large electro-magnetic pump conceptual design for the astrid sodium-cooled fast reactor

T. Suzuki, K. Asano, R. Aizawa, F. Dechelette

10th PAMIR International Conference - Fundamental and Applied MHD
June 20 – 24, 2016, Cagliari, Italy

LARGE ELECTRO-MAGNETIC PUMP CONCEPTUAL DESIGN FOR THE ASTRID SODIUM-COOLED FAST REACTOR

Tetsu SUZUKI[a], Kazuhito ASANO[a], Rie AIZAWA[b], Flanck DECHELETTE[c]

a: Advanced System Design & Engineering Dept., Toshiba Corporation Energy System Solutions Company.,

8 Shinsugita-Cho, Isogo-ku, Yokohama, 235-8523, JAPAN

b: Plant project engineering Dept., Toshiba Corporation Energy System Solutions Company.,

72-34, Horikawa-cho, Saiwai-ku, Kawasaki 212-8585, Japan

c: French alternative energies & atomic energy commission, Cadarache Center, DEN/CAD/DER/CPA, Batiment 155,

13018 Saint-Paul lez Durance Cedex, France

Tel: +81-45-770-2415, Fax: +81-45-770-2317, Email of corresponding author: tetu.suzuki@toshiba.co.jp

Abstract: Within the framework of the French Sodium Fast Reactor (SFR) prototype called ASTRID (Advance Sodium Technological Reactor for Industrial Demonstration), an application of Large capacity Electro-Magnetic Pump (LEMP) is considered as a main concept of the circulating pump on intermediate sodium circuits by CEA. For the developing of the LEMP for ASTRID, CEA conclude a collaboration agreement with TOSHIBA Corporation in April 2012, and carry out a joint work program on design and development of LEMP. In this collaboration, the design study such as the electromagnet design, electromagnetic fluid analysis, and etc for LEMP have been perfomed. This paper describes the dedicated design studies for the LEMP development within the framework of the CEA-TOSHIBA collaboration.

Key words: Electro-Magnetic Pump, ASTRID, Sodium Fast Reactor

1. Introduction SFR is one of the 4th –generation Sodium-cooled fast reactor (GENIV) concepts selected to secure the nuclear fuel resources and to manage radioactive waste. In the June 2006, French Government submitted CEA to design studies of ASTRID prototype as a part of sustainable management of radioactive materials and wastes [1] in collaboration with industrial partners. ASTRID will be an industrial prototype with improving safety, operability and robustness against external hazards compared with previous SFRs for aim at a GENIV safety and operation.

The ASTRID pre-conceptual design phase has been focusing on innovation and technological breakthroughs. This phase was conducted from mid-2010 to the end of 2012 and investigated numerous open options. In these options, it has been decided to implement LEMP as the main circulation pumps on the intermediate circulation system. LEMP has several advantages for the reactor design, operation and maintenance such as no muving parts and no auxialy system. In the conceptual design phase to be next to the pre-conceptual design phase, the ASTRID design choices will be organized and finalised by end of 2014.

10th PAMIR International Conference - Fundamental and Applied MHD
June 20 – 24, 2016, Cagliari, Italy

Toshiba has developed the LEMP for SFR.The basic structures of the LEMP is shown in Figure1, and it consists of the duct made of double concentric cylinder tubes and the inner / outer stator. The iron cores are installed on the individual stators toward the radial direction. The ring coils covered by heat-resistant insulation are installed in the slots of these iron cores. And, the casing is installed around the coils and the iron cores. The voltage applied to these electromagnetic coils yields an induced current in the sodium. The sodium is driven by the interaction of the sliding magnetic field and the induced current. LEMP is the most promising technology for the specific operating conditions of SFR. Therefore, CEA and Toshiba carryied out the conceotual design studied of the LEMP adappted ASTRID.

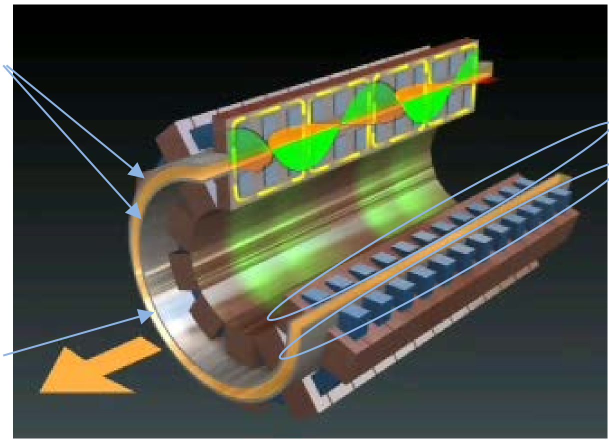

Figure1: Basic structures of the LEMP

2. Design study

2.1 Electromagnet design Electromagnetic design needs to satisfy the requirement as the pump head and the flow rate. There are the design parameters such as terminal current, voltage, frequency, size of the coil and the iron core and the duct (fluid boundary) thickness, material of the duct,...etc. Especialy, the duct thickness and material influences the pump efficiency. Pump efficiency is the ratio between the input power and the output power of minus the loss from the input power, and the duct has the loss by an eddy current. For this reason, it wants to make duct thickness thin. On the other hand, the duct needs to satisfy the fluid pressure and it wants to make duct thickness thick. Futhermore, if the electrical resistivity of the duct material is small, the loss increse because an eddy current occurs in the duct. Therefore, we investigated the relationship between the duct material, the duct thickness and the effciency.

Inner duct compares SS304, SS316 and Inconel600. SS materials are physical property value for design in ASME code, and Inconel 600 was chosen as a typical nickel alloy. Proof stress is big in order of SS304, SS316, Inconel600. Further more, the electrical resistivity is also big in same order.

The result is shown in Figure 1. This figure assumes outer duct SS304 of thickness 10mm and shows duct thickness and relations of the pump efficiency when inside duct materials were changed. A duct thickness is 15mm in SS316, 20mm in SS304 and pump efficiency excels SS304 in SS316. In the case of using Inconel600 as duct materials, pump efficiency and duct thickness is the best because of the larger proof stress and electrical resistivity. But, since main piping of ASTRID is SS316-based material, Inconel600 needs dissimilar joint and it worsens maintenance nature since it becomes the inspection item of a periodic inspection. Therefore, the duct material uses SS316.

And, the examination result of an electromagnetic design in case of SS316 duct is shown in Table 1. Pump efficiency is about 40%, this is worse than effciency of the mechanical pump (about 90%). However, 60% are losses and becomes heat, most of that is released into the sodium, and it is used to heat the sodium. Among all losses, the loss of duct was 24%. The other losses are the coil loss, the iron loss and the fluid loss. Therefore, the material selection and the thickness of the setting of the duct has a great influence on the pump effciency.

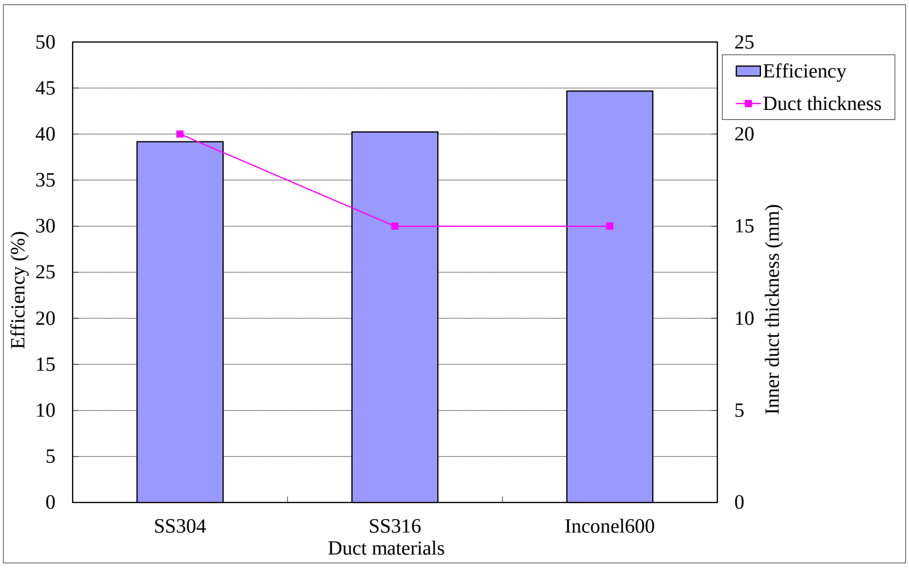

Figure 2: Compare result of the duct materials

Table1: Electromagnetic design specification in case of SS316 duct

Item	Specification	Unit
Type	ALIP / Double stator	-
Sodium flow rate	119	m^3/min
Pressure head	0.37	MPa
Sodium temperature	345	°C
Electric Power	1.94	MW
Terminal Voltage	1270	V
Terminal current	1800	A
Frequency	19.2	Hz
Efficience	40	%
Rm×S	0.99	-
Sodium channel width	65	mm
Sodium channel mean diameter	1030	mm
Number of coils	84	pieces
Number of poles	14	poles
Stator active length	4500	mm
Outside diameter of casing	1800	mm

2.2 Electromagnetic fluid analysis We performed an electromagnetic fluid analysis to confirm the pumping function and the electromagnetic characteristics for design of LEMP. For this analysis, a code developed by TOSHIBA was developed. This code solves coupled equations of the electromagnetism (Maxwell's equations) and the fluid dynamics (Navier-Stokes equation) in a two-dimensional axis-symmetrical model. By this analysis, the Q-H (flow rate vs. pressure head) characteristic, the electromagnetic force distribution, etc are confirmed.

The analysis model takes into consideration the anular channel, the concentric channel duct, the inner and outer iron cores, the coils and the casing. Analysis model is shown in Figure3. Analysis conditions were 345°C of nominal sodium temperature, and evaluated for the flow, the pump head characteristic, the electromagnetic force, etc as the constant V/f ratio.

The Q-H characteristics of the sodium temperature 345°C are shown figure 4. The ratio of voltage to frequency was set constant. The pressure reached at the nominal flow rate of 119 m^3/min fully satisfied the specified 0.37 MPa in a stable control of flow area.
The analysis result of the electromagnetic-force distribution in an annular sodium channel is shown figure.5. Although the negative thrust near 0.4 m and 4.7m in the axial direction is based on the end effect of the stator, this negative thrust (area) is smaller than the electromagnetic force of the stator. Therefore, it is thought that the fall of the pump performance by the end effect is small. And, almost electromagnetic force is committed to the axial direction used as developed pressure power, and there was almost no the invalid electromagnetic-force to the developed pressure of the radial direction.

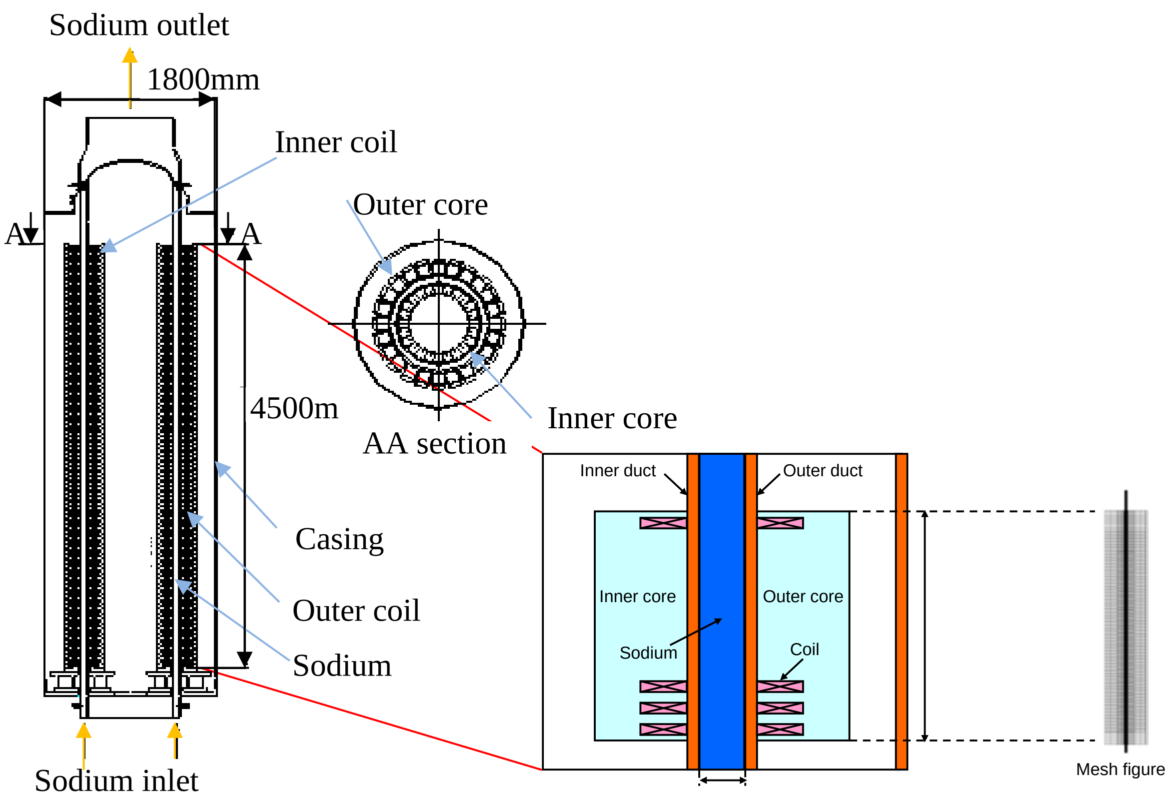

Figure 3: Electromagnetic fluid analysis two-dimensional axis-symmetrical model

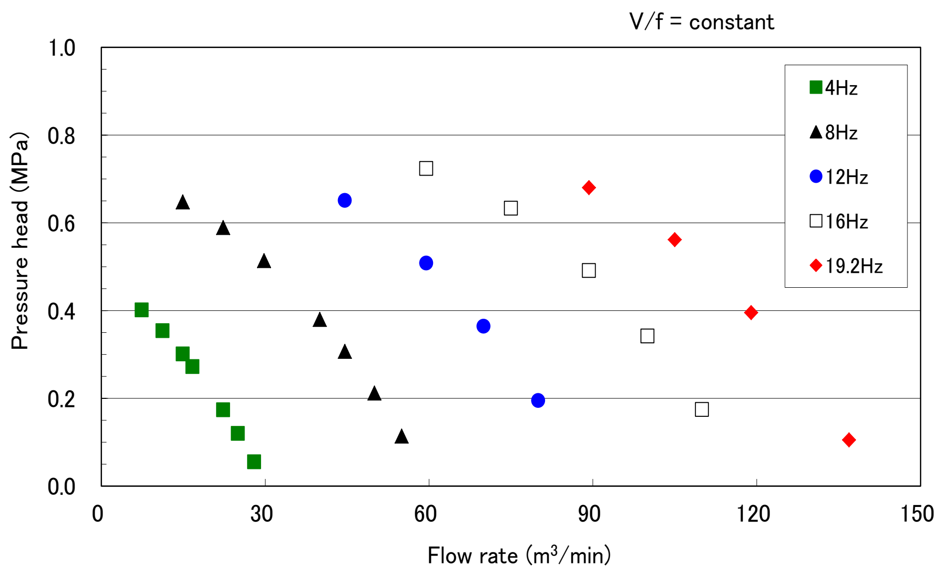

Figure 4: Q-H characteristic

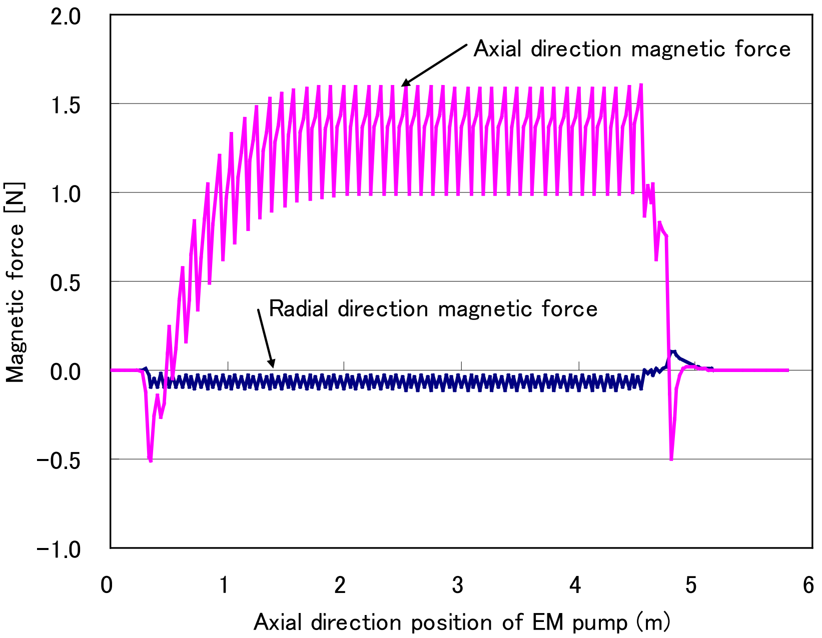

Figure 5: Electromagnetic- force distribution in an anular sodium channel

3. Conclusions CEA and TOSHIBA Corporation agreed for carrying out a joint work program on the design and development of LEMP for ASTRID intermediate sodium loop during 2012 - 2013. In this joint work program, calculations necessary for a pre-conceptual design of LEMP were carried out by the CEA and TOSHIBA. These pre-conceptual design results provided a good confidence in the main characteristics and the feasibility of LEMP for the ASTRID intermediate sodium loop.

This program is continued in 2016, theoretical and experimental investigations are currently in progress for the purpose of improving the numerical tools by CEA. That is necessary to confirm characterise of the instability phenomena and their impact on the LEMP performance.

In parallel, LEMP conceptual design studies for ASTRID such as the following items are ongoing by TOSHIBA: thermal analysis and thermal stress analyses of other structure, the structural analysis and the mechanical interfaces, etc [2].

REFERENCES

[1] F. Gauché; The French Prototype of 4th Generation Reactor: ASTRID; Annual meeting on nuclear technology, Berlin, May 17&18th; 2011.

[2] T. Suzuki *et al.*; LARGE ELECTRO-MAGNETIC PUMP DESIGN FOR APPLICATION IN THE ASTRID SODIUM-COOLED FAST REACTOR; ICAPP2015, Paper No.15132, Nice, France, May 03-06; 2015