Fast Defect Detection on Primary Pump Pipe for RSG-GAS Reactor Using Acoustics Emission Techniques

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Abstract. RSG-GAS reactor is one of the research reactors owned by National Nuclear Energy Agency of Indonesia (BATAN) which has been operated since 1987 and utilized its neutrons for radioisotope production and other research activities, and heat caused by nuclear fission reactions is discharged into the environment. To remove the heat is required coolant pumps taking heat from the reactor core to the environment. The RSG-GAS coolant pump consists of a primary coolant and secondary coolant with a heat transfer capacity of 33,000 kW and 5,500 kW respectively. The primary coolant pump takes heat directly from the core and the heat is then transported to the secondary coolant pump system as it passes through the heat exchanger. It then discharges the environment by the cooling system secondary on the cooling tower by blowing using a blower that works counter flow to the direction of the coolant flow. The drainage from the reactor core into the environment requires pipeline from the component system to other components at the pump. Since RSG-GAS reactor has reached 30 years, the RSG-GAS reactor coolant system has aging experienced and decrease of its performance. The occurrence of sound and vibration in the cooling primary pipe indicated a defect location or cavitation due to hard impact of water flow and exposure of gamma radiation on the pipe wall continuously during reactor operation. To ensure the occurrence of defect location, it is necessary to conduct research and testing on the material structure of the cooling pump pipe. Testing and research on the structure of the cooling pipe material cannot be done by disassembling the pipes because it is installed firmly and is at risk of high exposure gamma radiation. It is, therefore, nondestructive test method (NDT), one of them using acoustics emission method, should be applied. The experiments to detect the location defect on pipe of primary cooling pump of RSG-GAS reactor have been conducted. The results on this research showed primary cooling pump pipe degradation and low cavitation existence.

1. Introduction
The nuclear reactor coolant pump is one of the systems and components that ensure the safe operation of the reactor, as it removes heat generated by fission reactions to the environment. If heat dissipation is disrupted, it may then be possible to melt the fuel elements and other components within the core of the nuclear reactor. The GA Siwabessy Multipurpose Reactor (The RSG-GAS) is one of the research reactors owned by PRSG-BATAN which has been operated since 1987. The reactor is located at the Area of Center for Research of Science and Technology (PUSPIPTEK) Serpong, South Tangerang City. The RSG-GAS reactor coolant system consists of a primary coolant pump and a secondary coolant pump. The 33,000 kW primary cooling pump discharges heat from the reactor core to the coolant via a heat exchanger while the coolant is equipped with 6 cooling towers with a capability of...
5,500 kW each. The primary cooling system is a closed seamless flow with mineral free water as its cooling fluid.

The RSG-GAS reactor which is over than 30 years old [1] has a decrease in performance [2] characterized by the emergence of sound and vibration during operation due to both the occurrence of moisture or bubbles in the pumps and to the occurrence of the pressure drops below the saturated vapor pressure. Operating data of RSG-GAS showed after its 17 years of operation has been marked less than optimum heat dissipation into the environment [2]. Less optimum performance of the reactor is caused by primary coolant pumps, heat exchangers and secondary pump coolers.

The aim of the research is to investigate the possibility of cavity on pipe wall of RSG-GAS reactor primary cooling pump which causes the decline in the performance of the primary pump. The decrease in the performance of the primary pump is predicted by the cavitation of the pump [3], the bubble event in the primary pump pipe due to evaporation of the flowing liquid as the pressure is reduced to below the saturated vapor pressure. The effect of cavitation in the primary pump pipe will arise sound and vibration, if left, and the pump remains operated will lead to the wear of the pump wall. The severe consequences will cause a leakage of the pipe and will result in failure of the primary pump function as a coolant from heat arising from fission reactions when the reactor operates. To detect the presence of cavitation symptoms, the acoustic emission method (AE) is used.

Evaluation of the presence of cavitation symptoms in the primary pump pipe should be done to ensure whether the RSG-GAS primary pump feasible or not operated and to fulfill the mandate of the BAPETEN Regulatory N0. 2 / Year 2011 [4], requiring the Installation Operator to verify the safety of the reactor at least once in 5 year of reactor operation.

2. Theory

High Press Head Liquid Substance

Generally, if a liquid is inconvertible through a cross-section, it should have a total head which is expressed as [5]:

\[ H = \frac{P}{\gamma} + \frac{\theta^2}{2g} + Z \]  

where,

- \( H \): The total head of liquid (m)
- \( P \): Static pressure on liquids (N/m²)
- \( \theta \): Average velocity (m/s)
- \( Z \): The height of the liquid is measured from the reference plane (m)
- \( \gamma \): The weight of the liquid union volume (N/m³)
- \( g \): Earth's gravity (m/s²)

Based on the function and working principle of the centrifugal pump, the head and capacity of the generating pump capability depends on the design of the blade or pump impeller as follows [6]:

\[ H(t) = \frac{\mu^2}{g} - \frac{\mu Q}{g A \tan \beta} \]  

where:

- \( H(t) \): ideal total head pump (m)
- \( Q \): the pump capacity (m³/s)
- \( A \): area of inlet / side suction pipe cross section (m²)
- \( \mu \): the speed of the circumference of the pump (m/s)
- \( \beta \): angle of the pump blade (degree)

Acoustic cavitation refers to the presence of bubbles in a liquid host medium on exposure to acoustic radiation [7]. Applications that involve cavitation in moderate to high intensity insonations include sonochemistry, acoustic cleaning [8] and a relatively new field of medical therapy [9]. For the latter, cavitation in high intensity focused ultrasound (HIFU) is being investigated for its potential to selectively permeabilise regions of tissue, for the purpose of targeted drug delivery. An improved understanding of acoustically driven cavitation dynamics, and particularly the detection and
interpretation of signals emitted by bubble activity, are crucial for further development and refinement of such applications.

Cavitating bubbles act as secondary acoustic sources, and the spectrum of the signal generated is known to be strongly dependent on the frequency and intensity of the primary insonation, as well as characteristics of the bubble population itself. Broadly, for a given driving frequency \( f_0 \), cavitation can be classified as stable at low intensities and non-stable, or inertial, at higher intensities. At very low intensities, linear bubble response produces emitted signal at \( f_0 \). Increasing the intensity, but remaining within the stable regime, will cause bubbles to oscillate non-linearly, which generates harmonics of the fundamental (\( nf_0 \)), and weak, often intermittent sub harmonic signal (\( f_0/2 \)) and ultra-sub harmonics (\((2n + 1)f_0/2 \)). Above a threshold intensity, inertial cavitation is associated with a marked and sudden increase in broadband white noise, although strong harmonics and sub harmonics persist. In addition, higher-order sub harmonics (\( nf_0/ m, m > n \)) become apparent on increasing the intensity through the threshold value, along with a corresponding set of ultra sub harmonics, above the fundamental.

Nonetheless, acoustic detection at \( f_0/2 \) is commonly used to determine the onset of cavitation in the applications mentioned, particularly medical therapy, where it has been correlated to a range of associated bio effects including enhanced heating, mechanical tissue damage blood brain barrier disruption and blood-clot dissolution. The \( f_0/2 \) sub harmonic is a convenient detection frequency, as the driving intensities typically employed will produce cavitation in the regime where sub harmonic emissions are prominent. Moreover, higher harmonics of \( f_0 \) occurs in the absence of any cavitation activity, due to non-linear propagation of a sufficiently intense acoustic wave itself, and thus are not attractive detection frequency options.

3. Methodology

3.1. Evaluation of characteristics of primary cooling pump of RSG-GAS Reactor

While RSG-GAS reactor under operating conditions, it is carried measurements and observations on the RSG-GAS on panels of Main Control Room.

1) To observe rpm, capacity, head gauge, power and pump efficiency JE01 AP01, JE01 AP02 and JE01 AP03
2) To develop high curve of pump, pump power, pump efficiency, pump head flow rate function
3) To conduct calibration of Acoustic Emission (AE) sensor
4) To develop programming with LabVIEW for observation of RSG-GAS reactor primary pump signal
5) To implement experiment/measurement of RSG-GAS reactor primary pump signal
6) To analyze signals resulted from RSG-GAS reactor primary pump
7) To evaluate the primary pump performance after 30 years of the RSG-GAS operation.

3.2. Experiment setup

To conduct the observation and measurement of signal using AE method in RSG GAS reactor primary pump room.

1) To install the transducer at some point of the primary pump pipe
2) To switch on the primary pump (made when the reactor operates and the shutdown reactor)
3) To observe and record the output signal through laptop
4) To analyze signal occurred.

The instrumentation employed in this experimental study is shown in Fig. 1 and the acoustic emission AE) measurement was carried out using Physical Acoustic Corporation (PAC)'s A E system. The system consists of a wide band sensor with a flat response in range of 100–1000 kHz; a preamplifier with an optional gain setting of 20, 40 and 60 dB; and a notebook operated d4 channel-micro DiSP data.
4. Results and Discussion

4.1. Efficiency of RSG-GAS primary pump

The measurement of the efficiency of RSG-GAS reactor primary pumps has been carried out and the results are shown at Table 1.

| Pump    | N (rps) | Capacity (m³/hour) | Head (m) | Power (kW) | Efficiency (%) |
|---------|---------|--------------------|----------|------------|----------------|
| JE01 AP01 | 1485    | 1997.3             | 23.14    | 156.7      | 81.33          |
|         |         | 1638.9             | 27.30    | 148.8      | 80.60          |
|         |         | 1442.2             | 29.91    | 146.8      | 79.76          |
|         |         | 1994.1             | 31.93    | 144.1      | 65.80          |
|         |         | 944.9              | 32.94    | 143.2      | 59.00          |
| JE01 AP02 | 1485    | 2000               | 23.02    | 155.5      | 80.09          |
|         |         | 1700               | 27.35    | 152.7      | 82.26          |
|         |         | 1400               | 29.50    | 147.7      | 75.50          |
|         |         | 1150               | 31.08    | 144.7      | 66.64          |
4.2 Analysis of acoustic signal processing

After the acoustic wave signal is firstly captured by the AE detector, the signal enters the pre-amp becoming a pure signal with no background. Acoustic waves without a backlight to be captured by analog computers for computer readability must be converted into digital signals using ADC. The computer will then display the digital signals and analyze using fast fourier transform (FFT). The equipment scheme and data acquisition are shown in Figure 4 and 5 below.

|       | 1000  | 32.39 | 143.8 | 60.77 |
|-------|-------|-------|-------|-------|
| JE01 AP03 | 1485  | 1896.2 | 24.81  | 153.7  | 83.07  |
|        | 1695.4 | 27.42  | 150.7  | 83.74  |
|        | 1449.0 | 29.16  | 143.4  | 79.99  |
|        | 1298.3 | 29.65  | 136.8  | 76.35  |
|        | 1099.3 | 31.82  | 136.8  | 69.27  |

Figure 4. Observation scheme of acoustic wave signal using LabVIEW [11]

The experiment was carried out in the RSG_GAS reactor primary pump room on April 26, 2018 from 09.00-14.00 continuously. The reactor is shut down and the room temperature is 25C, each experiment can only be operated by two primary cooling pumps (AP01 and AP02 or AP01 and AP03 or AP02 and AP03). Each sample is taken with different time lags with sampling times including 3 minutes, 5 minutes, 10 minutes and 20 minutes. The data from the experimental results are then analyzed using fast fourier transform. The result of spectrums shows on figures of 6, 7 and 8.
Figure 6. Spektrum of JE01 AP01 RSG-GAS primary pump

Figure 7. Spektrum of JE01 AP02 RSG-GAS primary pump
From the figure of 6, 7 and 8, it can be seen that the amplitude at AP01, AP02 and AP03 is almost the same, indicating that in general the three pump pipes are in good condition and relatively normal. However, if it is observed that the pump AP01 indicates the presence of material degradation, it is shown that there is a relatively small amplitude, even though it is within normal limits. In anticipation of continuous degradation which can eventually cause damage or material defects, it needs to be monitored continuously so that the possibility of leakage in the AP01 pump pipe can be avoided. The above phenomenon when compared with the Table 1 is equivalent that the AP01 pump pipe has been degraded and the less an efficiency.

5. Conclusions
Early detection experiments on material damage in the primary cooling pipe of the RSG-GAS reactor can be carried out well and smoothly. The main obstacle during the experiment was the noise of the room due to the sound of the pump being operated, but it could be overcome by using a sound damper. From this experiment it can be concluded that the RSG-GAS reactor primary cooling pipe is still in good condition and safe to operate despite the vibration on the pipe wall, especially at the AP03 pump. To anticipate the failure of the operation, there is a need for strict supervision of the sound and vibration of the pipe wall when the pump is operated, the neglect of this supervision will result in severe consequences and result in failure of RSG-GAS reactor operation.

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