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Development of an algorithm to discriminate between valid and false alarms in a loose-parts monitoring system

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HIGHLIGHTS

- We developed a gun to generate impact signals to validate field experiment.
- We developed an algorithm to discriminate against false alarms in a LPMS.
- We proved that the algorithm minimized the false alarm rate in the LPMS.
- We identified the signal patterns causing false alarms by thermal shock and friction.

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ABSTRACT

Loose-parts monitoring system (LPMS) monitors loosened or detached parts and foreign parts inside the pressure boundary of a reactor coolant system. If any object is detected, the LPMS identifies the object's characteristics, and can contribute to improving plant safety, since it can identify loosened metal objects, which have a potential to cause severe damage to internal components of the steam generator chamber. The most significant problem of a traditional LPMS is the high false alarm rate. The most developed systems used more sophisticated methods for event identification. With these sophisticated systems, the false alarm rate could be reduced to below 1%. Even though the LPMS resulted in a false alarm rate of less than 1%, there is still a high false alarm rate when the unit increases or decreases power. As the unit increases power, the coolant starts to heat the metal structure, which causes false alarms. Plant operators should continuously identify all alarms, including false alarms, until the metal structure reaches thermal balance. It is difficult to discriminate between valid and false alarms, since the signal pattern by thermal shocks and structure friction is similar to that by loose metal impacts. The false alarm rate can be reduced to almost 0% by applying an algorithm to discriminate between the false and valid alarms. In this paper, an efficient algorithm is proposed to discriminate against signatures which are not related to loose-parts events, especially when the unit increases or decreases power. The algorithm can discriminate the signal pattern by the impact of loose parts against the signal pattern induced by thermal shocks and structure friction. The algorithm was validated in field tests by the proven automatic gun, and the false alarm rate was minimized.

1. Introduction

The most significant problem of a traditional loose-parts monitoring system (LPMS) is the high false alarm rate. Plant operators have tended to neglect the warnings given by LPMSs. In early applications, the main cause of the event recognition is based mainly on the root-mean-square (RMS) value or on the amplitudes of signals of the loose-part sensors. In these applications, the RMS value was compared with the previously estimated background RMS. The experimentally estimated alarm levels were used for signalization (Mayo et al., 1988; Tsunoda and Kato, 1985; Bechtold and Kunze, 1999; Mayo, 1994). In order to overcome limitations posed by the amplitude-based alarms, a multiple-level alarm process has been implemented including frequency analysis, pattern recognition techniques, and correlation analysis (Figedy and Oksa, 2005; Chiu et al., 2004; Rhodes et al., 2012). Using sophisticated techniques such as these to distinguish between background events and loose part impacts, modern LPMSs have demonstrated false alarm rates and missed alarm rate below 1% (International Atomic Energy Agency, 2009). A two-stage

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classification system using the combination of two data mining techniques and a hybrid method based on the autoregressive model and super vector machine were presented in these few years (Cao et al., 2012; Sotirios et al., 2008; Tjhai et al., 2010).

Even though the LPMS resulted in a false alarm rate of less than 1%, there is still a high false alarm rate when the unit increases or decreases power. As the unit increases power, the coolant starts to heat the metal structure, which causes false alarms. Plant operators should continuously identify all alarms, including false alarms, until the metal structure reaches thermal balance. It is difficult to discriminate between valid and false alarms, since the signal pattern by thermal shocks and structure friction is similar to that by loose metal impacts. Noise in the running unit can generate false alarms that reduce operator confidence, interfere with normal operations, and cause unnecessary expense. One example is in the manual stop of a pressurized water reactor (PWR) operating after detecting a foreign object of 113.4 g in the hot leg of a steam generator (SG), even though there were no loose parts, foreign objects, or impact signs in the steam generators (Point Beach-1, 2000).

The false alarm rate can be reduced to almost 0% by applying an algorithm to discriminate between the false and valid alarms. In this paper, an efficient algorithm is proposed to discriminate against signatures which are not related to loose-parts events, especially when the unit increases or decreases power. The algorithm can discriminate the signal pattern by the impact of loose parts against the signal pattern induced by thermal shocks and structure friction. The algorithm was validated in field tests by the proven automatic gun, and the false alarm rate was minimized.

2. LPMS

LPMS monitors loosened or detached parts and foreign parts inside the pressure boundary of a reactor coolant system (RCS). The primary purpose of the loose parts detection is the early detection of loose metallic parts in the primary system. Early detection can provide the time required to avoid or mitigate safety-related damage or malfunctions in primary system components. Whenever detached or loosened parts impact the inner surface of the pressure-retaining boundary of the reactor coolant or its internal structures, energy is transferred to the walls. If any object is detected, the LPMS identifies the object's characteristics such as mass, frequency, and impact location. LPMS can contribute to improving plant safety, since it can identify loosened metal objects, which have a potential to cause severe damage to internal components of the steam generator chamber (Electrical Power Research Institute, 2007; International Electrotechnical Commission, 2009).

LPMS generated many false alarms in the 1970s, which resulted in deteriorating reliability and damage to the components of SGs. The U.S Nuclear Regulatory Commission (NRC) established Regulatory Guide 1.133 (US Nuclear Regulatory Commission, 1981) entitled "Loose-part detection program for the primary system of light-water-cooled reactors" and has requested for installation of LPMS for Nuclear Power Plant (NPP) construction since 1978.

LPMS consists of an accelerator, pre-amplifier, LPMS-alarm unit (AU), loose parts alarm processor (LPAP), and the analysis computer, as shown in Fig. 1. The piezo-electric accelerometer senses the signal on the pressure boundary of the RCS. The pre-amplifier receives the electrical charge from the accelerometer, converts it to voltage signals, and amplifies and sends it to the LPMS-AU. The LPAP has a display, speaker, and control keyboard, and it discriminates the valid signals from the LPMS-AU. Each time a valid signal occurs, the analysis computer generates an alert alarm by analyzing a time chart and FFT chart.

3. Development of the automatic gun

3.1. Reliable development of the automatic gun using magnetic force

Plant operators should test the acquisition of background signals, the signal sensitivity, and the alarm set value by impacting specific points with steel balls. The freefall impact test with steel balls on an SG and a reactor can result in prolonged radiation exposure to plant operators, and it takes a long time. It is very difficult to test the bottom of a reactor and check the integrity of the testing channel, because it is in an area with high radiation. An automatic gun using magnetic force with less deviation needed to be developed to generate impact signals, because freefall impact tests using steel balls has limited accuracy. The automatic gun served another purpose of shortening the test time and providing accurate impact

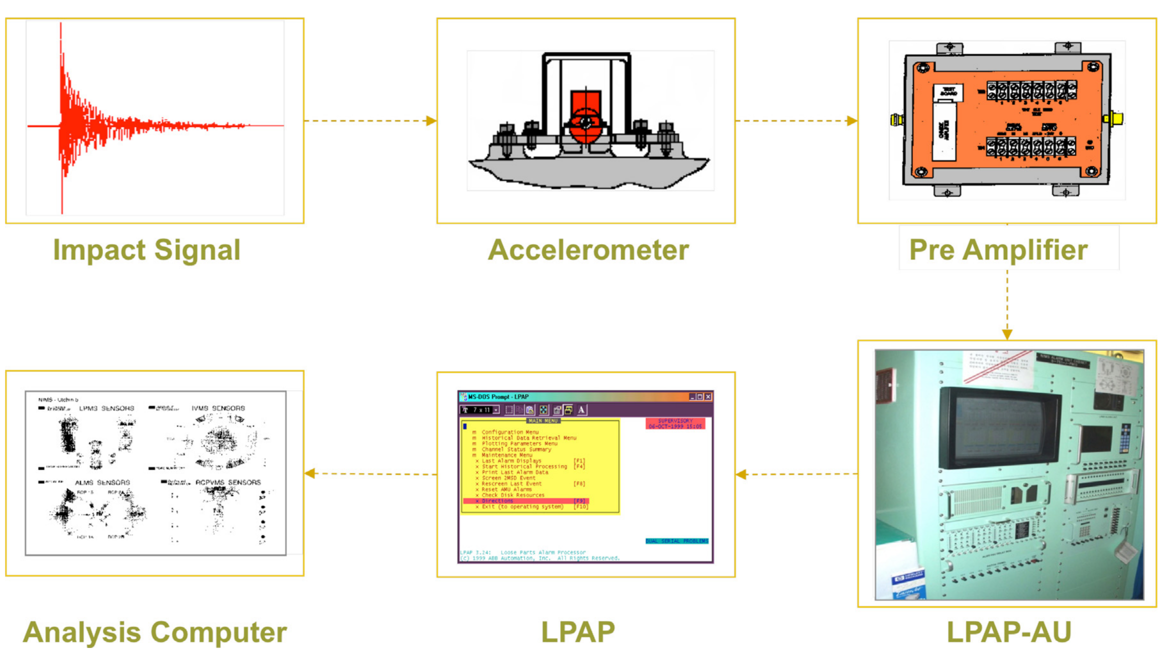

Fig. 1. Block diagram of LPMS configuration.