

Paper to be presented at the P/PM Technology conference being held
in Indianapolis, Indiana, December 6, 1995

CONF-951282--1

**The Use of the Motor as a Transducer
to Monitor Pump Conditions**

by

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Research sponsored by the U.S. Department of Energy, under contract DE-AC05-84OR21400 with Lockheed Martin Energy Systems.

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ABSTRACT

Motor current and power analysis methods have been developed to assist in the condition monitoring of a variety of motor-driven devices. The early work in this area was conducted at Oak Ridge National Laboratory (ORNL) on motor-operated valves in the mid-to-late 1980's in support of the U. S. Nuclear Regulatory Commission's Nuclear Plant Aging Research Program. The successful implementation of motor current signature analysis (MCSA) as a diagnostic for valves led to its application to other devices and to refinements in the methodologies used.

Early application of MCSA to centrifugal pumps, conducted in a more or less random fashion in the late 1980's identified discrete spectral components associated with the motor itself, as well as broadband noise (particularly at low frequencies) that was initially referred to as "flow noise". Response to some system natural frequencies was also observed. The absence of programmatic interests resulted in little additional investigation at that time.

In the last few years, work for the Nuclear Regulatory Commission and independent activities at ORNL and the Y-12 defense plant have resulted in additional, more thorough consideration of the merits of using motors as transducers for understanding pump conditions. A variety of pump applications, ranging from 5 to over 1200 horsepower have been analyzed, including low and high specific speed and suction specific speed pumps. For some of the pumps, the full range of flow conditions from shutoff to runout has been studied.

Motor current and power analysis have been found to provide information that is complementary to that available from conventional diagnostics, such as vibration and pressure pulsation analysis. Inherent signal filtering associated with rotor to stator magnetic field coupling does limit the high frequency response capability of the motor as a transducer; as a result, certain phenomena, such as vane pass energy, is not readily apparent in the motor electrical signals. On the other hand, the motor-monitored parameters have often been found to be much more sensitive than vibration transducers in detecting the effects of unsteady flow conditions resulting from both system and pump specific sources such as suction cavitation. By combining motor equivalent circuit models with pump performance characteristics, shaft power and torque fluctuation estimates have been assessed.

The usefulness of motor data in assessing some common sources of pump problems, such as mechanical and hydraulic imbalance, misalignment, and unstable flow conditions is shown. The results of testing several motor-driven pumps, including comparisons with vibration and pressure pulsation analysis are discussed. The development of a single figure of merit for pump load stability (as a function of pump flow rate and type) is presented.

performance is evident. Further, field performance of individual pumps may vary dramatically from both generic pump curves and even the performance of the specific pump in a flow test loop where physical layouts tend to be more optimized than is often the case in the field. In the absence of good baseline performance data for pumps and their motors in the field-installed configuration, it is a challenging proposition to estimate hydraulic performance parameters such as head and flow, even for pumps with well-defined power/flow relationships (such as the auxiliary feedwater pump of Figure 2).

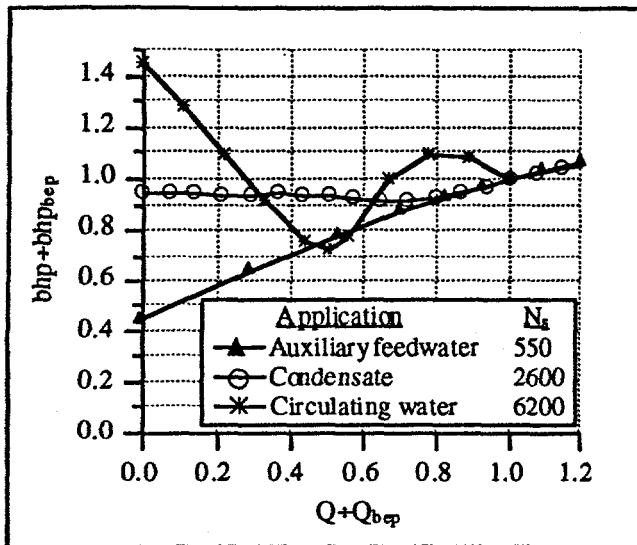


Figure 2. Example Pump Shaft Load vs Flowrate Curves

HOW CAN MOTOR DATA HELP UNDERSTAND PUMP CONDITIONS?

With these inherent difficulties, one might question whether any useful information can be extracted from motor performance data. Experience has shown that there are some useful insights that can be gained.

It is important to recognize that motor and pump performance curves such as those shown in Figures 1 and 2 are typically based on measurements averaged over periods of seconds or minutes. On an instantaneous basis, significant departure from these average values may occur. For example, the head and flow developed by a pump at low-flow conditions are often less stable than when the pump is operated near its best efficiency point. The instability may consist of both some relatively well-defined frequency components, such as vane-passing as well as more chaotic instabilities that are manifested as broad band noise. When such instabilities affect shaft torque (and as a result, motor load), it becomes possible to detect both the existence and magnitude of the instabilities, at least in a relative context.

To a great extent, vibration monitoring is a useful diagnostic technique because of similar considerations. Accelerometers, for example, do not measure absolute forces for rotating

equipment; rather, they sense the acceleration occurring in response to fluctuations in forces. The long history of vibration monitoring has provided a basis for not only rules of thumb, but industry standards.

At this point in time, there is minimal experience in the use of motor-transduced data as a pump diagnostic. At ORNL and at the Y-12 defense plant, motor current and power data for pumps and other equipment have been collected over the last few years. Motor current or power has been found to provide insights into both the monitored component specifically and to overall system conditions, as well. The balance of this paper will discuss examples of the types of results that have been found, with principal focus on issues that are relevant to pumps.

COMPARISON OF THE SENSITIVITY OF MOTOR INPUT POWER AND VIBRATION MEASUREMENTS TO COMMON SOURCES OF VIBRATION

From test data acquired on a variety of types of equipment over several years, fluctuations in motor spectral data that are related to some load component have been observed. In many cases, researchers and test personnel have been content to observe the existence of some load-related peak in the spectral data, and perhaps trend the amplitude with time. It was noted during certain tests that there were characteristic peaks in the motor current or power spectra that also existed in vibration spectra. Motor power and pump vibration spectra for a belt-driven positive displacement vacuum pump are shown in Figures 3 and 4. The loads associated with belt pass, pump stroke, and motor running speed can be clearly seen in the motor power spectrum. Some, but not all of the spectral peaks also appear in the vibration spectrum; the most noticeable difference is the absence of most of the belt pass frequency components from the vibration spectrum. This is typical for belt-driven devices, and is due to the torsional load fluctuations associated with both belt irregularities and belt looseness. While loose belts can result in elevated vibration in the radial direction, the radial effect is not nearly as dramatic as the torsional effect. As a result, radial vibration is often minimal, as was the case for the vacuum pump.

Positive displacement pumps, by their very nature, involve considerable torque fluctuations at the drive shaft during individual compression sequences. These torque fluctuations are readily transduced by the motor; as a result, the spectral amplitudes associated with pump compression frequencies are usually distinct (e.g., Figure 3), and are very sensitive to flow and head changes.

BACKGROUND

Almost all motor-driven devices, including motor-driven pumps, experience fluctuating loads. The types of load fluctuations are dependent upon the specific design features of the device and the system within which it is operated. The load fluctuations can be periodic or chaotic in nature. For those loads which are periodic, the period can vary from fractions of milliseconds to months or years.

The relatively straightforward recognition that the motor speed (for induction motors), current, power and power factor change in response to load changes led investigators studying potential means of diagnosing motor-operated valve conditions to evaluate the usefulness of the motor as a transducer in the 1980's [1]. The ability to identify a variety of load-related phenomena, such as lubricant degradation and gear tooth wear, by use of demodulated motor current was demonstrated. The researchers dubbed the methodology of analyzing the time and frequency domain current signals to understand the driven device conditions motor current signature analysis (MCSA). The application of this term has since been applied rather broadly to a variety of waveform and spectral analysis techniques, and has been used when characterizing both the motor and the driven device.

Probably the most common use of current monitoring is by operators simply observing permanently installed ammeter readings to verify that the motor is energized and that its current draw is consistent with expectations. In a diagnostic sense, spectral analysis of the motor current has been used to help understand the condition of the motor, with primary focus on rotor eccentricity and rotor conductor condition.

While the use of motor current data is helpful in understanding motor electrical and magnetic field conditions, this paper is focussed on understanding other conditions in the drive train. There are both some relatively straightforward as well as more complex applications of motor current or power data. This paper will not discuss in detail either the theory behind the approaches used to extract useful diagnostic information nor the various types of instrumentation used, but will rather identify some examples of effects that can be identified.

In no way is it the intent of this paper to suggest that motor current or power analysis be considered as a replacement diagnostic for technologies such as vibration. There are clearly many defects and conditions detectable through vibration measurements, for example, that are not detectable through the motor data. However, there are some conditions for which motor data is more sensitive than most other diagnostic methods. There are also situations where it is easier to implement than many other techniques. Finally, it can be useful in confirming indications developed from other diagnostic techniques.

TYPICAL MOTOR AND PUMP PERFORMANCE CHARACTERISTICS

The early applications of motor current signature analysis focussed on current specifically because of the ability to acquire current data in a relatively non-intrusive fashion (using a clamp-on current transformer, for example), as opposed to the somewhat more intrusive nature of power and power factor measurements which require direct connection to the motor supply leads.

A typical motor performance curve for a 4-pole 150 hp motor is shown in Figure 1. Note that the input power is very linear with output power across the full range of motor load; over the range from 50 to 150 bhp, the current is essentially linear as well. The power factor is relatively insensitive to load variations within this region, particularly near rated load. At very light loads, the current response to load changes is small, while the power factor changes dramatically with relatively small changes in motor load. Motor performance curves do vary somewhat for different designs, but the general performance characteristics are not dramatically different in the normal operating range.

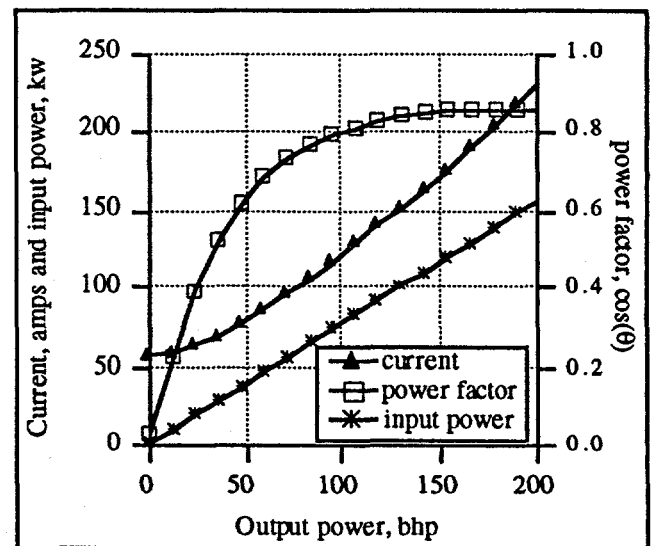


Figure 1. Typical Motor Performance Characteristics

There are complicating factors, such as deviation of actual bus voltage from design and power quality-related issues, that limit the accuracy of generic, or even motor-specific curves. However, a variety of motor models have been developed recently which have been found to be capable of predicting motor output power accurately to within three percent or better [2].

Pump shaft power performance curves are, on the other hand, much more widely varied. Example power vs flow curves for three centrifugal pumps with specific speeds ranging from 550 to 6200 are shown in Figure 2. The inherent difficulty in using shaft power measurements alone to understand pump

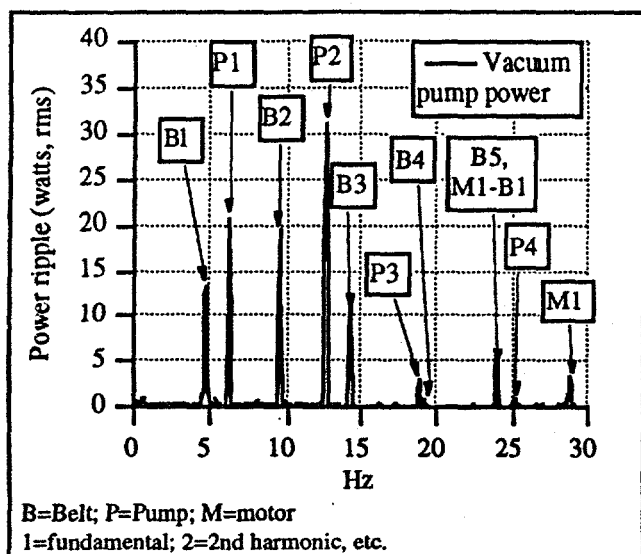


Figure 3. Motor Input Power Spectrum for Belt-Driven Vacuum Pump

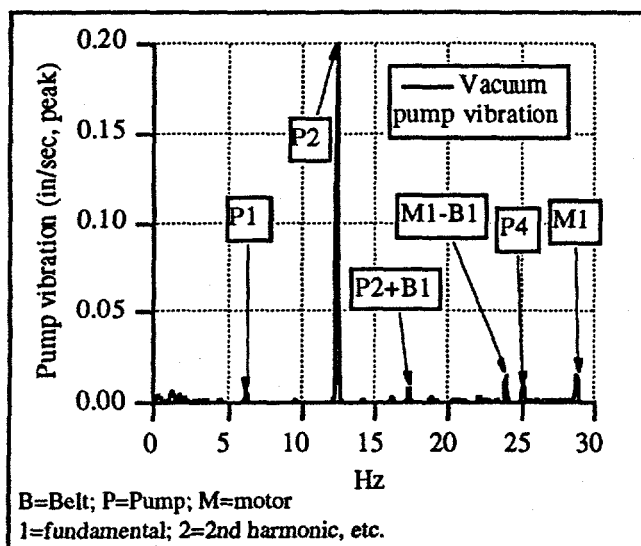


Figure 4. Vacuum Pump Vibration Spectrum

In general, motor-based measurements are more sensitive to torsionally-related loading than radial or axial vibration data. On the other hand, the motor is, generally speaking, a relatively poor transducer of radial and axial vibration that is not accompanied by torsional loading. Fundamentally, in order for a radial or axial load fluctuation to be seen in motor data, the radial or axial load must either result in relative motion between the motor rotor and stator and/or cause a change in torsional load.

SENSITIVITY TO MECHANICAL UNBALANCE

A comparison of the results of vibration and motor data measured during tests conducted to measure the effects of unbalance and alignment have validated the observation that the motor, as a transducer, is primarily sensitive to torsional

loads. In a controlled balance test performed at Oak Ridge, measurements of motor input and output data and vibration amplitude were made as the mechanical balance of a motor was changed. For this test, a 4-pole, 50-hp motor was connected to an eddy-current brake dynamometer, and the mechanical balance was changed by using a dynamic balancing device provided by Balance Dynamics, Inc. The dynamic balancer allows for on-line balancing of rotating equipment by moving fluid between chambers in a wheel attached to the shaft. The primary purpose of the test was to determine if mechanical balance had any effect on motor efficiency. While there was marginal, if any, effect on motor efficiency, a relatively well defined correlation was found between radial vibration and motor input power spectra. A plot of the energy of a running speed-related frequency from the motor power spectrum vs motor inboard horizontal vibration velocity is provided in Figure 5. This almost linear relationship is not necessarily reflective of all types of unbalance. For the test in which the Figure 5 data was acquired, the balance wheel was located between the motor and the coupling. In field testing conducted on a 6000-hp fan motor, where two balancing wheels were used on the inboard and outboard ends of the fan, there was no observable change in motor spectra as the balance was changed. In the case of the 50-hp motor, it is likely that the unbalance forces resulted in slight dynamic changes in rotor to stator air gap, and thus was reflected in the motor data, while for the 6000 hp motor, the unbalance location (on the fan side of the coupling) affected neither the torsional shaft load nor the rotor to stator air gap.

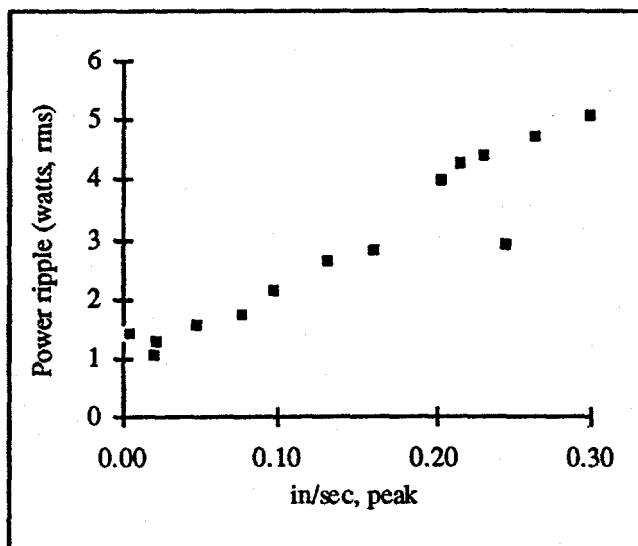


Figure 5. Power Ripple vs Vibration Amplitude - Running Speed-Related Components for an Unbalanced Rotor

In general, motor data is very insensitive to mechanical unbalance. Note that even for the data shown in Figure 5, only a few watts of energy are involved. The motor was being run at its rated condition of 50 hp (output). The motor input power was about 41000 watts. About 0.01 percent or less of the motor energy was associated with the unbalance. On the other

hand, the vibration data was dominated by the mechanical unbalance. Thus, although mechanical unbalance may be detectable from careful analysis of motor data, it is neither a reliable nor sensitive indicator of unbalance, particularly when the unbalance exists on the driven device side of the coupling.

SENSITIVITY TO MISALIGNMENT

Because misalignment fundamentally results in not only radial and axial vibration, but torsional loading, the motor has been found to be a very sensitive transducer of misalignment. Testing at the Y-12 plant is presently assessing the effects of alignment on motor system efficiency. In conjunction with this testing, the sensitivity of motor and vibration data to alignment changes are being evaluated.

Motor inboard vibration, output torque, and input power spectral data for a 10 hp, 4-pole motor after laser alignment to the dynamometer are shown in Figures 6-8. Spectra for the same parameters with the motor outboard feet elevated by 20 and 30 mils are shown in Figures 9-11 and 12-14, respectively.

The running speed and two times running speed motor power (input) ripple and vibration velocity vs output torque ripple for these and several other misalignment conditions are shown in Figure 15 and 16. Note that the amplitude of vibration is very low, even for the most severely misaligned condition (motor inboard feet elevated by 40 mils).

HYDRAULIC CONDITION MONITORING USING MOTOR DATA

In addition to being very sensitive to misalignment conditions, motor-monitored parameters have been found to provide some insights into the hydraulic conditions for pumps, specifically with regard to the stability of the pump operation.

Spectral power data for three pumps at near the best efficiency point flow and at minimum flow conditions are shown in Figures 17-22. Pump design information for the three pumps is provided in Table 1. The spectral power data is presented as normalized power - that is, the spectral rms power divided by the average running power. By so normalizing, the power data

for different pump sizes and styles can be more readily compared.

There are several features of note in the power spectra for the three pumps:

- In general, as the flowrate is reduced from near BEP to minimum flow conditions, the level of low frequency noise in the motor power spectrum increases. This pattern has been observed in essentially all pumps studied.
- There are considerable variations in response to reduced flow. In particular, note that the spectral noise level for the two higher suction specific speed pumps (pumps A and C) grew much more dramatically than did that for pump B.
- The amplitude of the running speed peak for pump B is significantly greater at both flow conditions than for the other pumps. In the limited data collected on double suction pumps, it has generally been found that they are more likely to have higher running speed load fluctuations than single suction pumps. It is hypothesized that this may be due to the greater difficulty in manufacturing double suction pumps that are flow-wise symmetrical. Any such asymmetries which result in fluctuating head development at rotating speed (or harmonics) would also result in torsional load fluctuations.
- The relative amplitude of the running speed peak for all three pumps increased as flow was reduced. This is due, in part, to the fact that the data are shown in a normalized fashion (normalized to average power), and the power at the lower flow rates for all three pumps is less than at near BEP. Even accounting for this factor, however, the running speed energy level is still higher at low flow condition.
- For both pump A and C, very low frequency load fluctuations were observed at the BEP conditions. For pump A, the frequency was less than 1 hz and poorly defined; for pump C, the spectral peak is relatively well defined, and is annotated in Figure 22 (1.45 hz). In the case of pump A, the apparent cause was system surge effects. For pump C, the peak was observed to occur from

Table 1. General Pump Design Information

Parameter	Pump A	Pump B	Pump C
General style	Horizontal, single suction	Horizontal, double suction	Horizontal, single suction
Flowrate (gpm)	2000	1000	200
Nominal speed (rpm)	1780	1765	3500
Head at BEP (ft)	137	170	100
Specific speed	1990	1185	1570
Suction specific speed	12750	5760	10700
Motor power rating (hp)	75	50	7.5
Number of impeller vanes	6	8	5

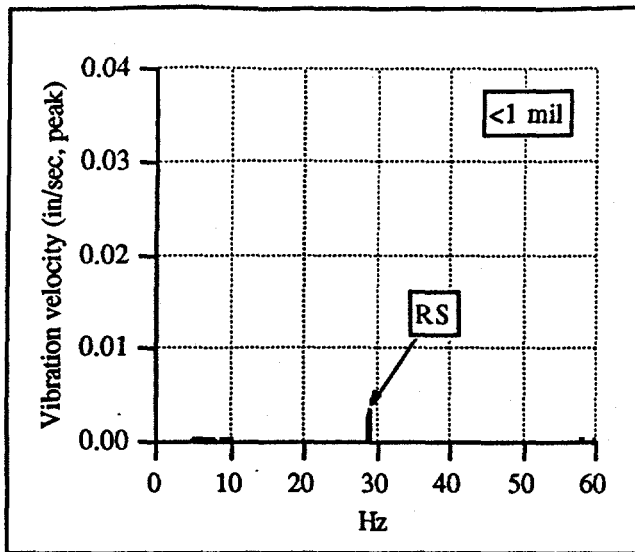


Figure 6. Well-Aligned Vibration Spectrum

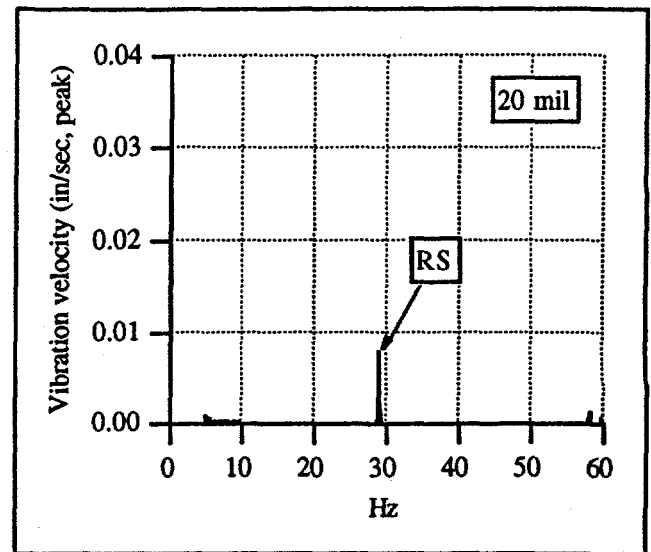


Figure 9. Vibration Spectrum with 20 Mil Shim

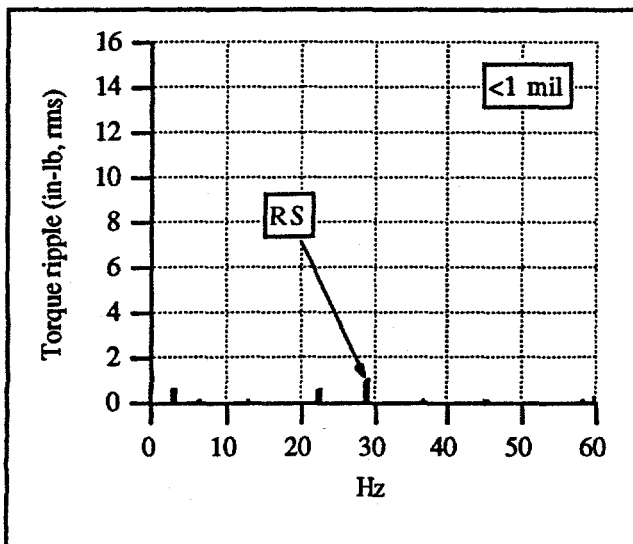


Figure 7. Well-Aligned Torque Ripple Spectrum

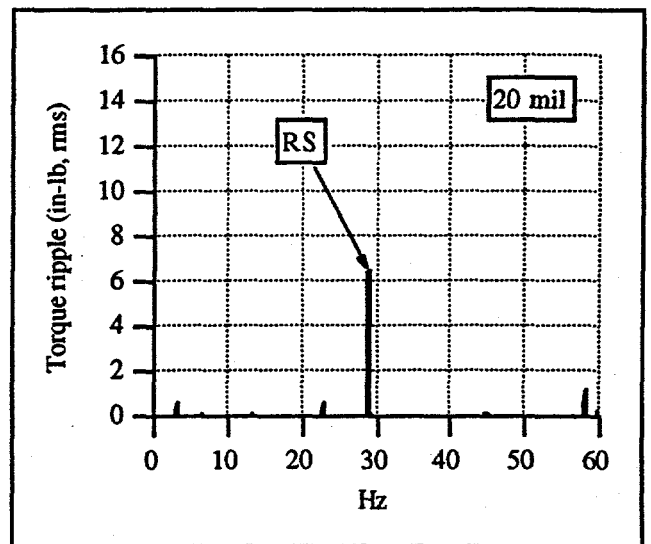


Figure 10. Torque Ripple Spectrum with 20 Mil Shim

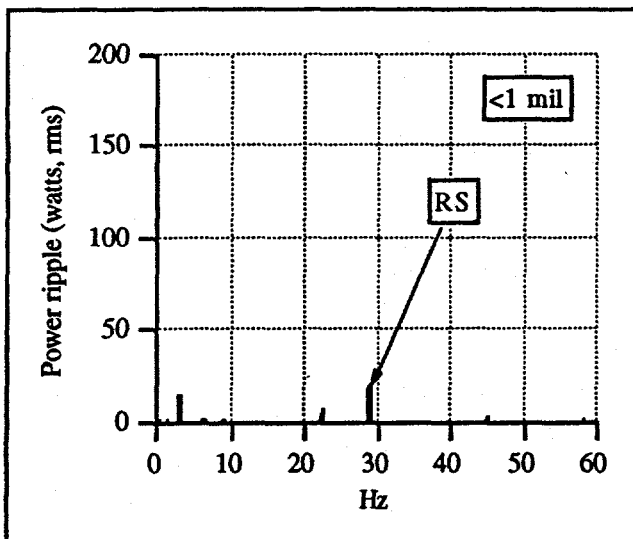


Figure 8. Well-Aligned Power Ripple Spectrum

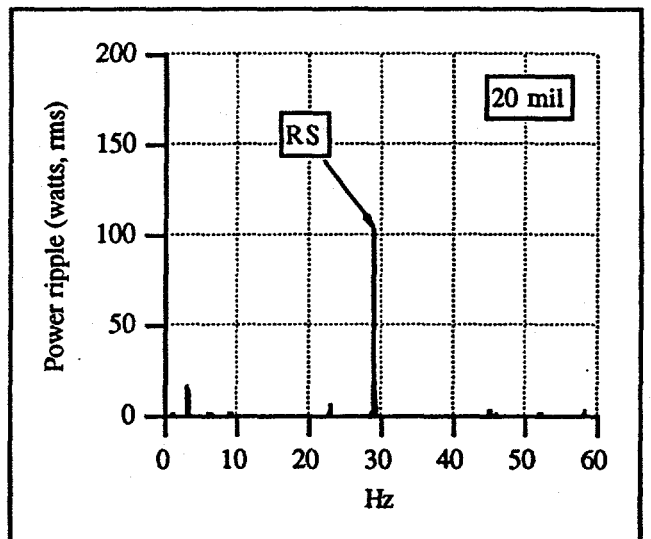


Figure 11. Power Ripple Spectrum with 20 Mil Shim

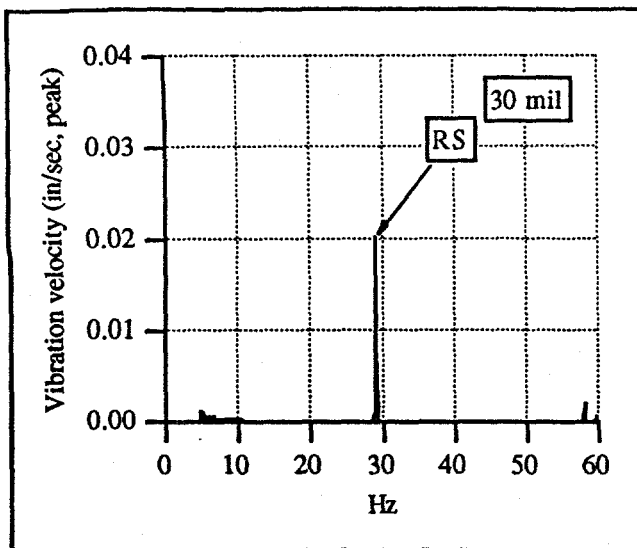


Figure 12. Vibration Spectrum with 30 Mil Shim

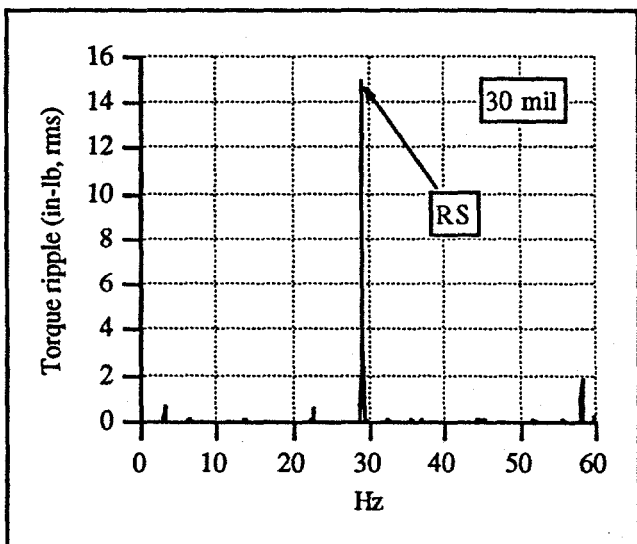


Figure 13. Torque Ripple Spectrum with 30 Mil Shim

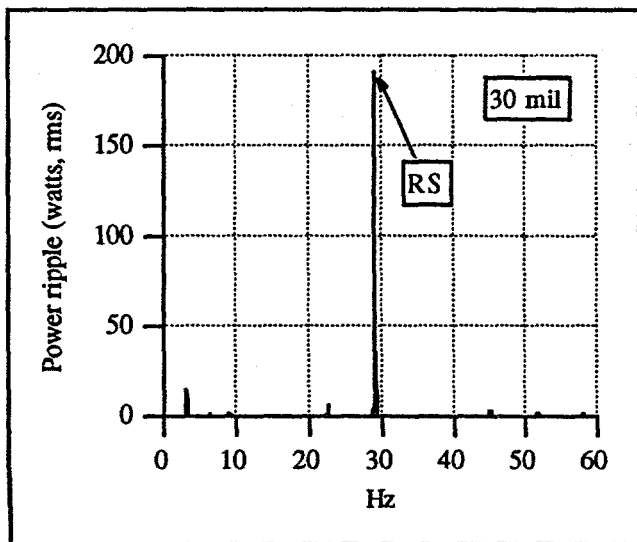


Figure 14. Power Ripple Spectrum with 30 Mil Shim

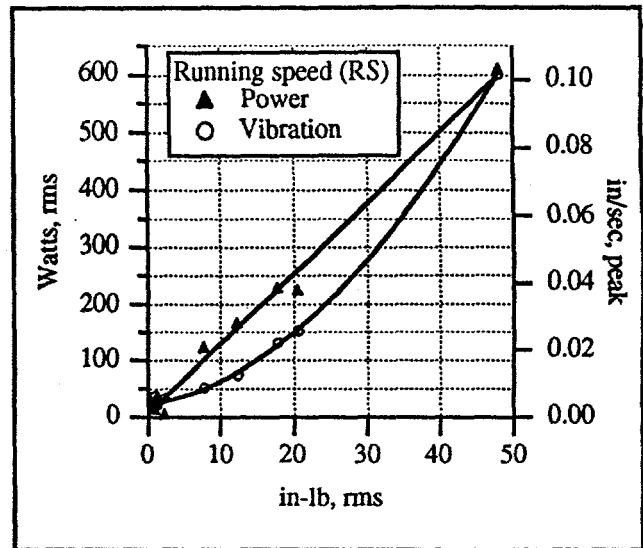


Figure 15. Running Speed Power Ripple and Vibration vs Torque Ripple at Various Levels of Misalignment

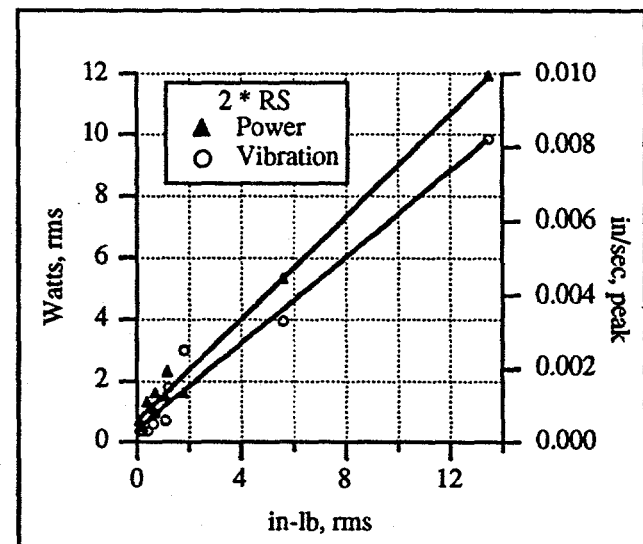


Figure 16. Two Times Running Speed Power Ripple and Vibration vs Torque Ripple at Various Levels of Misalignment

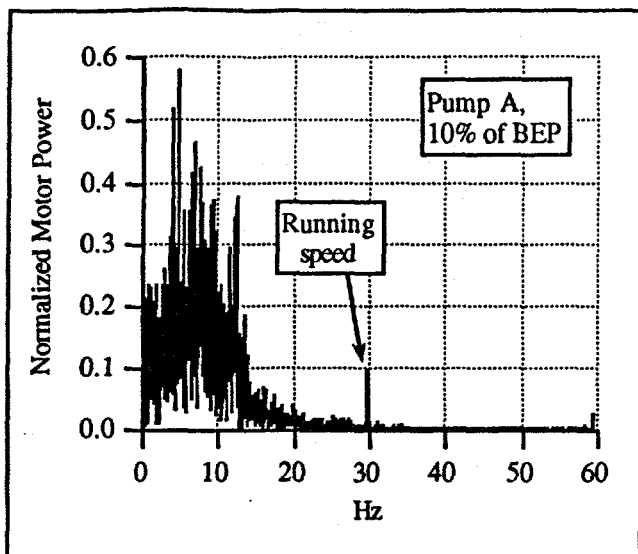


Figure 17. Pump A Motor Power Spectrum at 10% BEP

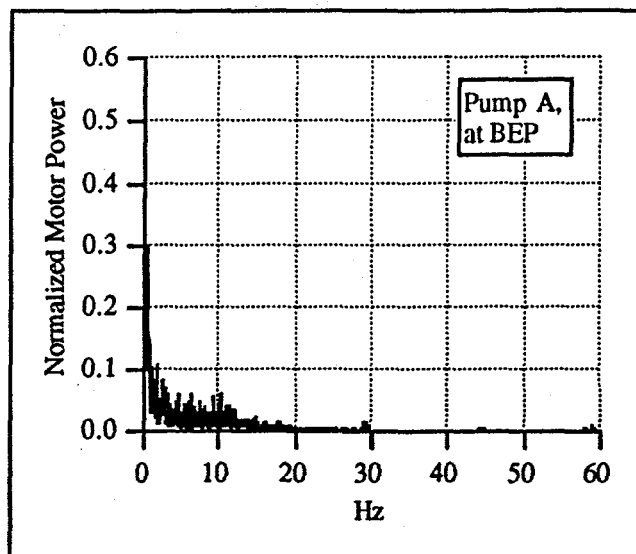


Figure 20. Pump A Motor Power Spectrum at Pump BEP

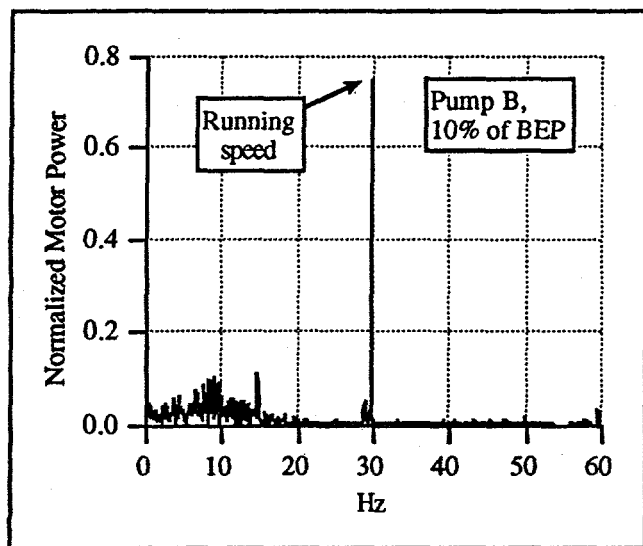


Figure 18. Pump B Motor Power Spectrum at 10 % BEP

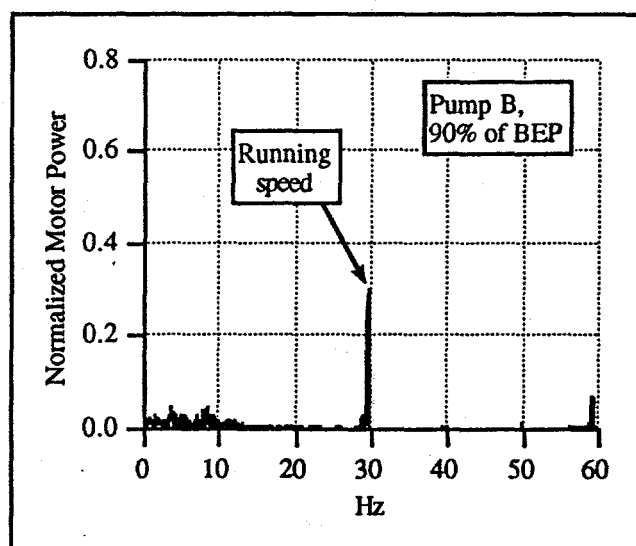


Figure 21. Pump B Motor Power Spectrum at 90 % BEP

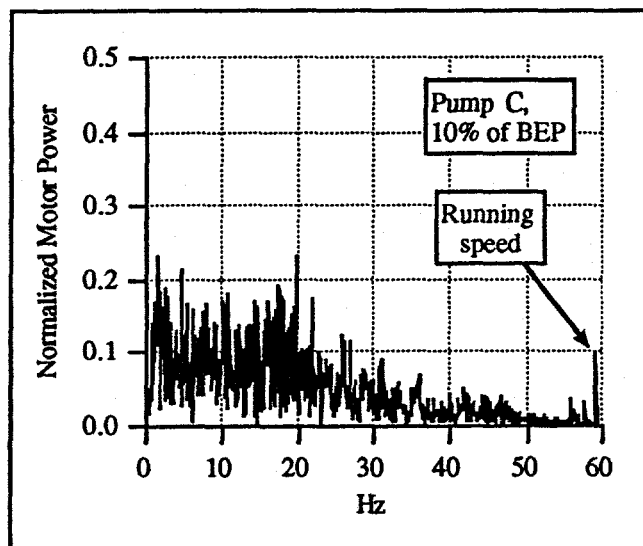


Figure 19. Pump C Motor Power Spectrum at 10 % BEP

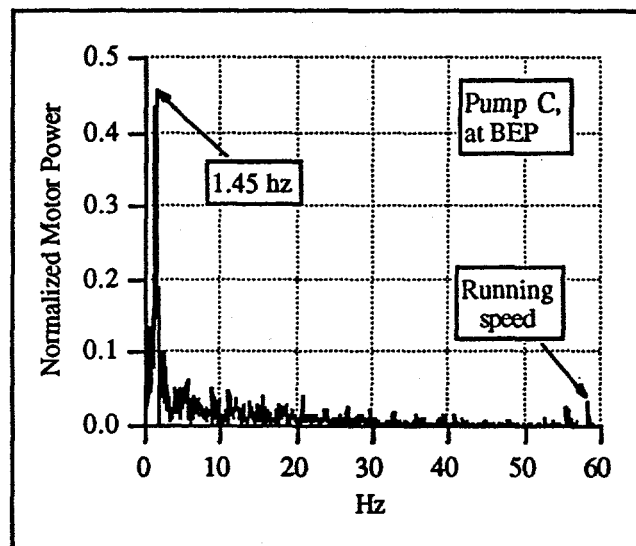


Figure 22. Pump C Motor Power Spectrum at Pump BEP

BEP to the maximum flowrate supported by the system in which the pump was installed (almost two times BEP). The frequency of the peak was found to be proportional to the flowrate.

Note that the power spectra are only shown up to 60 Hz. This is because the motor inherently acts as a low-pass filter. At higher frequencies, overall energy levels in the motor current or power that are load-related are greatly reduced. While energy transfer occurring at higher frequencies does appear in the spectrum, it is much lower in amplitude than the lower frequency components. In fact, it is important to recognize that a watt at 30 Hz in the motor power spectrum is not equal to a watt at 45 Hz in terms of their relationship to shaft torque fluctuations. This is a subject that has been seldom discussed, and merits additional attention.

For comparison, vibration data collected at the pump inboard bearing on all three pumps for the same flow conditions are provided in Figures 23-28. Vibration data collected with accelerometers has a much wider flat frequency response range; the spectral data shown include the range from DC to above vane-pass frequency. All three pumps exhibit low overall vibration amplitude. Of the three pairs of vibration spectra, the only particularly notable feature is that the pump A vane-pass peak actually drops as flow is reduced (contrary to what is often observed), and there are some minor changes in the amplitudes of some of the other running speed harmonics for pumps A and B.

In order to validate that the changes in the power spectra are, in fact, associated with hydraulic performance, pressure pulsation data were acquired for pump C at a variety of conditions. In general, the low frequency portions of the motor power and pump pressure pulsation spectra were found to be similar. Figures 29-34 are vibration, pressure (head) pulsation, and motor input power spectra for pump C operating at slightly greater than BEP flowrate under two suction conditions. The manufacturer's specified NPSHR at the tested flow is 8 ft; the as tested NPSHA conditions were 40 and 10 feet, respectively. The change in suction head was created by throttling a valve upstream of the pump suction. While it is recognized that this is not the desired means of reducing available head, it is actually somewhat representative of a condition that is not infrequently experienced in certain field applications - restricted inlet flow due to partially clogged suction strainers or partial ingestion of foreign material.

The pump operated relatively quietly at both conditions. There was no audible cavitation-induced noise (from either the throttled valve or the pump). The only observable change in the vibration data is a slight change in energy between 30 and 40 Hz. Even in the higher frequency regimes (not shown), there was minimal change in the vibration spectrum pattern.

There were, however, significant changes observed in both the pressure pulsation and motor power spectra. As the suction

head was reduced, the low frequency (<30 Hz) spectra of both the pump head and the motor power lost the well defined spectral peak at 1.71 Hz and transitioned to broadband noise.

The suction and discharge pressure spectra were examined individually and over a broader frequency range for both conditions (Figures 35-38). Both were found to change significantly with NPSHA. The most dramatic change in the suction pressure pulsation spectrum was the complete absence of vane-pass energy in the reduced NPSHA case. It is surmised that this was due to suction cavitation (even though, as noted above, there was no audible cavitation noise) which effectively suppressed the transmission of vane-passage energy back upstream. The suction pressure spectrum also had a somewhat higher level of broadband energy in the 0-150 Hz range. The vane-pass energy at the pump discharge was not affected by NPSHA, but the level of broadband energy from about 90 to 130 Hz increased significantly.

The increased energy in the low frequency (0-40 Hz) portion of the motor power spectrum for the lower NPSHA results from two portions of the pressure spectral energy. Obviously, the increase in pressure pulsation energy from 0-40 Hz directly affects the same energy range in the power spectrum. In addition, the modulation of the 120 Hz portion of the motor power (a dominant component, associated with the individual motor phases) by the aforementioned 90 to 130 Hz broadband energy also results in added energy. This modulation effect is a common feature that is relatively complex, and will not be dealt with here other than to note that the foregoing example does point out the importance of recognizing modulation patterns in interpreting current or power data. It should be noted that one of the most helpful approaches used to understanding driven device conditions from current data is the demodulation of the current signal (amplitude and/or phase demodulation, for example).

RELATIVE INDICATION OF HYDRAULIC STABILITY

The observed changes in motor spectral data with changing pump flowrate led to an attempt to define a simplified single figure of merit for the stability of the load. An instability ratio, defined as the ratio of the standard deviation of the power to the average power, was developed for this purpose. Because the broadband, unfiltered motor power is normally dominated by motor-related frequencies (120 and 360 Hz where line frequency is 60 Hz), the power data is low-pass filtered to eliminate these frequencies before calculating the instability ratio in order to provide a more meaningful indication.

The instability ratios (presented as percentages) for Pumps A, B, and C are shown in Figure 39. In a sense, the instability ratio can be considered as the relative noise level in the pump power. As might be expected, the pump with the highest suction specific speed, Pump A, showed the greatest tendency toward unstable conditions as flow was reduced. Note that

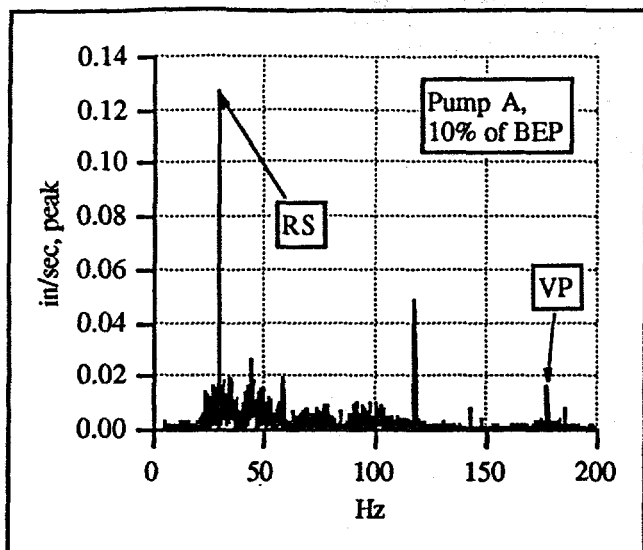


Figure 23. Pump A Vibration Spectrum at 10% BEP

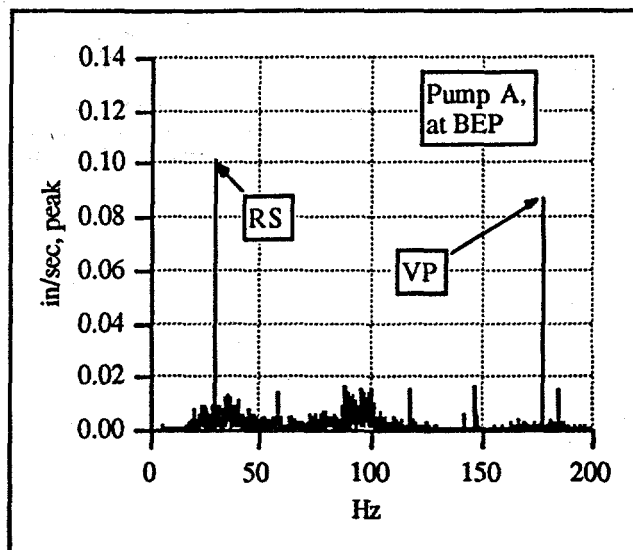


Figure 26. Pump A Vibration Spectrum at BEP

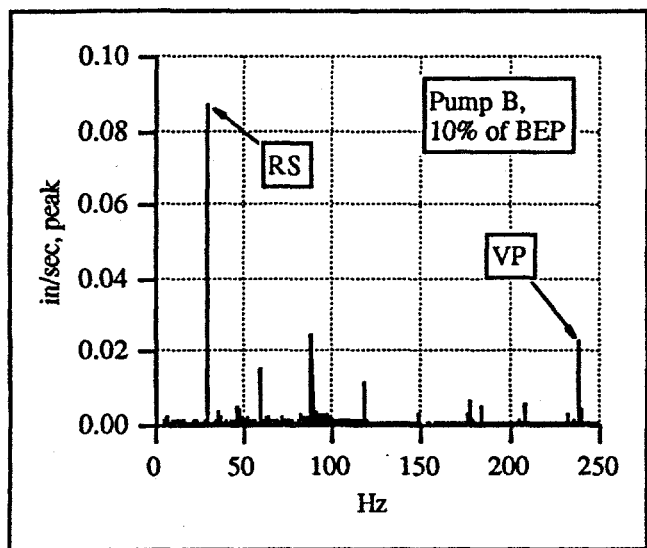


Figure 24. Pump B Vibration Spectrum at 10 % BEP

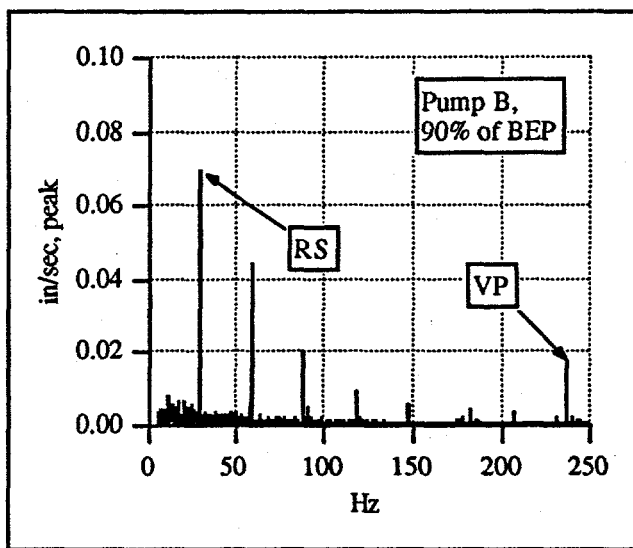


Figure 27. Pump B Vibration Spectrum at 90 % BEP

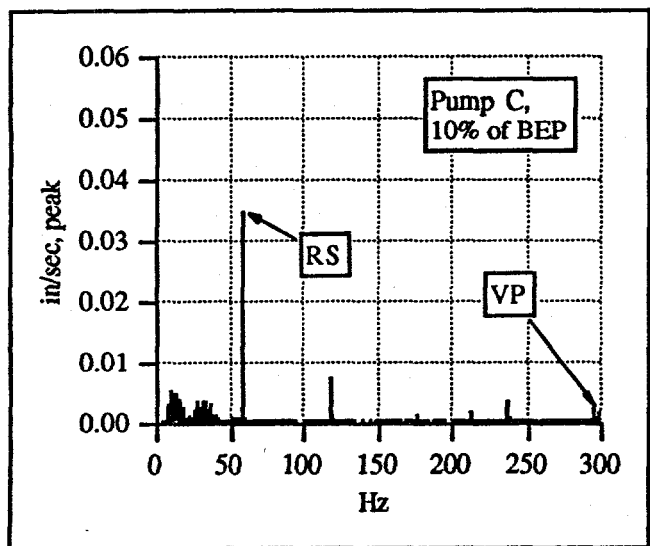


Figure 25. Pump C Vibration Spectrum at 10 % BEP

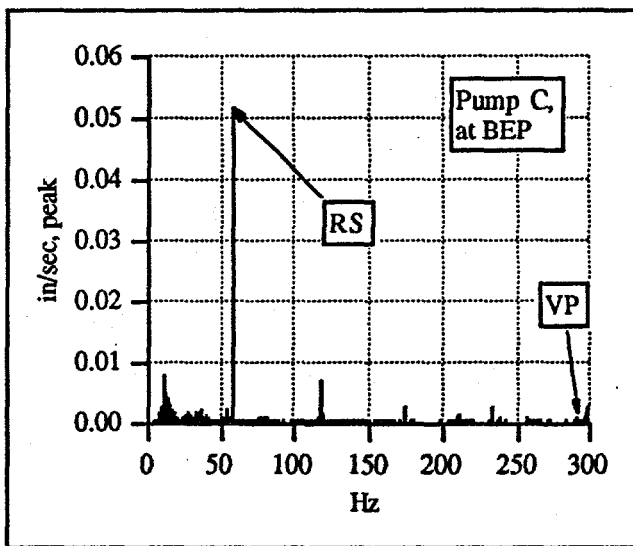


Figure 28. Pump C Vibration Spectrum at Pump BEP

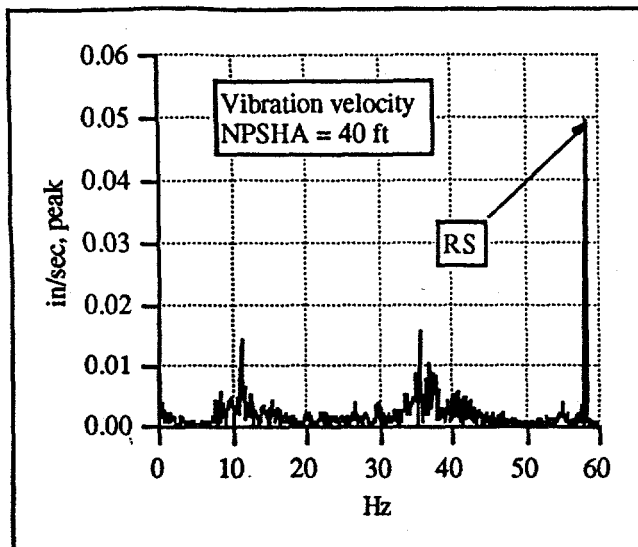


Figure 29. Vibration Spectrum - Substantial NPSHA

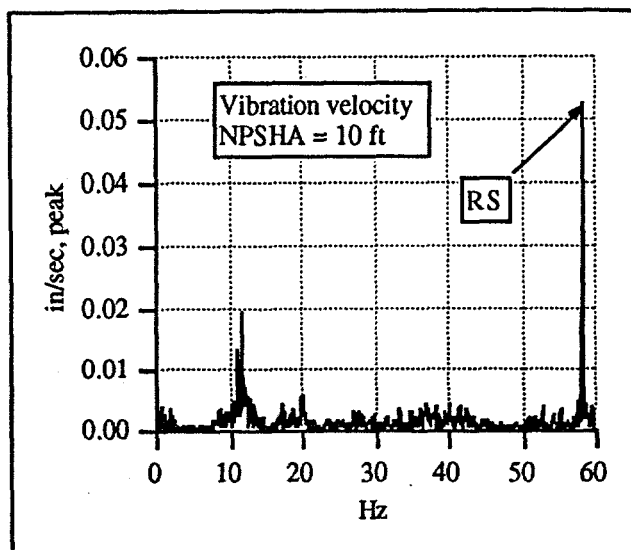


Figure 32. Vibration Spectrum - NPSHA = 1.25 * NPSHR

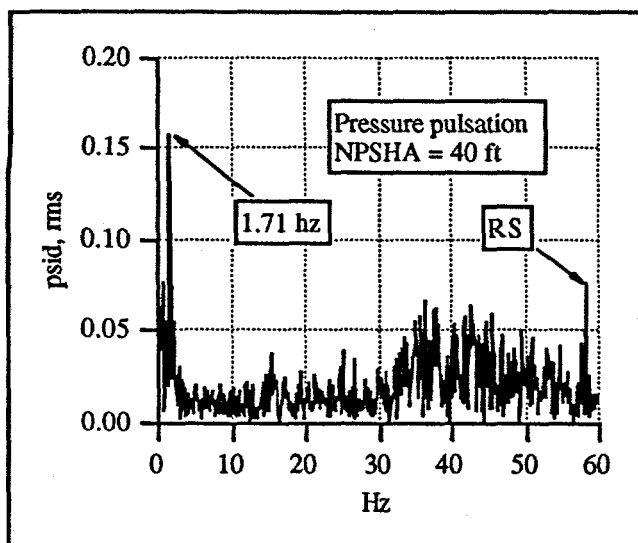


Figure 30. Pressure Pulsation (ΔP) Spectrum - Substantial NPSHA

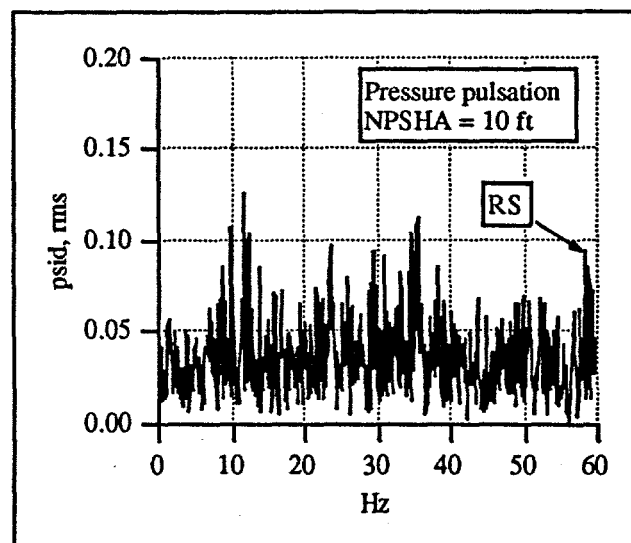


Figure 33. Pressure Pulsation (ΔP) Spectrum - NPSHA = 1.25 * NPSHR

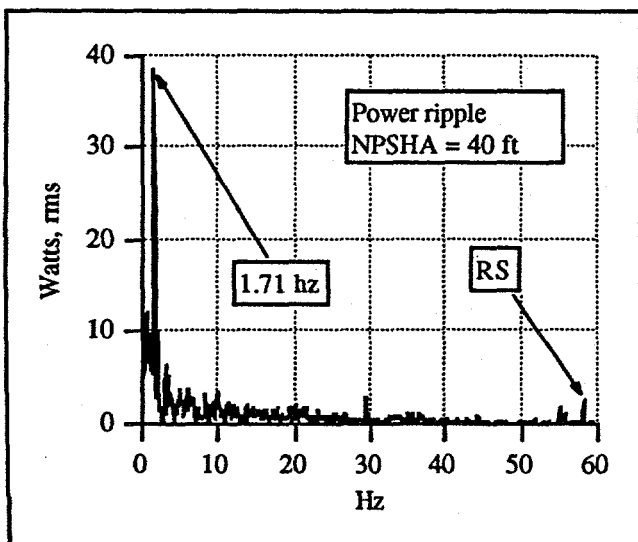


Figure 31. Motor Power Spectrum - Substantial NPSHA

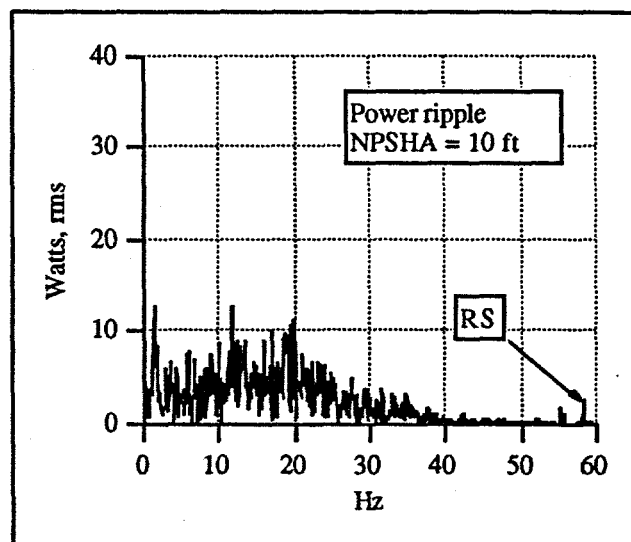


Figure 34. Motor Power Spectrum - NPSHA = 1.25 * NPSHR

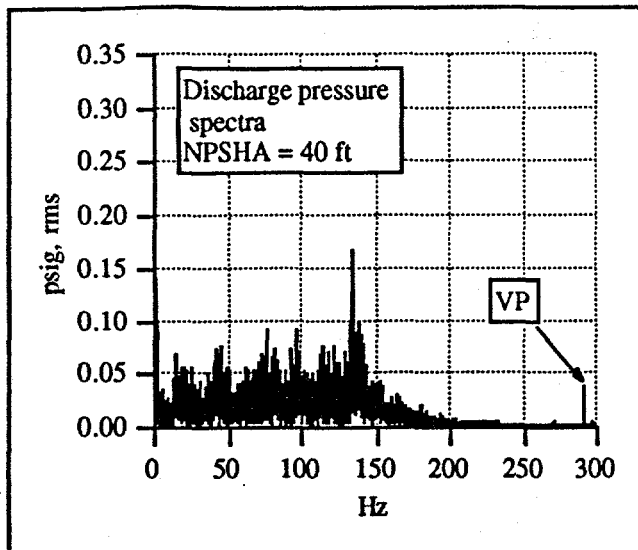


Figure 35. Disch. Pressure Spectrum - Substantial NPSHA

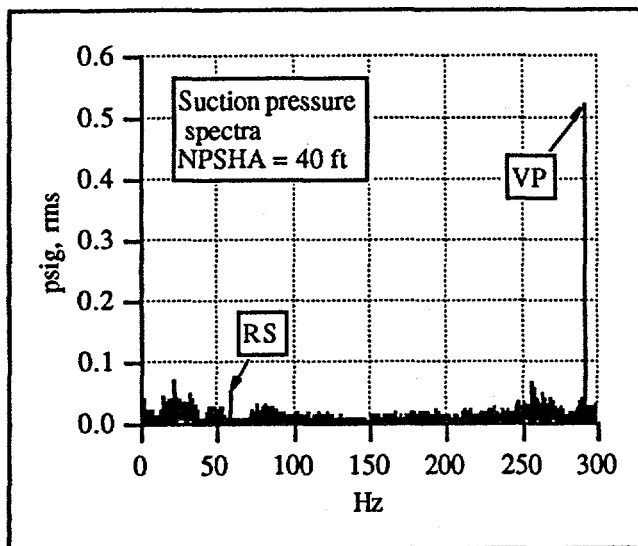


Figure 36. Suction Pressure Spectrum - Substantial NPSHA

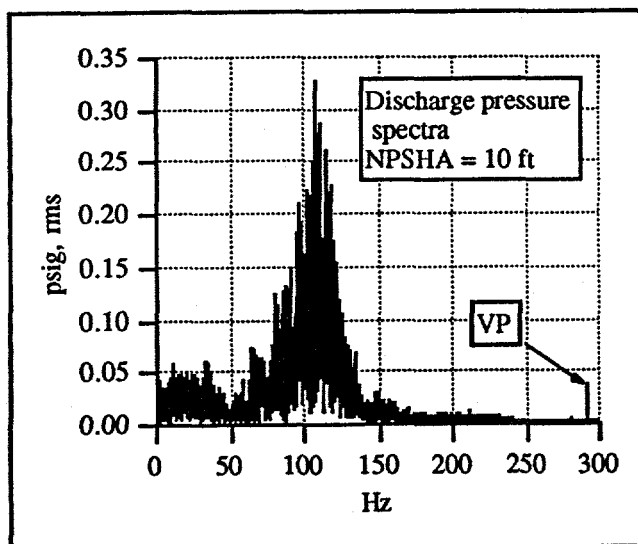


Figure 37. Discharge Pressure Spectrum - NPSHA = $1.25 \cdot \text{NPSHR}$

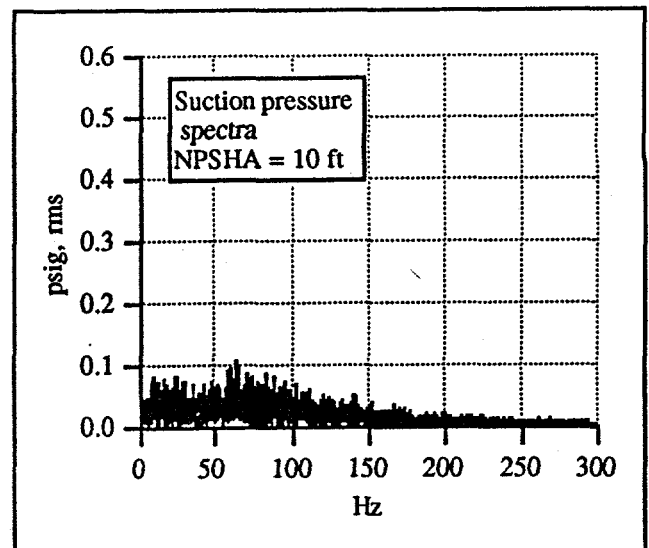


Figure 38. Suction Pressure Spectrum - NPSHA = $1.25 \cdot \text{NPSHR}$

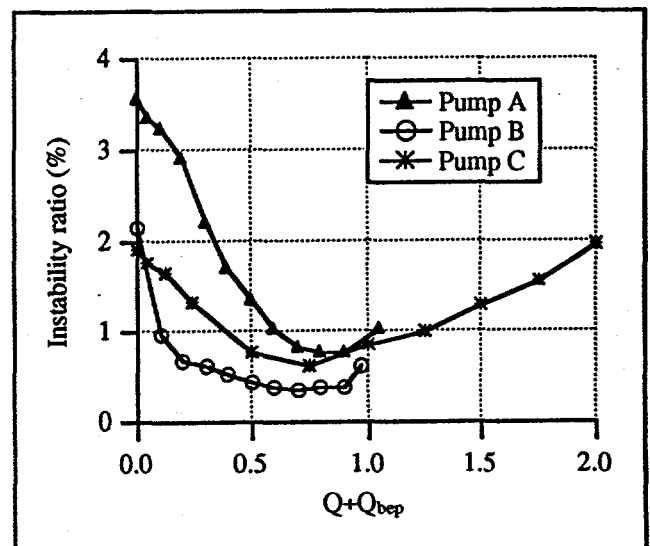


Figure 39. Instability Ratio vs Flowrate for Three Pumps

even though pump B exhibited a high running speed peak, in the overall sense it was relatively stable because of the minimal low frequency noise, and thus had a lower instability ratio over most of the flow range. This points out a limitation in this single figure of merit - its inability to depict the specific sources of instability. Another limitation is that associated with motor current or power data in general - the non-linearity of the data as a function of frequency, and specifically the inherent low-pass filtering of load fluctuations. A more representative measure of overall stability would address these limitations, particularly the low-pass filtering limitation. As additional motor studies are conducted at ORNL and Y-12, the potential for developing generic transfer functions or other factors to accommodate the limitations will be explored. The goal of an optimized instability ratio, by whatever name it might be called, would be to provide the user with a general indication of the range of pump operation over which relatively stable performance could be expected.

RESULTS OF ON-LINE MONITORING

The Y-12 plant is in the process of implementing on-line motor current monitoring for motors used in a variety of processes. Both overall amplitude and spectral data are periodically acquired and logged. The data are archived and trended in the same database used for periodic vibration monitoring.

This system is still not fully implemented, but it has proven useful in detecting degraded component conditions. Two examples are provided below which are illustrative of both the capability and limitations of motor current/power monitoring.

Clogged suction strainer

Motor current for several pumps used in a chilled water facility are periodically monitored. A trend plot of motor current for two identical pumps operating in parallel over the course of 35 days is shown in Figure 40.

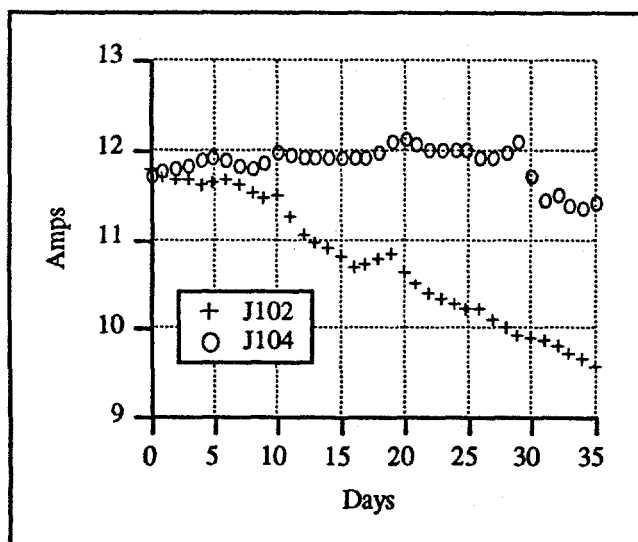


Figure 40. Motor Current Trend for Parallel Pumps

In Figure 41, the motor power spectrum for the J102 pump at the end of the trend period is shown. Power spectral data for the same pump with a clear suction strainer is shown in Figure 42. From the combination of overall current trend and spectral data, as well as knowledge of previous experience for these pumps, it was deduced that the J102 pump suction strainer had become clogged. Subsequent removal of the suction strainer showed considerable clogging (Figure 43). Vibration data acquired for these pumps (not shown) failed to indicate significant differences.

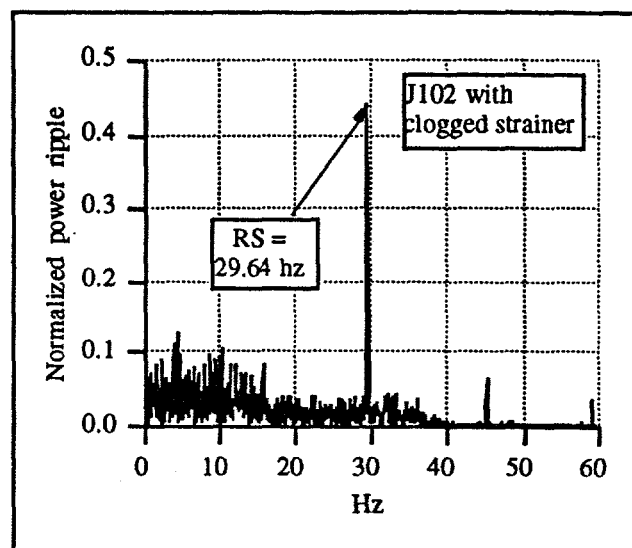


Figure 41. Motor Power Spectrum for Pump with Clogged Suction Strainer

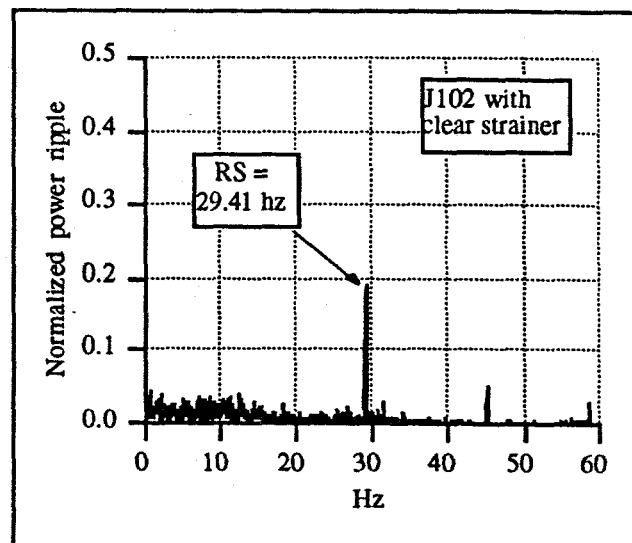


Figure 42. Motor Power Spectrum for Pump with Clean Suction Strainer

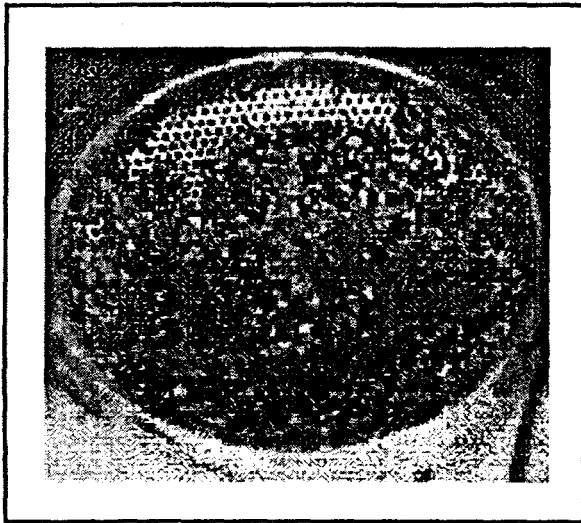


Figure 43. Clogged Suction Strainer

Damaged motor bearing

Spectral vibration data from a belt driven exhaust fan motor indicated the presence of a severe bearing defect (Figure 44). Since this motor had been recently put on the on-line current monitoring system, the motor current spectrum was evaluated for confirmatory indication. As shown in Figure 45, the fault frequency was also seen in the current spectrum.

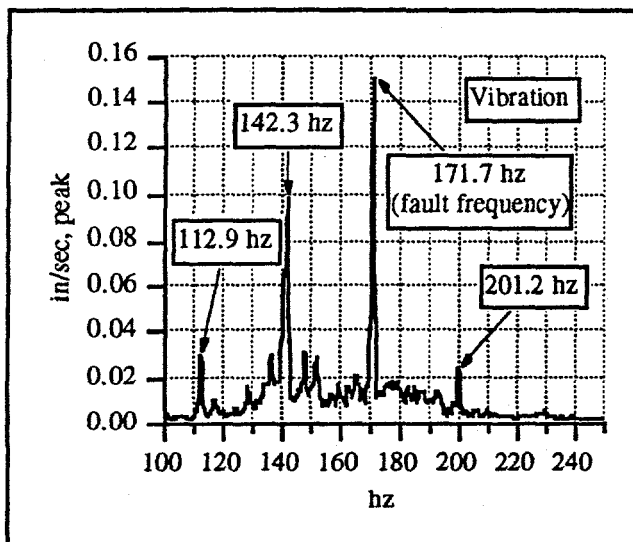


Figure 44. Vibration Spectrum for Motor with Damaged Bearing

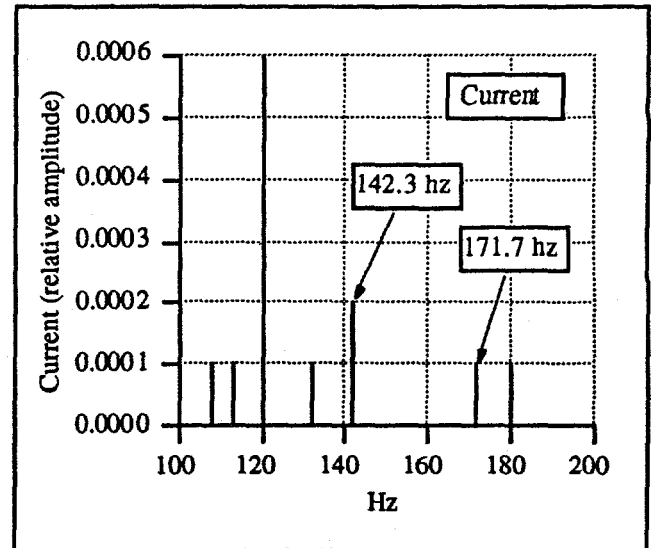


Figure 45. Motor Current Spectrum for Motor with Damaged Bearing

The amplitude shown for the current spectrum in this case is relative amplitude. Note that the fault here was in a motor bearing, and it was severe; even then, the amplitude of the fault frequency was extremely small. There have been no examples at the Oak Ridge facilities where bearing faults in the driven equipment have been detected by motor spectral data. Also, many cases have been found where less severe motor bearing flaws have been detected by vibration data with no corresponding indication in the motor spectral data. Two important conclusions from the vibration and current data analysis experience relative to bearing fault detection can be drawn:

- Spectral vibration data is much more sensitive to bearing fault conditions than motor data
- Although severely degraded motor bearing faults may be manifest in the motor spectral data, it is judged to be unlikely that anything less than a severe fault would result in detectable levels in the current or power spectrum. Degradation in driven device bearings would be even less likely to be sensed by motor current or power spectral data.

These observations relative to bearing degradation are not based on controlled research studies, but rather on observations from field data. They are certainly not conclusive, but represent experience from a variety of motors and driven equipment.

RESOURCES

The use of motor current or power data in analyzing load behaviour is not a well-developed field. For those that are interested in exploring its potential, the following may be of interest:

- The technologies developed at ORNL and at Y-12 to assess equipment performance from motor data have been licensed by several domestic diagnostic service companies, including ITI MOVATS, Inc. (a Westinghouse company), and Babcock and Wilcox, Inc. These organizations provide both diagnostic systems and field service based on the motor-monitoring technologies.
- ORNL and the Y-12 plant, both of which are Department of Energy facilities, have ongoing pump-related activities in both the research and facility operation support arenas. Motor data from pumps and other equipment are being used and analyzed in a variety of ways to improve operational efficiency and reliability, minimize unplanned maintenance, and reduce operational costs, as well as to support research objectives. Inquiries about technical aspects of these activities may be addressed to the authors.

CONCLUSION

Monitoring important pump performance parameters by using the pump motor as a transducer has been found to be both feasible and cost effective. Fundamentally, the motor is effective at transducing torsionally-related load phenomena.

The motor can be effectively used as a transducer to aid the understanding of both alignment and pump hydraulic conditions. In contrast, the motor has not been found to be a particularly effective transducer of mechanical unbalance or bearing fault conditions.

Motor current and power analysis offer an alternative diagnostic approach that may be used in conjunction with existing diagnostics, or in some cases, as a primary diagnostic. As more experience is gained in its field use, it is expected that it may become possible to establish experientially-based indications of the acceptability of certain characteristic loads, such as those associated with misalignment or overall load stability.

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Biographical sketch - Don Casada

Don Casada is Senior Development Associate at Oak Ridge National Laboratory (ORNL). He is responsible for leading research and development activities related to nuclear plant aging, and mechanical and electrical component diagnostics. Prior to joining ORNL in 1988, he worked for Carolina Power and Light Company in a variety of positions including nuclear fuel mechanical performance analysis and as a Project Engineer at the Shearon Harris Power Plant, where he was responsible for the development of the pump and valve test program. Mr. Casada is a registered Professional Engineer in the State of North Carolina. He received his B.S. in Nuclear Engineering and his Masters of Mechanical Engineering from North Carolina State University.

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Stan Bunch is a Staff Engineer at the Y-12 Plant in Oak Ridge, Tennessee. He is manager of the Oak Ridge Facilities Management Technology Center, a facility of the Oak Ridge Centers for Manufacturing Technology. The Oak Ridge Facilities Management Technology Center aides both the U.S. Department of Energy and private industry in new technology development, diagnostics, data collection, and training relative to facilities management. During the past four years Stan has been involved with the development of new technology utilizing Motor Current Signature Analysis at the Y-12 Plant. He has 18 years with Y-12 in the Facilities Management Organization. He has an electronics background with experience in digital circuits and computer programming.

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Paper to be presented at the P/PM Technology conference being held in Indianapolis, Indiana, December 6, 1995

**The Use of the Motor as a Transducer
to Monitor Pump Conditions**

by

D. A. Casada and S. L. Bunch

**Lockheed Martin Energy Systems, Inc.
Oak Ridge, Tennessee**

Research sponsored by the U.S. Department of Energy, under contract DE-AC05-84OR21400 with Lockheed Martin Energy Systems.

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ABSTRACT

Motor current and power analysis methods have been developed to assist in the condition monitoring of a variety of motor-driven devices. The early work in this area was conducted at Oak Ridge National Laboratory (ORNL) on motor-operated valves in the mid-to-late 1980's in support of the U. S. Nuclear Regulatory Commission's Nuclear Plant Aging Research Program. The successful implementation of motor current signature analysis (MCSA) as a diagnostic for valves led to its application to other devices and to refinements in the methodologies used.

Early application of MCSA to centrifugal pumps, conducted in a more or less random fashion in the late 1980's identified discrete spectral components associated with the motor itself, as well as broadband noise (particularly at low frequencies) that was initially referred to as "flow noise". Response to some system natural frequencies was also observed. The absence of programmatic interests resulted in little additional investigation at that time.

In the last few years, work for the Nuclear Regulatory Commission and independent activities at ORNL and the Y-12 defense plant have resulted in additional, more thorough consideration of the merits of using motors as transducers for understanding pump conditions. A variety of pump applications, ranging from 5 to over 1200 horsepower have been analyzed, including low and high specific speed and suction specific speed pumps. For some of the pumps, the full range of flow conditions from shutoff to runout has been studied.

Motor current and power analysis have been found to provide information that is complementary to that available from conventional diagnostics, such as vibration and pressure pulsation analysis. Inherent signal filtering associated with rotor to stator magnetic field coupling does limit the high frequency response capability of the motor as a transducer; as a result, certain phenomena, such as vane pass energy, is not readily apparent in the motor electrical signals. On the other hand, the motor-monitored parameters have often been found to be much more sensitive than vibration transducers in detecting the effects of unsteady flow conditions resulting from both system and pump specific sources such as suction cavitation. By combining motor equivalent circuit models with pump performance characteristics, shaft power and torque fluctuation estimates have been assessed.

The usefulness of motor data in assessing some common sources of pump problems, such as mechanical and hydraulic imbalance, misalignment, and unstable flow conditions is shown. The results of testing several motor-driven pumps, including comparisons with vibration and pressure pulsation analysis are discussed. The development of a single figure of merit for pump load stability (as a function of pump flow rate and type) is presented.

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