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Design, development and performance testing of fast response electronics for eddy current flowmeter in monitoring sodium flow

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ABSTRACT

The paper discusses the design, development and performance tests of a fast response processing electronics for an eddy current flowmeter that has been developed indigenously to measure sodium flow in the primary sodium pump discharge line, pumping liquid sodium to the core consisting of fuel sub-assemblies in the prototype fast breeder reactor at Kalpakkam, India. Liquid sodium is the main coolant in Fast Breeder Nuclear Reactor. Eddy current flowmeters are deployed in liquid metal cooled fast reactors. The measurement of flow rate of the coolant is important to maintain the overall performance of the pump which in turn is the safety requirement of the system. The faster response of the measuring system is required to ensure the protection of the reactor under pump seizer and discharge pipe rupture. This work mainly focuses on the reduction of response time of signal processing electronic delay.

1. Introduction

Sodium flow measurement is imperative in the context of Fast Breeder Reactors (FBR) to check the operation and safety of the reactors. In sodium cooled FBR, various types of flowmeters are employed for sodium flow measurement. Permanent Magnet Flowmeters (PMFM) are widely used for sodium flow measurement at the primary pump outlet in BN 350 loop type, by pass line in BN 600 and BN 800 pool type reactor [1]. PMFM is also been used in the primary circuit of Phenix reactor [2]. Fast flux test facility (FFTF), SNR 300, KNK, MONJU, Rapsodie and Fast Breeder Test Reactor (FBTR) [3]. These flowmeters are not suitable for use in regions of high radiation because of the damage to the magnets [4]. In addition, the magnets must be stabilized against the influence of demagnetization, temperature and mechanical shocks and these are heavier in nature [5].

In JOYO a loop type reactor, saddle coil flowmeter is in use in the primary circuit [3] and in the secondary circuit [6]. Saddle coil flowmeters have been used in the secondary circuit of Prototype Fast Reactor (PFR) [7,8]. Saddle coil flowmeters are comparatively lighter but are lengthy [9]. Hence it is not suitable for remote locations.

Lehde and Lang [10] patented the flow measurement device based on eddy current principle in 1948. The device consists of two primary coils excited by an AC generator and is placed in such a way that their magnetic effects oppose each other. The secondary coil is placed midway between the other two coils. These are placed in the insulated material housing. The device is centrally located to a tube where the conducting liquid flows. The resultant voltage induced in the secondary coil is directly proportional to the speed of the fluid. An alternate design with two primary coils in series and two secondary coils in series opposition was developed. A modified design adopting the first technique with 3 primary coils and 2 secondary coils was used as speed and distance measuring instrument for ships. This concept was proposed as a flow failure alarm in the British PFR in the early 1960s [11]. Probe type eddy current flowmeter (ECFM) has been used in the British PFR [12].

ECFM has been developed and used in Hanford Engineering Development Laboratory (US), Argonne National Laboratory (US) and in Indira Gandhi Centre for Atomic Research (IGCAR, India) for monitoring the flow of sodium through the core in a Nuclear Reactor. The ECFM is used for void detection in the Liquid Metal FBR (LMFBR) core exit at O-arai Engineering centre (Japan) [13]. A conceptual design of a contactless ECFM for liquid metal flows

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based on phase-shift measurement is presented in Ref. [14]. These used an improved design with single primary coil excited by an AC source and placed centrally to the two secondary coils. The secondary coils are connected in series opposition.

The ECFM has been proposed for measurement of sodium flow in FBR where space constraint and high ambient temperature is prevalent [15–17]. The use of ECFM is appreciable for its small size, ability to withstand high temperature and resistance to radiation damage [5]. The ECFM eliminates the use of permanent magnets and other ferromagnetic parts whose degradation generally tends to affect the performance of a flowmeter [18,19]. Maintenance of ECFM is much easier than any other type of flowmeter. The disadvantage of ECFM is that it has a slower response time than PMFM and is highly sensitive to temperature changes and flow turbulence.

2. ECFM and existing electronics

ECFM works on the principle of change in the magnetic field due to induced eddy currents as a result of sodium flow. The ECFM consists of a system of AC operated coils, fixed in space and electromagnetically coupled conducting fluid. The ECFM has one primary and two secondary coils placed symmetrically along the flow axis, one in upstream side of primary and other in downstream side of primary. The system has a built in symmetry and hence the output signal of the coils is zero when fields are stationary. Motion of the fluid causes eddy currents to move downstream from their symmetrical locations and the resulting magnetic field imbalance generates an output signal which serves as a measure of the fluid velocity.

Fig. 1 represents the schematic of ECFM. The flow sensor used in IGCAR is of 14 mm diameter and 150 mm long. It has three coils and is wound over the bobbin made of magnetic material and encapsulated in stainless steel pocket to maintain physical separation of flowing fluid with primary and secondary coils. Central primary coil is excited by constant current source at a constant frequency. In British PFR, 700 Hz is used as the primary excitation frequency [12]. The FFTF reactors use excitation source of 1000 Hz, 500 mA for the primary winding of ECFM [20]. It is shown analytically that both the velocity-profile errors and temperature errors can be minimized by selecting a suitable operating frequency [19]. The frequency response test performed on ECFM proved that 400 Hz is the optimum primary excitation frequency of ECFM for use in Prototype Fast Breeder Reactor (PFBR) [17]. The optimum excitation frequency for MK-3 Probe is 375 Hz as described in [13].

The ECFM for this study is developed for use in Prototype Fast Breeder Reactor (PFBR) by IGCAR, India. In PFBR, the primary system consists of two vertical centrifugal pumps operating in parallel. The flow through the pump is adjusted by changing the pump speed. The flow delivered by each pump is separately measured to monitor the pump performance and to obtain the total flow through the core. ECFM is employed in the Primary Sodium Pump (PSP) of the PFBR to measure pump flow and in individual sub-assemblies before the start up of the reactor in FBTR [21]. Sodium flow is measured in fast reactors mainly at pump outlet in the primary circuits, secondary sodium circuits and at the outlet of the fuel sub-assemblies to detect flow blockage as described in literatures [9,13,22]. The measurement of sodium flow is important to protect the reactor from events like one primary pump seizure, one primary pump trip, off site power failure and rupture of pipe joining primary pump to grid plate. Flow monitoring is important to find performance of the sodium pumps and observing the core cooling.

The output voltage of secondary coil of ECFM has two components – one due to transformer action and other due to motion of conducting sodium in the magnetic field. The magnitude of voltage in two coils can be thus qualitatively expressed as follows [23]:

$$S_2 = E_{trans} + E_{motion} \tag{1}$$

$$S_1 = E_{trans} - E_{motion} \tag{2}$$

where S_1 is secondary coil voltage in upstream and S_2 is secondary coil voltage in downstream.

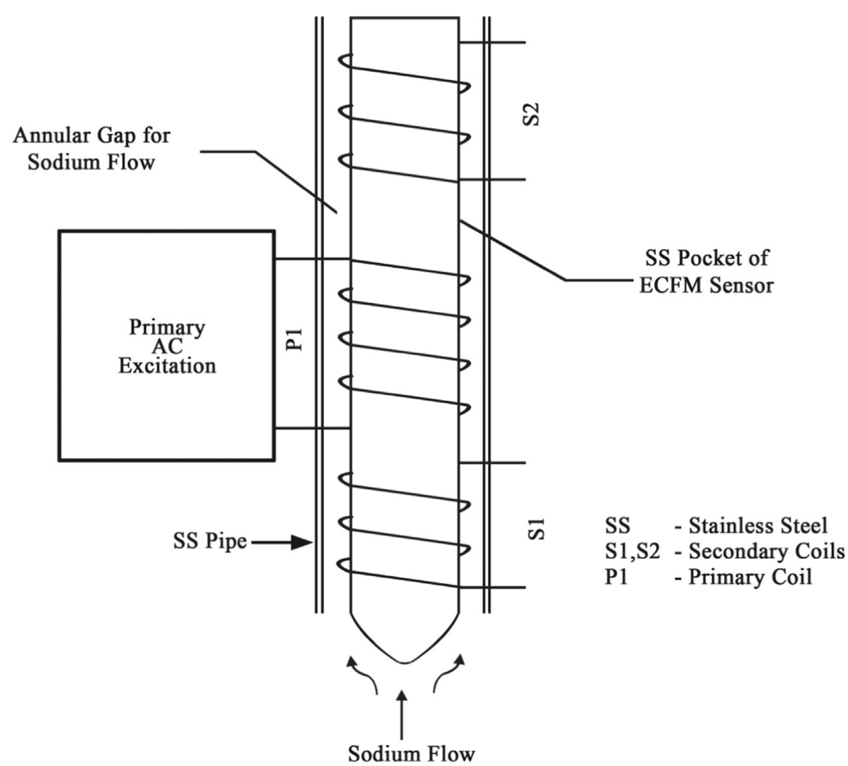

Fig. 1. Schematic of ECFM (Courtesy [IGCAR]).