

## Task 32

# Modeling and Design Algorithms for Electromagnetic Pumps

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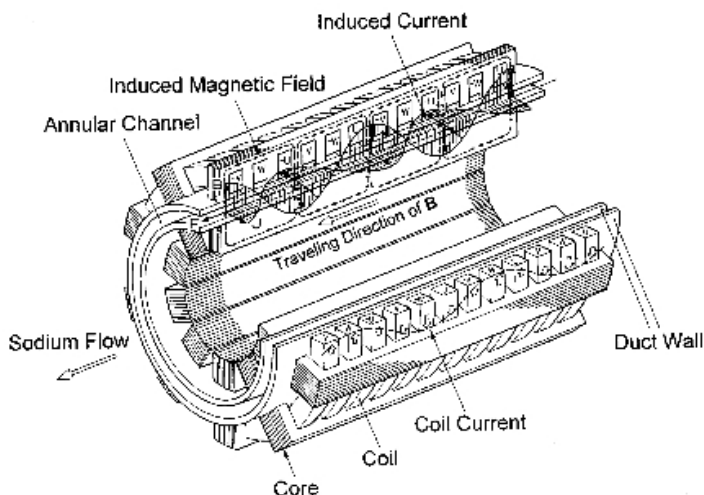
## BACKGROUND

Electromagnetic (EM) induction pumps are used in a number of nuclear energy related applications, such as circulation of molten lead-bismuth eutectic alloys in neutron targets, and circulation of liquid sodium metal in Gen IV Sodium-cooled Fast Reactors (SFR). Because EM pumps have no moving parts which can fail, they are considerably more reliable than conventional mechanical pumps for molten metal usage, and thus EM pumps are favored over mechanical pumps even though their pumping efficiency is lower and their initial cost is higher when compared to mechanical pumps of similar flow rates.

The figure below shows a cut-away picture of an annular, linear induction pump (ALIP), such as has been used in prototype SFRs and the Target Complex 1 (TC-1) loop at UNLV. These ALIPs consist of three main parts:

- an inner cylindrical core fabricated from a ferromagnetic material,
- an annular channel through which the liquid sodium flows, and
- an outer ferromagnetic core in which a set of inductor coils are embedded.

During operation, a 3-phase, alternating current travels through the inductor coils. This current produces a magnetic field which, in turn, induces a current in the liquid sodium in the pump annulus and inner core. Pumping forces develop in the liquid sodium due to the interaction of the magnetic field and the induced current, causing the liquid sodium to flow down the length of the annulus. The magnitude of these pumping forces, and hence the operational efficiency of the pump, is dependent on a large number of design parameters, including coil current and position, ma-



*Cut-away picture of an annular, linear induction pump (ALIP)*

terial selection for the inner and outer cores, and size of the annular gap.

Research on the design of EM pumps has been conducted by a number of researchers in Korea, Germany, Japan and Russia. No major papers on the topic have been published by researchers in the U.S. in the past 10 years. If the U.S. is to continue to maintain a research presence in nuclear power research and development, it is imperative that a solid foundation in EM pump design be developed by researchers within this country. The development of this foundation is the primary aim of this research task.

## RESEARCH OBJECTIVES AND METHODS

The research objectives of this task are:

- A literature review of topics pertinent to EM pump design. These topics include the equations governing the physical phenomena occurring in EM pumps and mathematical algorithms used in modeling these physical phenomena, different EM pump configurations, and the effects of materials properties on pump performance.
- Development of computational models of the TC-1 loop at UNLV.
- Evaluation of the computational models through comparison with experimental data taken on the TC-1 loop.
- A parametric study of the TC-1 loop investigating the pumping efficiency as a function of operating conditions, materials properties, and geometric parameters.

## RESEARCH ACCOMPLISHMENTS

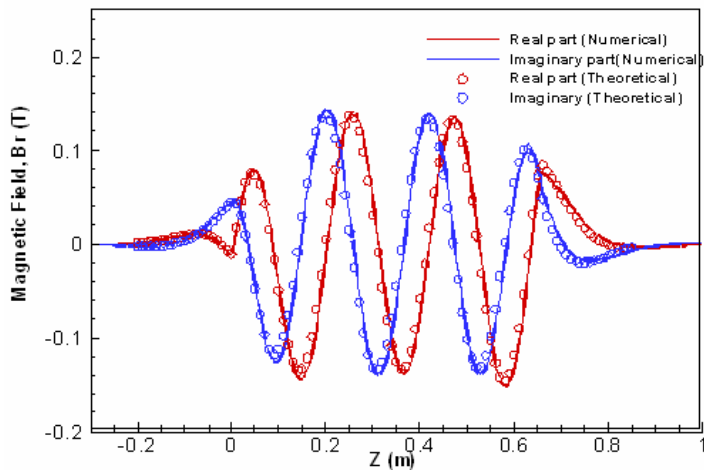
### On-line EM Pump Literature Database

An on-line literature database has been set up on a UNLV website and now contains over 120 entries. Further work will continue this next year. The database will be expanded in terms of the number of entries, and key word searches will be incorporated into the database. This database can be found at:

<http://nstg.nevada.edu/mmrgr/research/LitSurvey/EMP-Literature.html>

### Computational Modeling

Several preliminary models of EM pumps have been developed. The results published to date from this task have focused on the calculation of the EM phenomena (current density, magnetic field, and electromagnetic body forces) in the pump. The first of these EM models was an analytic formulation of Maxwell's equations, in which the magnetic vector potential was the primary solution variable. Use of the method of separation of variables and Fourier transforms allowed the expression of the magnetic vector potential to be expressed in an integral form that could then be



Comparison of the analytic and numeric calculations of the radial component of the magnetic flux density in the TC-1 pump along the pump axis.

solved numerically.

The second model was developed using Comsol, a MATLAB-based platform, and relies on the finite element method to discretize and solve the partial differential equations. The software can run the finite element analysis together with adaptive meshing and error control according to a variety of iterative numerical solvers. The figures above and bottom right show a comparison of the radial and axial components of the magnetic flux density calculated in the pump from the analytic and numeric model. It should be noted that, in these calculations, the velocity of the liquid metal, which can have a significant effect on the magnetic field, was specified, not calculated via solution of the Navier-Stokes equations.

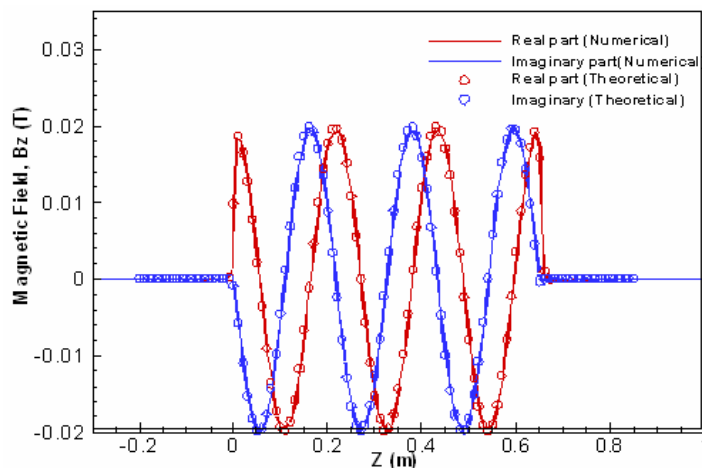
## FUTURE WORK

The next phase of the project involves development of a fully-coupled magnetohydrodynamic solver, for calculating both the EM and fluid flow phenomena in the EM pump. For this model, the EM field phenomena will be calculated using an integral formulation of Maxwell's equations, and the fluid flow phenomena will be calculated using a finite volume formulation of the Navier-Stokes equations. This model has been under development for several months and should be completed during Summer 2007.

## ACADEMIC YEAR HIGHLIGHTS

- ◆ D.P. Cook, J. Ma, H. Chen, Y. Chen, and L. Ratliff, "Numerical Modeling of EM Pump Efficiency," *Proceedings, International Mechanical Engineering Conference and Exposition, IMECE-2006*, Chicago, IL, November 5-10, 2006.
- ◆ D.P. Cook, J. Ma, H. Chen, Y. Chen, and L. Ratliff, "Numerical Modeling of EM Pump Efficiency," *Comsol Users Conference 2006*, Las Vegas, NV, 2006.

Results from the current mathematical models have shown that the efficiency of EM pumping systems can be very dependent on several operating parameters, in particular the frequency of the applied three-phase current and the inductor winding patterns. To further explore the sensitivity of the system to these parameters and to ensure the validity of the computational models that are being developed, plans to construct a lab-scale EM pumping system have been discussed. The system would be a rectangular loop, roughly 2 meters by 1 meter in dimension. The EM pump that would be providing the motive force to the fluid would be of variable frequency, allow changes in the inductor winding pattern, and have removable magnetic cores. This type of pumping system would allow extensive opportunity to validate the computational models.



Comparison of the analytic and numeric calculations of the axial component of the magnetic flux density in the TC-1 pump along the pump axis.

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