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DATA ACQUISITION TECHNIQUES FOR ROTATING MACHINERY

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ABSTRACT: Monitoring the condition and performance of a hydraulic turbine or pump requires the simultaneous collection of data related to shaft speed, torque, power, water and airborne sound pressure level, temperature, flow rate, and vibration. Computerized data acquisition and analyses procedures are well suited to this task. Fixed and rotating sensors are used to evaluate machine problems. Some problems may be flow induced, such as cavitation, draft tube surging, and steady oscillatory flow phenomena while others are strictly related to structural and mechanical properties. This paper will describe traditional as well as some new sensor and acquisition methods currently being investigated by the Bureau of Reclamation.

BACKGROUND

The acquisition of data from hydraulic turbines as with any type of rotating machinery can be a challenging task. Anyone who has attempted to make such measurements has some appreciation for the difficulty. This is why fixed sensors have been used whenever possible. Fixed in this case means the sensor does not rotate. Through extensive testing and calibration, important information can be gained using fixed sensors. When use of a fixed sensor is not possible, such as with strain measurements, simple tasks like getting excitation to the sensor and then reading the output become complex.

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In general, hydraulic turbines are known for their relatively low rotational speeds. Data collection is somewhat simplified due to this, however, the size of the machines, in particular shaft diameters, can range from a few inches up to several feet (11 ft (3.35 m) @ Grand Coulee Third Powerhouse), creating a whole new series of problems and concerns.

The use of instrumentation to monitor the condition of rotating hydraulic machinery is somewhat of a new science. Industry seems to have been much more concerned with performing measurements and analysis on high-speed rotating machinery, such as gas turbines. Currently, the Bureau of Reclamation is involved in a wide scoping program to instrument and initiate a comprehensive maintenance program which uses our current knowledge concerning machine signature analysis and diagnostics. In addition, we plan to apply techniques developed for use in analyzing high-speed machinery to better understand hydraulic turbines and pumps.

SENSORS and DATA ACQUISITION

Proximity Probes. In the past the use of sensors in hydroelectric plants has been limited and usually restricted to fixed-type. One of the more popular types of monitoring instruments used has been the proximity probe (eddy-current or inductance-type). These probes are typically mounted near bearing locations and are used to sense turbine shaft runout. Runout is defined as the peak-to-peak displacement at the bearing location.

Output from this type of sensor may be used to signal alarms of high vibration in a unit or provide a repeative test point for signature analysis. Recent studies [Frizell and Agee, 1991], [Wahl and Frizell, 1991] have found that proximity probes mounted at the major bearing locations are very good vibration sensors and can also be used to detect draft tube surging when the output is analyzed in the frequency domain.

Strain Gages. The use of strain gages to acquire data from rotating machinery has traditionally taken two paths. By installation of gages on bearing races you can get information pertaining to shaft whirl, similar to what proximity probes can do. However, the measurement of stress in a component of a rotating machine is usually done directly. This means you must locate the strain gage at the point you wish to measure the stress. This leads to installation of the gages on portions of the machine which rotate, such as the shaft, turbine runner, generator rotor, etc.

In most instances, the strain gage is wired in a bridge circuit which provides amplification of the output and can also provide temperature compensation. The difficulty then arises in providing the excitation voltage and reading the circuit output. The most popular method to accomplish these tasks is through telemetry. Static and dynamic stress measurements can be performed. The application to hydraulic turbines is especially good since the shaft size is large and the rotational speed is low. This allows for placement of the excitation voltage (battery) and the transmitter directly on the rotating parts. The transmitter relays the signal to a receiver via an antenna placed around the shaft. The output can then be recorded by a variety of methods. Reclamation recently completed tests at Seminoe and Hoover Dams on stresses developed in generator rotor spiders. These tests involved installing numerous strain gages on the rotor spider and then measuring stress levels for various load and overspeed conditions. The data were acquired with a commercially available telemetry system. We found the system to work well and managed to acquire high quality data.

Accelerometers. Additional types of fixed instrumentation have been used to monitor machine condition. The use of accelerometers is wide spread. The correct placement of an accelerometer can give valuable information as to the machines condition. However, the optimal placement of accelerometers in not overly standardized and can vary from unit to unit depending on the manufacturer, etc.

The use of accelerometers to detect flow-induced problems such as cavitation and draft tube surging has also been attempted. Placement of an accelerometer on the draft tube mandoor gives a good indication when a surging condition is present in the draft tube. The surging frequency can be deduced through a proper frequency analysis. Accelerometers have also been used to detect cavitation. The first work was done on Kaplan turbines, extending work which was carried out by the Navy and its contractors on cavitation detection on propellers. The transfer of the this knowledge to Francis turbines has been attempted, [Abbot and Walsh, 1990] using high frequency fixed accelerometers located on the wicket gate, and close vicinity. Initial data show some correlation with historical cavitation damage.

The placement of accelerometers on the rotating components of the machine has not been very popular. This has largely been due to the fairly low frequency response characteristics of data telemetry systems and the expense of installation and maintenance of a slip ring configuration.

Acoustic Emissions.

Acoustic emission (AE) sensors are normally associated with the monitoring of solids under stress. An example is the micofracturing of a solid under load. As materials are stressed microcracks occur when the localized stress exceeds the local fracture strength of the material. The formation of microcracks is coupled with the rapid release of energy in the form of transient elastic waves, commonly referred to as acoustic emissions. Highly sensitive transducers are required to monitor stress wave emission. The most sensitive AE sensors are piezoelectric resonant frequency (undamped) types. These transducers exhibit high sensitivity about their resonant frequency but give up the quality of a flat response.

The application of AE for monitoring hydraulic generated acoustic noise was demonstrated by Hutton [1969]. Hutton investigated the detection of acoustic emissions in the presence of hydraulic background noise. He made measurements of both cavitating and noncavitating flows. Acoustic emission transducer response due to cavitating noise was significant at frequencies below 500 kHz. Signal levels for cavitating flows were in excess of 30 dB greater than noncavitating flow.

Hutton's work demonstrated that AE sensors are effective for cavitation detection. Cavitation noise is typically broad band, covering frequencies from kilohertz to megahertz. In contrast, acoustic energy from rotating machinery and flow turbulence is largely concentrated below 100 kHz. Therefore, acoustic emission transducers with resonant frequencies above 100 kHz generally offer good signal to noise response for cavitation detection.

Using AE sensors to detect turbine blade cavitation has been experimented with at Reclamation. A study was conducted to determine if AE sensors could be used to define turbine blade cavitation separate from general cavitation within the unit. Studies were conducted on a 9-inch (229 mm) model turbine of Grand Coulee Dam's 700 MW units. Initially, a survey of signal strength versus sensor location was conducted for the model under stationary conditions. To simulate a cavitation event, an AE sensor was mounted to the model runner and excited using a pulse generator. A second AE transducer was then roved about the machine while measuring signal strength and interference from other randomly generated machine noise. The only sensor position providing good signal transfer and relative insensitively to extraneous noise contamination was the unit shaft just above the turbine. As might be expected, the shaft acted as an effective wave guide for transmitting stress waves generated on the runner. Although, mounting sensors on a shaft would offer the best results, to our knowledge no rotating shaft signal transfer systems have been developed for AE systems. Of the stationary sensor locations tested, the upper turbine guide bearing cap provided the best signal strengths. This location was then tested under operating conditions with both cavitating and noncavitating flow on the runner. Cavitation within the unit was easily detected but runner cavitation could not be uniquely identified from other cavitation sources.

Magnetostictive Materials. Magneotstriction refers to the strain changes that occur in a material in the presence of an imposed magnetic field. Conversely, magnetostrictive materials also experience changes in magnetization when placed under mechanical stress. James Joule first discovered the magnetostrictive effect in nickel in 1840. Subsequently, it has been shown that all ferrous metals are magnetostrictive. However, the maximum strains in most of these materials is small (50 ppm), making changes in the magnetic field difficult to detect.

The greatest advantage of magnetostrictive material for sensing applications is that the output is in the form of a changing magnetic field. Changes in the magnetic field can be detected with an inductive loop, requiring no physical contact with the material. This eliminates the need for slip rings or telemetry systems.

The production of sensors which use amorphous magnetic materials as the major element has been somewhat experimental to date. A couple of torque sensors have been developed and numerous other applications have been attempted in experiments [Sasada, I. et.al., 1986], [Wun-Fogle, M. et.al., 1989] The use of thin ribbons or small iron based metallic glass wire have received the majority of the research. These materials when properly annealed have been shown to have a magnetomechanical coupling factor of 0.95. When used as a strain gage, gage factors or figures of merit have been measured $> 2 \times 10^5$ (compared to ~ 250 in semiconductor strain gages).

Using this new technology to acquire data from rotating machinery seems logical. It is a non-contact measurement technique, allowing the sensor to be placed on a rotating component as easily as a fixed location. The high sensitivity and good signal to noise ratio also are key factors for use on rotating machinery. In particular, there seems to be promise associated with their use in cavitation detection. The detection of cavitation implosions on a turbine runner has long been a subject of study as was discussed in the section on AE sensors. While the detection of cavitation noise is fairly simple using a number of different sensors and methods, pinpointing the location of the cavitation is more difficult. Experiments with acoustic emission sensors have hinted that the noise signature from an implosion occurring in the flow field versus one occurring on the structure which the AE sensor was mounted will be substantially different. It is for this reason that mounting a metallic glass ribbon on a turbine shaft should give a direct indication of cavitation implosions through the high frequency shear waves which travel through the runner and up the shaft. Coupling losses, as with AE sensors, are extremely high, so care needs to be taken in the placement of the magnetostrictive transducer.

CONCLUSIONS

The collection of data from rotating machinery, in particular hydraulic turbines, is becoming increasingly simplified due to improvements in sensor types and acquisition techniques. The use of new technologies such as acoustic emissions and magnetostrictive materials is leading to enhanced and simpler data collection. The use of more traditional instrumentation is also being enhanced by further electronic development and the availability of off-the-shelf data telemetry systems. With miniaturization of microprocessor based data logging and recording systems we are approaching the point of being able to install the control and recording systems directly on the rotating parts of a machine.

Reclamation is beginning to institute a broad signature analysis and maintenance program based on acquiring data from its hydraulic turbines. There is not an overabundance of experience in the collection and analysis of data from hydraulic machinery. However, using knowledge gained from others' experience with high-speed rotating components and new instruments and data acquisition methods, there is great anticipation that a successful monitoring program can be developed.

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