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300 kW 급 대용량 초전도 직류 유도가열로 개발

최종호*, 고병수*, 박희철*, 박민원*, 유인근*, 김석호*, 심기덕**, 조상호***, 조진식***
창원대*, 한국전기연구원**, (주)텍스틸***

Development Progress of a 300 kW-class HTS DC Induction Furnace

Jongho Choi*, Byeong-Soo Go*, Hee-Chul Park*, Minwon Park*, In-Keun Yu*, Seokho Kim*, Kideok Sim**, Sangho Jo*** and Jinsik Jo***
Changwon National University*, Korea Electrotechnology Research Institute**, TECHSTEEL Co., Ltd.***

Abstract - In the end of 2014, Changwon National University and TECHSTEEL Co., Ltd. had initiated a project on the development of a 300 kW-class HTS DC Induction Furnace(HTS DC IF) for preheating non-ferrous metal billets funded by the Korea Institute of Energy Technology Evaluation and Planning for 3 years. This is the one of the most realistic commercial machines applying the coated conductors. In this paper, the development progress of a 300 kW-class HTS DC IF was introduced. The major characteristics of the furnace including its capacity, structure and operation scheme were presented. For ensuring the successful design, a pre-validation study was performed through the electromagnetic, heat transfer and solid mechanical analysis using a multi-physics FEM tool. The aluminum billet was heated up to 540 °C under 1 T of the magnetic flux density at the center of the billet, and the simulation results were described in detail.

1. Introduction

The research on the development of an high temperature superconducting(HTS) power machineries applying 2G HTS wires such as an HTS motor [1] and generator [2] and current limiter [3] has steadily proceeded for decades. However, there is not any success of the commercialization after the research.

The research team, Center for Advanced Power Technology Applications (CAPTA) in Changwon National University, got a fund for the development of a 300 kW-class HTS DC induction furnace (HTS DC IF) with over 90% system efficiency through superconducting technology from the government and has conducted the research project with an aim to commercialize the developing machine since the end of the last year. It is expected to become the first successful case among 2G HTS power machineries on commercial scale.

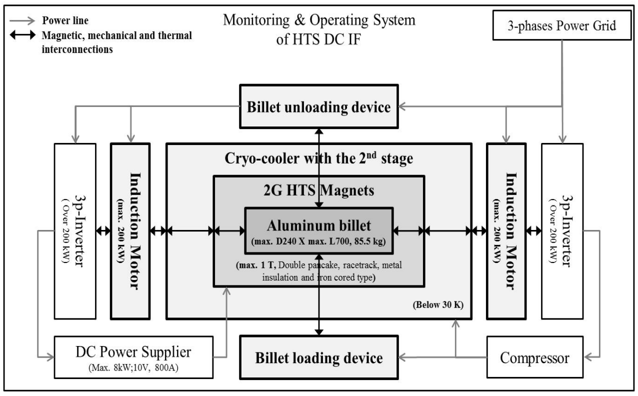
Conventional industrial furnaces are broadly useful in primary metal, automobile, plant and heavy industries and usually divided into two types which are atmosphere furnace and AC induction furnace. Atmosphere furnace has very poor efficiency of 20-30% and it is being replaced by AC induction furnace with the improved efficiency of 50-60%, especially, in the case of heating the non-ferrous metal billets such as aluminum, copper and magnesium in extrusion plant [4].

An HTS DC IF has the target efficiency of 90% [5] and is one of the solutions to replace the large scale conventional furnaces with the system efficiency of 20-60%, and is considered as one of the eco-friendly power electric machines. This project is proceeding to three stages, which are composed of design, manufacture and test, for three years and is now on the design stage.

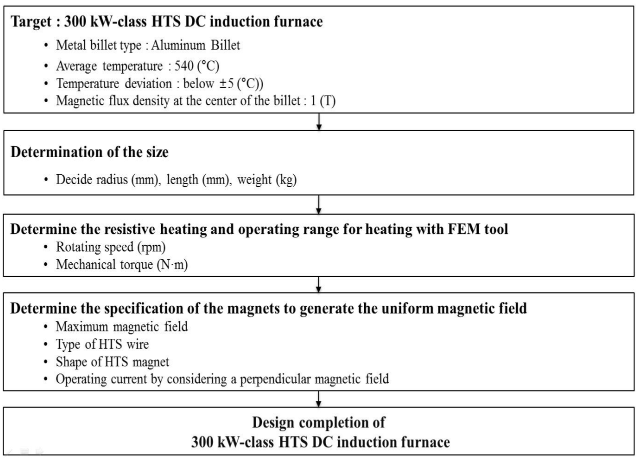
In this paper, the development process of the 300 kW-class HTS DC IF was presented. The targets and major characteristics of the furnace including its capacity, structure and operation scheme were introduced. The HTS magnets, one of the key components of the HTS DC IF, were designed and their electromagnetic, thermal and solid mechanical characteristics were analyzed through an finite element method tool with multi-physics functions. The results were obtained. We got the most important targets under the design process. The highest power of the furnace is over 300 kW and its maximum magnetic flux density is over 1 T at the center of the aluminum billet and the best system efficiency is over 90%. These outcomes of the paper will be useful as the fundamental data to manufacture the real machine.

2. System configuration and target setting

This project is to develop a 300 kW-class HTS DC IF with the system efficiency of over 90%. As shown in Fig.1, the system, HTS DC IF, has two induction motors with the total power capacity up to maximum 400 kW, and its rotation velocity is controlled by each 3phase inverter, individually. The 2G HTS magnets generate an uniform magnetic field under a conduction cooling condition using two cryo-coolers with the 2nd stage cooling method. A DC power source is operated with a constant current mode and supplies the operating current to the magnets in series connection. And an aluminum billet is heated up by rotating with a specific angular velocity under the uniform magnetic field.



<Fig. 1> System configuration of a 300 kW HTS DC IF

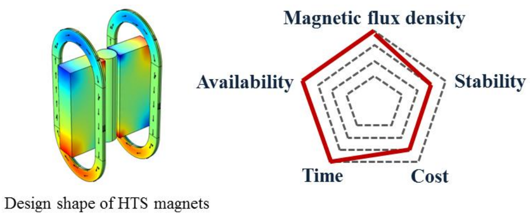


<Fig. 2> The flow chart for setting the targets of the HTS DC IF

As following the flow chart of setting the targets of the HTS DC IF, their design targets and major specifications were determined as shown in Table 1. With inputting the operating current of 440 A to the HTS magnets, we can get the magnetic flux density of 1 T at the center of the aluminum billet. The HTS magnets are fabricated with an iron cored and metal insulated types as shown in Fig.3.

<Table 1> Design targets and major specifications of the 300kW-class HTS DC IF

Design target and major specification of the HTS DC IF	
Specifications	Value
System capacity	300 kW
System efficiency	90 %
Target temperature	540 ℃
Temperature deviation	±5 ℃
Magnet types: Double pancake, racetrack, metal insulation and iron cored type	
Target magnetic flux density	1 T
Operating temperature of HTS magnets	30 K
Metal billet materials	Aluminum
Length range of the billet	Max. 700 mm
Radius range of the billet	Max. 120 mm
Penetration depth rate	70 %
Operating current for the HTS magnets	440 A
Controllable heating time depended on the billet type	

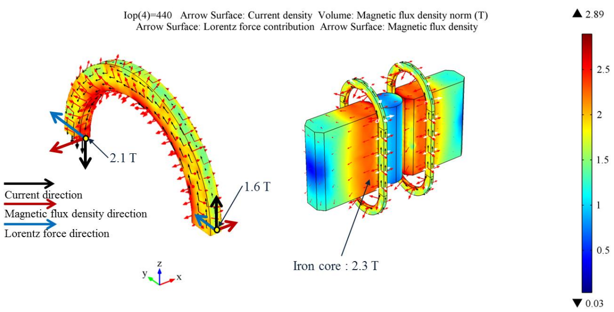


<Fig. 3> A candidate of the HTS magnets and its pentagonal advantage graph

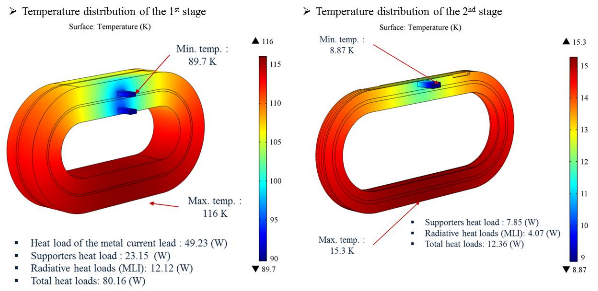
The HTS magnets have several advantages in comparison to the other types of the magnets. The highest magnetic flux density is obtained by securing their stabilities and it takes the shortest time to heat up the aluminum billet. Availability to heat up the various size's aluminum billets is the broadest among them.

3. Development of the FEM analysis models

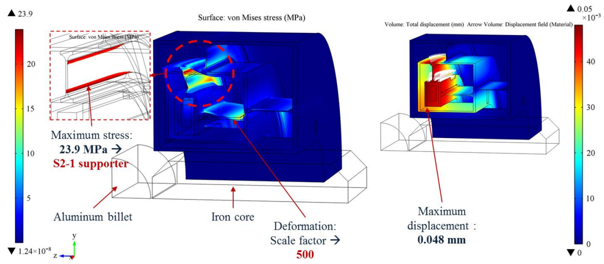
In the first year of the project, the design of the HTS DC IF has to be performed with detailed drawings. On the process of the design, the electromagnetic, heat transfer and solid mechanical characteristics were analyzed through multi-physics FEM models and the results were shown in Fig. 4 – Fig. 6. Each of the HTS magnets was installed in a cryostat. The supporters were ideal and designed with G-10 to minimize the conduction heat invasion. We got the cooling power data with the function of the temperature from the maker of the cryo-cooler and it was set in FEM tool.



<Fig. 4> Electromagnetic analysis results including the magnetic flux density distribution, magnetic flux density direction and the Lorentz forces direction



<Fig. 5> Heat analysis results of the HTS magnets in the 1st stage and 2nd stage under conduction cooling method



<Fig. 6> The solid mechanical analysis results show the maximum stress and displacement of a HTS magnet with supporters in a cryostat

<Table 2> The summary of the three analysis results of the HTS magnets

	Supporter name	Thickness (mm)	Length (mm)	Total area (mm^2)	Max. Stress (MPa)	Max. heat invasion at 1st stage (W)	Max. heat invasion at 2nd stage (W)
Outer cryostat → Radiation shield	S1-1	2	84	8,406	12	16.72	
	S1-2	3	138	3,778	13	6.45	
Radiation shield→ HTS magnets	S2-1	3	85	10,913	23.9		4.44
	S2-2	6	142	7,613	15		3.16
Sum	**Max. displacement : 0.048 mm**			**30,710**	**Max. 23.9**	**23.17 (Min.89.7K)**	**7.6 (Max.15.3K)**

4. Conclusion

The highest magnetic flux density was 1.02 T with the operating current of 440 A and the minimum temperature of the 1st stage was 89.7 K and the maximum temperature of the 2nd stage was 15.3 K. The maximum stress of G-10 supporters in a cryostat was 23.9 MPa and the maximum displacement was 0.048 mm. These analysis results satisfied the criteria we've set and will be useful of the real fabrication of the HTS DC IF.

[Acknowledgements]

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