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A Selection of the Optimal Structure and Material for Braking Resistor Using Thermal Analysis

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Abstract: The electric braking system of high-speed train uses dynamic braking in which the braking force is obtained by a resistor that radiates the energy obtained by operating the traction motor as a generator to heat, and regenerative braking in which the braking force is obtained by circulating the energy through a power line to a substation or another train. If excessive heat generated in the resistor during dynamic braking is not properly dissipated, the braking force will be reduced due to the malfunction, heavy loss and short circuit of the braking resistor. In this study, the resistance of the braking resistor that is used for the dynamic braking of high-speed trains was proposed to meet the design criteria by changing its structure and material. In addition, the temperature rise characteristics of the braking resistor due to the changes in current were analyzed by using a thermal analysis and the optimal structure and material were selected.

Key words: Braking resistor, dynamic braking, high-speed train, thermal analysis, radiates, optimal structure

INTRODUCTION

Traction performance and braking performance for safe operation and control of trains are very important elements. Effective design and thorough performance verification of traction systems and braking systems are required (Kim *et al*., 2007). The braking system is divided into mechanical braking which converts kinetic energy into heat and electric braking (Teramoto *et al*., 2012; Huh *et al*., 2010) which converts power energy to heat. Mechanical braking uses disk braking and tread braking while electric braking uses regenerative braking and dynamic braking (Fletcher, 1991; Sone and Ashiya, 1998; Mathew *et al*., 1995; Kwon *et al*., 2006; Youn *et al*., 2013). The braking resistor used in electric braking of high-speed trains is a device that suppresses voltage surge and absorbs regenerative power. It is normally used for regenerative braking that regenerates electric power through an electric line by using a converter. When regenerative braking is inevitable due to emergency control or dead sections it is used for dynamic braking that consumes accumulated electric power by dissipating electric energy as heat energy. When excessive heat is continuously generated in the braking resistor during the braking of high-speed trains, the electric energy cannot be consumed properly due to the cracks or short circuit of the resistor wire. The braking force of high-speed trains and the life of the braking resistor are heavily affected by the problems such as damage to braking choppers and heat generation in inverters for traction. In this study, the braking resistor was designed by analyzing the structural arrangement characteristics of the braking resistor wire to address these problems. It was investigated whether the resistance of the braking resistor meets the design criteria by applying various materials such as Kanthal and Nikrothal that are mainly used for the braking resistor wire. Thermal analysis was conducted to analyze the temperature rise characteristics and to select the optimal structure and material.

MATERIALS AND METHODS

Composition of dynamic braking system: The block diagram of the braking device for dynamic braking contains braking resistors (01 and ZB-BK-02) in the circuit as shown in Fig. 1. During regenerative braking when the regenerative voltage control by the converter reaches the limit, the voltage value generated during electric braking is controlled by chopping the DC power supply which is generated by the ON/OFF switching operation of the braking chopper (CO-BK-01) Gate Turn-Off (GTO) thyristor at 300 Hz. At this time, the electric braking

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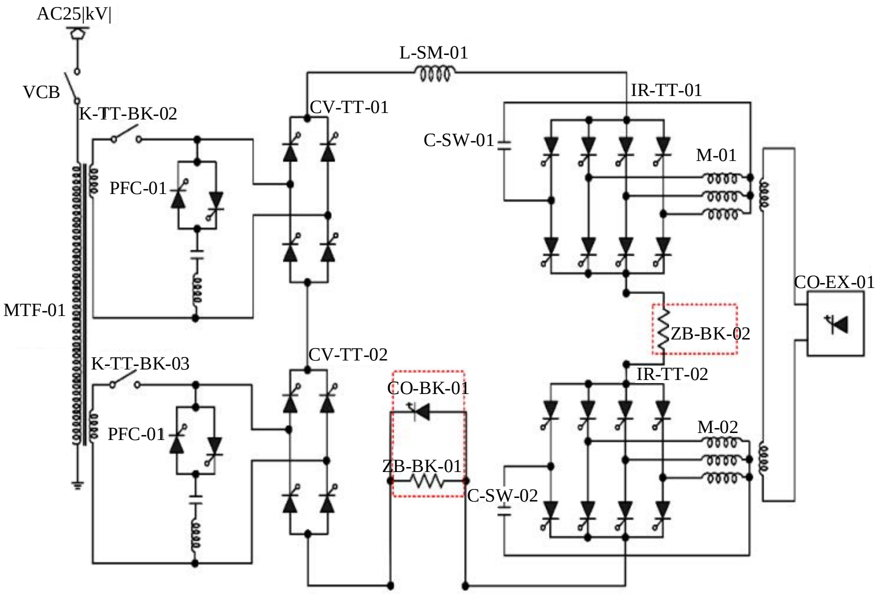

Fig. 1: Block diagram of dynamic braking system

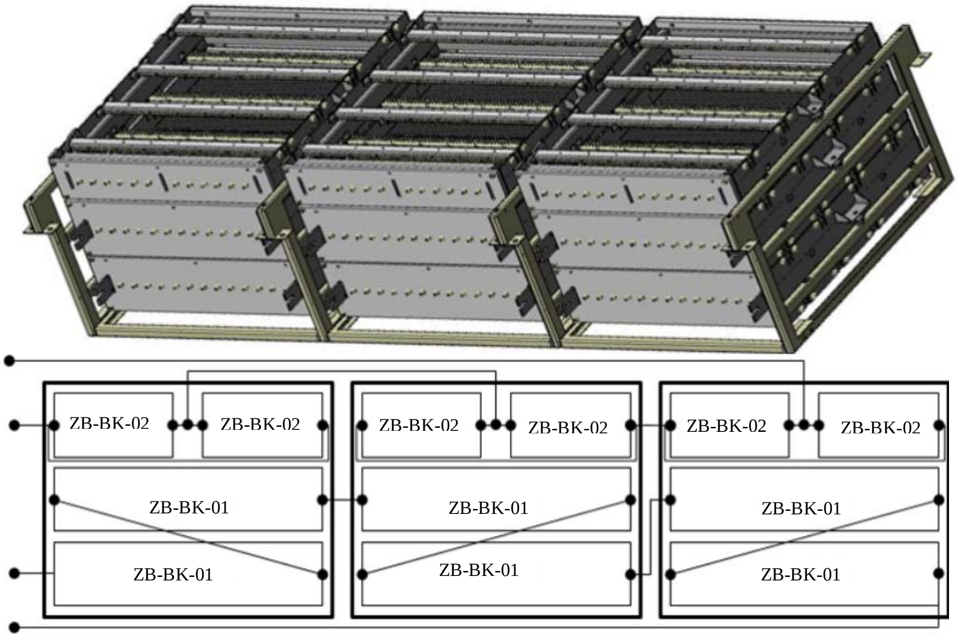

Fig. 2: Composition of braking resistor

power at the time of GTO thyristor off is consumed by the braking resistor (ZB-BK-01). During dynamic braking, the braking chopper (CO-BK-01) is turned off and most of the electric braking power is consumed by the braking resistors (ZB-BK-01, ZB-BK-02). Some of the power is used as the fan power for motor block and traction motor cooling. The braking resistors are arranged in a lattice structure as shown in Fig. 2. The braking resistor (ZB-BK-01) consists of 6 sets of single 0.55 Ω resistors serially connected in a zigzag line and its combined resistance is 0.81 Ω.

RESULTS AND DISCUSSION

Thermal analysis model and resistor materials: The braking resistor (ZB-BK-01) among the two braking resistors (01 and ZB-BK-02) was focused in this study. It was designed as shown in Fig. 3 in order to propose the

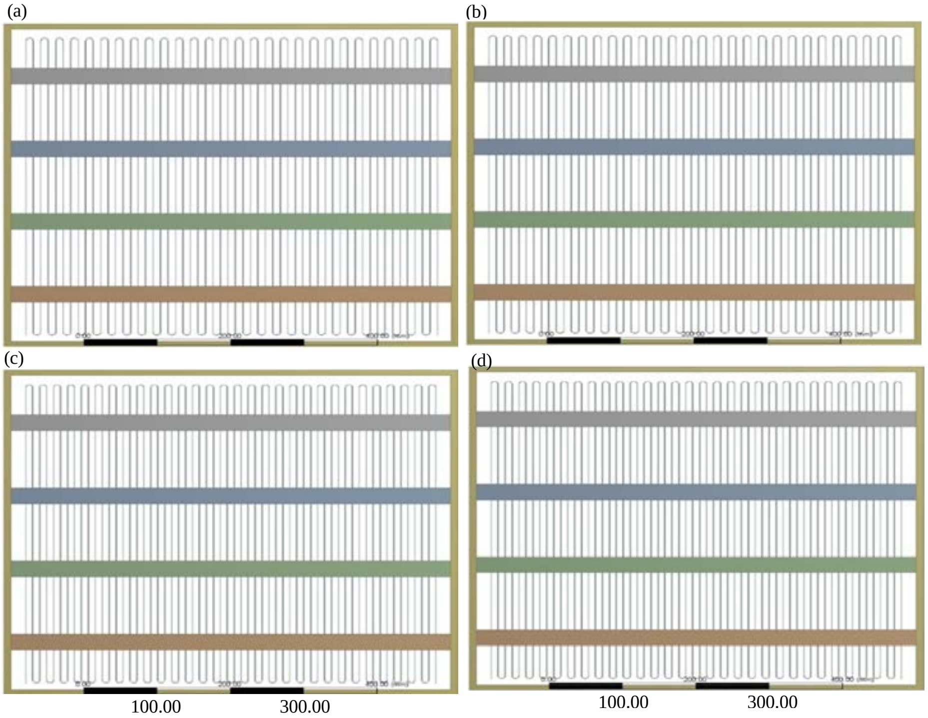

Fig. 3: Modeling of braking resistor: a) 28S/0.5T; b) 28S/0.6T; c) 30S/0.5T and d) 30S/0.6T

Table 1: Specification of braking resistor

Items	28S/0.5T	28S/0.6T	30S/0.5T	30S/0.6T
Width	56 cm	56 cm	56 cm	56 cm
Length	57 cm	57 cm	57 cm	57 cm
Height	14 cm	14 cm	14 cm	14 cm
Area	0.70 cm^2	0.84 cm^2	0.70 cm^2	0.84 cm^2
Total length	3225 cm	3225 cm	3449 cm	3449 cm

Table 2: Resistivity changes by temperature changes

	Resistivity (Ωmm^{2}m^{-1})						
	Kanthal			Nikrothal			
Temp. (°C)	A-1/APM	AF	D	80	70	60	40
20	1.45	1.39	1.35	1.09	1.18	1.11	1.04
100	1.45	1.39	1.35	1.10	1.19	1.13	1.07
200	1.45	1.39	1.36	1.11	1.20	1.15	1.10
300	1.45	1.40	1.36	1.12	1.22	1.17	1.14
400	1.45	1.42	1.38	1.13	1.23	1.18	1.16
500	1.46	1.43	1.39	1.14	1.24	1.20	1.20
600	1.48	1.45	1.40	1.13	1.24	1.21	1.22
700	1.48	1.45	1.42	1.13	1.23	1.21	1.24
800	1.49	1.46	1.43	1.13	1.23	1.22	1.26
900	1.49	1.46	1.44	1.13	1.23	1.22	1.27
1000	1.51	1.47	1.44	1.14	1.24	1.23	1.28
1100	1.51	1.47	1.44	1.16	1.25	1.24	1.29
1200	1.51	1.47	1.46	1.17	1.25	1.25	
1300	1.51	1.47	1.46				
1400	1.52						

optimal arrangement by changing both the composition of the resistance wire and the lattice structure. Figure 3a shows the 0.5 mm thickness of 28 lattice structures, Fig. 3b the 0.6 mm thickness of 28 lattice structures, Fig. 3c the 0.5 mm thickness of 30 lattice structures and Fig. 3d the 0.6 mm thickness of 30 lattice structures. Table 1 shows the specifications of the designed braking resistor. The materials for the designed braking resistor were Kanthal A-1/APM, AF and D as well as Nikrothal 80, 70, 60 and 40. Table 2 explains the change in resistivity with temperature (Kanthal, 2003).

The change in the resistance of the modeled braking resistor was investigated when the specific resistance changes with temperature rise. The results are shown in Fig. 4. As shown in Fig. 4, the products that met the resistance design criteria of 0.52-0.59 Ω were Nikrothal 70 for the 28S/0.5T Model and Kanthal A-1/APM, Kanthal AF and Kanthal D for the 28S/0.6T Model. Nikrothal 80 was the most suitable for the 30S/0.5T Model. There was no model suitable for the 30S/0.6T Model.

Thermal analysis and result: Natural convection thermal analysis simulation due to the change in the applied current was performed using the ANSYS Software for the designed braking resistor shown in Fig. 3 and the products in Fig. 4. The current changing between 100-500 (A) was applied to the braking resistor under an initial temperature of 22°C. The analysis was conducted for 100 sec. and the convection heat transfer coefficient of 5 W/m^{2}K was applied. Figure 5 and 6

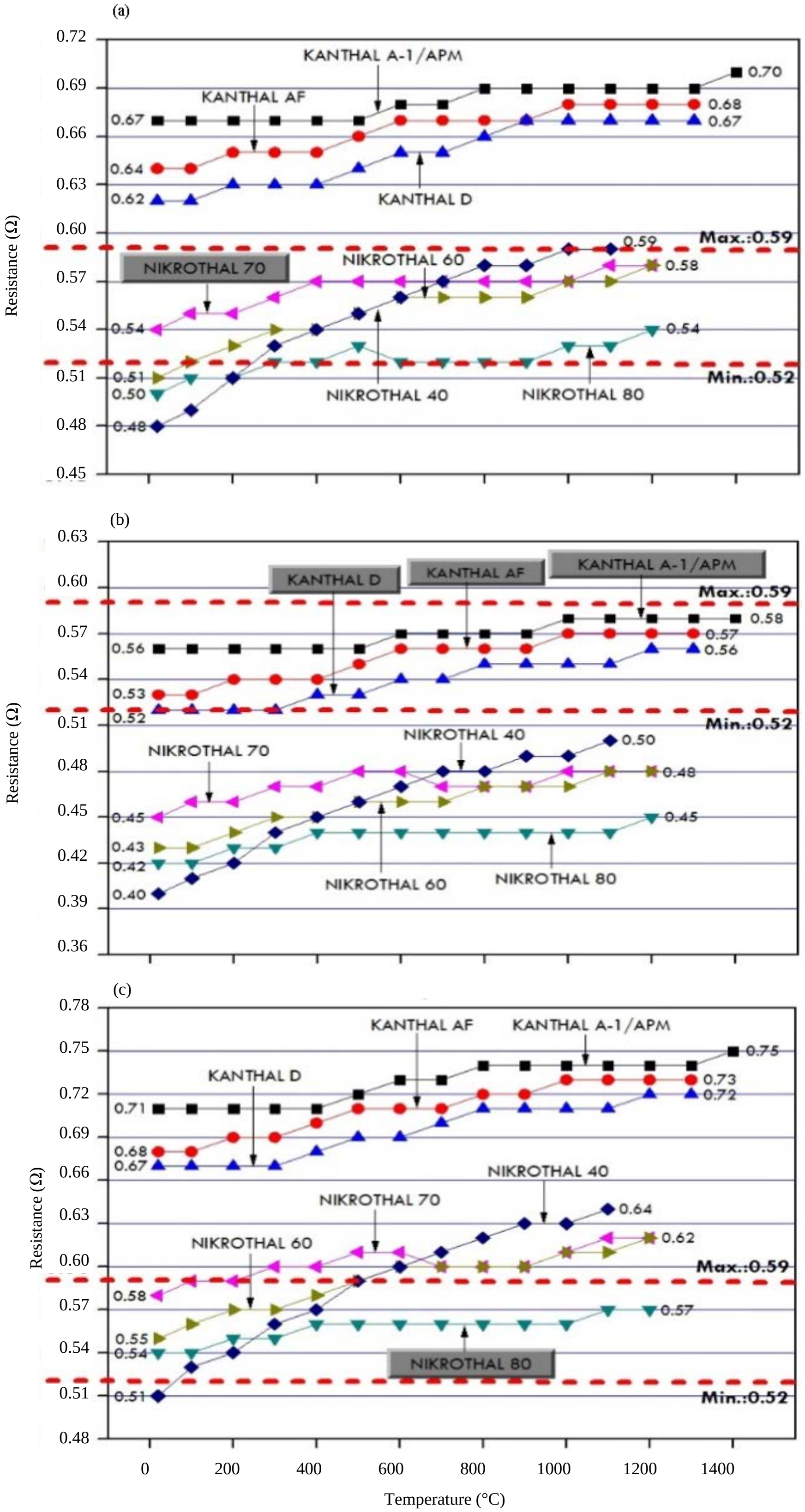

Fig. 4: Continue

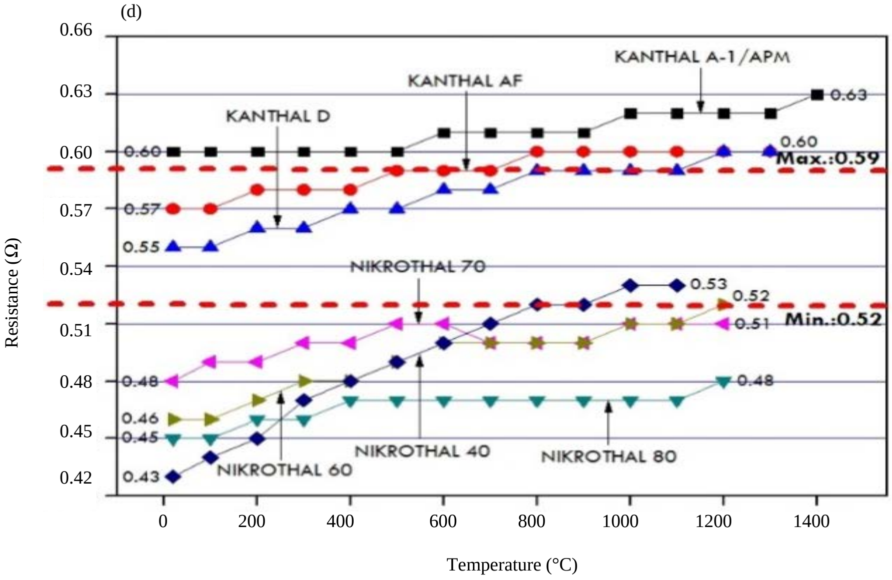

Fig. 4: Resistance changes of braking resistor by structure changes: a) 28S/0.5T; b) 28S/0.6T; c) 30S/0.5T and d) 30S/0.6T

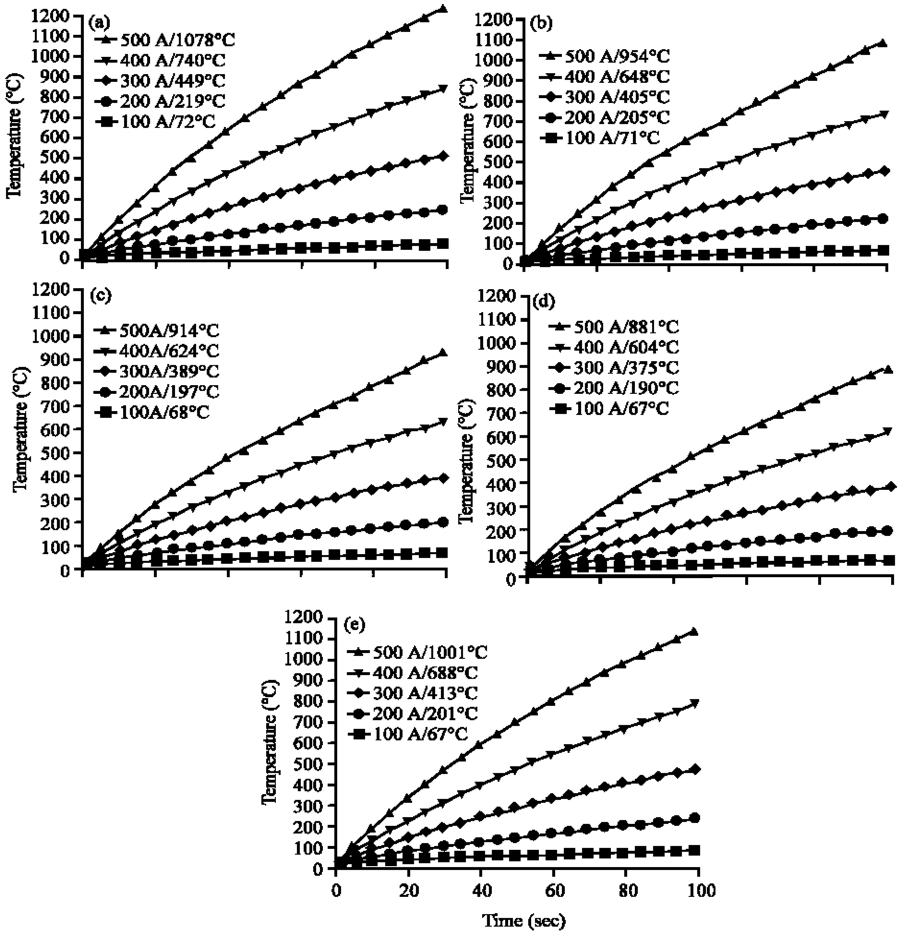

Fig. 5: Temperature rise curves by input current: a) Nikrotahl 70 (28S/0.5T); b) Kanthal A-1/APM (28S/0.6T); c) Kanthal AF (28S/0.6T); d) Kanthal D (28S/0.6T) and e) Nikrothal 80 (30S/0.5T)

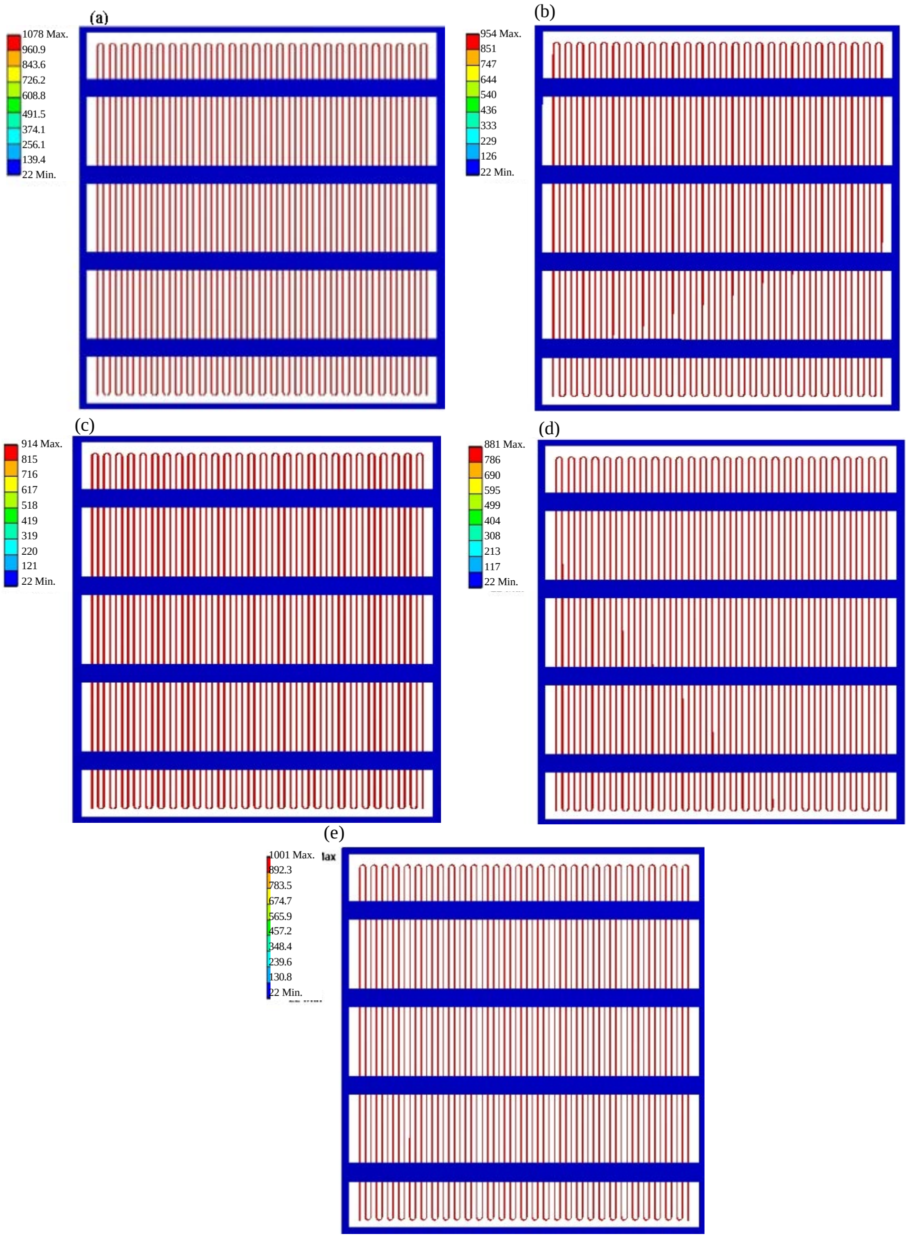

Fig. 6: Thermal distribution map (500 A): a) Nikrotahl 70 (28S/0.5T); b) Kanthal A-1/APM (29S/0.6T); c) Kanthal AF (28S/0.6T); d) Kanthal D (28S/0.6T) and e) Nikrothal 80 (30S/0.5T)

Table 3: Temperature rise results by input current

Items	100 A (°C)	200 A (°C)	300 A (°C)	400 A (°C)	500 A (°C)
Nikrothal 70(28S/0.5T)	72	219	449	740	1078
Kanthal A-1/APM(28S/0.6T)	71	205	405	648	954
Kanthal AF(28S/0.6T)	68	197	389	624	914
Kanthal D(28S/0.6T)	67	190	375	604	881
Nikrotha 80(30S/0.5T)	67	201	413	688	1001

and Table 3 shows the results of the thermal analysis. As shown in Table 3, the maximum temperature when 500 (A) was applied was 1078°C for Nikrothal 70 (28S/0.5T), 954°C for Kanthal A-1/APM (28S/0.6T), 914°C for Kanthal AF (28S/0.6T), 881°C for Kanthal D (28S/0.6T) and 1001°C for Nikrothal 80 (30S/0.5T). Therefore, it was confirmed that Kanthal D of the 28S/0.6T Model had the most excellent temperature rise characteristics for the input current.

CONCLUSION

A braking resistor with the optimal structure and material was proposed in this study to improve the temperature rise characteristics of the braking resistor for high-speed trains. It was investigated whether the resistance of the braking resistor met the design criteria through the structural changes of 28S/0.5T, 28S/0.6T, 30S/0.5T and 30S/0.6T and the material changes of kanthal and nikrothal. Thermal analysis was conducted using the proposed braking resistor. As a result it was confirmed that the kanthal D material of the 28S/0.6T Model had the most excellent temperature rise characteristics for the input current. The results of this study will be used to predict the temperature rise according to the structure and material of the braking resistor for high-speed trains.

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