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APPLICATION OF DIAGNOSTICS TO DETERMINE MOTOR-OPERATED VALVE OPERATIONAL READINESS

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APPLICATION OF DIAGNOSTICS TO DETERMINE MOTOR OPERATED VALVE OPERATIONAL READINESS

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ABSTRACT

ORNL has been carrying out an aging assessment of motor-operated valves (MOVs) with the primary objective of recommending diagnostic methods for detecting and trending aging.

As a result of experimental investigations at ORNL, it was discovered that the motor current during a valve stroke was a very useful diagnostic parameter for detecting and trending many MOV drive train load variations. The motor current signatures were analyzed at four levels: mean value for a stroke, gross trends during a stroke, transients, and noise frequency spectra. Examples illustrating the use of this technique are presented.

The use of motor current signature analysis was also shown to apply to other electric motor driven equipment.

Future work includes developing a data base of MOV diagnostics, including criteria for determining the extent of degradation and application of the technique to other LWR motor driven safety equipment.

INTRODUCTION AND OBJECTIVES

As part of the Nuclear Regulatory Commission Nuclear Plant Aging Research (NPAR) program, Oak Ridge National Laboratory (ORNL) is carrying out a comprehensive aging assessment of the motor-operated valves (MOV's) used in safety systems of nuclear power plants.

A primary objective of the NPAR program is to identify and recommend diagnostic methods for detecting, differentiating, and trending time-dependent degradations and service wear (aging) of important components on nuclear plant safety systems such that timely maintenance can be performed prior to loss of safety function. The approach used to achieve the objective is to carry out comprehensive aging assessments of each component of interest.

The aging assessments contain these elements:

- review and analysis of the application of the component to specific nuclear plant safety systems, including identification of important design features and materials of construction, and the expected impact of the stressors to which they will be exposed under both normal and accident conditions.

- review and analysis of operating experience with that component in both nuclear power plants and other applications, in order to identify and characterize the significant failure modes and causes.
- identification and selection of diagnostic parameters to monitor during the operating life of the component which can be used to differentiate and trend defects and other degradations in the component prior to failure to perform its safety function.
- identification of suitable instrumentation and techniques with which the diagnostic parameters can be measured at appropriate times.
- demonstration, by means of laboratory and field tests, that the selected parameters can be monitored and trended, using suitable instrumentation, in an effective and reliable manner.

Early in the NPAR program life, motor-operated valves were identified as a component to be studied. Motor-operated valves are used in almost all nuclear plant safety systems. Failures of MOVs have resulted in a significant amount of plant maintenance and loss in operational readiness. A review of LERs and other failure data bases, IE Bulletins and Notices, and AEOD reports documented the types, frequency, and impacts of the failures. As a result of this and similar experiences with other types of valves, NRC has designated "In-situ Testing of Valves" as a high priority generic issue.

ORNL was assigned the task of performing a comprehensive aging assessment of motor-operated valves using the NPAR strategy, i.e, with the goal of identifying and demonstrating improved diagnostic techniques for use with motor-operated valves used in nuclear plant safety systems. Part of the task, including the first three elements listed above, has been completed and a Phase 1 report (1) issued. This paper describes activities in support of the final two elements listed above.

BACKGROUND

Periodic surveillance tests are performed on motor-operated valves which are part of nuclear plant safety systems to demonstrate their operability. The tests are described in each licensed nuclear plant's Technical Specifications, and, by reference, in Subsection IWV (In-service Testing of Valves) which is part of Section XI of the ASME Boiler and Pressure Vessel Code. Additional leak test requirements (dealing with containment isolation valves) are described in the Code of Federal Regulations Title 10 Part 50. It should be noted that these tests apply to other types of valves in addition to motor-operated valves.

The surveillance tests are of three types:

- determination of movement of the obturator when actuated
- stroke time measurement
- leakage rate

The tests and the criteria associated with each are intended to demonstrate operability, i.e., they demonstrate that the valves meet the specified criteria under the test conditions and at the time of the test. They only indirectly demonstrate the operational readiness of the valves and the ability of the valves to actuate as required at future times under all anticipated operating conditions (including accident conditions) since there are no provisions for monitoring and trending degradation.

As part of Phase 1 of the comprehensive aging assessment, ORNL reviewed the current surveillance practices described above, and identified a list of diagnostic parameters that could be used to monitor and trend degradation on MOVs. In addition, ORNL reviewed recently developed surveillance techniques, including those developed by MOVATS Inc. (2) and by EPRI (3), to determine their applicability to measuring the effect of aging operational readiness. The results of the evaluation of the MOVATs technique has been published (4).

In order to carry out Phase 2 of the aging assessment, two MOVs (including a nuclear qualified valve obtained from a cancelled nuclear power plant) were obtained and installed in test stands. The valves were connected to switchgear so that they could be actuated, and instrumentation was obtained and installed which would demonstrate the feasibility and practicality of monitoring and trending the various diagnostic parameters identified in the Phase 1 report.

A typical motor-operated valve is shown in Figure 1, along with a cutaway drawing showing the internals of the operator. This operator was manufactured by Limitorque Corporation. Valve operators manufactured by that company account for an estimated 90% of all MOVs used in nuclear power plants in the United States.

As seen in Figure 1, the motor transmits power to the valve through a complex drive train. Included as a part of the operator in addition to the drive train elements are two switches which are used to control the voltage supplied

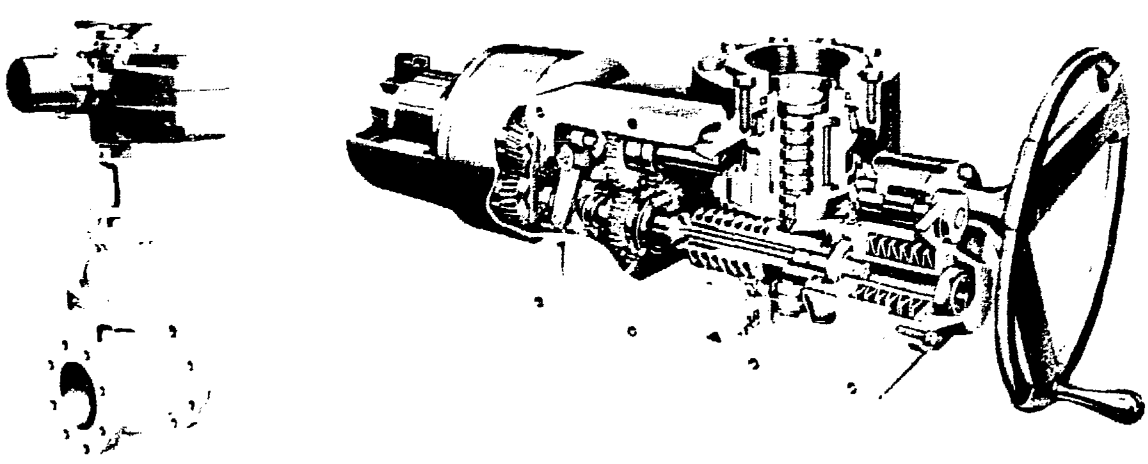

Figure 1. Limitorque motor operator installed on a gate valve.

to the valve motor. One switch indirectly senses the valve stem position and the second the torque or load being transmitted to the valve stem. The torque is measured by the amount of compression of a spring pack resulting from the axial translation of a worm.

Preliminary tests were carried out using the two valves in the test stand to determine the type and potential value of diagnostic information that could result from using instrumentation to measure the following MOV parameters:

- MOV vibration (three locations)
- motor temperature (two locations)
- motor current
- valve stem strain
- valve stem velocity and acceleration
- torque and limit switch (including torque switch angle)

Based on the results of the preliminary tests, it was concluded that although all of the parameters appeared to provide useful diagnostic information about the valve, the motor current signature appeared particularly attractive as the primary or initial diagnostic for detecting and trending degradation occurring in the MOV drive train. The other parameters then could be used to supplement motor current in cases where they would be useful in differentiating among possible degradations, or in detecting additional degradations not picked up by monitoring the motor current.

MOTOR CURRENT AS A DIAGNOSTIC

The current flowing in the leads to the motor of the MOV was found to be a sensitive and selective indicator of the mechanical loads driven by the motor. From the standpoint of diagnostics, the motor is acting as a transducer, converting the drive train mechanical loads and their variations with time into variations in voltage across the windings. The resulting net current flow in the motor power leads then reflects the characteristics of the motor load. Changes over time reflect MOV degradations which appear as load changes.

MEASUREMENT OF MOTOR CURRENT

The measurement of motor current has advantages compared to other parameters which could be used to monitor MOVs to provide similar information about MOV drive train loads (such as torque switch angle or spring pack deflection). The principal advantage is that it is capable of being measured remotely and non-obtrusively. It can as a result be measured during plant operation, since no leads need to be lifted to attach the sensor. Figure 2 shows the arrangement used to monitor motor current at the motor control center (MCC) of the MOV test stand. A clamp-on current sensor is attached to one lead of the power cable running between the MCC and the valve motor. The location of the attachment can be selected for convenience, since it does not affect the current reading. Clamp-on current sensors are inexpensive and can be simply installed. Reading and recording the motor current can be carried out rapidly, either manually or automatically.

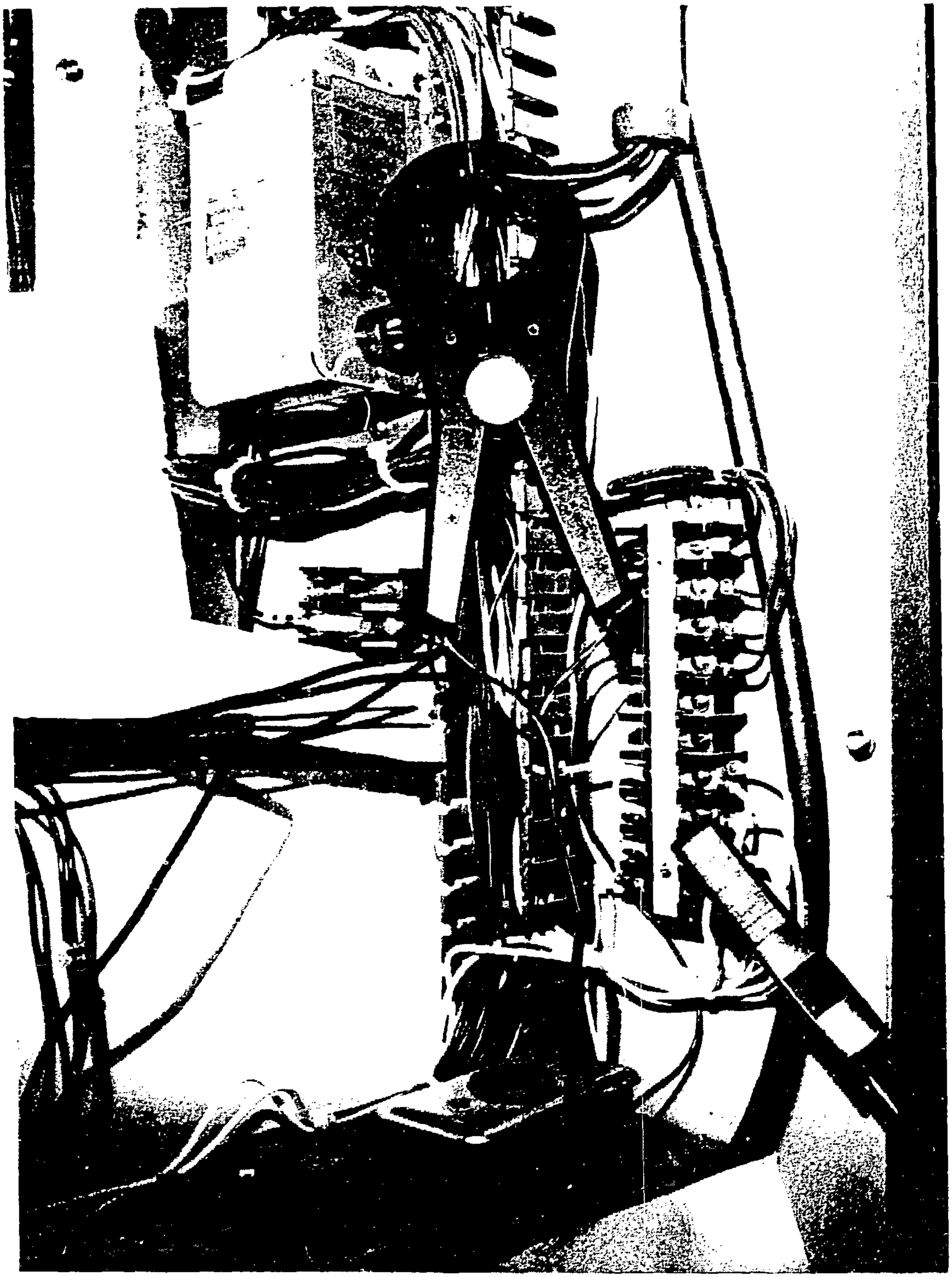

Figure 2. Measurement of motor current at the motor control center.

INFORMATION CONTENT OF A MOTOR CURRENT SIGNATURE

A motor current signature has been found to contain four levels of information:

- mean value over a valve stroke
- gross variations during a stroke
- transients
- frequency spectrum of periodic variations

Each level of information has been found to be useful for detecting and trending different features of the MOV mechanical load. By analyzing all four levels of information during a valve actuation, it is expected that many types of degradation associated with MOV aging will be detected and trended in an incipient stage so that corrective measures can be taken prior to loss of safety function.

In the following discussion, examples will be presented of motor current signatures obtained from MOVs which clearly show different features of the mechanical train which the motor drives. In several instances, a defect (not necessarily serious) was identified and diagnosed using motor current signatures.

In addition, the application of motor current signature analysis to other motor driven mechanical equipment is demonstrated. It is anticipated that this technique will find application in the diagnostic monitoring ot degradation in other motor driven components used in nuclear power plant safety systems, as well as in many nonnuclear applications.

A patent application has been submitted by the U. S. Department of Energy covering features of this technique.

APPLICATIONS OF MOTOR CURRENT SIGNATURE ANALYSIS

Stem Taper

The first example of the application of motor current signature analysis involves the gross variation observed during a valve stroke. In Figure 3 are two plots of motor current versus time, obtained for a type SMA-2 motor operator connected to an 8 inch globe valve. It is observed that, in these expanded scale plots, there is a gradual decrease in motor current with time in the open-to-close direction, while there is a slightly larger but symmetrical decrease occurring in the close-to-open stroke. Although the magnitude of the decrease and increase is less than 2% of the current flow, it was found to be reproducible.

The diagnosis based on the gross variation was that there was a characteristic of the valve stem responsible, either near the stem nut or the packing. When the valve was disassembled, and the stem inspected, it was found (Figure 4) that the diameter of the valve stem changed monotonically in the region where the stem passes through the packing. Although the change was small, it was

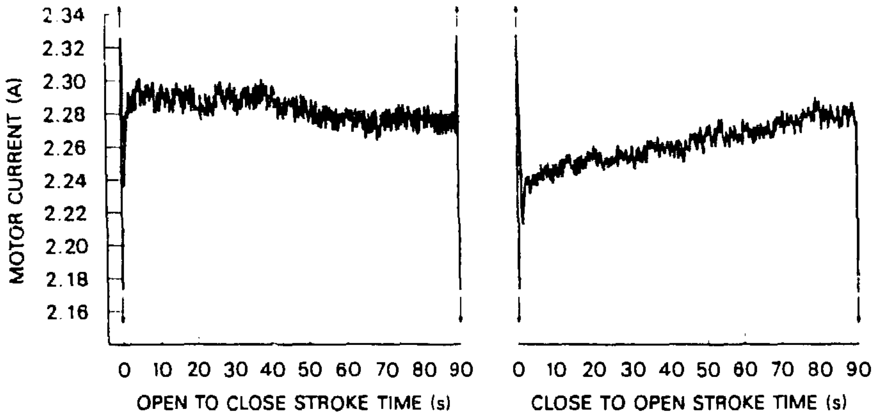

Figure 3. Motor current gross variation signatures from a limitorque operator connected to a six-inch gate valve.

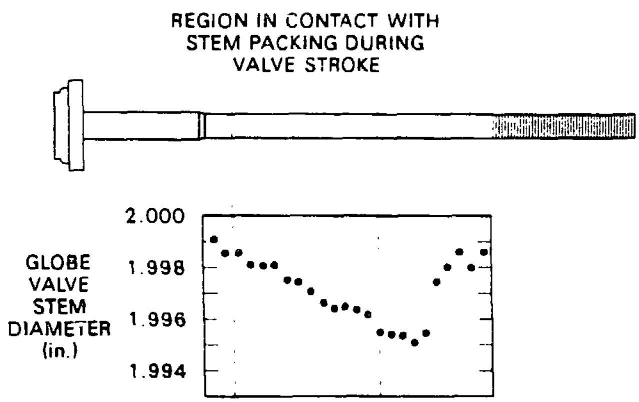

Figure 4. As-found stem dimensions of the six-inch gate valve.

sufficient to alter the friction coefficient between stem and packing. Subsequent tests have shown that the motor current variation is more or less pronounced as the packing is tightened or loosened.

WORM AND WORM GEAR LUBRICATION

Motor current signature analysis assisted in detecting and differentiating a problem in an MOV used for training purposes by a utility. The valve was being tested to develop a data base of motor current signatures of presumed normal valves. Figure 5 shows plots of open-to-close motor current signatures obtained from an SMB operator on a 3 inch gate valve. The as-found valve had loose packing, and the signature obtained (left) was that which would be expected in the open-to-close direction. The peak at the start of the stroke was due to the inrush current, while the peak at the end resulted from the seating of the gate. The magnitude of the peak current at seating was determined by the actuation of the torque switch, which occurred at a preset value of compression of the spring pack.

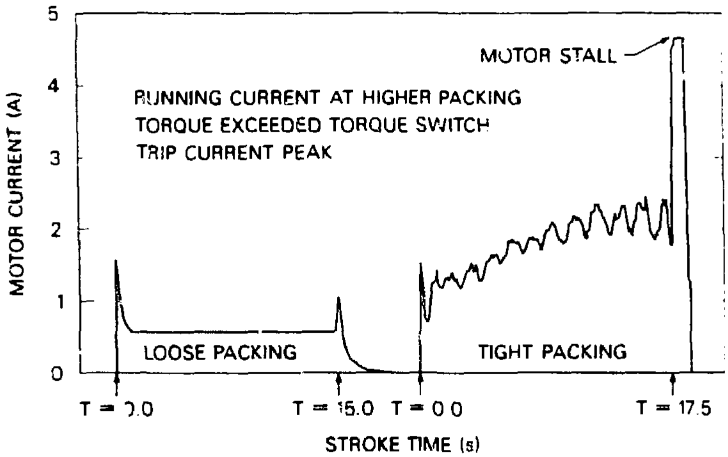

Figure 5. Motor current gross variation signatures for the as-found three-inch gate valve.

When the packing was tightened, the expected change in signature was a slight increase in the current during the middle portion of the stroke. The peak motor current at end of stroke should not have changed since it should have reflected the same spring pack deflection as before. What was found (right) was a gross increase in the motor current during the middle portion, and (in the case shown in Figure 5) a stalled motor at the end of stroke. This general effect was also observed in the close-to-open direction and was repeated in both directions at different packing tightness.

It was noted that with tight packing, the torque switch did not trip during the early part of the stroke, even though the motor current exceeded the amount at torque switch trip when the packing was loose. This observation led to the diagnosis that the increase in motor load must have been occurring in the drive train between the motor and the spring pack in a way that prevented the spring pack from compressing. This limited the problem to the drive train between the motor and the spring pack.

The operator was disassembled and inspected. It was found that there was essentially no lubricant in the region of the worm and worm gear. The operator drive train had been sprayed rather than packed with lubricant, since it was regularly disassembled and assembled as part of a classroom training program. When the operator was properly lubricated, the tests were rerun, with the results as shown, for both loose and tight packing, in Figure 6.

SETTING TORQUE AND BYPASS SWITCHES

Motor current signatures can be used to capture transient events during a valve stroke. This is useful not only as a diagnostic for detecting and trending degradation but also can be used in the critical process of correctly setting the torque and bypass switches. This latter application is illustrated in Figure 7, which is a plot of the motor current during the first 2.5 seconds of a close-to-open stroke.

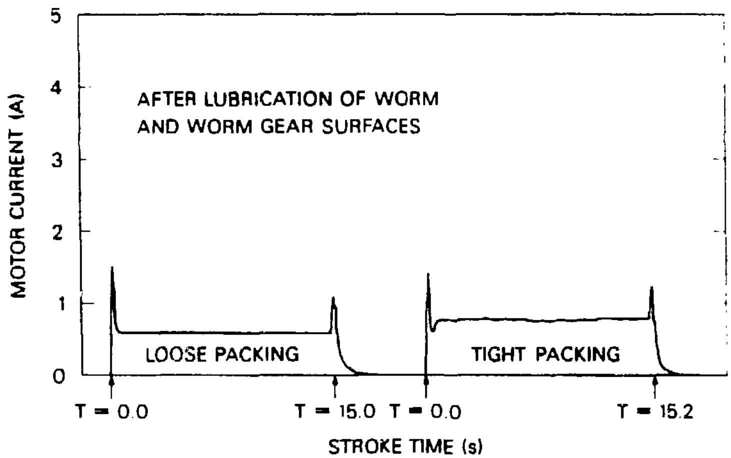

Figure 6. Motor current gross variation signatures for the three-inch gate valve following lubrication.

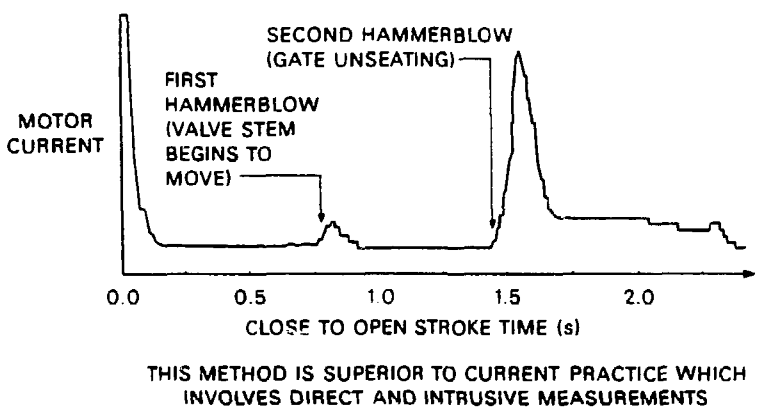

Figure 7. Motor current transient signature during open stroke.

The first transient event seen in the motor current plot is the first hammerblow, resulting from the contacting of the lugs on the worm gear with the lugs on the drive sleeve following rotation of the worm gear through approximately a one half turn. It signifies the start of motion of the valve stem. The second transient or hammerblow occurs after the valve stem rises sufficiently to use up the available clearance and start lifting the valve gate. Its magnitude, which is proportional to the load felt by the motor in overcoming the static friction between the gate and the valve seat and the inertia of the gate, is an important criteria in setting of the torque switch. Its location with regard to the start of the stroke determines the setting of the bypass switch.

Determining the switch settings using motor current transient signature analysis is superior to methods based on monitoring the compression of the spring pack, or alternately, listening to the noise associated with the hammerblows. Both of these methods require direct access to the valve. The method based on monitoring spring pack deflection requires, in addition, the direct installation and removal of complex test equipment as well as partial disassembly of the spring pack closure. The application of motor current signature analysis for this procedure may contribute to speeding up the process of verifying the torque switch/limit switch settings of safety related MOVs as required by IE Bulletin 85-03.

MOTOR CURRENT SPECTRUM ANALYSIS

The motor current signature, when amplified and conditioned (see Figure 5), is seen to contain a "noise" component. When this "noise" was analyzed using a Fast Fourier Transform (FFT) spectral analyzer, it was observed that contained within the noise were discrete frequencies which could be associated with specific periodic phenomena.

Figure 8 is a plot of an MOV motor current signature after FFT analysis. The plot of relative amplitude versus frequency over the range 0-35 Hz shows peaks associated with the rotational speed of the worm (15.3 Hz) and its first harmonic (30.6 Hz), and the rotational speed of the motor shaft (29.3 Hz). Also appearing are peaks associated with the motor slip frequency [the difference between the synchronous speed of the motor (30 Hz), and the actual speed of the motor (29.3 Hz)]. The peaks occur at four times the slip frequency (2.8 Hz) and its first harmonic (5.6 Hz).

The relatively small magnitude of the first harmonic compared to the fundamental in each case is an indication that there is little or no degradation in either the worm gear or the motor bearings or shaft.

The motor slip frequency, because it is the difference between two larger numbers, is an accurate measure of the motor speed. The change in motor speed due to a change in load is determined by the motor design parameters, whereas

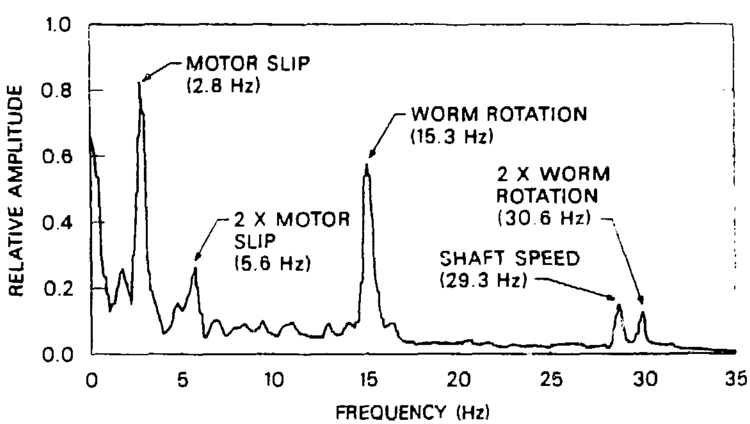

Figure 8. Motor current spectral signature (0-35 Hz) during MOV actuation.

the change in motor current due to a change in load is to some extent independent of the motor design. As a result, the relative change in motor speed with motor current may be used as a diagnostic of the performance of the motor itself.

The low frequency spectra of the MOV motor current provides additional details of the drive train loads. In Figure 9, the FFT spectrum in the range 0-1 Hz is shown. The peaks occur at the stem nut rotation frequency (0.268 Hz) and its first and second harmonic. It is observed that the second harmonic has about the same amplitude as the first. Subsequent tests show that the harmonics beyond the second also have similar amplitude, suggesting that the stem nut or stem may show degradation.

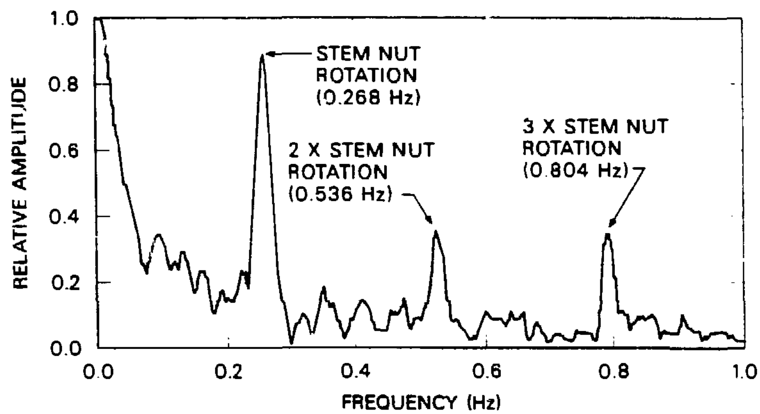

Figure 9. Motor current spectral signature (0-1 Hz) during MOV actuation.

OTHER MOTOR CURRENT SIGNATURES

Based on the experience with MOVs, it appears reasonable that motor current signature analysis should be useful for the diagnosis of other motor driven mechanical equipment. Several tests have been carried out to determine its feasibility.

Figure 10 is a motor current spectrum obtained from a 1/3 HP electric fan. The peaks shown are those due to the motor slip frequency and its first and second harmonic, and the motor shaft rotational speed. It is observed that in this case the harmonics decreased in amplitude, as expected for a simple system with little or no degradation.

The motor current spectrum for a portable laboratory vacuum pump is shown in Figure 11. The reciprocating pump was driven by a belt from an electric motor. The characteristic peaks occur at the calculated belt rotation speed and the pump rotational speed. A small peak occurs at the motor shaft speed. It is observed that the first harmonic of both belt and pump frequencies is greater than its respective fundamental frequencies. It is also

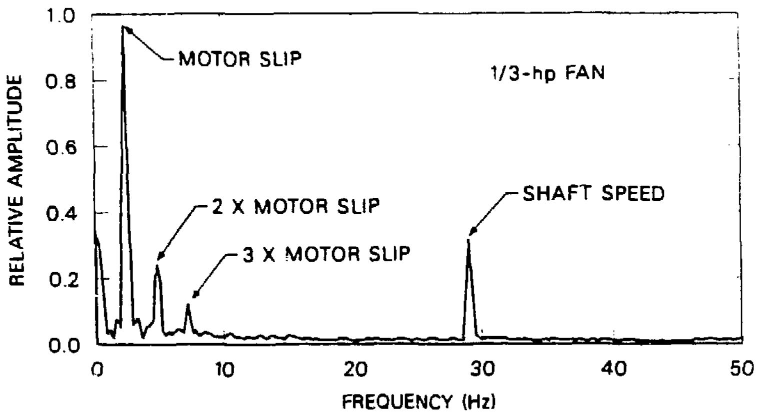

Figure 10. Motor current spectral signature for an electric fan.

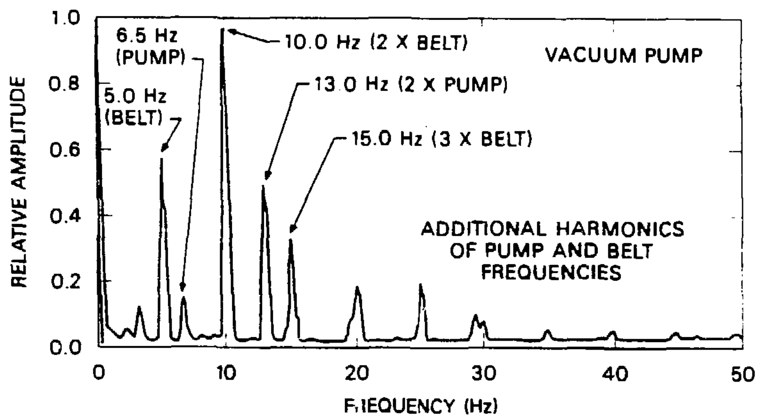

Figure 11. Motor current spectral signature for a motor-driven vacuum pump.

noted that the belt fundamental has many harmonics. In this case, it is likely that the cause of the strong pump first harmonic is simply that the pump is a reciprocating pump, with two direction (and load) changes per cycle. The harmonic content of the belt frequency may have been due to looseness or degradation of the belt.

COMPARISON WITH VIBRATION SPECTRA

Since the cause of the spectra obtained from motor current FFT analysis (load variations) could also result in equipment vibration, a comparison was carried out between the spectra obtained from the motor current and that obtained from a portable accelerometer located on the pump housing. Signals from the motor current sensor and the accelerometer were fed to two separate FFT analyzers to produce the spectra shown in Figure 12. Although the relative magnitudes of the various peaks differ, substantially all of the peaks are seen in both spectra.

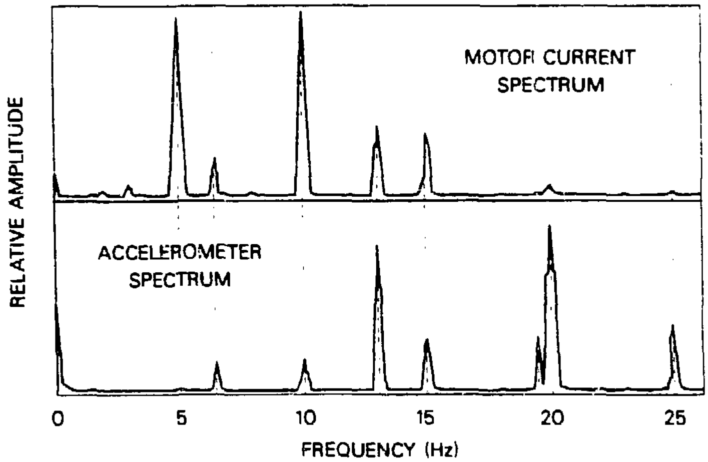

Figure 12. Comparison of spectral signatures based on motor current and on vibration.

Differences between motor current and accelerometer spectra should be expected based on differences in the nature of the signal being analyzed. These differences include the following:

- The motor current only detects load generated spectra, while the accelerometer can detect spectra generated frm outside sources, such as adjacent equipment
- The motor current acts as a single transducer, detecting all spectra generated from the power train, whereas the accelerometer spectra may be limited to one plane of vibration, and may be highly localized
- In the case of motor current, the transducer is directly linked to the load (i.e., the drive train), while the accelerometer is generally attached to a casing or other component, with the vibration signal passing through different materials from its source to the accelerometer.

In addition to these differences in the spectra, it is noted that the motor current sensor can be mounted remotely and non-intrusively, whereas the accelerometer must be directly linked to the device to be monitored.

CURRENT AND FUTURE ACTIVITIES

The work reported here has confirmed that for MOVs and other motor driven mechanical equipment, the motor current signature provides four levels of information about the mechanical loads and its time dependent variations. However, it is recognized that in order to utilize this information for determining operational readiness, the relationship between the signatures (and their changes with time) and the degradations which may lead to loss of operational readiness must be determined.

To accomplish this a data base will be developed of diagnostics versus degradations. These will be developed from tests conducted at ORNL and also from field tests at nuclear power plants and other similar facilities.

The tests to be conducted at ORNL will involve implanting defects in the valve and operator in order to determine the effect that they will have on the motor current signatures. These tests are currently in progress.

The tests at nuclear plants will consist of obtaining motor current signatures of a large number of MOVs of different sizes and types during actuation both under shutdown conditions and where possible during operation. Where signatures are obtained that appear to have unusual features, these will be reviewed with the utility and the valve examined at a future shutdown. The field tests are scheduled to begin in the next month.

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