Advancements in Flow Measurements of Sodium Cooled Fast Reactor Circuits

Dr K K Rajan,

Former Director, Fast Reactor Technology Group & Distinguished Scientist,
IGCAR, Kalpakkam

Introduction

Sodium cooled fast breeder reactors (SFRs) have primary, secondary and auxiliary circuits with liquid sodium as the coolant. Safe and economic operation of SFR systems depends on the successful monitoring of flow and other process parameters accurately in various circuits. Electromagnetic (EM) flow meters are used for sodium flow measurements in sodium cooled fast reactors. The pipe size in various circuits of a typical 500 MWe SFR ranges from 15 NB to 800 NB. An electromagnetic flow meter based on induced voltage basically consists of a pipe made of a non-magnetic material (SS) mounted in a transverse magnetic field between the two poles of a permanent magnet or electromagnet structure. If the field is produced by coil with DC power supply, it is known as saddle coil type EM flow meter. If the field is generated by a permanent magnet structure, it is known as permanent magnet flow meter (PMFM). Both these types work on the principle of DC generator and are based on the Faraday's law of electromagnetic induction. Electrical contacts (electrodes) positioned diametrically opposite to each other are welded to the outer surface of the pipe, with their central axis oriented normal to the direction of the lines of magnetic field and sodium flow. A small DC voltage is developed across the electrodes as conductive liquid metal (sodium) flows perpendicular magnetic field. The critical part of the PMFM is the magnet assembly.

The scheme for the measurement of sodium flow in pipelines using PMFM has been established and the flow meters have also been put to use for reactor applications. However, a few of the problems currently faced in pipeline flow meters are

a) They are bulky and heavy for large size pipes
b) Their sensitivity is relatively low for large size pipes
c) Sodium calibration of PMFM is costly and time consuming
d) Conventional PMFMs are not suitable for large pipes

Significant improvements are required in sodium flow measurement methods to achieve compactness, high sensitivity, better accuracy, stability and economy. These form the motivation further research. Following are the key areas where work is focused:

a) Studies on Alnico-V based pipe flow meters, factors affecting the sensitivity, establishing an effective calibration method and quantification of error and sensitivity
b) Development of in-situ calibration techniques by cross correlation of noise signals from different pairs of electrodes of the same flow meter
c) Analysis, Design and development of Samarium Cobalt based PMFM with the objective of compactness and improved sensitivity
d) Analysis and design of side wall type permanent magnet flow meter for sodium flow measurement in large pipes of SFRs.
e) Modeling, design, optimization and validation of bypass flow meters to improve accuracy and resolution, specifically for the main secondary circuit flow measurement.

Studies on Alnico-V Based Permanent Magnet Flow Meters

As part of the research a permanent magnet flow meter with Alnico-V magnet assembly suitable for 100 NB pipe is designed and manufactured. Many novel features are incorporated in this flow meter. EMF, output from the flow meter is estimated based on established formula. Sodium calibration of flow meters has been carried out in a setup by absolute constant volume method. A procedure for error analysis has been established and from the errors associated with voltage volume and time measurements, the overall error in the flow meter sensitivity has been determined as ± 1. 2%. In-situ calibration of permanent magnet flow meters has been carried out by cross correlation of voltage fluctuations from two sets of electrode pairs in a PMFM. The transit time of fluctuation is found from the peak value of the cross correlation function. From the known spacing between the electrode pairs, flow rate is calculated. The accuracy of the flow rate estimated using cross-correlation technique was found to be within ±5.5%.

Samarium Cobalt Based Permanent Magnet Flow Meter

For the operating conditions of SFR sodium circuits, magnet assemblies with Sm_2Co_{17} are found to be suitable and selected as the magnetic material for the compact design. A flow meter for 100 NB pipe with Sm-Co magnet assembly have been designed, analyzed, fabricated and tested in a sodium calibration setup. Multiphysics modelling of this PMFM has been carried out in FEM code COMSOL 3.5a. The sensitivity of the Sm-Co PMFM at various process conditions has been estimated. Also sodium testing and calibration of the Sm-Co PMFM have been carried out. Calibration accuracy is estimated as 1.06%. Sm-Co flow meter sensitivity increased by 202% with a net weight reduction of 55% in comparison with Alnico-V PMFM.Experimental and simulation results of the flow meter output voltage signal and the sensitivity have been compared. Long term stability test, Sm_2Co_{17} magnet assemblies were carried out on two assemblies. There was no significant reduction in the flux density after the endurance test at operating temperature and higher temperature. The temperature coefficient of reversible losses is found to be 0.0312%/ ºC for the range of temperatures from 28 ºC to 100 ºC, which is the expected range of temperatures of the magnet during its service and matches well with the value reported in Magnet materials producers association (MMPA) standard.

Side Wall Type PMFM For Flow Measurement In Large Pipes

As part of the research work one side wall flow meter (SWFM), in which an Alnico-V permanent magnet block mounted on one side of a SS pipe of 100 NB size has been designed, fabricated, analyzed and tested. Two pairs of electrodes are provided at 60º and 120º angle. SWFM has been tested and calibrated in a calibration set up and the relationship between its voltage amplitude and sodium flow rate has been established. Calibration of the SWFM flow meter has been done at various process conditions. The calibration accuracy is ±1.4%.Three dimensional Finite Element Method (FEM) modeling of SWFM has been carried out using COMSOL 3.5a software and the results of the modeling have been validated with experimental results. FEM model has been then used to analyze the effect of electrodes position and sodium flow rates on SWFM sensitivity. From the calibration results, it is found that the electrode pair at 120º angle is more sensitive than the electrodes pair at 60º angle at low

sodium flows, while the trend reverses at higher flows. The maximum value of the variation in sensitivity in the full flow range is around 9% for 60° angle electrodes pair and 4% for 120° angle electrodes pair.

By Pass Flow Meters For Flow Measurement In Large Pipes

For sodium flow measurements in large main secondary pipelines of SFRs bypass type flow meters are used. The hydraulic characteristics of the bypass flow meter system have been evaluated numerically and experimentally using water as simulant for a scaled-down model of the Proto type fast breeder reactor (PFBR) secondary bypass flow meter. The scaling down has been only done for the main line from 792.6 to 254.5 mm diameter, by keeping the bypass line geometry same. The same scale-down geometry has been modelled and analyzed with three dimensional 180^{o} symmetric model using a computational fluid dynamics (CFD) code. The bypass flow covering the full range of main flow velocity has been evaluated by numerical calculations and experimentally validated. The results were in good agreement. Using the same numerical tool with suitable correction factor, flow ratio for full scale actual Proto Type Fast Breeder Reactor (PFBR) circuit has been computed. The overall accuracy achieved ± 2.5% which is adequate from the process and safety considerations. The numerical and experimental studies in the search of optimum bypass geometry have been done with a main line size of 254.5 mm and water as flowing fluid. Experiments have been conducted with the model of the optimized geometry and numerical results are validated.

The current research work is focused on the problems presently faced in pipeline sodium flow measurement in SFRs which needs improvement. They are addressed successfully and redundant, alternative, cost effective, sensitive and accurate flow measurement methods have been selected and detailed studies and analysis are carried out.