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Fault Monitoring System for Thermal Reduction Reactor

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Abstract

Onset of the research on the monitoring system for detecting faults in the thermal reduction reactor has, for the first time, begun at 2001 and the preliminary study has performed in order to support the successful reduction process. The task of the fault monitoring system is to identify the reactor and agitator drive integrity. Appropriate sensors and related electronic equipment were constructed for the acquisition and analysis of fault-induced signals. Fault signal acquisition was performed in the small-scale reduction reactor and the agitator drive experimental facility. Through the series of experiments, the various signals such as background noise, operating signals, and fault signals were measured and their characteristics were identified. In this presentation, the monitoring system for the internal reduction reactor integrity is only described.

1. Introduction

The research for the fault monitoring system of the reduction reactor that is a main process in the advanced spent fuel management process has been performed since 2001. In the reduction reactor, the metal reduction takes place by very reactive de-oxidizer (Li) under high temperature about 600^{o}C. The internal vessel of the reduction reactor, therefore, is to be designed to cope with the thermal stresses from high-temperature distribution and any chemical attack on the reactor surface.

The objective of this study is the development of the monitoring technique for detecting the incipient defects such as cracks, corrosion pits, etc., which will grow to the high-risk failure, at the surface of or within the boundary of the internal vessel in the reduction reactor. And from this monitoring result, the operator can recognize the status the internal vessel integrity and might set up the schedule for maintenance or decide whether the process should be halted down or not.

In order to achieve the monitoring technique satisfying the objective described above, the acoustic emission (AE) method, which is most widely used in the non-destructive testing, is employed. AE method is only one of the non-destructive testing methods for fulfilling the detection of some defects distributed globally within the structure during operation. In reality, this method has been applied intensively to the nuclear power plants and other pressurized systems [1][2][3][4] and to the cemented waste canisters [5], but rare has been done in the field of spent fuel management in which high-temperature furnace is involved.

In the study of 2001, the major purposes were the identification of the possibility of detecting some defects within the internal vessel of the reduction reactor and also identification of the characteristic features of defects, when it is possible to measure, for further delicate signal analysis. In order to achieve the purposes, a wideband AE sensor was installed on the small-scale reduction reactor and the data acquisition system was configured.

2. Basic Description of Acoustic Emission

Acoustic Emissions are stress waves produced by sudden movement in stressed materials [6]. Fig.1 shows the process of stress wave generation and the detection procedure. Sudden movement at the source produces a stress wave, which radiates out into the structure and excites a sensitive piezoelectric transducer. The detection equipment of the acoustic emission signals are composed of a transducer, which was coupled to the material using a so-called couplant like a gel, a pre-amplifier, a band-pass filter which is sometimes replaced by low-pass or high-pass filter depending on the application, and a data acquisition system which is far apart from the sensing position. The excitation of the piezoelectric transducer is converted into the electric voltage change and the resulting voltage signal is amplified in the pre-amplifier for transmitting this signal to the data acquisition system through the long BNC cable unless it is too attenuated to acquire. The pre-amplifier also filters out the amplified signal. The data acquisition system receives the signal and amplifies again, if necessary, and filters out accurately. Then, this signal is digitized and the signal analysis technique is performed on the digitized data.

A major benefit of the acoustic emission detection or inspection is that it allows the whole volume of the structure to be inspected non-destructively during a single operation. It is not necessary to scan the structure looking for local defects and it is only necessary to connect a suitable number of fixed sensors without removal of insulation, decontamination for entry into vessel interiors, scanning of very large area. Thus, this technique is the most suitable for application to the monitoring the internal integrity of the reduction reactor covered fully by the high temperature furnace.

3. Experimental Setup

Fig.2 shows the configuration of the data acquisition system. The data acquisition system composes of the three parts: the main processor and peripherals, two digital signal processor (DSP) boards, and the signal-conditioning module. In this configuration, one DSP board and the signal-conditioning module are provided for use in the agitator drive and so these components are not described here. Another DSP board, i.e., AE DSP board, is configured for AE signal processing by use of the product, PCI/DSP, from the Physical Acoustics Co. AE DSP board has 4 input channels and the maximum 10MHz/Channel. The sampling can be varied to 5, 2.5, 1.2 MHz. It has various low-pass, high-pass, band-pass filters. In the experiment, the wide-band AE sensors are selected for identifying the overall characteristics of fault and other signals. The pre-amplifier shown in the upper right in Fig.2 has the amplification gains of 20, 40, and 60dB and the band-pass filter with the range of 100kHz ~ 1MHz.

For the experiments, the Advanced Spent Fuel Management team in KAERI developed the small-scale reduction reactor for preliminary testing the metal reduction process and the fault monitoring experiment was carried out for this small-scale reduction reactor during operation period. Fig.3 shows the small-scale reduction reactor. The small-scale reduction reactor has the poorest sensing environment because of full coverage over the reduction reactor by the furnace except the upper part, so that AE sensors should be installed at small flange surface of internal vessel as shown by Fig.4. Moreover, AE sensors are to be mounted on the so-called waveguide to protect from the effect of high temperature with the expense of the AE signal attenuation. The waveguide was adhered to the flange surface by the spot welding. The most of reactions and events are occurred below the horizontal middle of the internal reactor. In order to acquire the signal from lower portions of the internal reactor, the amplification gain in the pre-amplifier is set to the maximum level of 60dB. In this experiment, single AE sensor was installed because more installing AE sensors and waveguides induce the serious problems in the operator's operation in performing the metal reduction process. The couplant was used to couple between the AE sensor and the sensor holder on the waveguide. The couplant used was mainly for high temperature environment up to 500^{o}C but, in fact, the temperature on the surface of the sensor holder was below 150^{o}C.

4. Experiments

For the reduction process, before heating up, the air environment is changed into the inert gas environment and the metal and salt powder is placed into the internal reactor. The furnace starts to heat up and the temperature is controlled to rise to about 650^{o}C under the continuous flow of the inert gas into and out of the interior of the reduction reactor. At 650^{o}C, the salt powder begins to melt down. Then, it begins that the de-oxidizer is inserted into the internal reactor and at the same time, the agitator drive starts to rotate the agitator. After the overall process is completed, the valve in the bottom of the internal reactor is opened and the power for the furnace is shut off to cool down the reactor.

In performing a series of experiments, various signals such as operational signals (Ar flowing, agitator operation, furnace interference, etc.) and background noise levels for temperature variations were measured and analyzed. For the background noises, Fig.5(a), (b), and (c) show the background noise signals for various temperatures. As can be seen in these figures, the noise level is varied to the temperature change and the level of signal magnitude is reduced remarkably as the temperature increases. From this result, the threshold level in the AE DSP board should be set by the floating type rather than set to a fixed point in order to cover the all range of the temperature change. Fig.6 show the AE signal for the discharge of inert gas (Ar) at the onset of the experiment. The AE signal induced by the inert gas flow is reduced enough to below the threshold level at high temperature above 200^{o}C. Fig.7 shows the AE signal resulted from the rotation mechanism of the agitator drive. This signal sometimes interfered the fault signal acquisition by triggering the threshold level. The high-frequency AE signal by the agitator drive mechanism is, in this experiment, due to the misalignment of the motor and the rotating axis of the agitator drive. The problem could be circumvented by slightly raising the threshold level and it is expected that in the application of the real-scale reduction reactor, the agitator drive will not make a significant AE signals because of better alignment than in the small-scale reduction reactor.

With the small-scale reduction reactor, AE signal acquisition was performed four times. At every operation, none of noticeable AE signals was detected when heating-up from 200^{o}C to 650^{o}C was performed normally and the chemical reactions at 650^{o}C performed stably except the operation-related AE signals described above. When a certain event in the internal reactor takes place, however, the flourishing AE signals were detected.

Fig.8 shows the AE signal from the molten salt leak through a valve. The AE signals of this type were measured for second experiment during short period around the melting temperature of salt powder. The appearance of this signal on the time axis is similar to that of the background noise but the signal level of this signal is slightly higher and the noticeable difference between these signals are appreciated when comparing both frequency behaviors. The AE signal induced by the molten salt leak is usually weak and so it is hardly possible to detect this signal for the case of high level of background noise.

Fig.9 and Fig.10 show the AE signal when the corrosions were produced extensively on the surface of the internal reactor at the 4th experiment. The AE signals in Fig.9 and 10 are occurred simultaneously and the AE signals in Fig.9 had more frequency than those in Fig.10. Both signals are generated enormously right after the de-oxidizer is inserted and their intensive generation tendency was elapsed for a long time (about 3~4 hours). The surface defects by extensive corrosions were identified after cooling down and opening the cover of the reduction reactor. It is supposed that the AE signals as in Fig.9 are occurred from the crack in the corrosion product layer on the surface of the internal reactor and the AE signals as in Fig.10 are due to the spalling of the corrosion product layer [7][8].

5. Conclusions and Future Research

From the experimental results, the faults or the (incipient) defects are measured and characterized. At this time, the hardware settings are being altered from the wideband type to the band-pass type whose bandwidth is constrained to encompass the dominant frequency of the fault signal. More than 3 AE sensors are going to be installed along the circular small flange surface in the reduction reactor for more reliable detection via real time defect location identification. This activity will help improve the safe operation in the advanced spent fuel management process or any other processes that handle spent fuels thermally.

References

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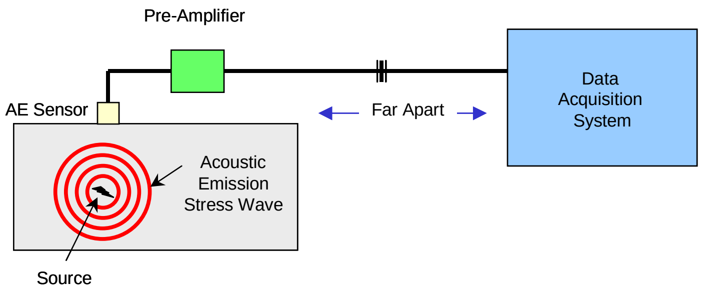


Fig.1 Basic Principle of Acoustic Emission Method

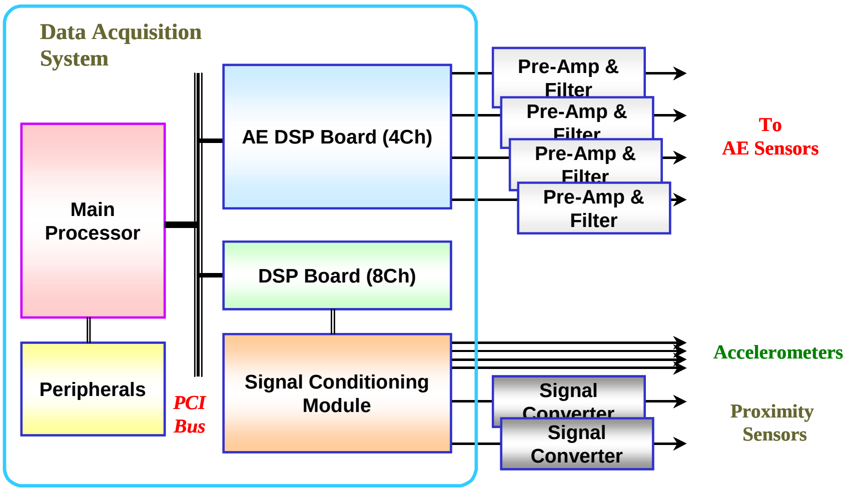


Fig.2 Configuration of Data Acquisition System

Fig.3 Small-Scale Reduction Reactor

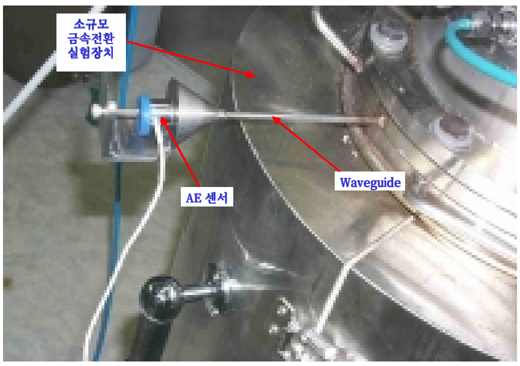
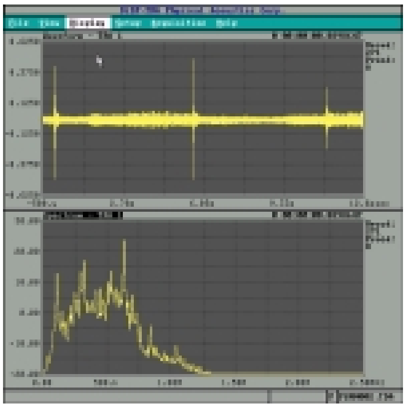
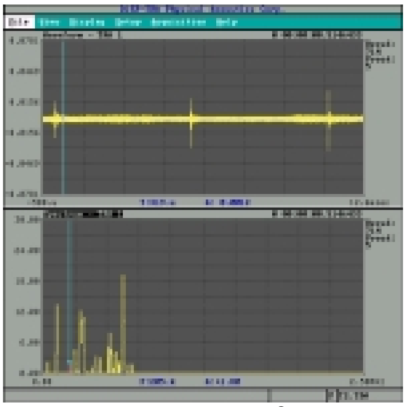


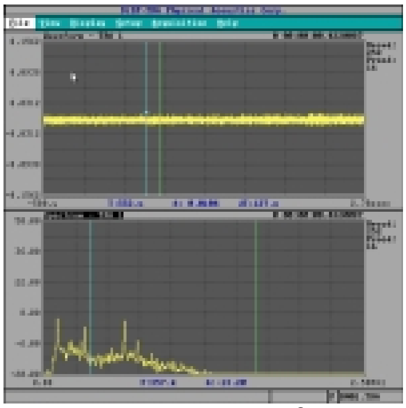
Fig.4 AE Sensor and Waveguide



(a) At Start Up



(b) At 200~300^{o}C



(c) At 400~600^{o}C

Fig. 5 Background Noises for Temperature Changes

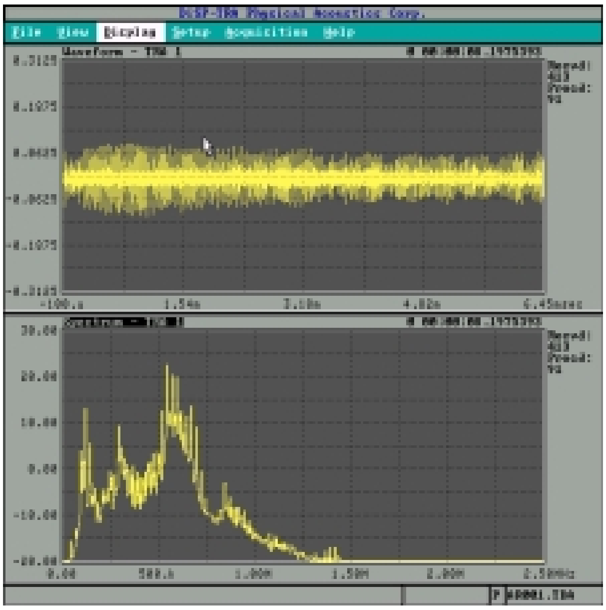


Fig. 6 Inert Gas Discharge

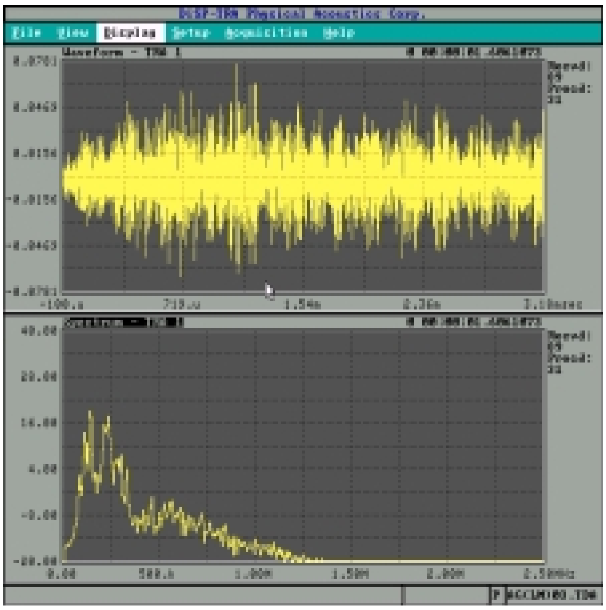


Fig. 7 Agitator Driving (at 200 rpm)

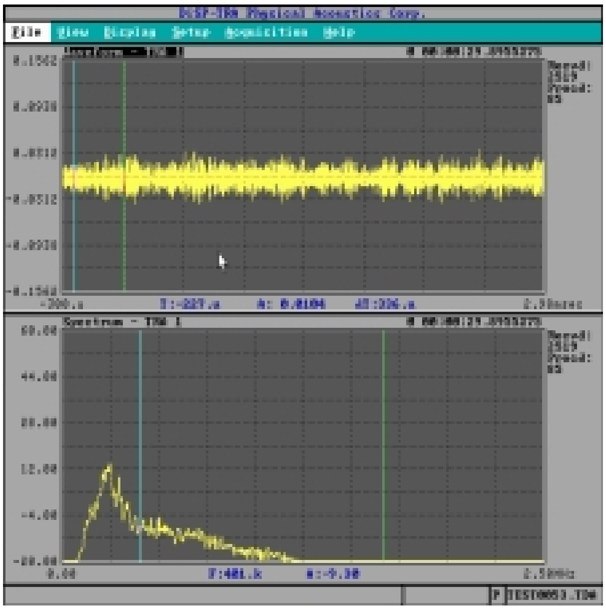


Fig. 8 Molten Salt Leak

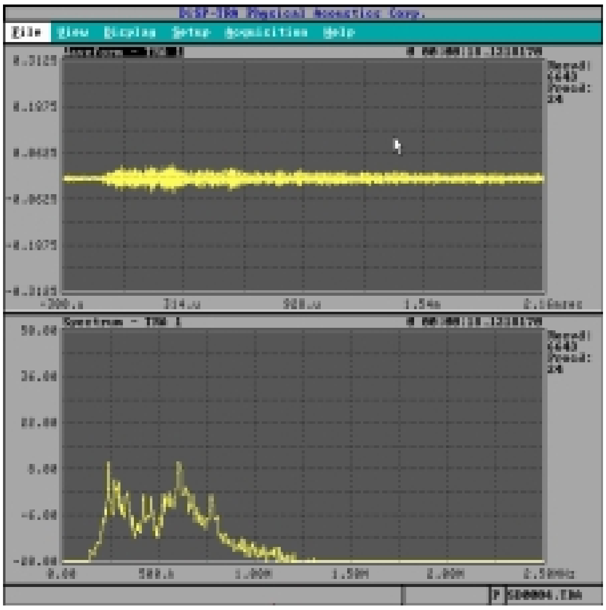


Fig. 9 Local Crack in Corrosion Product Layer

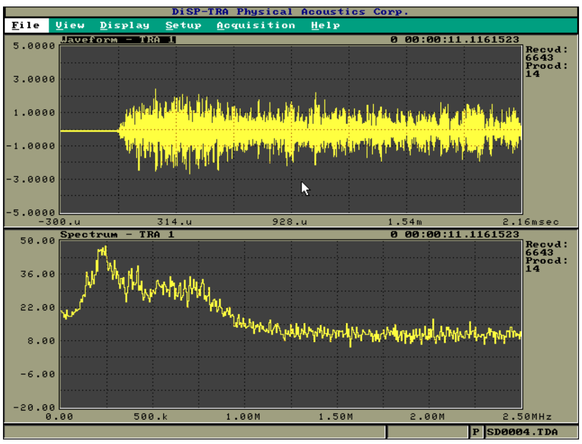


Fig.10 Surface Pit by Spall of Corrosion Product Layer