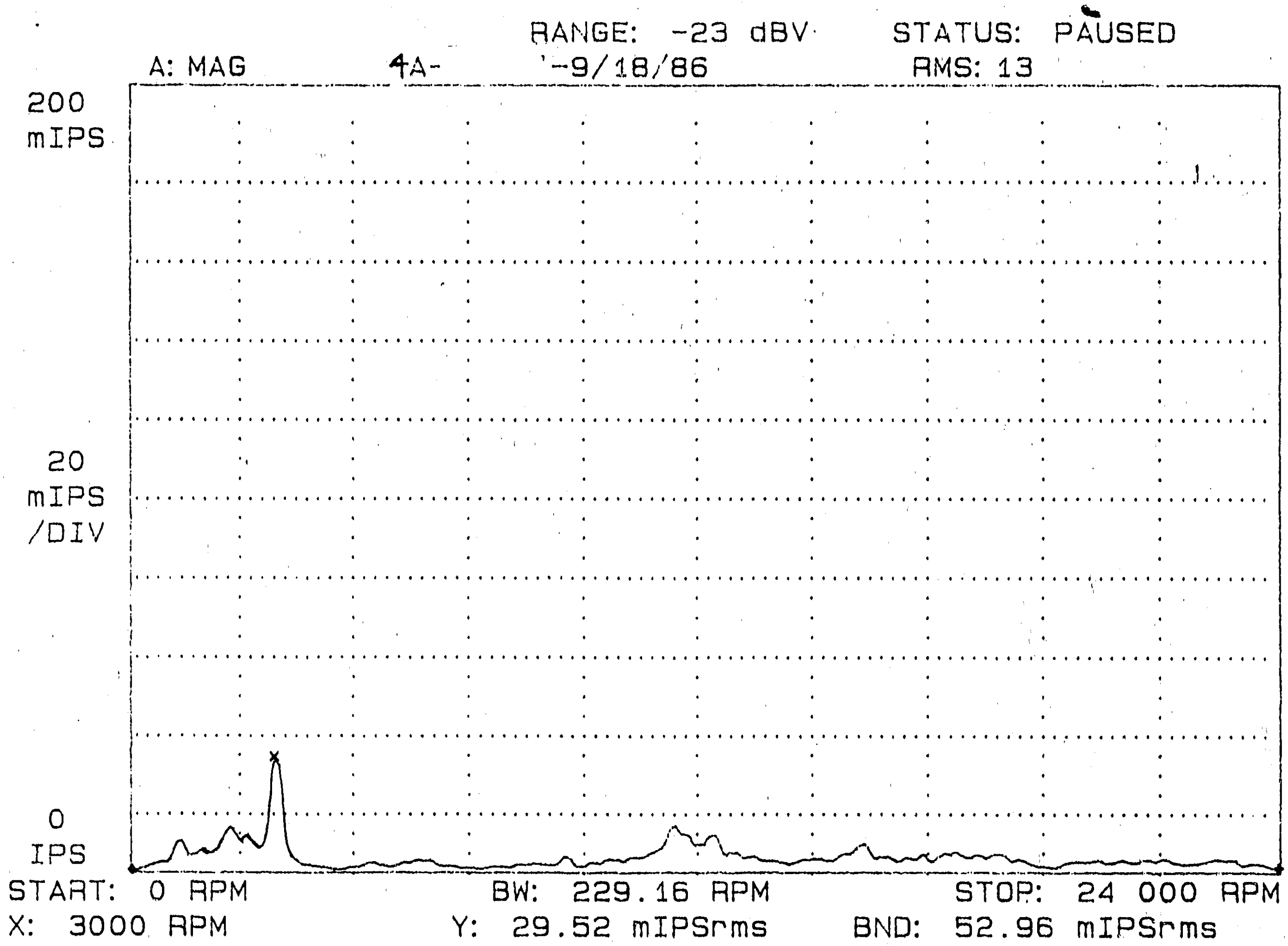


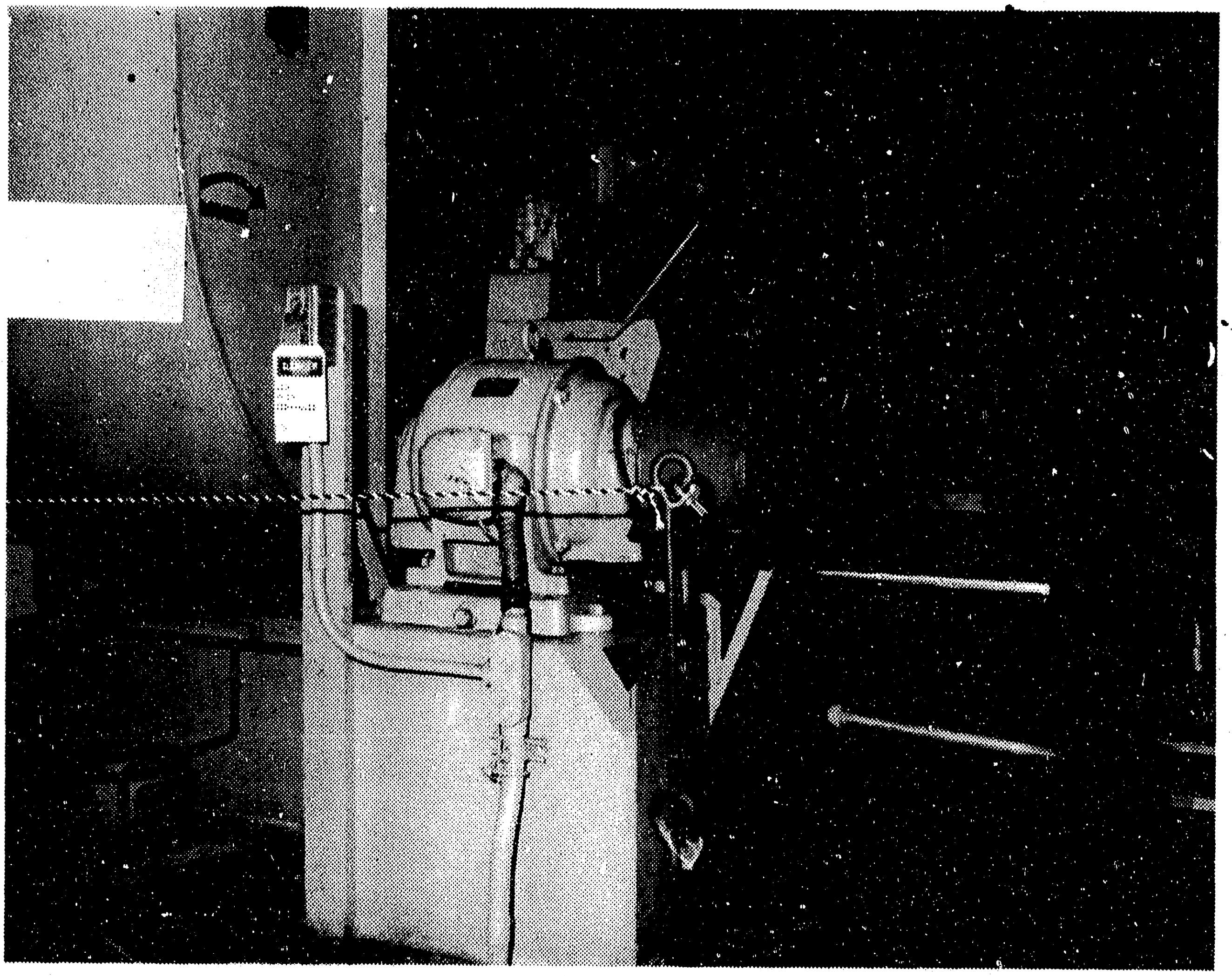
Figure 5. Axial vibration on outboard bearing following repairs

EXAMPLE 3

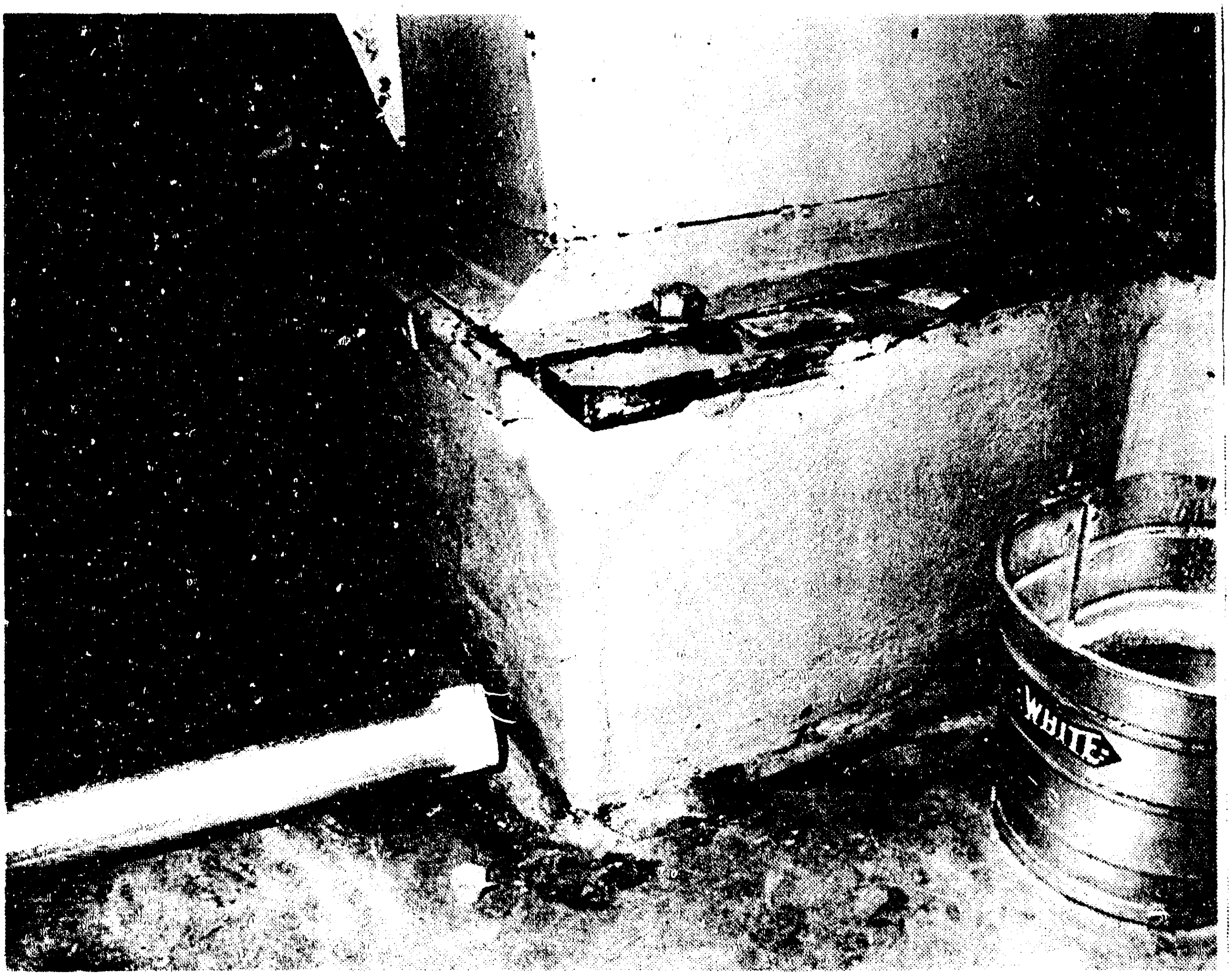
On a regularly scheduled vibration route, which are performed on a biweekly frequency, high vibration levels were detected on a ventilation fan (Picture 5). Readings were high on the two fan shaft bearings. Figure 6 is the vibration signature of the inboard fan shaft bearing in the horizontal direction, Figure 7 is the overall amplitude trend plot of this point, and Figure 8 is the waterfall (vibration signatures versus time) plot. From Figures 7 and 8, it can be seen that the overall level had been trending up from September of 1988 to February of 1989, and that the vibration signature was different from the prior signatures. The vibration signature in Figure 6 reveals the primary frequency of vibration was 1800 rpm, which is the fourth harmonic of the fan running speed. An interesting aspect of the overall vibration levels on the fan shaft bearings, was that the vertical readings were very high, in fact, on the inboard bearing, the vertical reading was higher than the horizontal, 0.22 ips-rms versus 0.16 ips-rms. Due to the structural of most equipment, vibration in the vertical direction is constrained more so than in the horizontal direction. The high vertical readings and the 4X running speed peak indicated that looseness was probably responsible for the vibration levels.

A visual examination was made of the unit to try and pin point the source of the looseness. It was observed that the fan shaft sheave was moving up and down. The vibration between components, such as the bearings and the structure they were sitting on, was checked to see if there was looseness between them. Everything was tight until the baseplate and concrete slab were examined. Picture 6 and 7 revealed the condition that was found. The baseplate was loose, allowing the whole structure to vibrate in the vertical direction. The grout around the baseplate was cracked and missing in spots and one hold down bolt had broken.

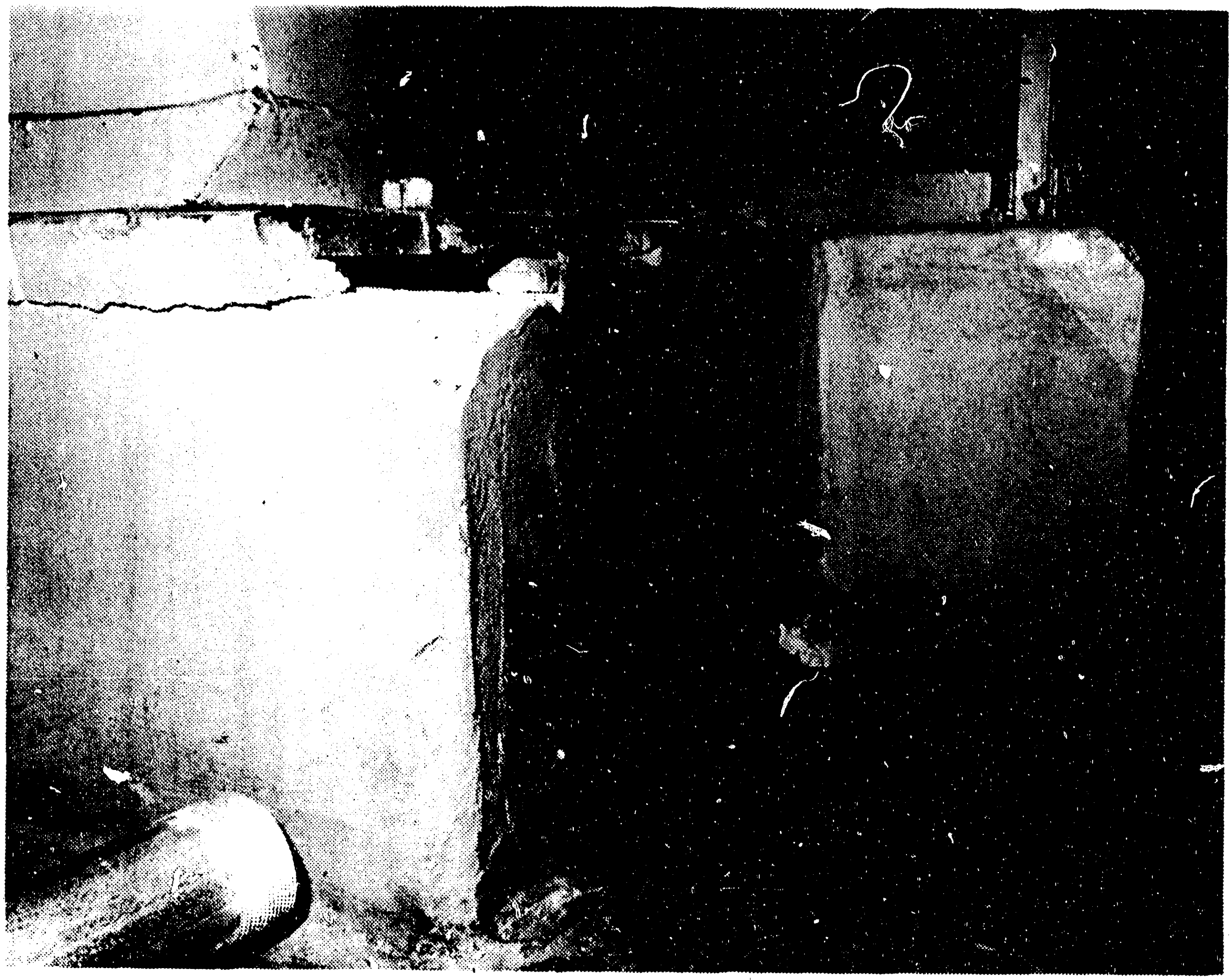
The foundation for the baseplate was repaired and the hold down bolt replaced. Figure 9 is the vibration signature following these repairs. As can be seen, a major reduction in vibration levels occurred.



Picture 5. Ventilation Fan



Picture 6. Base plate / foundation condition



Picture 7. Closeup of base plate / foundation

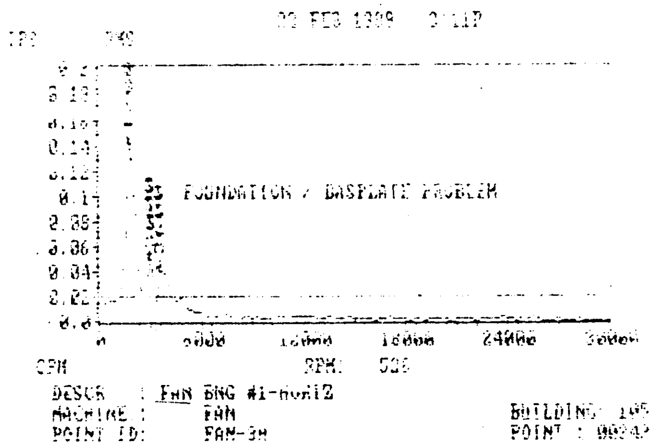


Figure 6. Vibration signature from a ventilation fan shaft bearing

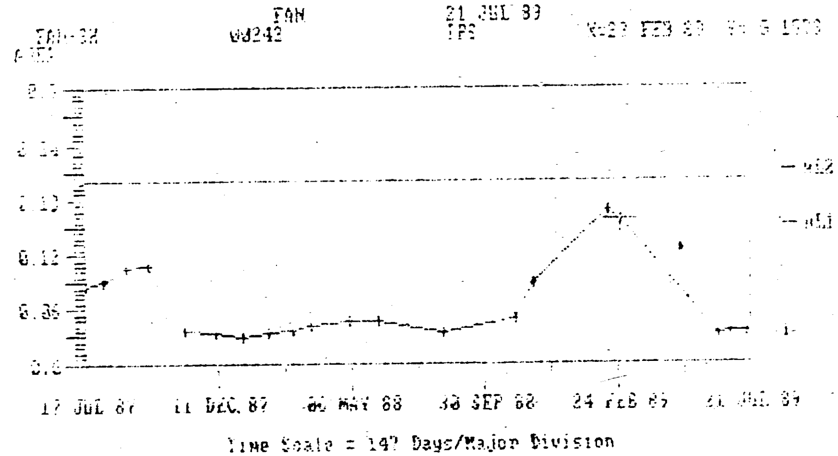


Figure 7. Trend plot of overall amplitude levels

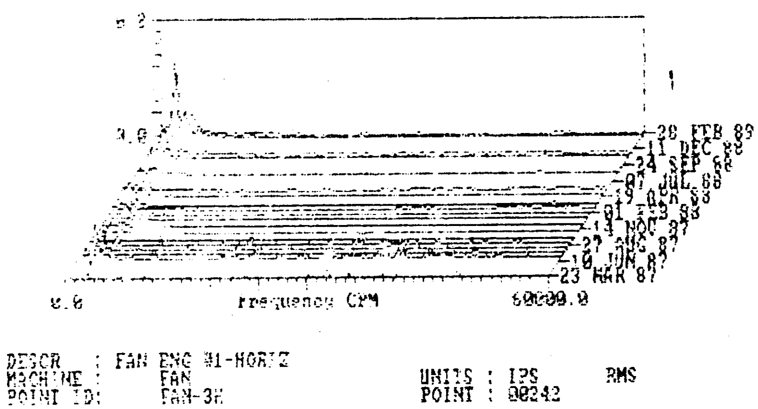


Figure 8. Waterfall of vibration signatures

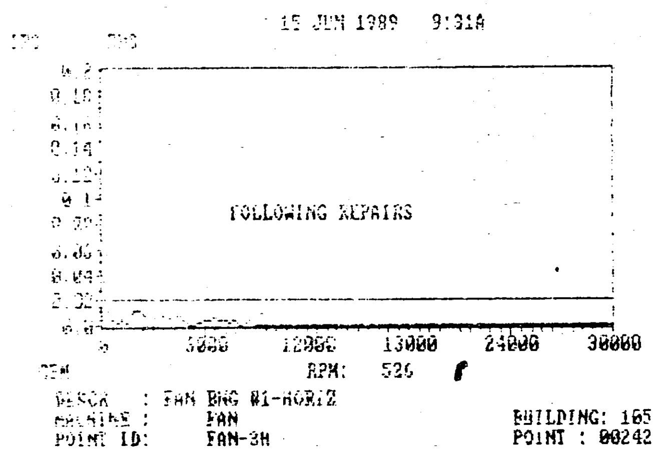
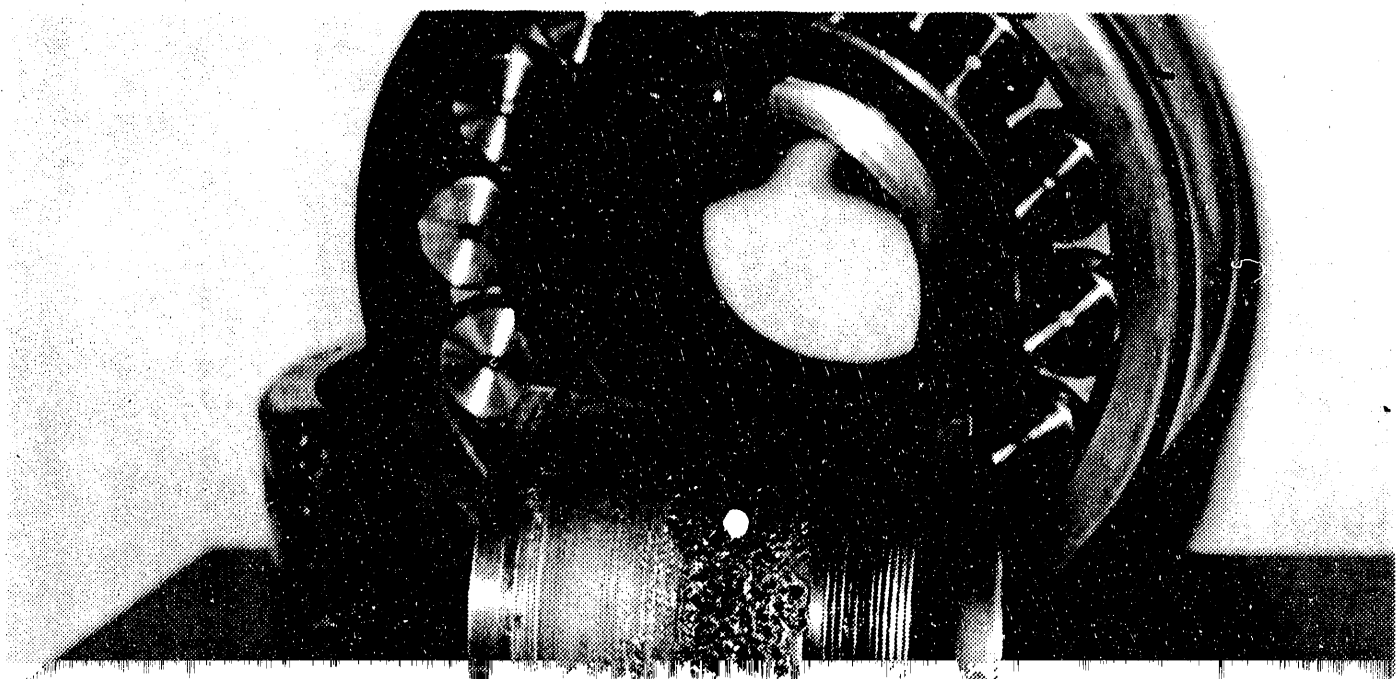


Figure 9. Fan shaft bearing vibration signature following repair

EXAMPLE 4

In a previous example, it was seen that the fourth harmonic of running speed can be an indication of looseness. It can also be an indication of slippage, such as a bearing turning in the housing or on the shaft. Figure 10 is the vibration signature from the fan shaft bearing of another ventilation fan. The major peak is the fourth harmonic of running speed, 1800 rpm. The trend plot of the overall amplitude for this plot (Figure 11) indicated a large increase had occurred between March and June. The fan was then not operated for a period of six months. The next set of readings taken on the fan exceeded the alarm value, causing further analysis to be performed. Based on the 1800 rpm primary vibration frequency, a report was issued to inspect the fan bearings for signs of turning on the shaft or in the housing. Picture 9 and 10 are of the bearing following its removal. It is a tampered bore bearing that uses a sleeve and a lock washer and nut to fix it to the fan shaft. When the bearing was open it was found that the lock nut had backed off the sleeve. The locking tab on the lock washer had broken, allowing it to do so (Picture 9). In Picture 10, the damage to the sleeve is evident. Sufficient heat was generated by the motion between the sleeve and inner race of the bearing to actually melt metal. Figure 12 is the vibration signature of the fan bearing following its replacement, a reduction from 0.23 to 0.02 ips-rms was achieved.

Picture 8. Fan shaft bearing after removal



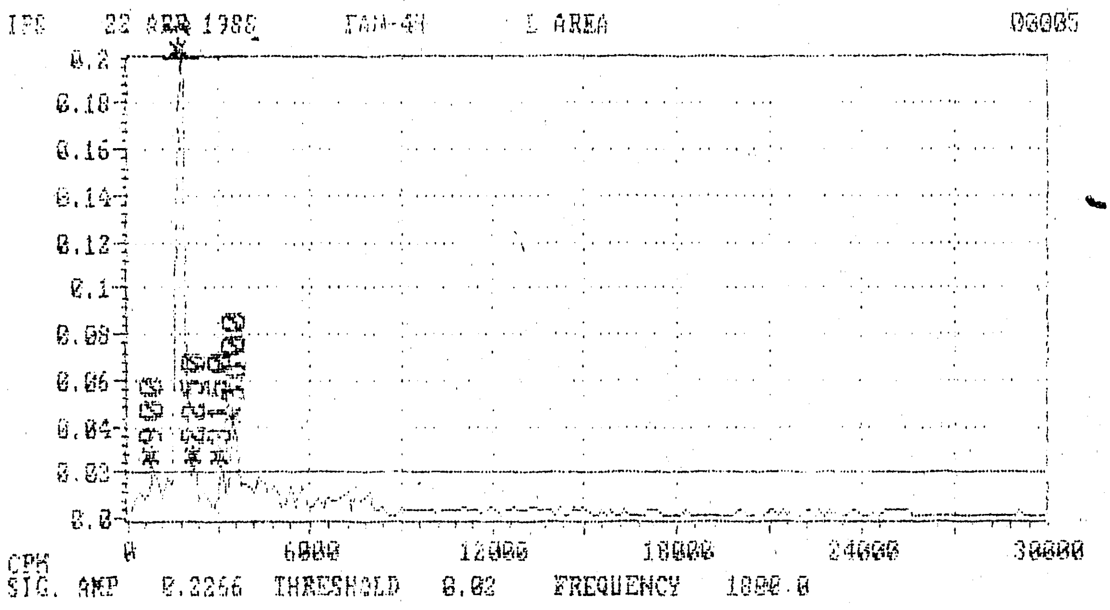


Figure 10. Ventillation fan shaft bearing vibration signature

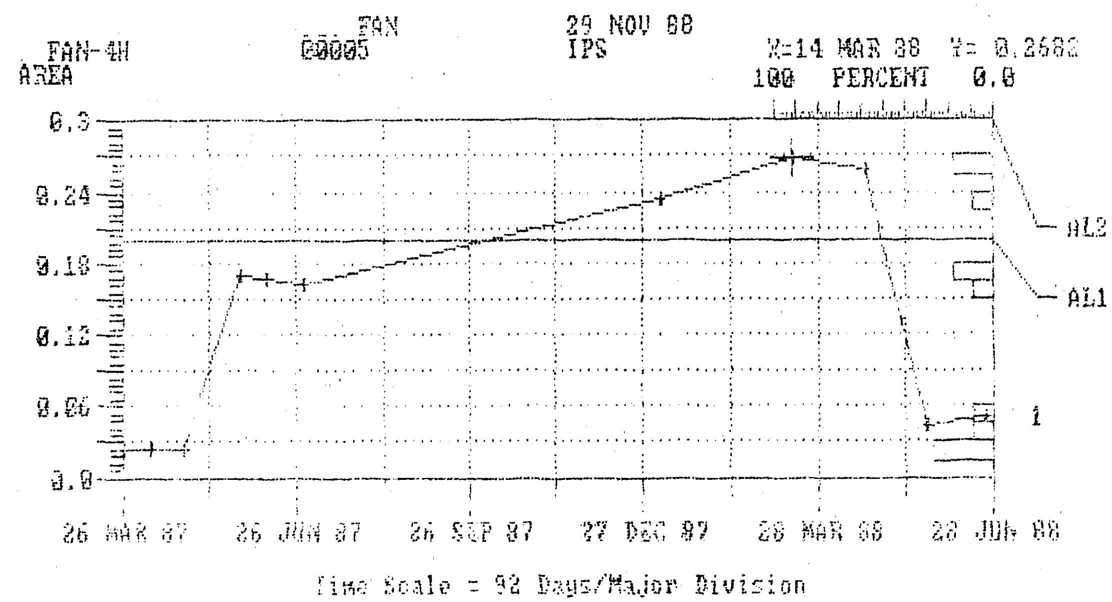


Figure 11. Trend plot of overall amplitude levels

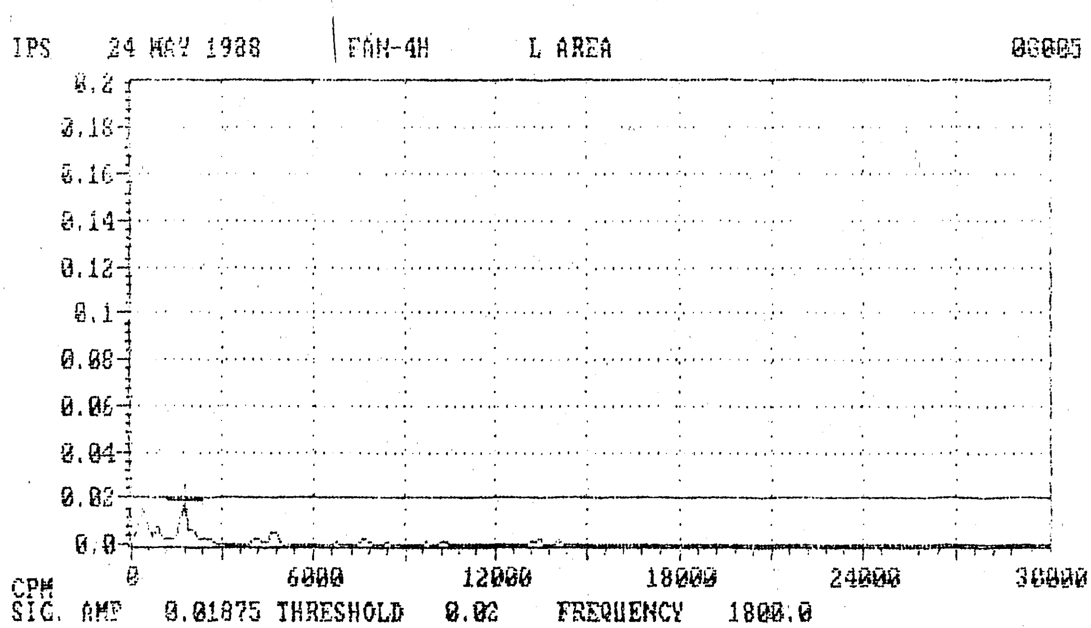


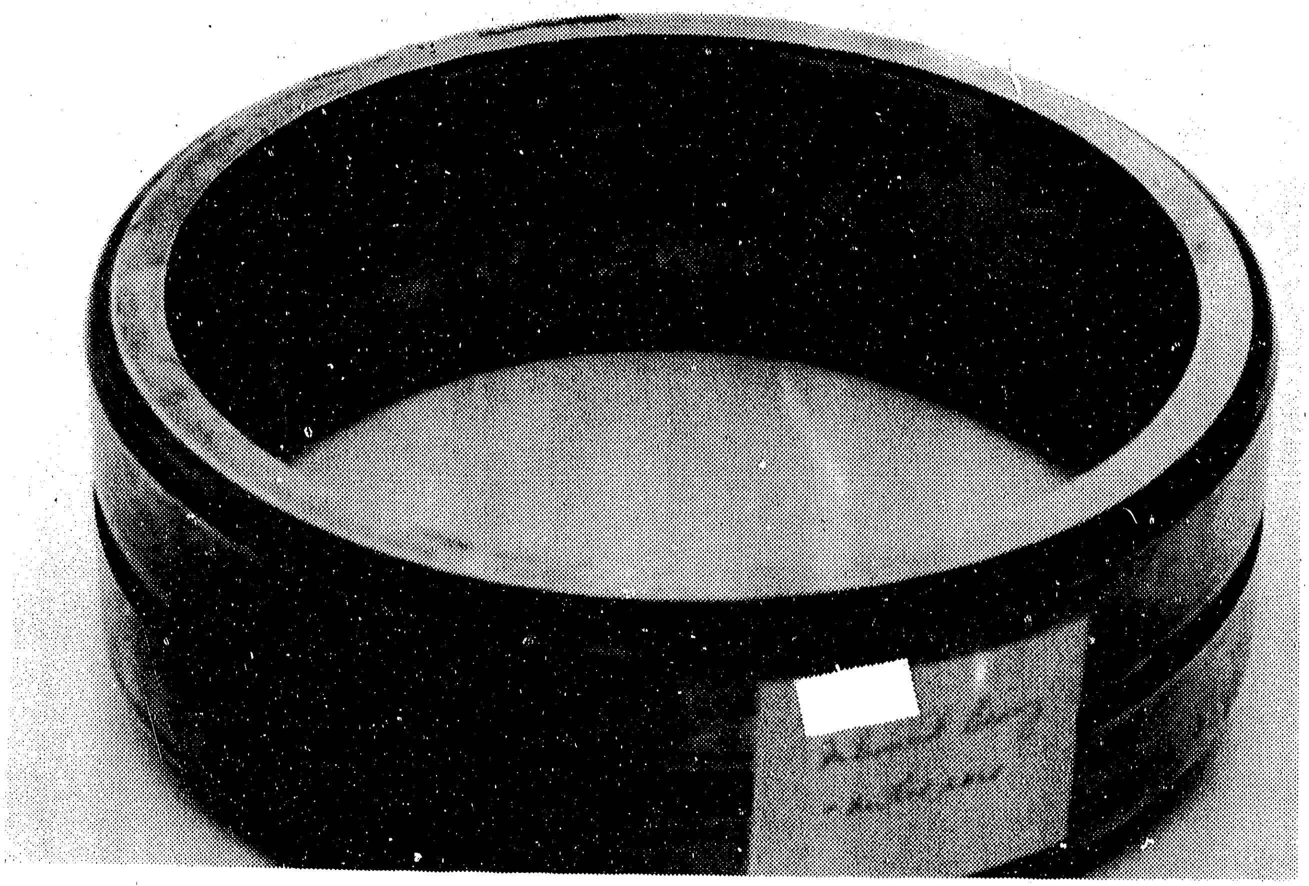
Figure 12. Fan shaft bearing vibration signature following repair

EXAMPLE 5

When a ball bearing begins to fail, it will often generate high frequency vibration. The frequency of vibration is typically occurs at one of the bearing failure frequencies depending on the nature of the defect. These frequencies are the ball pass frequency outer (BPFO) - defective outer race, the ball pass frequency inner (BPFI) - defective inner race, the ball spin frequency (BSF) - defective roller element, and the fundamental train frequency (FTF) - defective cage and rollers.

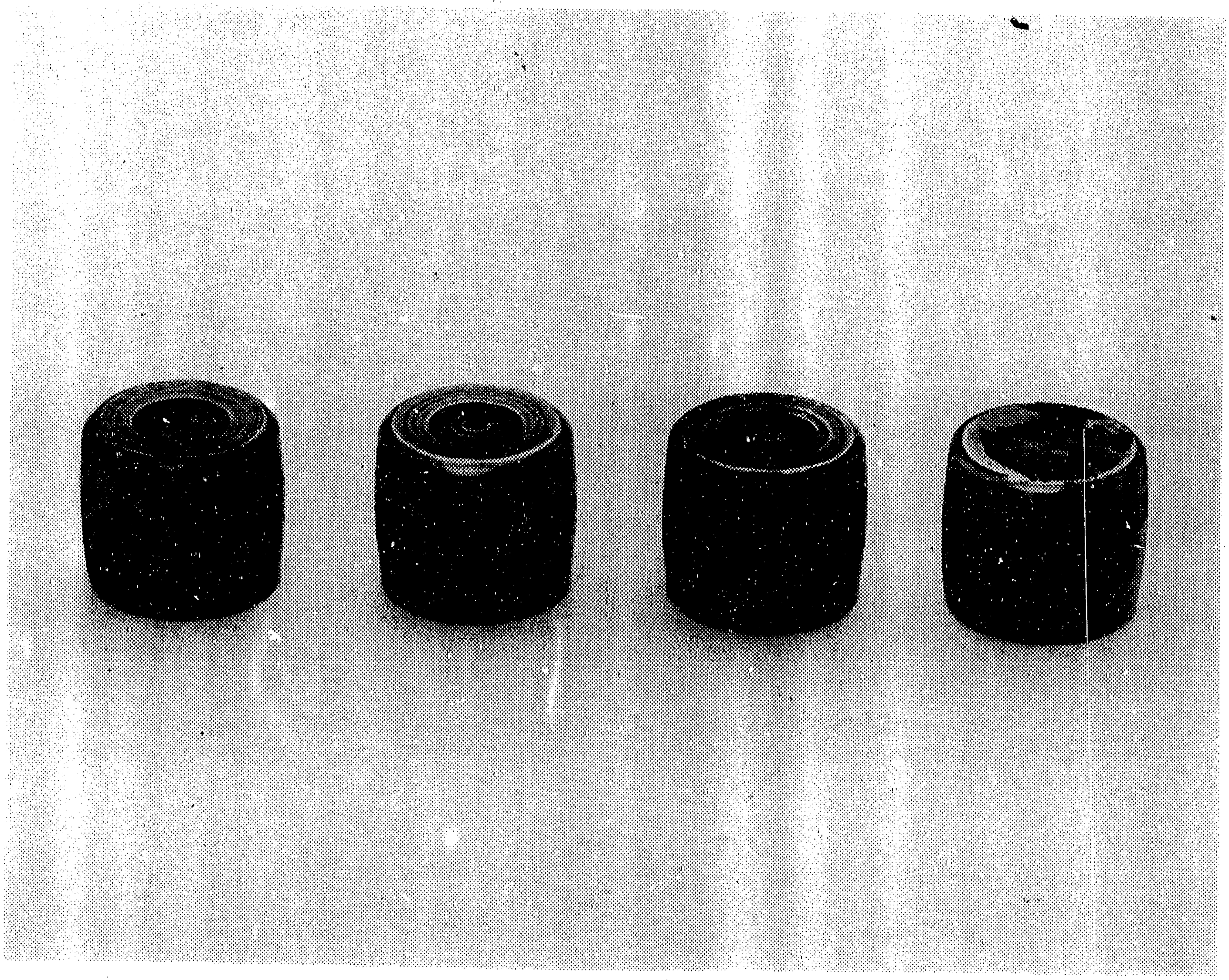
The vibration signature in Figure 13 is a typical signature for the inboard pump bearing of a Worthington pump. It is characterized by by a lone peak at 6300 rpm, which is the vane pass frequency for this pump. Figure 2 and 3 are the horizontal and vertical signatures collected on this bearing while the pump was being operated during a Start-Up Test. There was high frequency vibration present. Multiples of the BPFO, 5101 rpm (represented by vertical lines on Figure 14 and 15), and multiples of the 2X BSF, 4576 rpm, were present in the signatures. These indicated that the bearings had multiple defects present.

The pump was torn down and the bearings removed for examination. While the bearings were being removed, a great deal of water was observed to be in the bearing cavity. Picture 10, 11 and 12 are the outer race, inner race and some rollers from the bearing. Apparently the grease and water mixed forming an acid which etched the various surfaces of the bearing. These areas appear black in the pictures. This left the surfaces very rough and thus, the generation of the failure frequencies.



Picture 10. Inboard bearing outer race

Picture 11. Inboard bearing inner race



Picture 12. Inboard bearing rollers

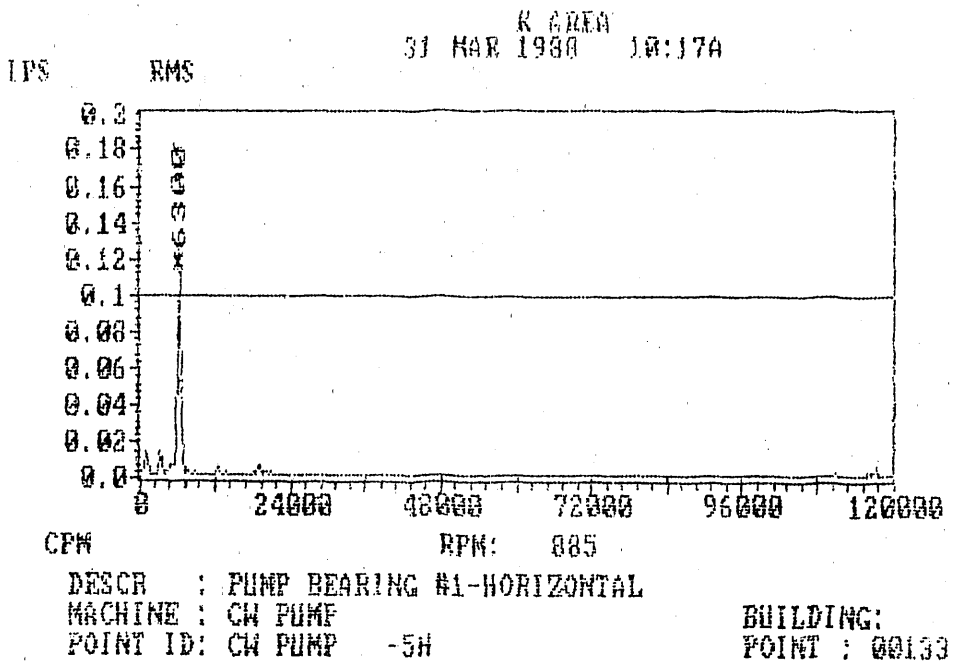


Figure 13. Normal vibration signature for inboard pump bearing

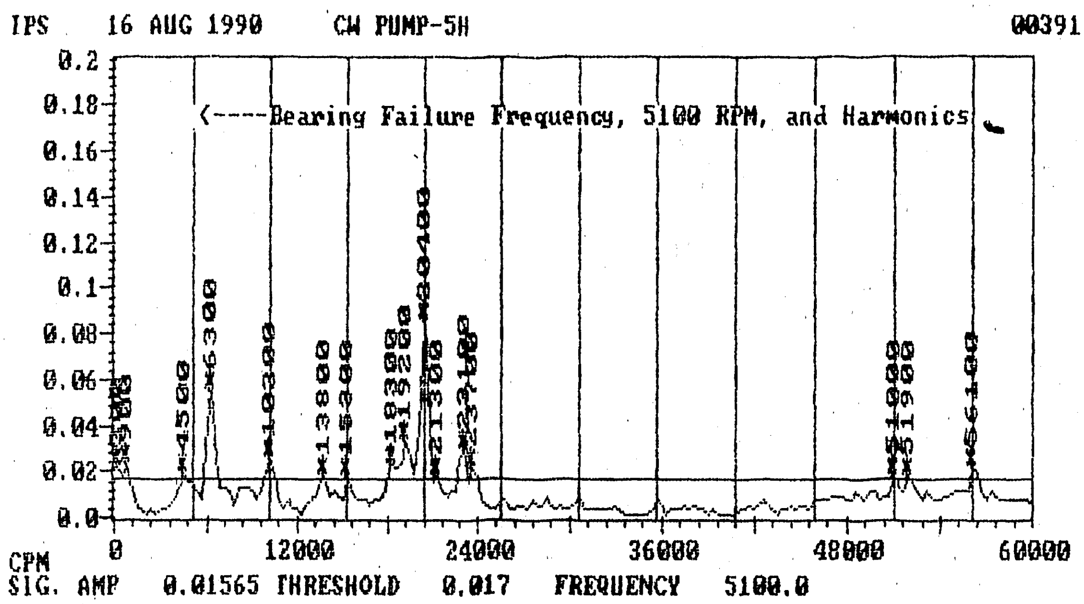


Figure 14. Horizontal vibration signature

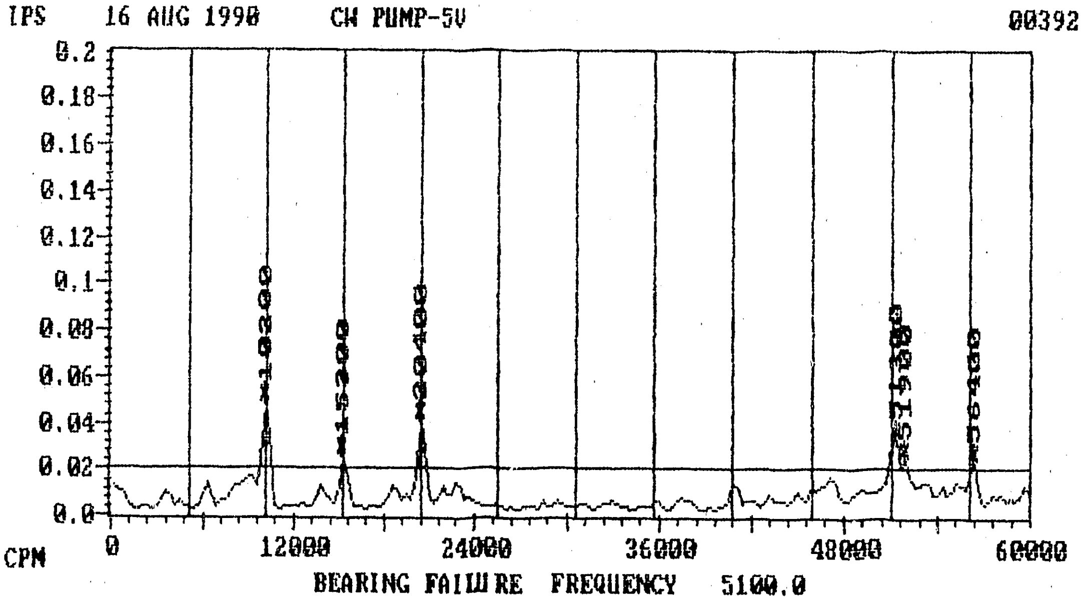
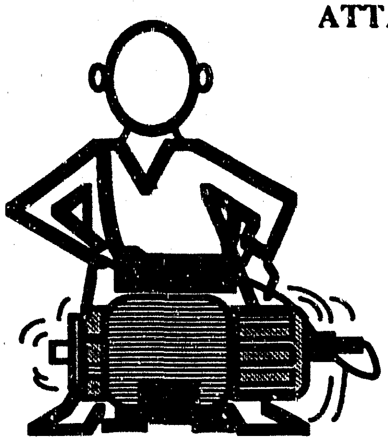


Figure 15. Vertical vibration signature

ATTACHMENT I OPS-VIB-900097



REACTOR MAINTENANCE'S MACHINERY VIBRATION MONITORING PROGRAM

VIBRATION REPORT

August 17, 1990

To: J. S. Pender, 704-K
RM Area Maintenance Manager

F. M. Grimm, 704-K
RM Area E & I Manager

From: R. S. Davis, 717-K
MVMP Specialist

M. M. Potvin, 717-K
MVMP Coordinator

Equipment Description: **Cooling Water Pump**

Date of Survey: 8/15/90
DPSOL or
Work Request requiring survey: ________
Vibration Report Number: 0890073

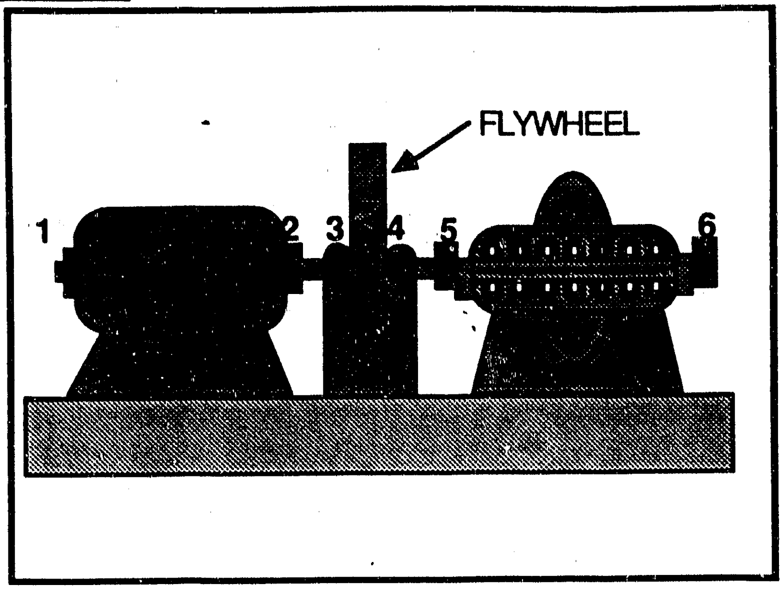
Microlog MTE #: 3190-015
Calib. Exp. Date: 6/14/91
Accel. MTE #: 3190-013
Calib. Exp. Date: 6/14/91

Machinery Condition and Recommended Action

__ **Danger** - Shut unit down immediately and repair
__ **Failure Near** - Run only if necessary and repair as soon as possible
_X_ **Faulty** - Repair at first convenient opportunity
__ **Satisfactory** - No Additional Work Required
__ **Other Action:**

CC: L. E. Weisner, 717-K
T. J. Lang, 717-K
M. J. Cercy, 717-K
R. F. Keenan, 704-K
A. J. Byrne, 704-P
Central Files, 703-A
Test Group, 704-K
Bobby Hanberry, 704-K

Sketch:



Vibration Readings (Filtered/Overall) in IPS-RMS

Bearing/ Position	Horiz	Vert	Axial
1	/.01	/.01	/.01
2	/.02	/.01	
3	/.02	/.02	
4	/.02	/.02	
5	.08/.21 (20,400 rpm)	.05/.16 (10,200 rpm)	
6	/.13	/.08	/.09

Comments:

The inboard pump bearing (#5) was detected to be noisy and running rough. Examination of the vibration signatures revealed that the vibration was occurring at 10,200 and 20,400 rpm, which are multiples of the ball pass outer race failure frequency (5100 rpm). This indicates a defect on the outer race of the bearing. Typically, the only frequency seen on this bearing is 6300 rpm, vane pass frequency. This bearing should be replaced before restart or continuous running of this pump. An NCR had been issued on this pump earlier, due to its bearings sitting in water. This may have contributed to the premature failure of these bearings.

Results of Vibration Analysis:

Inboard pump bearing (#5) has defects present on the outer race.

Repair Recommendations:

Replace the pump bearings.

Corrective Action:

Work Request Number: NL819

If the bearings are to be replaced, the old bearings should be tagged such that they will be kept for examination by MVMP personnel. Notify MVMP Coordinator at ext. 77274 so that arrangements to pick them up can be arranged. By inspecting the bearings, the ability of MVMP personnel to interpret vibration data can be enhanced.

ATTACHMENT II

Data Sheet #: 20

Machine Name : Secondary Cooling Water Pumps

Rev. 0

EP or EN # :

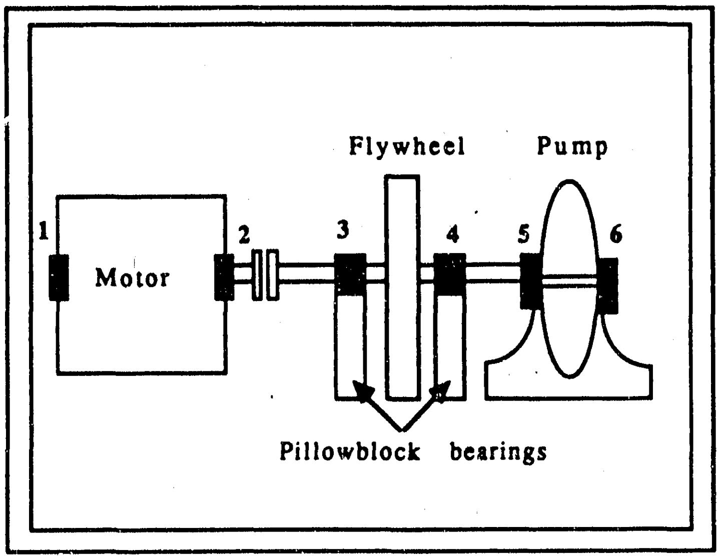
Location :

Purpose : Provide cooling water to heat exchangers inorder to remove heat from process water

Machinery Classification

☐	**Class I**	- Critical, not spared
☐	**Class II**	- Critical, spared
☐	**Class III**	- Noncritical
☐	**Class IV**	- Problem Units

Equipment Diagram



Frequency of Monitoring

Periodic :	**Weekly**	☐
	Biweekly	X
	Monthly	☐
	Other	☐
Event Triggered/ Trouble Shooting		☐
Continuous		☐

Evaluation Criteria

Overall levels - 0.05 ips-rms on motor and flywheel
0.10 ips-rms on pump except on 5H - 0.20 ips-rms

Trend - Positive increase in the overall level in excess of 100%

Vibration Signature - Comparison to baseline - new peaks in excess of 20% of 1X component

Process Parameters to Monitor

Note motor amperage and pump discharge pressure at the center console.

Additional Machine Information

Running Speed : 895 rpm

Driver : Electric motor

Size : 600 hp

Manufacturer : General Electric

Bearings : [X] Journal or plain

[ ] Rolling element

Maunf. & Number :

1).

2).

Running Speed :

Driver :

Size :

Manufacturer :

Bearings : [ ] Journal or plain

[ ] Rolling element

Maunf. & Number :

1).

2).

Driven : Pump

Manufacturer : Worthington

Bearings : [ ] Journal or plain

[X] Rolling element

Maunf. & Number :

1). SKF 22317C

2).

Driven : Flywheel

Manufacturer :

Bearings : [ ] Journal or plain

[X] Rolling element

Maunf. & Number :

1). SKF 22317C

2).

Monitoring Locations & Type

Bearing No.	Position	Vib. Signature *	HFL	Freq Range	Alarm Levels	HFD Eval Crit
				(cpm)	(ips-rms)	(g's-rms)
1	Horiz	X		120-30K	.05/.10	
	Vertical			120-30K	.05/.10	
	Axial			120-30K	.05/.10	
2	Horiz	X		120-30K	.05/.10	
	Vertical			120-30K	.05/.10	
3	Horiz	X	X	120-120K	.10/.15	
	Vertical			120-120K	.10/.15	
4	Horiz	X	X	120-120K	.10/.15	
	Vertical			120-120K	.10/.15	
5	Horiz	X	X	120-120K	.20/.30	
	Vertical			120-120K	.10/.15	
6	Horiz	X	X	120-120K	.10/.15	
	Vertical			120-120K	.10/.15	
	Axail			120-120K	.10/.15	

* Vibration signatures will be collected on any point on which the overall value exceeds the overall evaluation criteria.

Potential Machinery Faults

	Condition	Characteristics
1).	Vane pass	6240 cpm (7X running speed)
2).		
3).		
4).		
5).		

Bearing Failure Frequencies (cpm)

Bearing Manuf. & Model #	Ball Pass Freq. Outer	Ball Pass Freq. Inner	Ball Spin Freq.	Fundamental Train Freq.
SKF 22317C	5101	7411	2288	364

END

DATE FILMED

02 / 14 / 91