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Recent Development Trends of a 1.2 MW Superconducting Induction Heater using MgB_2 NI Magnets

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I. INTRODUCTION

In industries, there are many issues against the implementation of conventional heating furnaces.

- ✓ First, the government recently executed and environmental protection policy that requires industries to use better technologies against low efficiency and CO_2 emission, etc.
- ✓ Second, industries use old and inefficient technologies for heating metals with large capacity and low efficiency.
- ✓ Third, the work space is sometimes large, dirty, dangerous, and dull.
- ✓ Finally, engineers with various skills are required to operate advanced heating furnaces.

As one of the solutions to resolve these issues, the superconducting induction heater (SIH) with high efficiency has been developed using MgB2 magnets manufacturing technologies first in Korea.

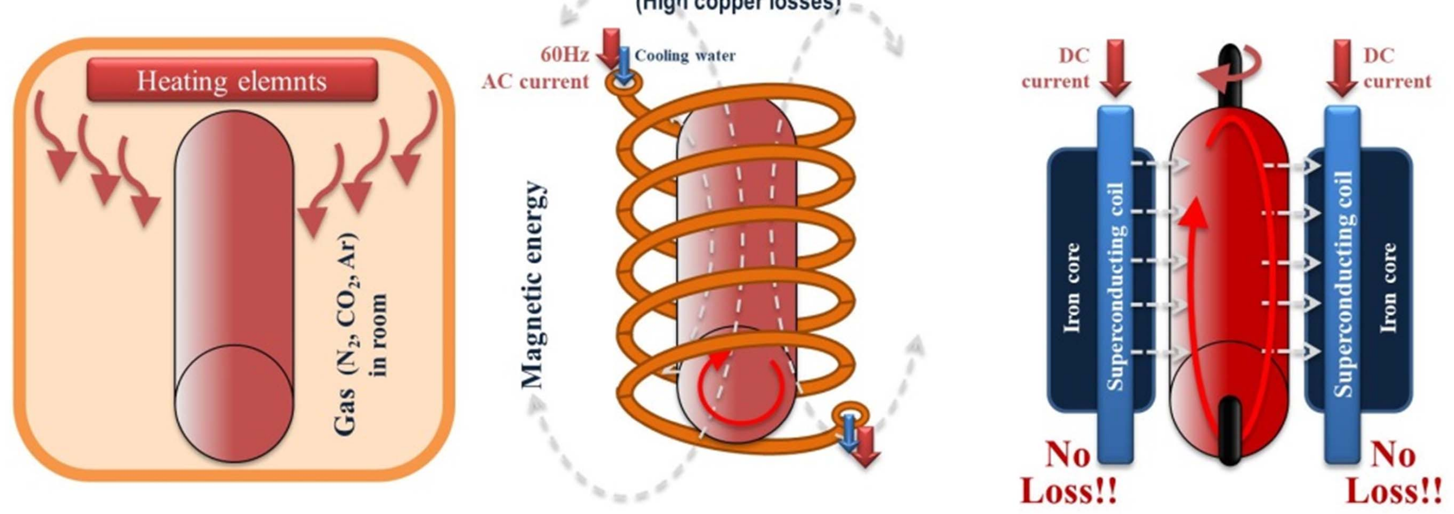
In this paper, the novel design and experimental results of MgB2 magnets were presented for a 1.2 MW SIH. Large bore MgB2 magnets were designed newly. The heating capacity was decided and the target magnetic flux density of the HTS magnets with iron cores selected for 1,200 kW heating power for an iron metal billets.

II. ENERGY TRASNFER RELATIONS AND INFORMATION OF MgB_2 WIRE

Comparison of conventional heating methods

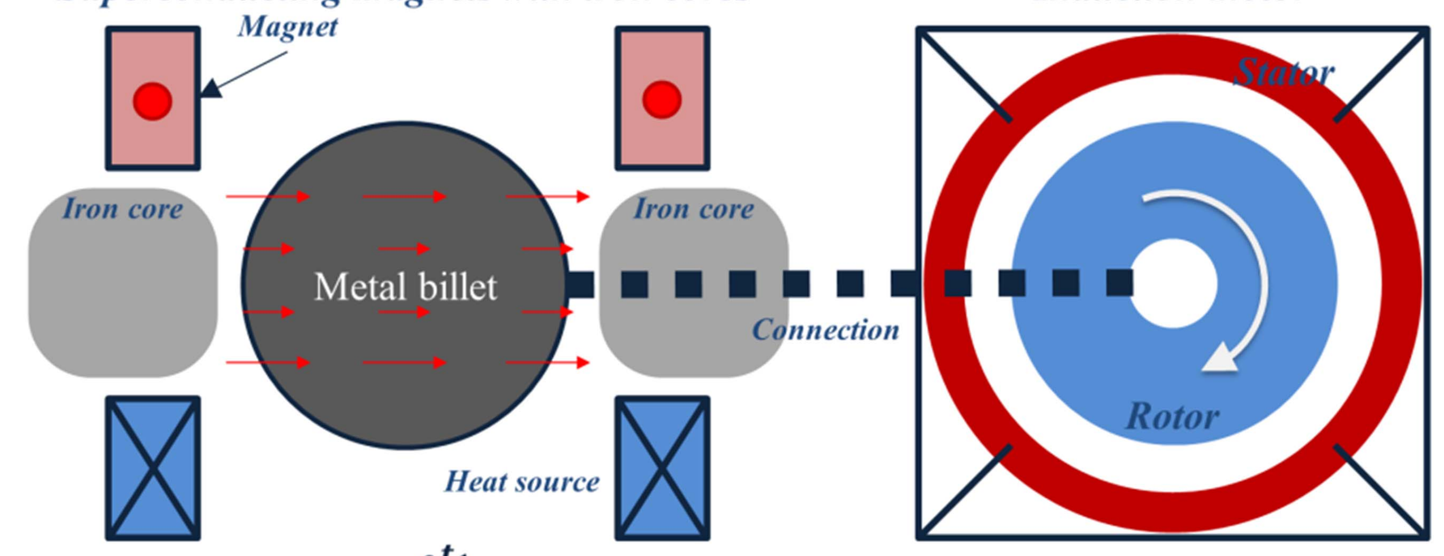
➢ Superconducting Induction Heater; it is expected as 30~70% Energy efficiency improvement than conventional furnaces

System efficiency: 20~30% < System efficiency: 50~60% (High copper losses) < System efficiency: 80~90%



Atmosphere furnace (Gas furnace) | AC induction heater | Superconducting induction heater

Energy Transfer Relations of SIH

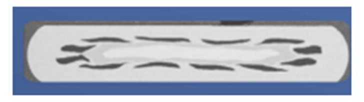


$$Q = M \cdot C_p(\Delta T) \cdot \int_{t_0}^{t_1} T dt = R_m \cdot I_{ind}^2 \cdot \Delta t = k \cdot \tau \cdot \omega \cdot \Delta t$$

Heat transfer energy | Electrical energy | Mechanical energy

Superconducting wire selection

Columbus PRF.00030



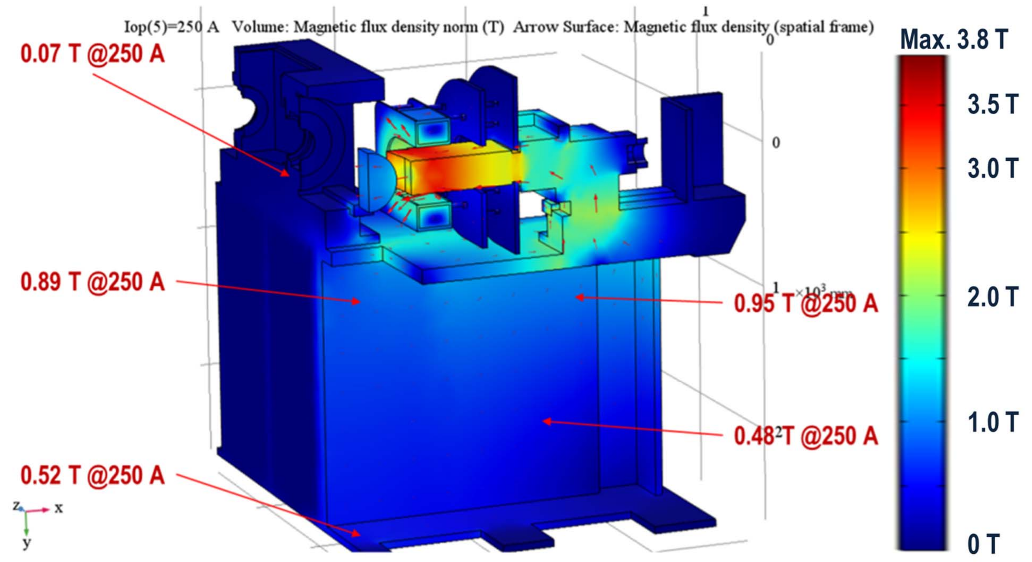
Chemical composition (%)	
MgB_2	12
Nickel 200 inner sheath	63
Copper inner core	15
Iron barrier	10

Wire specs	
Critical current at 20 K, 1 T	Typically 400 A
Wire dimensions	3.65 x 0.65 mm
Filament count	12
Filament twist pitch	300 mm
Critical bending radius	60 mm
Critical tensile strength	> 120 MPa
N-value	Typically >20
Unit piece length	>1 km

Item	HTS (High temperature superconductor)		
	Ceramic type		Metallic type
	Coated conductor	BSCCO	MgB_2
Period	1987	1988	2001
Material	Y,Ba,Cu,O	Bi,Sr,Ca,O	Mg,B
Operational temperature	~ 77 K (-196℃)	~ 77 K (-196℃)	~ 25 K (-253℃)
Stability	GOOD	GOOD	NOT Bad
Operational M.F. range	~ 20 T ~	~ 20 T ~	~ 5 T
Lamination	Copper, brass, STS	Siver	Copper
Manufacturing method	Coating	PIT (extruding)	PIT (extruding)
Maker	SuNAM (KOR) THEVA (GER) SuperPower (JAN) SuperOX (RUS) etc.	Fujikura (JAN) Sumitomo (JAN) Bruker (EUR)	ASG (ITA) KAT, Samdong (KOR), Hitachi, Hypertec(JAN)
Cost	60~180 $/m	~120 $/m	5~10$/m

III. DESIGN AND SPECIFICATIONS OF MgB_2 NI MAGNET

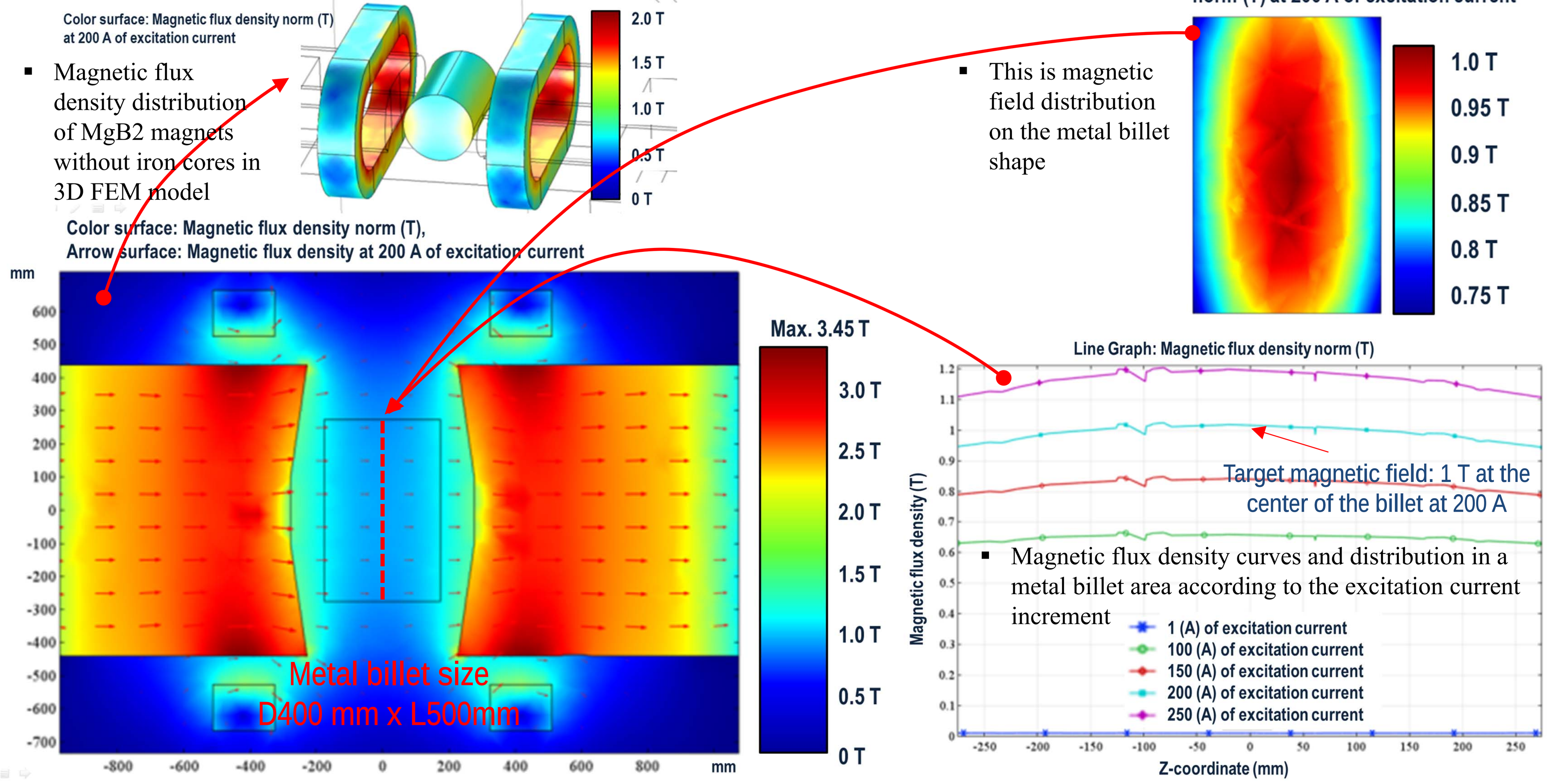
Electromagnetic 3D FEM design model analysis



Specifications

Parameter	Value
MgB_2 wire maker	Columbus superconductor, ASG, Italy
MgB_2 wire (Width×Thickness)	W3.7 (±0.1) mm×T650 (±15) μm
Stainless steel tape (STS)	W3.5 (±0.1) mm×T100 (±15) μm
Minimum critical current	≥400 A @20 K, 1 T
MgB_2 magnet type	No insulation, racetrack, a double pancake, iron cored type, STS co-wound
Size (Hight x Length x Thickness)	H748 mm×L1390 mm x T246 mm
Number of turns in a DPC	370 turns in a double pancake (370 x 8 DPCs = 2,960 turns =1 set magnet)
Total length of the MgB2 wire for two magnets	18 km (2 sets magnets)
Inductance of a DPC magnet	8 H without an iron core, 32 H with iron cores
Operating current (I_{op})	200 A
B_{max} at the MgB2 magnets	2 T with iron cores

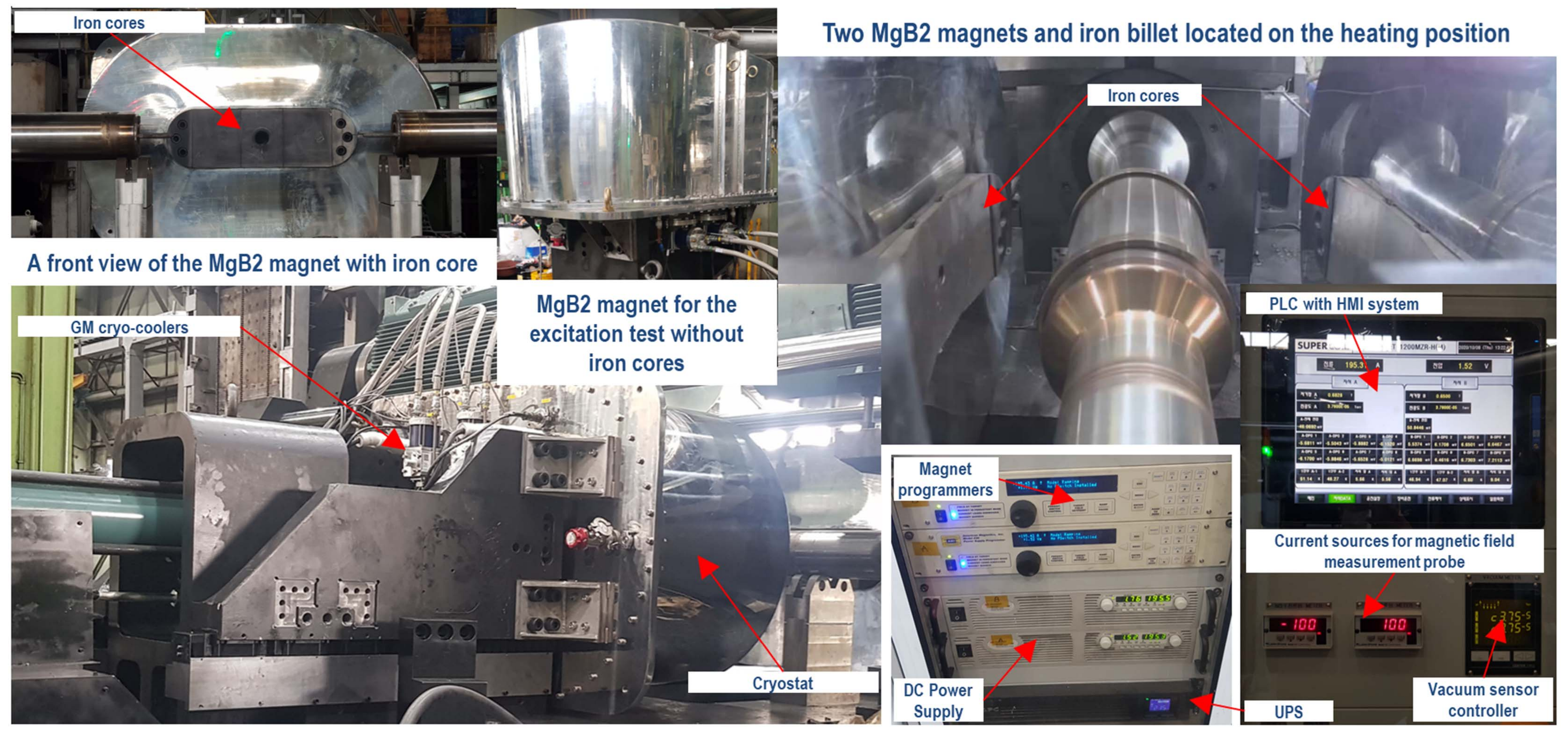
Magnetic field analysis at the metal billet position



- Magnetic flux density distribution of MgB2 magnets without iron cores in 3D FEM model
- This is magnetic field distribution on the metal billet shape
- Magnetic flux density curves and distribution in a metal billet area according to the excitation current increment

IV. MANUFACTURE AND EXPERIMENTAL RESULTS OF THE MgB_2 MAGNETS

Manufacture of the MgB2 magnets and test preparation



Experimental test results of two MgB_2 magnets installed on 1.2MW SIH

- ✓ MgB2 magnet A reached at almost 6 K and MgB2 magnet B reached at almost 8 K after the current of 200 A was excited.

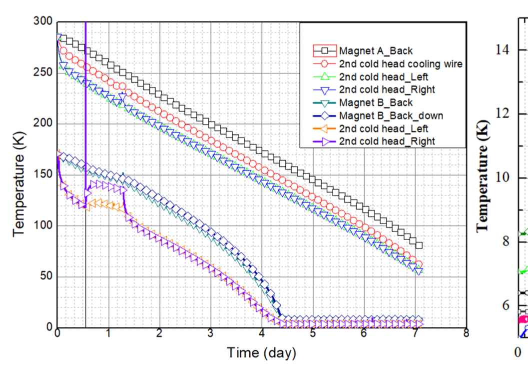


Fig.1 Temperature curves when two MgB2 magnets cool down for almost 7 days

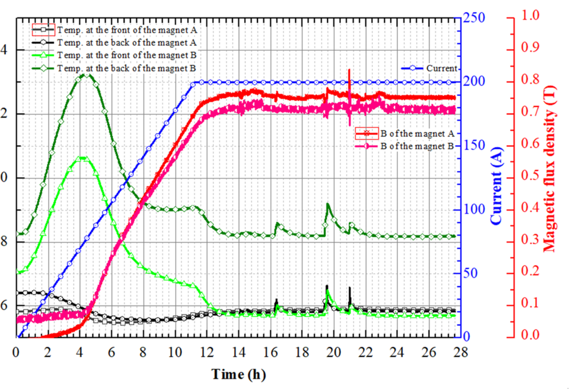


Fig. 2 Temperature curves when two MgB2 magnets were excited to 200 A

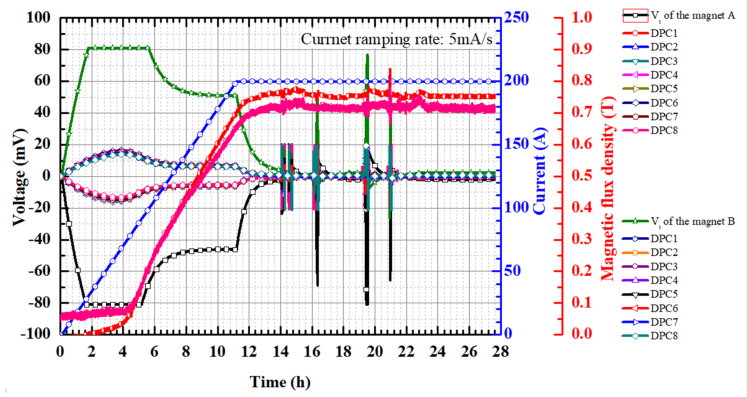
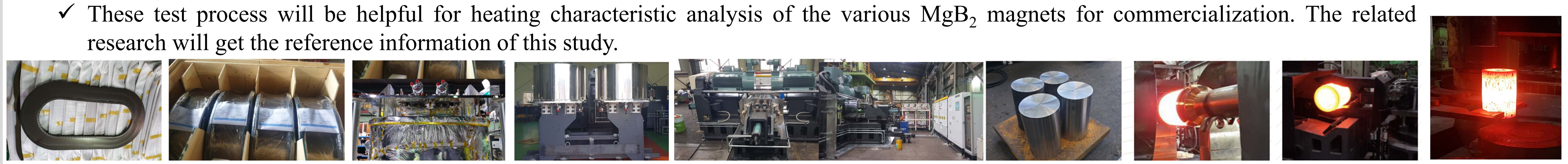


Fig. 3 Terminal voltage and magnetic flux density curves when two MgB2 magnets were excited to 200 A

IV. CONCLUSION

- ✓ In this paper, the simulation and experimental results of the MgB_2 magnets were presented in detailed. The largest MgB_2 NI magnets in the world were fabricated and tested with outstanding operational results.
- ✓ The biggest MgB2 NI coils were fabricated and tested successfully.
- ✓ The magnetic field at the target position far from 250 mm iron core was 0.7 T and
- ✓ The 1.2 MW SIH was operated and the iron billet was heated. Temperature of the iron billet reached 1,300 Celsius degree.
- ✓ These test process will be helpful for heating characteristic analysis of the various MgB_2 magnets for commercialization. The related research will get the reference information of this study.



Bobbins | MgB_2 wires | MgB_2 magnet was assembled. | 1.2 MW SIH was installed on site | Iron billets | Heating process | Unloading and forging process