Analysis of the Transient Performance of an Annular Linear Induction Pump Using COMSOL®

Prashant Sharma * [a,b], B. K. Nashine [b], Awadhesh Mani [a,b]
[a] Homi Bhabha National Institute, Kalpakkam, TN-603102, INDIA
[b] Indira Gandhi Centre for Atomic Research, Kalpakkam, TN-603102, INDIA
*Corresponding Author: pacific@igcar.gov.in

Abstract

Annular Linear Induction Pump (ALIP) is used for pumping liquid metal in fast reactors and in experimental test facilities. In order to understand the transient response behaviour of this pump, a 2-dimensional axisymmetric model in time domain is developed. The transient performance prediction requires simultaneous solution of Maxwell's and Navier-Stokes equations. This is achieved using the multi-physics based finite element method software COMSOL®. Coupling of the fluid velocity with magnetic field and of the electromagnetic force with fluid is also carried out. One of the main aims of such analysis is to study double supply frequency pressure pulsations. In the analysis carried out, variation in various parameters like output pressure, input current, power were studied and are presented in this paper.

Introduction

This paper deals with the transient performance prediction of an Annular Linear Induction Pump (ALIP) using Finite Element Method based software COMSOL®. ALIP is used for pumping of liquid sodium in various experimental facilities and in auxiliary circuits of fast reactors. This paper presents the results of the transient response analysis of ALIP in COMSOL®.

Applicable equations

The simulation of ALIP has been done in time transient domain and coupled with transient hydrodynamic Navier Stokes equations. Following are the applicable equations.

$$\nabla \times H = J \qquad \ldots (1)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad \ldots (2)$$

$$J = \sigma(E + V \times B) \qquad \ldots (3)$$

$$\nabla . B = 0 \qquad \ldots (4)$$

$$f_{EM} = J \times B \qquad \ldots (5)$$

Navier Stokes equation for steady state flow is given by

$$\rho \frac{\partial V}{\partial t} + \rho (V\nabla) V = -\nabla p + \eta \nabla V + f_{EM} \qquad \ldots (6)$$

For incompressible steady state flow, the mass conservation equation becomes

$$\frac{\partial \rho}{\partial t} + \nabla .(\rho V) = 0 \qquad \ldots (7)$$

The coupling between electromagnetic field and the fluid flow is simulated by adding the volume electromagnetic force f_{EM} to the force term of the Navier Stokes equation. The effect of velocity on the magnetic field is simulated by adding the term $V \times B$ to the ohms' law $J = \sigma E$.

COMSOL® simulation

The simulation of ALIP has been done in the 2D axisymmetric mode with both electromagnetic and hydraulic equations being solved simultaneously [1]. The dimensional details and rating of the pump can be found in [2]. In order to analyze the transient response of ALIP for a sudden change in flow rate to half of its rated value, a step change in input velocity boundary condition is implemented using the inbuilt step function of COMSOL®. The voltages supplied to the coils remain constant. This step change is given as shown in Fig. 1. This step change represents a sudden decrease in flow rate of pump due to some external cause. In practice, the change is unlikely to be so sudden yet this analysis will help in understanding the behaviour of the pump. The aim of this simulation is to study the response of the ALIP to this sudden change and observe the variation in various parameters like output pressure, input current, power. Study of double supply pressure pulsations and its variation is another goal.

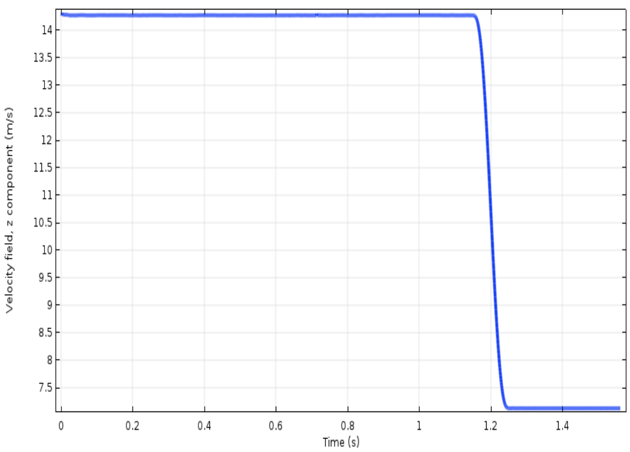

Figure 1. Step change in velocity

Coupling Between Electromagnetic And Fluid Models

The geometry of the pump as modeled in COMSOL® is shown in Fig. 2. The electromagnetic force produced in the liquid metal is coupled to the fluid flow by adding the electromagnetic force to the Navier-Stokes equation as a volume force. The Navier-Stokes and Maxwell's equations are then solved simultaneously to obtain the solution with respect to time.

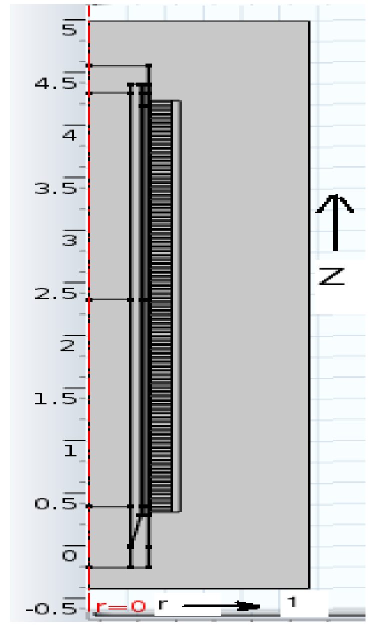

Figure 2. Geometry of the ALIP as modeled in COMSOL

Simulation Results & Discussion

The simulation was carried at a constant sodium temperature of 459 °C. The variation in developed pressure with respect to time at pump outlet is shown in Fig. 3. With decrease in flow to half, first there is a transient phase with sudden increase of pressure and then the pressure settles at a value corresponding to steady state pressure vs flow characteristics of the pump. The presence of double supply frequency pulsations is also evident in figure 3.

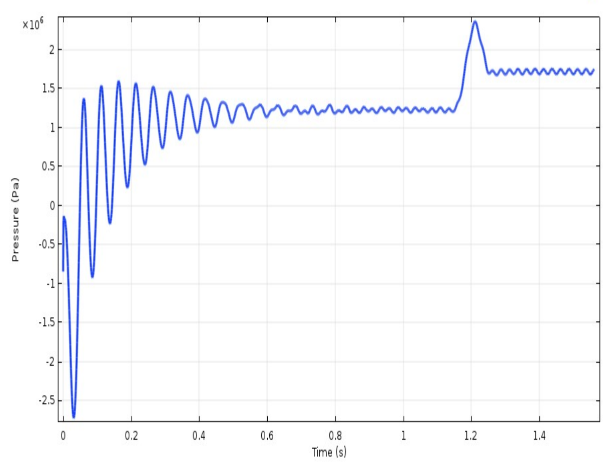

Figure 3. Developed Pressure

The variation of input phase currents of the three phases is depicted in Figures 4, 5 and 6. From these figures it can be noted that as the flow rate decreases the current increases and settles at a higher current. With decrease in flow, the slip increases and hence the relative velocity between liquid metal and traveling magnetic field increases which leads to higher induced currents in liquid metal. The demagnetizing action of these induced currents tend to decrease the flux. Since coils are connected to constant voltage source the winding tends to maintain the flux constant by drawing more current from the mains power supply. The initial values of current for each phase are different due to different instantaneous values of each phase voltage at time t=0 which lead to different in-rush current in each phase.

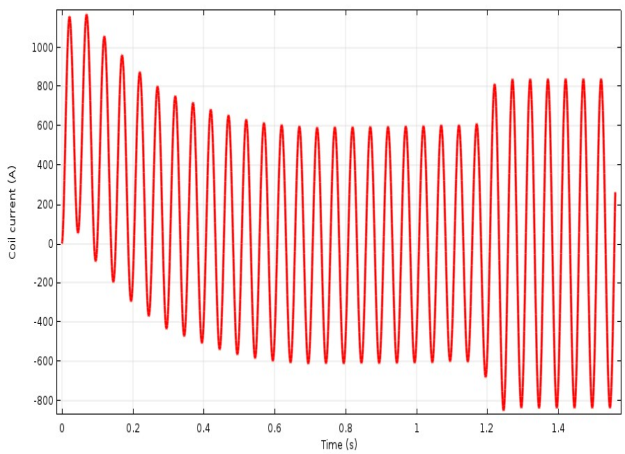

Figure 4. R- Phase Current

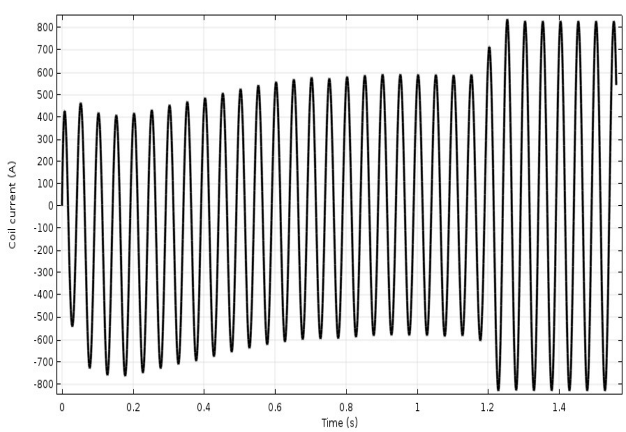

Figure 5. Y-Phase Current

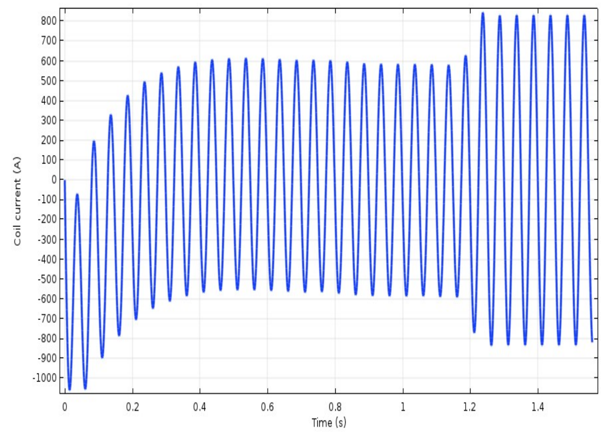

Figure 6. B- Phase Current

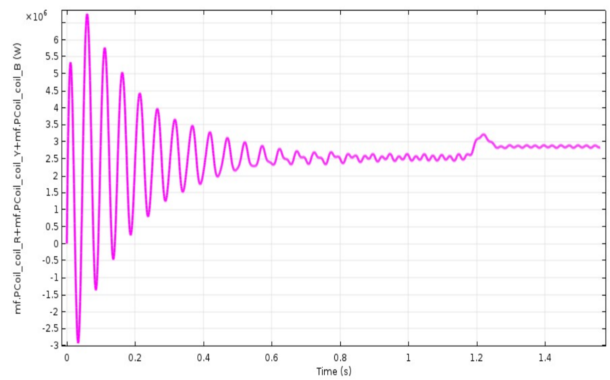

Figure 7. Variation in instantaneous Input power

The variation of instantaneous input power is shown in Figure 7. With decrease in flow rate the power taken by the pump increases due to higher input current drawn from the supply for the given constant input voltage.

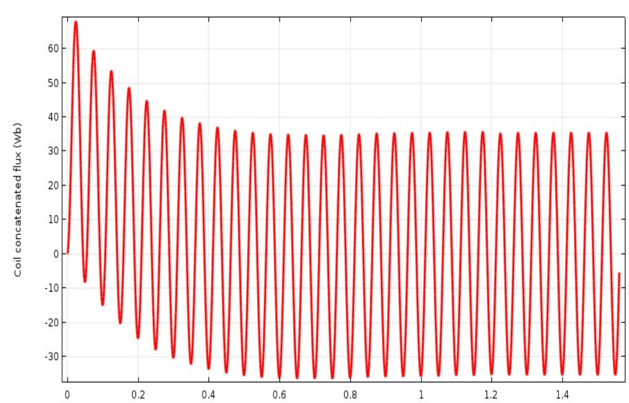

Figure 8. Variation of R-phase flux

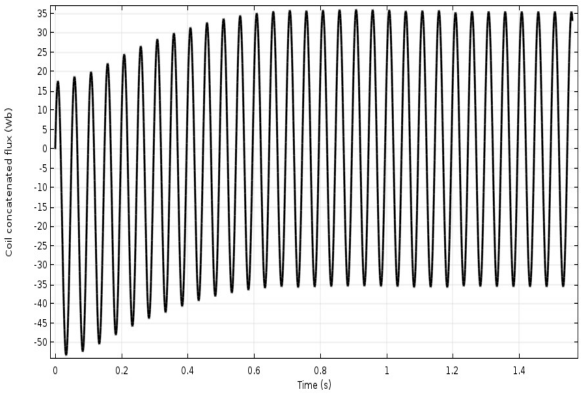

Figure 9. Variation of Y-Phase magnetic flux

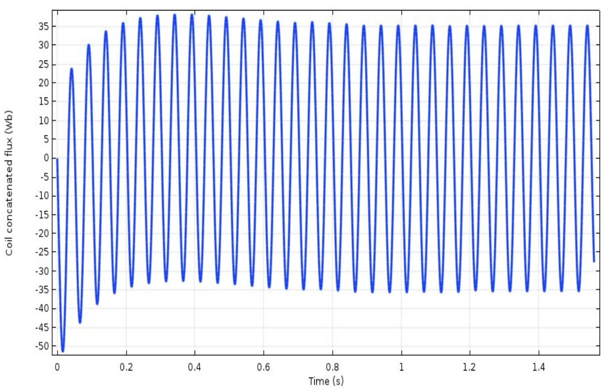

Figure 10. Variation of B-Phase flux

Variation of coil flux is shown in Figures 8-10 where it can be observed that once the flux settles at its steady state value, its value is not affected by the change in flow rate. The coils are fed from a constant voltage source and hence they tend to maintain the flux constant regardless of the change in flow rate. The value of current changes so as to maintain this flux constant.

Results for step increase in flow

A 20 % step increase in flow from the rated flow is also simulated. The step change in velocity is fed as shown in figure 11.

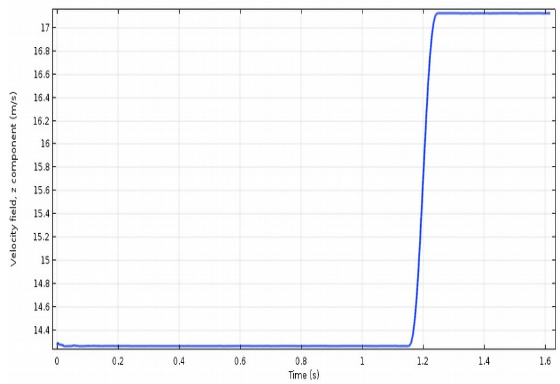

Figure 11. Step increase in flow rate

The response as observed in various pump parameters is depicted in figures 12-16.

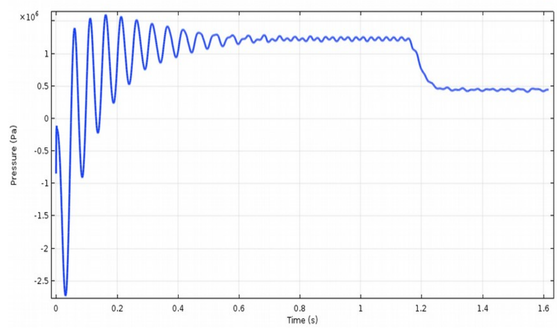

Figure 12. Transient response of output pressure

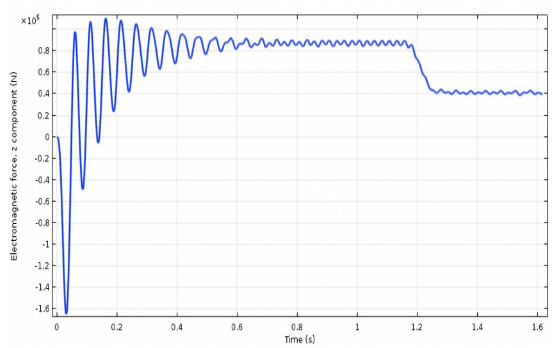

Figure 13. Variation in Volume force

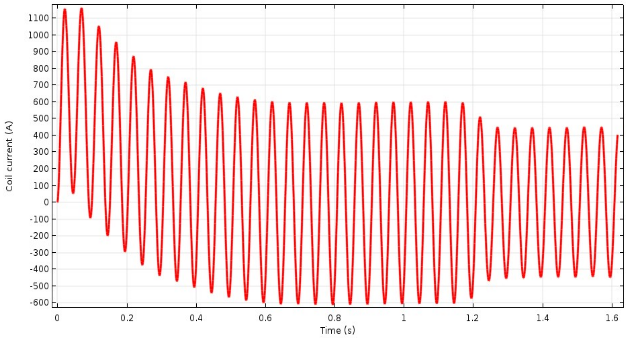

Figure 14 . R- Phase Current transient response

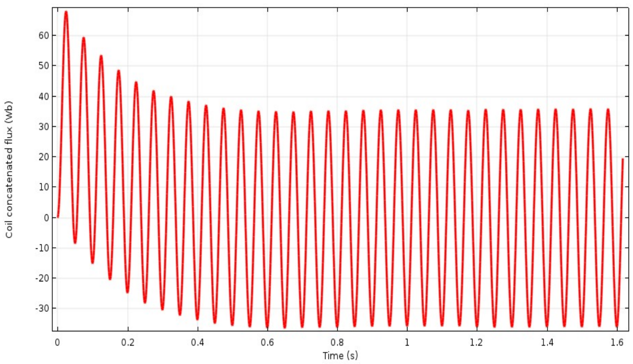

Figure 15. Variation of R-phase flux

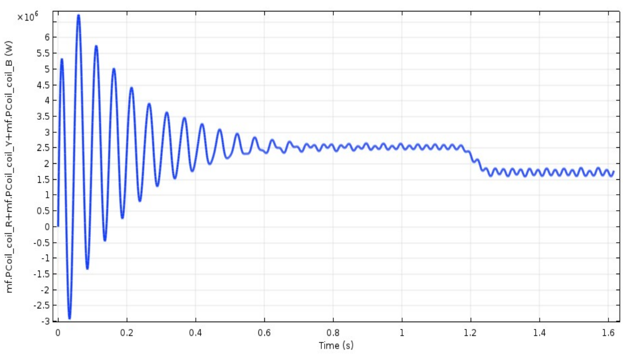

Figure 16. Instantaneous 3-phase power variation

As flow rate increases, the relative motion between the liquid metal and the traveling magnetic field decreases which leads to reduction in circulating eddy currents in liquid metal and also in demagnetizing action of these currents on the stator flux. This leads to reduction in stator current (figure 14) though the stator flux (figure 15) remains same since the applied voltage is kept constant. The input power also decreases (figure 16). The volume force which is product of current density and magnetic flux density also decreases (figure 13) and this results in decrease in pressure produced by the pump (figure 12). The flow remains stable after the transient.

Conclusions

This paper presented the transient modeling of ALIP. The response of ALIP to a sudden change (increase and decrease) in flow rate has been analyzed and it was found that once the transients die out, the various parameters attain values corresponding to steady state pressure vs flow characteristics of ALIP. Presence of double supply frequency pulsations is also observed in developed pressure, though no significant double supply frequency pulsation was observed in flow rate.

References

1. L. Goldsteins, L. Buligins, Y. Fautrelle, C. Biscarrat, S.Vitry, Numerical Quasi Stationary and Transient Analysis of Annular Linear Electromagnetic Induction Pump, Proceedings of COMSOL® 2013 Rotterdam conference.

2. Kliman, Gerald B. ‘Large Electromagnetic Pumps’, Electric machines and electromechanics, 3, 129-142, 1979.

3. COMSOL® 5.3a , Reference Manual