Study of the Characteristics of Water into Sodium Leak Acoustic Noise in LMR Steam Generator

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1. Introduction

A successful time for detecting a water/steam leak into sodium in the LMR SG (steam generator) at an early phase of a leak origin depends on the fast response and sensitivity of a leak detection system. It is considered [1], [2], that the acoustic system is intended for a fast detecting of a water/steam into sodium leak of an intermediate flow rate, 1~10 g/s. This intention of an acoustic system is stipulated by a key impossibility of a fast detecting of an intermediate leak by the present nominal systems on measuring the hydrogen in the sodium and in the cover gas concentration generated at a leak.

During the self-wastage of a water/steam into sodium leak in a particular instant, it is usual in 30~40 minutes from the moment of a leak origin [1], there is a modification of a leak flow out regime from bubble regime to the steam jet outflow. This evolution occurs as a jump function of the self-wastage of a leak and is escorted by an increase of a leak noise power and qualitative change of a leak noise spectrum.

Subject of this study is by means of two experiments, one is an acoustic leak noise analysis of the water into sodium leak results in no damage to the LMR SG tube bundle, and another is for prediction of the frequency band under a high outflow leak condition. We experimented with the Argon gas injection considered with the phenomena of secondary leaks in real.

2. Experiments

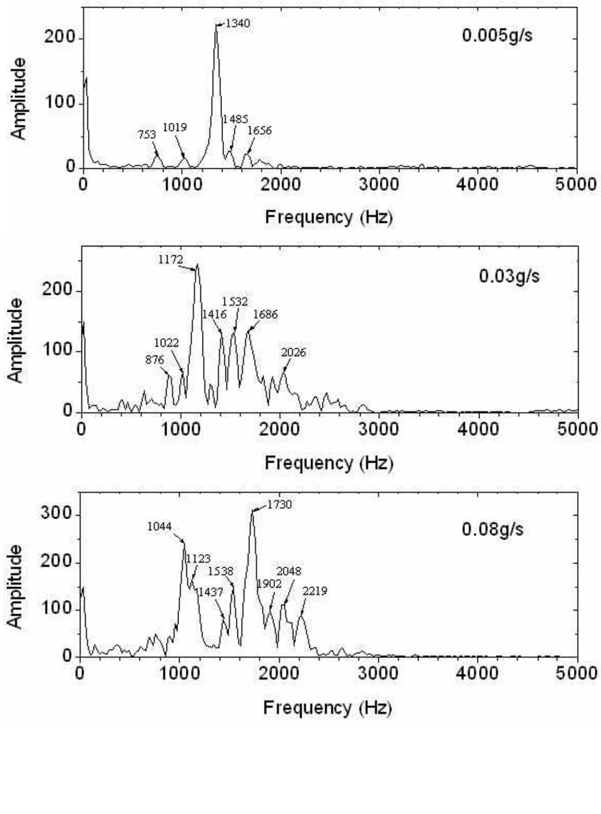
Measurements of the micro-leak noises in circulating sodium at a sodium temperature of 350~500^{o}C were executed in the IPPE facility and have confirmed the prospects of a passive acoustic method for micro-leak detection in an industrial steam generator. The experimental works of the Argon gas injection were in a water mock-up facility of KAERI. The container for the acoustic leak experiment in this facility was constructed with stainless steel 304, and its sizes are height 2000mm, diameter 500mm and thickness of wall 10mm. The Argon gas injection system consists of a micro nozzle, diameter 0.006~0.16mm, and a high-pressure outflow system supplied up to 100kg/cm^2.

3. Results and Discussion

3.1 Signal properties by initial hydrogen bubbles for water into sodium leak and by the Argon gas injection

The experimental data of the noise spectra resulting at leak beginning stage is presented in Fig. 1 and Fig. 2 are its FFT analysis results. At the steam leak rate of 0.005 g/s the prevalence of $r = 1.8$~1.9mm hydrogen bubbles was observed [3]. The presence of smaller sized and larger hydrogen bubbles was insignificant. At a leak rate of 0.03 g/s a spectrum expansion was observed in a higher frequency band due to the bubbles of smaller dimensions. At a leak rate of 0.08 g/s a prevailing maximum frequency of 1730 Hz was especially observed. At a leak rate increase from 0.005 g/s to 0.183 g/s, an increase in the amplitude of the raw signal, and the frequency relative to the spectrum maximum was approximately observed at more than three times. In the Argon gas injection to compare the bubbling frequency regime, the frequency by a bubbling was also around 1~2 kHz followed with the Argon gas flow rates, 0.26~210cm^3/sec, according to the diameter of the micro nozzle under 100kg/cm^2. Eq. (1) was to calculate the predicted frequency generated by a bubbling, used in sodium-water reaction.

$$f_o = \frac{1}{2\pi R_o}\sqrt{\frac{3\gamma P_{H_2}}{\rho_{Na}}} \qquad (1)$$



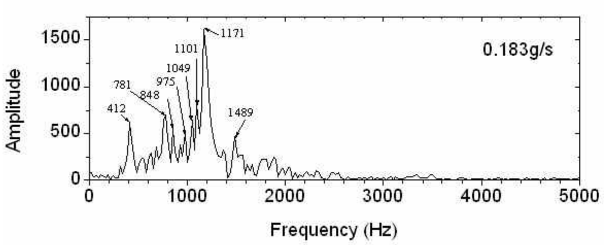


Figure 1. FFT analysis results of the experiment for water into sodium leak.

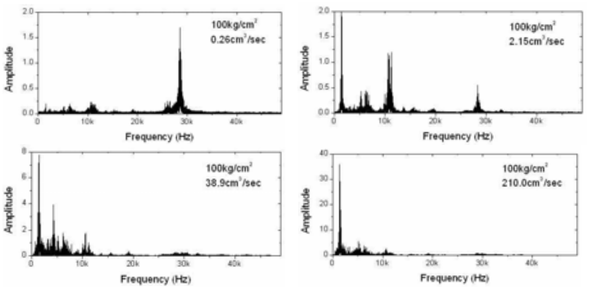


Figure 2. FFT analysis results for the Argon gas injection experiments.

3.2 Limited outflow rate by defect channel

Using the experimentally established ratio between the outflow channel diameter d_o and length of a torch of water with a sodium interaction L, it is possible to estimate the flow rate of a leak, at which there will be no damaging action of a torch on the next tube in a tube bundle of the LMR SG. Minimum distance between the tubes in a tube bundle of LMR SG constitutes 35 mm [4]. The ratio of the length of a torch and the diameter of the channel of the outflow for steel 2.25Cr1Mo at a temperature of sodium of 450^{o}C is equal: L/d = 280 for the economizer part of a steam generator, L/d = 160 for the evaporator and the super heater part of a steam generator [1]. Thus, the leak channel diameter, at which there will be no damaging action will be equal to 0.125 mm and 0.219 mm, at a leak in the economizer and it is evaporative-super heater parts of a steam generator accordingly. The maximum water/steam flow rate for such leak channel diameters will be equal to 1 g/s approximately.

At the well-developed turbulence the Strouhal number is 0.2 and 1-th mode frequency of vortex formation will be not more than a few of MHz (sub-cooled region) and not more than 100~200kHz (superheated region).

Apparently, with a increase of the size of a defect these frequencies decrease. Boundaries of the leak hydrodynamic flow regime for the LMR SG have already been calculated and presented [6]. According to this data the transition to the turbulent regime for the LMR SG in its bottom tube bundle part is expected by a volumetric water-steam flow rate of $1x10^{-2}cm^3$/sec.

3.3 Prediction of hydrodynamic noises

For this leak hydrodynamic regime according to our experimental results a more probable hydrogen bubble radius and peak frequency for the regime of a leak noise spectra is predicted.

For a mass leak rate $1x10^{-3}$ g/sec estimated the Reynolds number is equal to 357. For a leak rate less than $1x10^{-3}$ g/sec it is possible to expect the bubbling low regime and for a leak rate more than transition rate the jetting outflow regime of a leak is expected. Using the characteristics of the water-steam mixture for the LMR SG [6], we could be calculated, that the turbulent steam flow out regime is impossible if the defect size (2r) is less than 0.143 mm in a sub-cooled part, and 0.84 mm in a superheated part of LMR SG.

3. Conclusion

To protect the LMR SG from a damage of a tube bundle owing to the origin of secondary leaks it is necessary to detect a leak during its self-wastage up to the moment of the outflow diameter, equal to less, than 0.125 mm in economizer part and 0.219 mm in evaporator - super-heater parts of a steam generator.

The experimental and calculation study shows, that the application of an acoustic leak detection system allows for time to detect a leak in the LMR SG at an early phase of its self-wastage. The key moment of an acoustic leak detection system is the leak noise identification for the transition from a bubbling to a jet steam outflow. And we will present the test results to detect the leak noises under higher background noises using a neural network in the future.

ACNOWLEDGEMENT

This study was performed under the Mid and Long-term Nuclear R&D Program sponsored by the Ministry of Science and Technology (MOST) of Korea.

REFERENCES

[1] V.M. Poplavsky, F.A. Kozlov, Sodium-water steam generators safety, Moscow Energoatomizdat, 1990.

[2] Kim Tae-Joon, Valery S. Yughay, Hwang Sung-Tai, Advantages of Acoustic Leak Detection System Development for LMR Steam Generators, Journal of the Korean Nuclear Society. Vol. 33, No. 4, pp. 423-440, 2001.

[3] S.S. Kutateladze, M.A. Sturikovich, Hydrodynamic of gas-fluid systems, Moscow, Eergiya, 1976.

[4] KALIMER/FS400-DD-01-Rev.1/1999, System Description for Steam Generation System, KAERI, Korea, 1999.

[5] IAEA - TECDOC-946, Acoustic Signal Processing for the Detection of Sodium Boiling or Sodium-water Reaction in LMFRs, May, 1997.

[6] Kim Tae-Joon, Valery S. Yughay, Hwang Sung-Tai, Simulation of Water/Steam into Sodium Leak Behavior for an Acoustic Noise Generation Mechanism Study, Journal of the Korean Nuclear Society, Vol. 33, No. 2, pp. 145-155, 2001.