Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 30-31, 2008

Acoustic Leak Detection under Micro and Small Water Steam Leaks into Sodium for a Protection of the SFR Steam Generator

Tae-Joon Kim[a*], Valeriy S. Yugay[b], Ji-Young Jeong[a], Jong-Man Kim[a], Byung-Ho Kim[a], DoHee Hahn[a]
[a]*Korea Atomic Energy Research Institute, 150 Dukjin-dong, Yuseong-gu Daejeon 305-353, Korea*
[b]*SSC RF Institute for Physics and Power Engineering, Obninsk, Russia*
[*]*Corresponding author: tjkim@kaeri.re.kr*

1. Introduction

The results of an experimental study of water in a sodium leak noise spectrum formation related with a leak noise attenuation and absorption, and at various rates of water into a sodium leak, smaller than 1.0 g/s, are presented. We focused on studying the micro leak dynamics with an increasing rate of water into sodium owing to a self-development from 0.005 till 0.27 g/s. Conditions and ranges for the existence of bubbling and jetting modes in a water steam outflow into circulating sodium through an injector device, for simulating a defect in a wall of a heat-transmitting tube of a sodium-water steam generator were determined. On the basis of the experimental leak noise data the simple dependency of an acoustic signal level from the rate of a micro and small leak at different frequency bands is presented to understand the principal analysis for the development of an acoustic leak detection methodology used in a K-600 steam generator, with the operational experiences for the noise analysis and measurements in BN-600.

2. Experimental Works

Existing experience of industrial steam generator operations indicates the primary occurrence of water into a sodium leak through a defect in a tube wall which has not been found during manufacturing a steam generator tube bundle. It is obvious, that the size of such defects is very small, and it means, that the occurrence of a micro-leak during the initial stage of a commissioning and an operation of steam generators is the most probable. Thus, it is most probable that the outflow through a defect which size is equal to several millimeters, is a tenth, even at 100 grams of water/steam per second.

Adverse feature of water in a sodium leak is its fast self-development, an increase in the defects because of a tube material destruction in a zone of sodium with a water reaction. When a leak rate achieves 2 ~4g/s, then a fast destruction of adjacent tubes and an emergency situation in a steam generator are probable.

Experimentally it has been established that the water steam process into a sodium leak in a SG represents a long-lived multi-stage intrinsic process depending on the design of a tube bundle, structure material of the heat-transfer tube, place of a leak origin and the thermal parameters of the water steam and sodium.

We have defined the outflow mode of a steam injection into circulating sodium on the bases of the measured leak rate at the beginning, the duration and the end of an experiment. To observe the relationship with an increase in the initial size of the expiration channel we have calculated it on the basis of experimental data on a leak self-development at a temperature of 450°C for 2.25Cr-1Mo steel [1]. To observe the relationship with an averaged steam outflow velocity we have calculated it at a 0.5MPa pressure of steam and a temperature of 450°C, which was then compared to the sound speed in steam at the same parameters.

3. Background

In the case of the outflow generated as a result of a growth of a crack in a tube wall, a material defect causes a complicated configuration which is distinct from a cylindrical, rectangular or slot-hole channel.

Applied assumptions to simplify the calculation with the Reynolds number and Mach number were permissible in terms of their insignificant impact on the acoustic characteristics of a leak noise. The steam outflow channel was considered as a cylindrical channel with a diameter d_e and a tube wall thickness L. The relative length of a channel is $\lambda = L/d_e$. For the determination of the range of a bubble mode of a leak [2], a quasi-static equilibrium of the hydrogen bubble in the liquid sodium at the time of its separation from the output section of the channel was assumed as shown in Fig. 1.

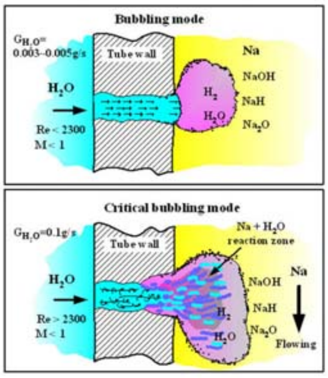

Figure 1. Flame in an out-flow of the sodium-water reaction

4. Results and Discussion

4.1 Leak phenomena in out-flow of tube wall

For the outflow mode of a steam injection into the circulating sodium during the experiment we have defined it on the base of the measured leak rate at the beginning, the duration and the end of an experiment [1]. For an increase of the initial size of the expiration channel we have calculated it on the basis of experimental data for a leak self-development at a temperature of 450°C for 2.25Cr-1Mo steel.

For the averaged steam outflow velocity we have calculated it at a steam pressure of 0.5MPa and a temperature of 450°C. For the mode of a water steam outflow through an injector we have determined it for the initial, intermediate and final stages by means of a calculation with a Reynolds number and Mach number for a subsequent calculation of the frequency of the wall pulsations and a definition of the probable structure of a leak noise spectrum.

4.2 Acoustic noise measurements and FFT analysis

Acoustic noise measurements were conducted using the experimental sodium test circuit in IPPE. By using a water-steam into liquid sodium injection with a flow rate equal to 0.005 g/s in the test section. Fig. 2 presents the raw signals for different rates of the water/steam-into-sodium leaks. At a leak, a flow rate increase with the acoustic signal power was observed, plus oscillations of the separated bubbles were also clearly seen. The spectra of the raw acoustic signals for the background noises are presented. The analysis of the Fast Fourier Transform (FFT) spectra in Fig. 3 in each frequency band selected by us allows for a judgment to be made on the distribution of the hydrogen bubble radii, their magnitude relation, and the dynamics of a bubble cluster in accordance with the flow rate of a leak in Table 1. Results of the calculations and the used data are presented in the Table 1.

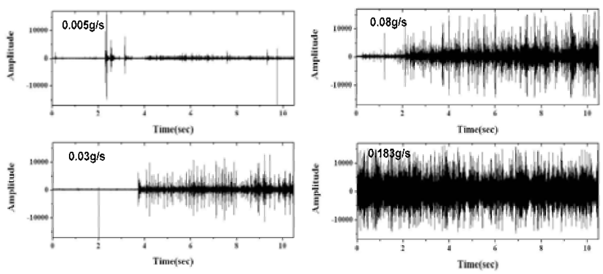

Fig. 2. Raw acoustic signals for differential leak rates under the experimental working conditions in IPPE

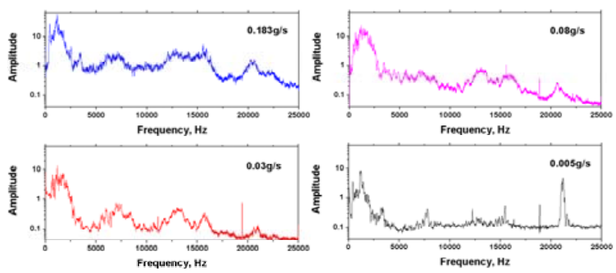

Fig. 3. Relative averaged FFT spectra for different water-in-sodium injection rates

Table 1. Relative average power of the frequency band in the FFT spectra according to the leak rates

Frequency band(kHz)	Leak rates (g/sec)			
	0.005	0.03	0.08	0.183
1 ~5	0.80044	1.62770	4.13714	5.10557
5 ~10	0.12723	0.25596	0.35317	1.30238
10 ~12	0.12129	0.12666	0.19876	1.01055
12 ~17	0.15027	0.21596	0.39868	1.99067
17 ~25	0.11805	0.06557	0.10977	0.58182

With the performance results by the developed acoustic leak detection methodology it was possible to detect a leak up to S/N: -22dB, in some cases to detect a leak up to S/N: -27dB according to the learning conditions.

5. Conclusion

Two results established in our study, are favorable for an early detection of small and micro leaks. First, the presence of a high-frequency ultrasonic noise to increase the process of a leak rate growth. Secondly, decrease in the background noise level for an ultrasonic band of the frequencies, promoting an improvement of the ratio of a leak noise signal to a background noise.

In the case of a micro-leak in the range of a rate from 0.005 ~0.1g/s and when the S/N ratio is expected to be less than 1, for a safe detection, more complex leak signal processing technology on the basis of the methods successfully applied in the mentioned program of the IAEA is required.

To protect a SG from 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 an outflow diameter. With the performance results by the developed acoustic leak detection methodology it was possible to detect a leak up to S/N: -22dB ~ -27dB. At present the system has no errors for detecting a leak, but in the future it must be absolutely assured that it has no error for detecting a leak.

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] Annual Report on the Agreement 410/0862430/30-12-98 Between KAERI and IPPE, "Development of ALDS, Investigation of Water-in-sodium Leak Self Development", May 1999.

[2] Tae-Joon Kim, Valeriy S. Yugay, Sung-Tai Hwang et al "Hydrogen bubble characteristics during a water-sodium leak accident in a steam generator", Journal of Industrial and Engineering Chemistry, Vol 6, No. 6, pp395-402, November 2000.