Detection of void in sodium cooled fast reactors using eddy current based technique

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Abstract

In sodium cooled fast reactors, argon is used as cover gas above the sodium free surface to isolate the sodium hot pool from outside environment. Entrainment of argon gas into the core of the reactor is always possible in nominal or accidental conditions by means of various mechanisms inside the hot pool viz. free level fluctuation, vortex formation etc. This entrainment of gas creates void (absence of sodium) in the core and is undesirable as it may lead to reactivity fluctuations, reduced heat transfer in IHX and also result in measurement disturbances. A flow meter is developed in-house based on eddy current technique, named as Eddy Current Flow Meter (ECFM) for measurement of sodium flow through individual subassemblies during reactor shutdown. Studies were carried out in sodium loop using ECFM to detect the gas entrainment during reactor operation. Argon gas was injected into sodium system at different mass flow rates and different sodium flow rates to simulate void fraction in the range of 0 to 2%. ECFM primary and two secondary coil signals were acquired during argon injection experiments. Experiments were carried out at sodium temperature of 300ºC and 400 ºC.Void induced signals were extracted from the flow induced signals and correlated to the void fraction. It was observed from the experiments that gas entrainment could be detected by means of eddy current flow meter. This paper presents the details of the ECFM, experiments carried out in sodium system, results and conclusion.

Key words: Fast Reactors, Gas entrainment, Eddy Current Flow Meter.

1. Introduction

In sodium cooled fast reactors, argon is used as cover gas above the sodium free surface. Argon can enter into the sodium pool by various mechanisms including shear type entrainment, liquid fall type entrainment and Vortex induced entrainment (Fig.1). This entrainment depends on the factors like geometry and flow pattern in the hot pool of a reactor and also the velocity of sodium at the free surface [1]. The other source of gas is the fission gas release from failed fuel pin. Argon entrainment in the primary sodium circuit

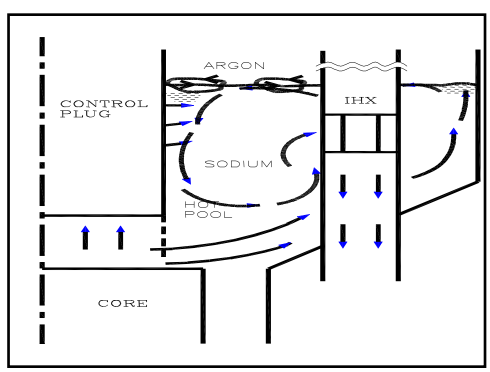

Fig.1: Mechanism of gas Entrainment

is undesirable as it can cause reactivity fluctuations, boiling, cavitation and thermal effects. It is therefore required to continuously monitor the gas bubbles in the primary sodium pool of the reactor to avoid reactivity perturbations and measurement disturbances.

In Prototype Fast Breeder Reactor (PFBR), it is required measure the core flow under all operating conditions from the safety point of view. A device named Core Flow Monitoring Mechanism (CFMM) was developed for measurement of sodium flow through individual subassemblies during reactor shutdown with Eddy Current Flow Meters (ECFM) as the sensor. High flow in fuel subassemblies will be measured by CFMM-I and low flow in blanket and storage subassemblies will be measured by CFMM-II. Sodium flow through the core is monitored at the primary sodium pump using ECFM, which is located in a bypass line from the pump discharge to suction [2]. The ECFM was employed at simulated subassembly outlet regions of JOYO reactor to detect argon gas [3]. Earlier studies carried out in 500kW sodium loop in IGCAR by using ECFM as gas entrainment detection device has shown encouraging results. Experiments were carried out with ECFM sensor of Core Flow Monitoring Mechanism (CFMM-I). Argon gas was injected into the sodium system at different mass flow rates and different sodium flow rates to simulate void fraction of 0 to 2%. The time signals were acquired at each test condition. The experiment was conducted at sodium temperature of 300ºC and 400ºC. This paper discusses the test setup, instrumentation and the results of the experiment.

2. Eddy current technique

Eddy Current Flow Meter consists of three coils wound on a soft iron bobbin. The two secondary coils (S1 and S2) are wound symmetrically on either side of the primary coil (P1) on the same core (Fig.2). The primary winding is made up of mineral insulated (MI) cable with Copper core whereas the two secondary windings are made up of MI cables with Nichrome core. The bobbin is made up of soft iron and is enclosed in a stainless steel tube to prevent direct con-tact with sodium. Fig.3 shows the assembled view of the developed probe. Magnetic flux is generated when the primary coil is excited with a constant current source (typically 200mA) at a constant frequency (typically 300Hz). When sodium is static, this flux induces equal voltages in both the secondary windings due to transformer action. When sodium is in motion, the interaction between the radial component of the magnetic field and fluid velocity creates circular eddy currents in fluid near both edges of the primary coil. The direction of the magnetic field at the upstream side of the coil is opposite to that at the downstream side. The voltage induced in moving annular sodium ring induces voltage in S1 and S2 coil which is subtractive to transformer voltage in upstream coil and additive to transformer voltage in downstream coil. As a result of this the voltages induced in the two secondaries differ from each other and this difference is proportional to the sodium velocity. When temperature of surrounding sodium increases, its electrical resistivity increases resulting in less eddy currents and hence an increase in both voltages due to transformer action and sodium flow. The effect of

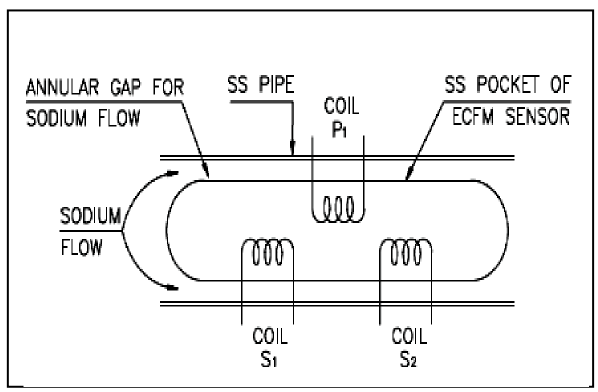

Fig.2: Principle of Eddy Current Flow Meter

temperature is compensated by normalizing the signal using the equation given below [4]. ECFM normalized Output = (S1-S2) / (S1+S2). The overall designed flow sensor is compact with a size of 20 mm diameter and 150 mm length.

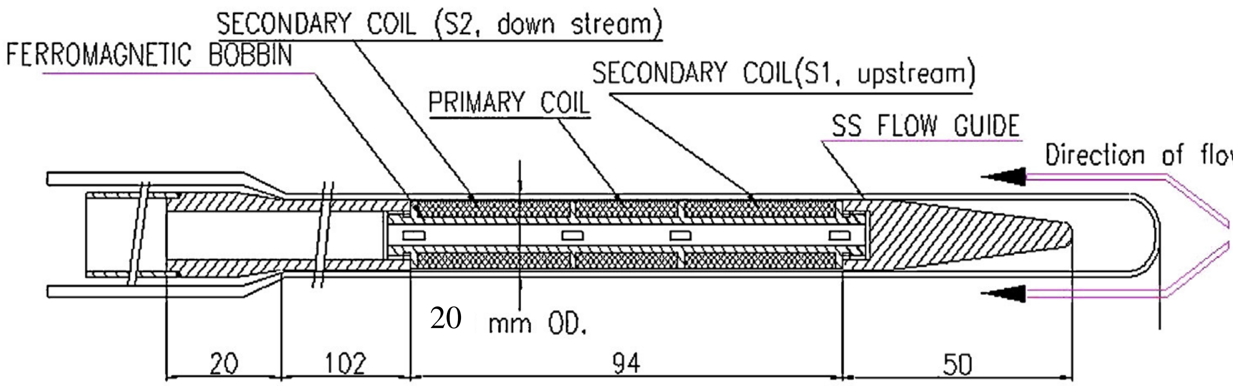

Fig.3: ECFM after assembling.

3. Experiment Details

Sodium loop of Steam Generator Test Facility (SGTF) was modified to conduct calibration of CFMMM-I and CFMM-II under different sodium temperatures and flow and also by changing the ECFM primary excitation frequency.

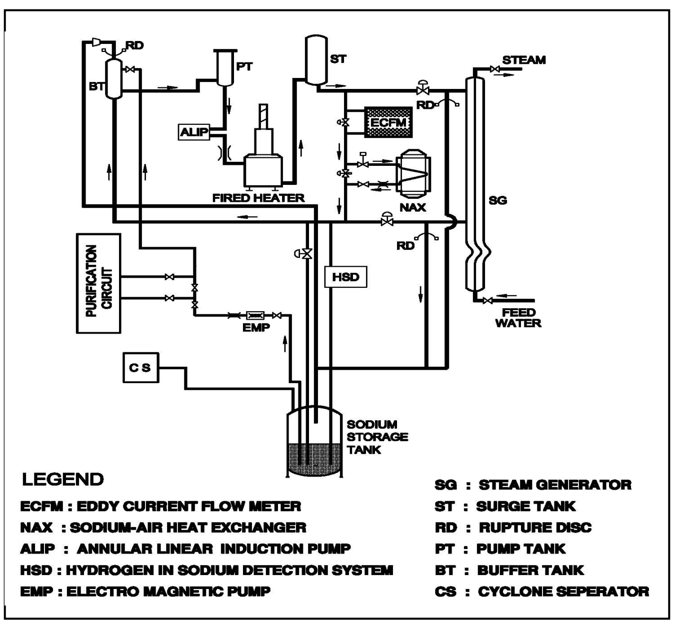

Fig.4: Flow sheet of sodium system in SGTF

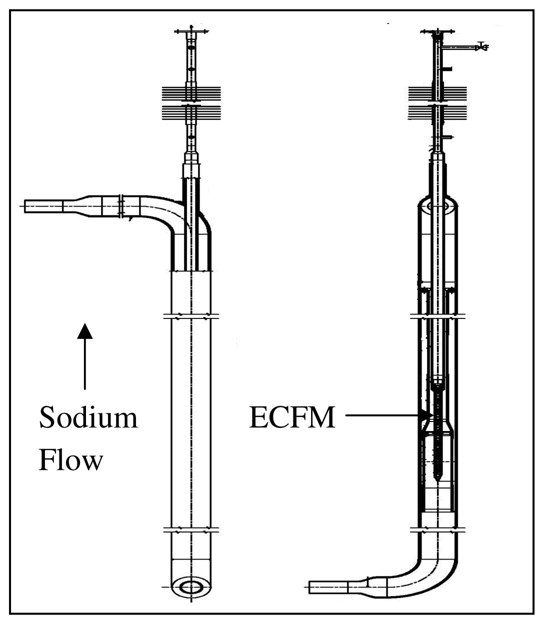

Fig.5: Test section with CFMM-I sensor

Sensitivity of CFMM-I sensor was found to be 0.378 mV/ m^3/h for 300Hz excitation frequency for sodium temperature of 300ºC. After the calibration campaign, the same sensor was used for gas entrainment detection experiment by injecting argon. The argon injection set up provided at the upstream of the ECFM probe consists of a gas cylinder with pressure regulator, pressure gauge, standard SS vessel with known volume, mass flow controller, rotameter and valves. The range of mass flow controller of AALBORG GFC-37 is 0-30 lpm. The gas flow rate was adjusted between 1.0 lpm to 10.0 lpm and sodium flow was adjusted between 12 m^3/h to 30 m^3/h to get the void fraction of 0 to 2%. The duration of the argon injection was about one minute. The experiment was carried out with CFMM-I probe (Fig.5) at sodium temperatures of 300ºC and 400ºC.

4. Signal Processing

When the argon bubbles in sodium (void) are carried by fluid sodium, they move randomly, and increase the instantaneous output of ECFM. When void passes near secondary coils of the flow meter, the magnetic flux generated due to primary excitation increases due to absence of conducting medium that causes eddy current and hence flow signal changes momentarily. This fluctuation in secondary coil voltage variation is treated as void signal. So the information about

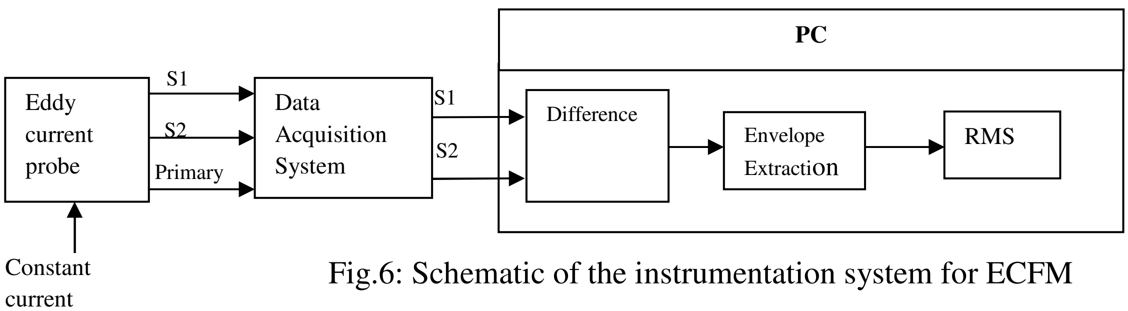

Fig.6: Schematic of the instrumentation system for ECFM

the presence and volume (or void fraction) of bubbles can be extracted from the fluctuating signal of ECFM by signal analysis. It is observed that void induced fluctuation signal (also called void signal) is modulating the flow induced signal (Background signal). ECFM primary and two secondary signals were acquired during the experiment using data acquisition system at a sampling rate of 10 kS/s (Fig.6). Sodium flow signal (Permanent Magnet Flow Meter) and Mass flow controller output was also acquired. Void signal was obtained extracting the envelope of the ECFM difference output. RMS of the band pass filtered (0.1-30Hz) void signal was plotted against the void fraction.

5. Results and conclusion

Initially experiment was carried out at sodium temperature of 300ºC. Typical time signals obtained during argon injection of 4.0 lpm at sodium flow of 12 m^3/h and sodium temperature of 300 ºC were shown in Fig.7. The void signal extracted from ECFM difference output is shown in Fig.8. Enlarged view of the time signal and void signal are shown in Fig.9 and Fig.10 respectively. It can be observed that when bubble passes through ECFM, there was an amplitude rise of ECFM secondary signal output. RMS values of void signals obtained at 300ºC and 400 ºC were compared and plotted in Fig.11 and Fig.12. It was observed that void signal was varying almost linearly with the void fraction and the RMS value was slightly high at higher temperature. This is due to the fact that sodium resistance would be high at higher temperature and eddy currents induced in sodium would be low. As a result, ECFM output was high at higher temperature. It was seen from experiments that the gas entrainment could be detected successfully using ECFM. Since the applicability of void detection system for FBRs require detection for very low void fraction present in the system, further experiments to explore the feasibility of its application at low void fraction will be conducted.

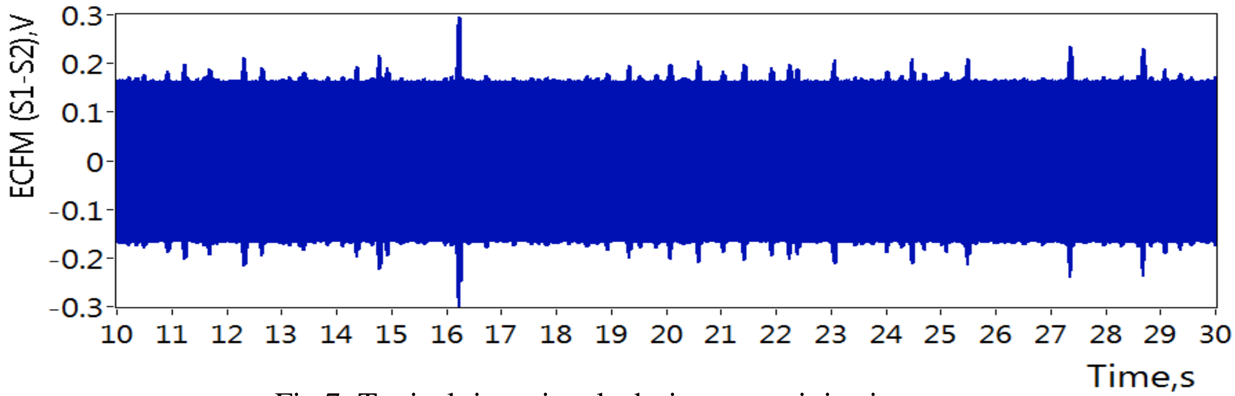

Fig.7: Typical time signals during argon injection

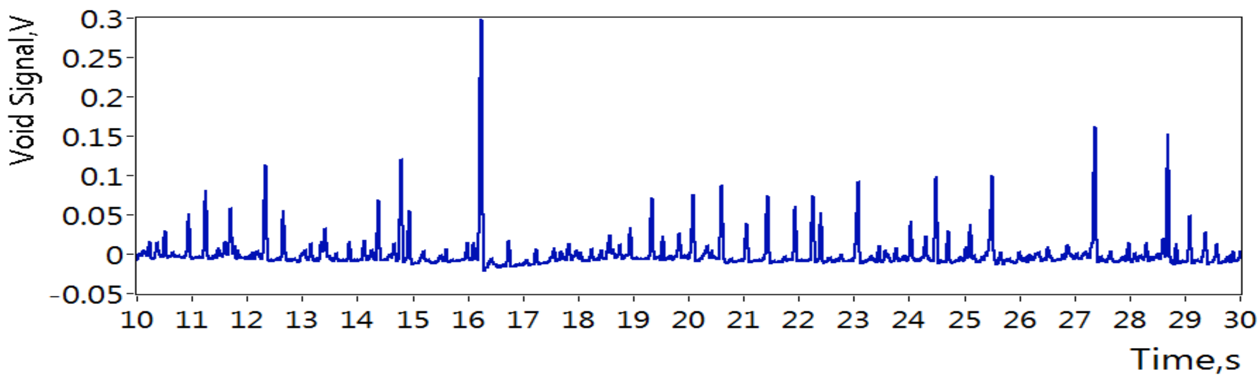

Fig.8: Typical void signal after envelope extraction

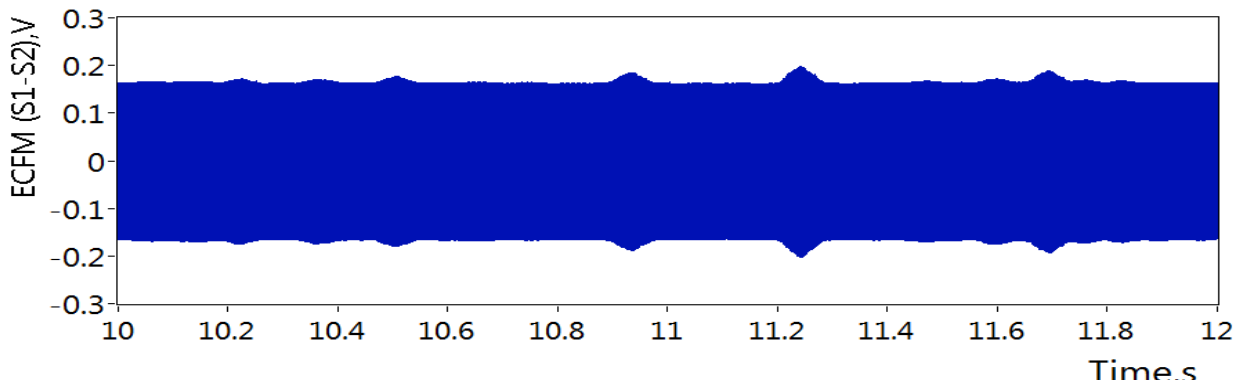

Fig.9: Enlarged view of the time signal

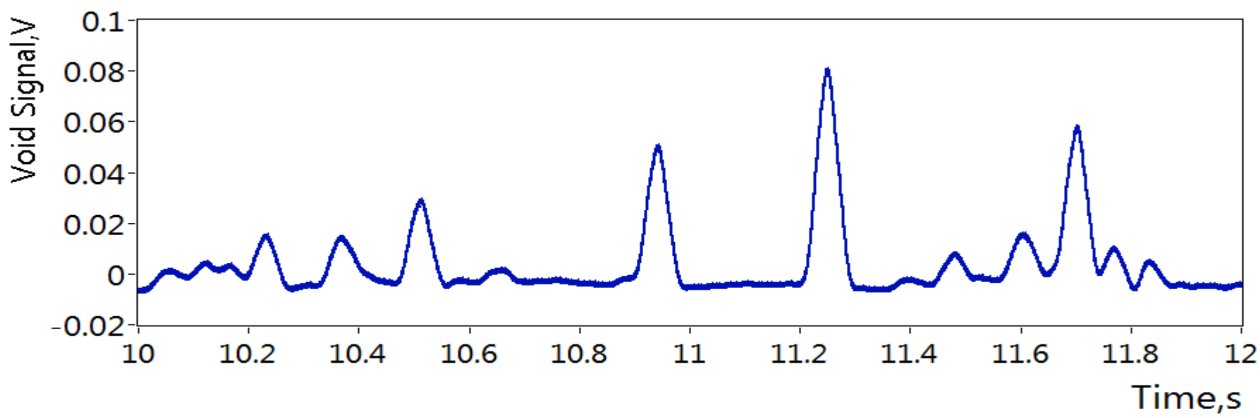

Fig.10: Enlarged view of the void signal

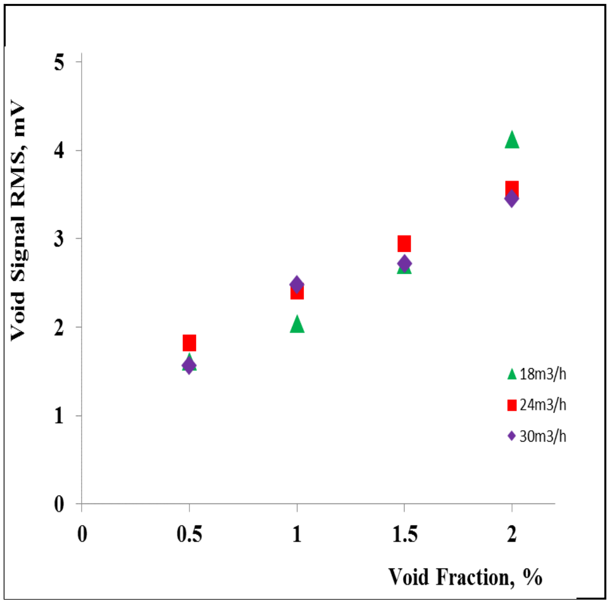

Fig.11: Void signal RMS Vs Void fraction at sodium temperature of 300ºC

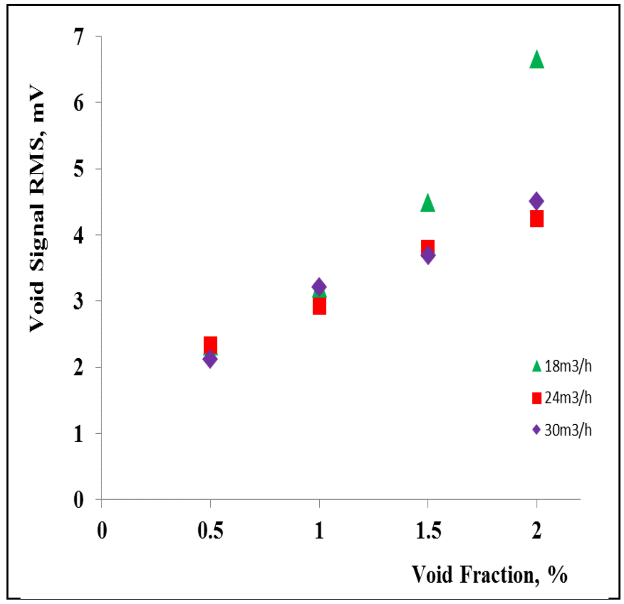

Fig.12: Void signal RMS Vs Void fraction at sodium temperature of 400ºC

Acknowledgments

We would like to thank all the staffs of Steam Generator Test Facility in IGCAR for their kind cooperation and support given during the experiment.

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