Acoustic Emission (AE) Loose Parts Monitoring Application in a Nuclear Power Plant

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Abstract:

The purpose of the Loose Parts Monitoring Equipment (LPMS) is to monitor for, detect and evaluate, large metallic loose parts, in the primary coolant system of Nuclear power plants. Loose parts can come from failed or weakened components or from items inadvertently left in the primary coolant system during construction. It is important to detect these loose parts before they can create a partial flow blockage and could increase the potential for control rod jamming, either of which could trigger a major problem in the nuclear system operation.

Loose Parts systems design and function is described in some critical nuclear regulatory documents including the U.S. Nuclear Regulatory Guide #1.133 and ASME document OM-S/G, part 12 which are used around the world.

One of the most critical aspects of a Loose Parts Monitoring system is minimizing the false detection of loose parts events, a major problem existing in older analog loose parts system designs. The purpose of this presentation is to discuss the application and operational aspects of a Loose Parts monitoring system for Nuclear power plants and how present day digital AE systems can improve the operation, eliminating false calls.

Figure 1. LPMS Cabinet

1 Introduction:

The purpose of the Loose Parts Monitoring Equipment (LPMS) is to monitor for, detect and evaluate metallic loose parts, using transient acoustic signal analysis. Low frequency Acoustic emission sensors (also known as accelerometers) are located at strategic positions along the reactor vessel (in direct contact with pipes and the vessel) where loose parts are most likely to travel. The accelerometers detect the impact of these loose parts as they come in contact with the pipe or vessel wall. This impact usually occurs with high force due to the speed at which these large loose parts are traveling. The accelerometers are able to detect the mechanical vibration propagating from the point of impact and convert this mechanical vibration into an electrical signal which is amplified in the system preamplifier, processed by the Loose Parts data acquisition system and recorded by the data acquisition computer. The software is the key thread needed by the data acquisition computer to provide a friendly user interface for the operator, analyze the acoustic emission transients, differentiate between noise and impact signals and alert the operator and control room when a loose part is detected.

Existing analog based Loose Parts systems used a simple threshold detection strategy to detect large impact signals, which would trigger a loose parts alarm and trigger an analog tape recorder, which would record the waveforms on all active channels for up to 2 minutes. This then required the use of an “expert” to replay these signals on a multi-channel oscilloscope to determine if the signals received were from noise or an actual loose parts event. Present day digital system have the capability of not only automating the entire process but at the same time offer, more stringent, multi-level, alarm detection criteria, eliminating false alarms due to noise and the need for an “expert” operator analysis.

The following describes each important part of a Loose Parts monitoring system followed by a description of the advanced software and signal processing and alarm detection.

2 AE Sensors for Loose Parts Monitoring

Special AE sensors are required for loose parts monitoring. First, since the sensors need to operate on a very hot nuclear reactor pipe or vessel wall, the sensor must be capable of withstanding very high temperatures and nuclear radiation exposure. The sensor must withstand continuous temperatures as high as 325 degrees C (or higher) and gamma radiation as high as 1000 MRads, over its 40 year rated life. In addition, the sensor must be sensitive to mechanical vibrations up to 20 kHz while at the same time immune to electrical and electromagnetic disturbances.

3 Charge Preamplifiers

Due to the very high temperatures in the nuclear containment area and the high radiation environment, special considerations are required when it comes to installing and using AE preamplifiers. Traditional voltage preamplifiers cannot be used as the preamplifier must be located a long distance (sometimes up to 100 meters) away from the system to keep within the temperature and the radiation limitations of today’s electronics. In these cases a charge preamplifier is used. The specific advantage of a charge preamplifier over a voltage amplifier is that the preamplifier can be located long distances away from the sensor without degradation in signal amplitude.

Other preamplifier considerations that have been taken into account in the specific application is in the ability to remotely change the gain of the preamplifier as well as the ability to run diagnostics remotely including an on-board “preamplifier signal input” which injects a known amplitude and frequency sine wave signal into the front of the preamplifier, and an “Auto sensor Test” function to excite the sensors on the structure to determine operability. These remote control gain and diagnostic functions are very important especially when the preamplifiers and sensors are inside containment and it is necessary to determine system integrity at specific test intervals.

4 Data Acquisition System Console

A data acquisition system console as shown in figure 1 contains the digital data acquisition system utilizing multiple Physical Acoustics, PCI-8's, 8 channel Acoustic Emission system on a single PCI card, the industrial chassis and PC compatible computer, a user friendly, intuitive, graphical user interactive interface, an alarm and control room interface and a color printer. The data acquisition processes all AE signals from the sensors and performs real time feature extraction and processing to monitor the health of the system and detect suspect loose parts. The system also provides automated and user demand frequency analysis to help distinguish between noise and loose parts. The console has been thoroughly tested and certified to operate in the presence of EMI and has also been seismically tested to assure its operation, even in earthquake conditions.

5 Loose Parts Monitoring Software

The Loose Parts Monitor software has been designed with multiple data presentation screens, specifically for easy understanding and to offer a complete graphical and icon related analysis for fast problem identification. There are 6 basic AE monitoring software screens including monitoring of AE signal level versus channel for background noise monitoring and leak detection, AE signal level versus time where a user can utilize trending principles to determine channels of concern, the AE monitoring screen which contains multiple key AE graphs including Hits versus channel, Hits versus time, Hits versus amplitude and Amplitude versus Energy correlation graph. In addition, there is a real time waveform analysis screen which allows a timed or on-demand waveform capture and frequency analysis and Correlation analysis to aid in location of sources. Finally there is a Sensor Layout screen which shows the nuclear components being monitored, and a color-coded sensor placement to show the sensor location and the current alarm status.

6 Loose Parts Alarm Detection

The most important part of the new digital Loose Parts Monitoring system is the alarm detection mode. As mentioned earlier, it is extremely important to eliminate false calls. Any alarm in a nuclear plant needs to be taken very seriously and because of that, each alarm must be genuine and important. Loose parts systems have suffered a poor reputation over the years due to the older analog systems lack of good alarm discrimination and need to be followed up with a manual, human assisted (via monitoring replayed waveforms on an oscilloscope) decision. It was for this reason that a lot of time was spent to come up with an automated, on-line, multiple level alarm criteria in the Loose Parts Monitoring system. We have implemented a three level alarm criteria including both time and frequency analysis, as well as incorporating pattern recognition techniques in the decision making.

The following is the alarm detection process that has been employed in the Loose Parts Monitoring system. First, a "suspect" loose parts alarm is generated when AE activity meets a defined 2 dimensional alarm based on a correlation graph of two AE features. Once detected, this starts an alarm determination process that includes performing a pattern recognition analysis using AE feature analysis. If the criterion for a loose parts alarm is met, a frequency analysis is performed comparing the high frequency/low frequency content against the alarm criteria for a loose part. Only after all three conditions are met, will a loose part be triggered. Upon detecting a loose part, a 2 minute waveform capture mode is initiated including pre-trigger waveform information. In addition, an alarm output signal is generated to the control room to indicate a loose parts detection. At that point, information is available for waveform review. Also, the location determination can be analyzed using waveform correlation techniques built into the system.

Summary

An advanced, digital, AE Loose Parts Monitoring system has been developed that is capable of operating in a nuclear environment, monitoring the primary coolant system of a nuclear reactor. The system replaces old analog signal processing techniques that were very prone to false alarms. The benefit of this new system includes the advanced diagnostics to minimize test time as well as the application of an advanced alarm detection criteria that has been developed to eliminate false calls, and a very user friendly graphical user interface.