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Synopsis :
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Rotary Furnace for Silicon Steels*

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A new type of coil annealing furnace, No. 1 and No. 2, for silicon steel production started operation, in October 1979 and September 1983 respectively, at Hanshin Works of Kawasaki Steel Corp. It helps save both time and money substantially and contributes significantly to quality improvement. This furnace is a rotary furnace equipped with muffles. The annealing temperature is 1 200°C and a pure hydrogen gas is used to get a good glass film and purification. Hydrogen gas which has leaked from the muffles into the heating zone is burned in the furnace with excess air, and the hydrogen gas which has leaked from the muffles into the cooling zone is diluted with air and made incombustible. The new-type No. 1 furnace saves 20% energy compared with the conventional batch type furnace and also shortens the cycle time by 30%. Furthermore, 50% energy saving is achieved in No. 2 furnace. Coil annealing is a critically important process in the manufacture of grain-oriented silicon steels. By using this new equipment, the production system and operation technology have been successfully established for producing silicon steels with high productivity at lower cost.

1 Introduction

The final annealing process for coil annealing is one of the most important processes in the manufacture of grain-oriented silicon steel sheets used in the cores of transformers, power generators and other electrical equipment. This process has the following purposes:

(1) Development of (110)[001] texture generally known as "Goss texture" in the secondary recrystallization.
(2) Formation of a glass film ($2MgO\cdot SiO_2$) with good adhesion.
(3) Purification of steel strip.

To achieve the above-mentioned purposes, it is necessary to perform high-temperature annealing (at more than 1 100°C) using atmospheric gases (H_2 and N_2) and to rigidly control the annealing temperature and the gases.

Because of the relatively lengthy annealing cycle of the above process, coil annealing has so far been performed by the batch annealing furnace.

Under this method, however, many handlings and complicated operations were required for transporting coils, and setting and removing of muffles, and raising furnace temperatures, as well as for changing the atmospheric gas. Therefore, much labor was necessary and operation control during annealing (control of the annealing pattern, and the atmospheric gas supply, etc.) was complex, with the result that quality varied widely. Furthermore, this method had the disadvantage in that the loss of regenerative heat is great due to the repetition of heating and cooling, resulting in high annealing costs. To remedy these drawbacks of the batch annealing process, Kawasaki Steel started the annealing operation using a continuous annealing furnace for the first time. Effects obtained by this continuous annealing furnace are summarized as follows:

(1) Decrease in the loss of regenerative heat and in radiation heat.
(2) Stable product quality by the automatized control of temperature and atmospheric gas.
(3) Labor-saving by process continuation and automation.
(4) Increase in productivity by reducing the annealing cycle (the cooling time).
(5) Improvement in working environment.

The No. 1 furnace was started in October 1979 after about one year of development stage and has been operating smoothly. Thereafter, the No. 2 furnace larger than the No. 1 was brought into operation in September 1983.

This Kawasaki Steel type rotary annealing furnace for silicon steels is called Kawasaki Silicon Steel Rotary Furnace (KSR furnace).

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** Hanshin Works

2 Equipment Specifications of Nos. 1 and 2 KSR Furnaces

2.1 Main Specifications

The main specifications of the Nos. 1 and 2 KSR furnaces are shown below:

Material treated	: Grain-oriented silicon steel
Coil thickness	: 0.2–0.35 mm
Coil width	: 600–1 200 mm
I.D. of coil	: 510 mm
Max. O.D. of coil	: 2 000 mm
Coil weight	: 10–20 t
Max. furnace temperature	: 1 200°C
Atmospheric gas	: H_2 and N_2
Cap. of No. 1 furnace	: 4 000 t/month
Cap. of No. 2 furnace	: 8 000 t/month

2.2 Equipment Makeup

Tables 1 and **2** give the equipment specifications of the Nos. 1 and 2 KSR furnaces, respectively. **Fig. 1** is a schematic drawing showing the outline of the No. 1 KSR furnace. **Figures 2** to **5** schematically show the sections of the heating and cooling zones. **Photo 1** shows a general view of the No. 1 KSR furnace.

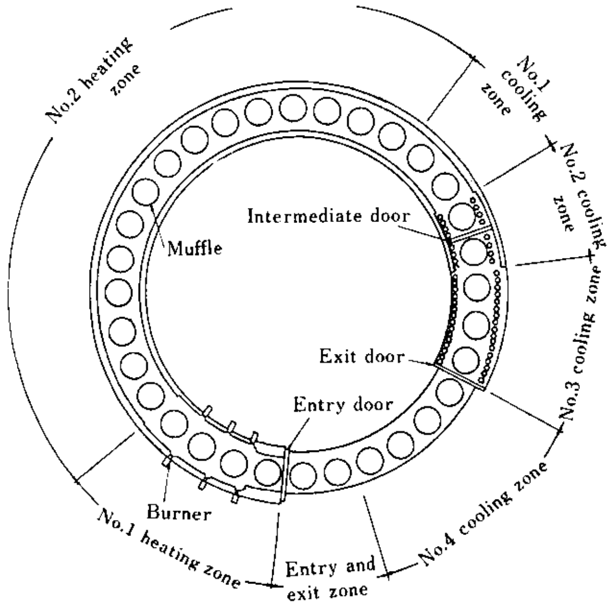

Fig. 1 Schematic drawing of KSR-1 furnace

Table 1 Specifications of KSR-1 furnace

Equipment	Type of heating or cooling	Capacity	Furnace length	Insulator
No. 1 heating zone	Kerosene direct burner	750 000 kcal/h	4 stacks	Brick
No. 2 heating zone	Electric heater	175 kW/stack	15 stacks	Ceramic fiber
No. 1 cooling zone	Furnace cooling	—	2 stacks	Ceramic fiber
No. 2 cooling zone	Air cooling tube	3 000 m^3/h (blower)	2 stacks	Ceramic fiber
No. 3 cooling zone	Water cooling tube	60 m^3/h	3 stacks	Ceramic fiber
No. 4 cooling zone	Top edge cooling fan	200 m^3/min·stack	4 stacks	—
Entry and exit zone	Top edge cooling fan	200 m^3/min·stack	2 stacks	—

Table 2 Specifications of KSR-2 furnace

Equipment	Type of heating or cooling	Capacity	Furnace length	Insulator
Pre-heating zone	–	–	8 stacks	Ceramic fiber
No. 1 heating zone	Butane direct burner	300 000kcal/m·stack	6 stacks	Ceramic fiber
No. 2 heating zone	Butane direct burner	300 000kcal/m·stack	12 stacks	Brick
No. 1 cooling zone	Furnace cooling	–	2 stacks	Ceramic fiber
No. 2 cooling zone	Air cooling tube	8 100m^3/h(blower)	12 stacks	Ceramic fiber
No. 3 cooling zone	Natural cooling	–	6 stacks	–
Entry and exit zone	Natural cooling	–	2 stacks	–

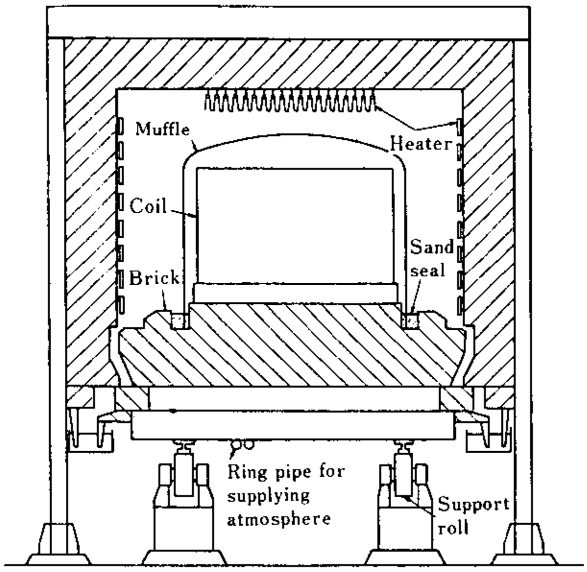

Fig. 2 Sectional view of No. 2 heating zone of KSR-1 furnace

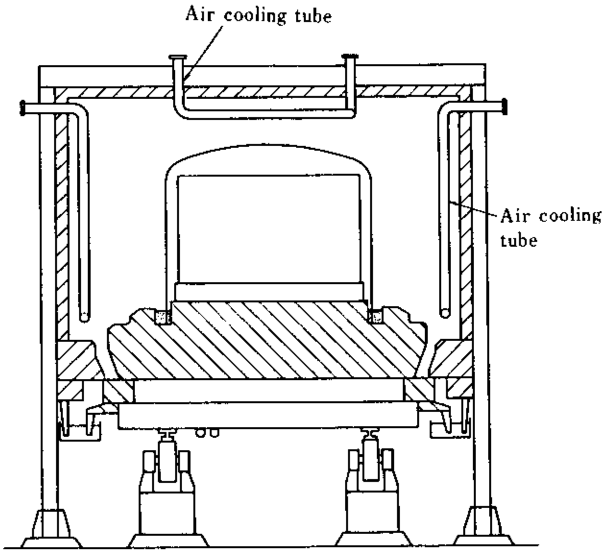

Fig. 3 Sectional view of No. 2 cooling zone of KSR-1 furnace

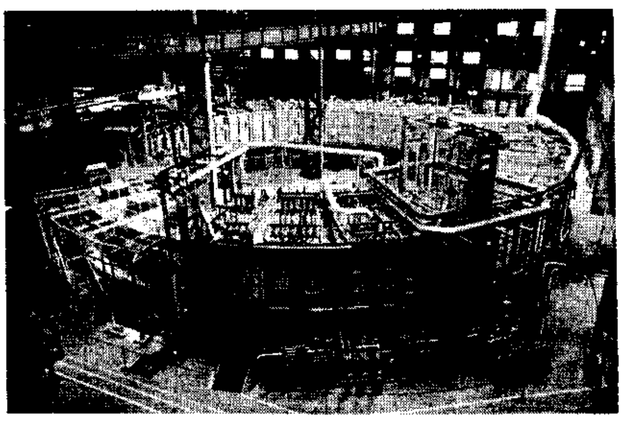

Photo 1 General view of KSR-1 furnace

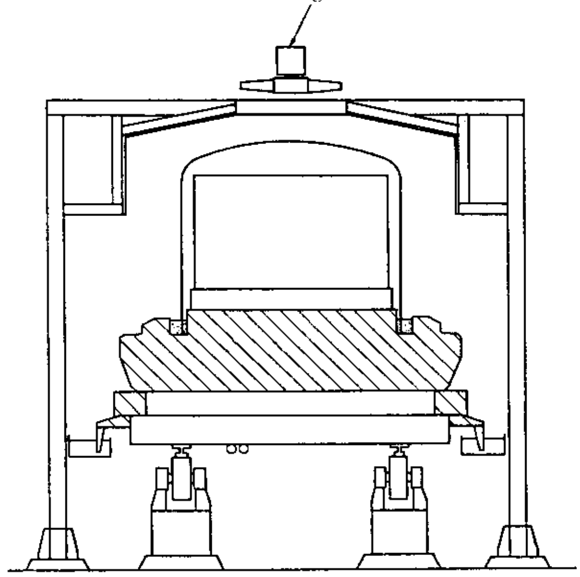

Fig. 4 Sectional view of No. 4 cooling zone of KSR-1 furnace

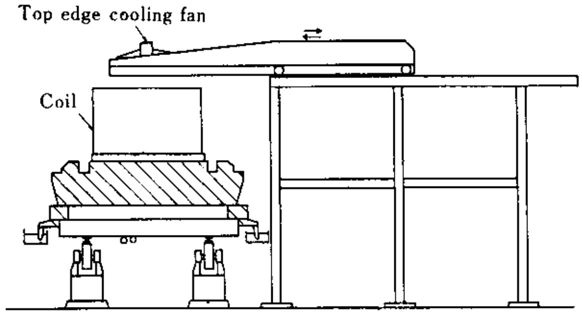

Fig. 5 Entry and exit zone of KSR-1 furnace

3 Features of KSR Furnace

The basic concept for the development of the KSR furnace, reasons for deciding on the furnace type, and the concrete measures adopted are described in the following by referring to the No. 1 furnace because the Nos. 1 and 2 furnaces are basically the same except the heat source.

3.1 Furnace Type

A land space left for a new furnace to be constructed was among rows of buildings, leaving not even 100 m in straight length, while it was necessary to design the furnace large enough in capacity and long enough. Therefore, the circular rotary-hearth type of simple construction was adopted after a comparison with the straight type.

3.2 Measures against Hydrogen Gas Explosion

In annealing with muffles, the atmospheric gas passed into the muffles leaks from the muffle skirts and fills the furnace. A 100% H_2 atmospheric gas is used in this annealing process for the production of silicon steel sheets. Therefore, this hydrogen gas may react abruptly with air and may explode if air enters the furnace during annealing or during the charging and discharging of coils. To avoid this danger in batch type furnaces, the air in the muffles and furnace is purged with nitrogen gas when heating is started after coil charging. Nitrogen gas is replaced with hydrogen gas during heating. When cooling is started and a certain temperature is reached, the hydrogen gas in the furnace is purged with nitrogen gas and coils are discharged after that. As an example (in a tunnel furnace[1, 2]), a special chamber is installed each at the entry and exit of the continuous furnace. These chambers are purged with nitrogen gas before the charging and discharging of coils.

To prevent air infiltration, the furnace must be of a complete gas-tight construction. Special consideration must be given to the gas sealing of equipment passing through the furnace wall from the outside, such as power supply, thermocouple and atmospheric gas supply pipe. The seal construction is complex and maintenance requires much labor.

To avoid this complicated furnace construction was one of the issues in the development of this furnace. Various examinations and experiments were made. As a result, two methods were adopted; one for the heating zone where the furnace temperature is high, and the other for the cooling zone where the furnace temperature is low. In the former method, the hydrogen gas leaking from the muffle skirts is caused to burn rapidly at the muffle skirts by forcing the outside air into the furnace, and in the latter, the hydrogen gas is diluted to below the explosion limit by feeding a large volume of air. In both cases, a stable oxidizing atmosphere is generated in the furnace and it is unnecessary to prevent the air infiltration into the furnace. Thus the furnace construction is very simple. The KSR furnace is quite different from other continuous furnaces[1] in this point. However, it has become necessary to protect metallic parts in the furnace, such as muffles and heaters, from being subjected to high temperatures under an oxidizing atmosphere. In this KSR furnace, heat resistant stainless steels such as SUS 310 are used in the muffles and Fe-Cr-Al bands are used as the heaters of electric resistance type.

3.3 Atmospheric Gas Supplying System

The atmospheric gas supplying system shown in **Fig. 6** was developed to continuously supply an atmospheric gas to each muffle on the hearth that rotates intermittently. This system is composed of two supply devices, the fixed type and the traveling type, for one type of gas. The operation of this system in one cycle is shown below:

(1) During the standstill of the hearth, the gas is supplied to the common pipe under the rotary hearth from the fixed type supply device, and is distributed to each muffle.

(2) When the hearth rotates one pitch, the coupler of the traveling type connector is attached before start and the coupler of the fixed type connector is detached after that. Therefore, the gas is supplied to the common pipe from the traveling type supply

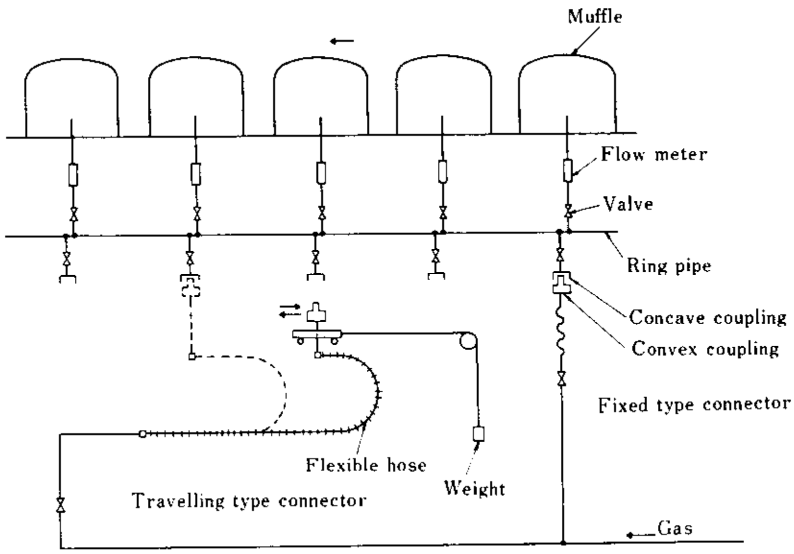

Fig. 6 Atmospheric gas supplying system of KSR furnace

device.

(3) When the one-pitch rotation is completed, the coupler of the fixed type connector is attached, the coupler of the traveling type connector is detached, and only the convex coupling returns to the standby position.

The concave couplings installed in the common pipe under the hearth are all arranged at the same pitch as in the muffle, and this pitch is designed to correspond to the fixed side convex couplings and those in the standby positions of the traveling side convex couplings.

The type of gas used during annealing is more than one, and each gas has its own supplying system. A gas to each muffle is selected by operating the stop valve.

3.4 Features of No. 2 Furnace

Photo 2 shows a general view of the No. 2 KSR furnace. The features of this furnace are enumerated below:

(1) LPG is used as the heat source for all of the heating and soaking zones.

(2) The arrangement of the burners is contrived so as to assure uniform heating.

(3) The reduction in losses of regenerative heat in the furnace hearth is aimed at by saving the weight of hearth refractories.

(4) The sensible heat of coils is recovered in the cooling zone as the heat for preheating the combustion air.

4 Results of Operation

Effects obtained by the KSR furnace are described in the following by comparing with the conventional batch type furnaces operated by Kawasaki Steel.

4.1 Energy-Saving

The unit energy consumption of the No. 1 KSR furnace is about 80% of that of the conventional batch type furnace owing to the reduction in the regenerative heat loss accomplished mainly by the continuous process, strengthening of waste heat recovery and thermal insulation, and a use of larger coils than before.

In the No. 2 furnace, a further energy-saving was achieved by the heat recovery in the cooling zone, thus reducing energy consumption to 50% of the conventional level.

4.2 Stable Quality

In the manual operation of the conventional furnace, variations in temperature, gas flow rate, etc. were noticeable, making quality unstable. In the KSR furnace, operation is standardized by mechanization and automation and therefore, stable product quality is obtained. **Figure. 7** shows an example of improvement in magnetic properties for lesser variations.

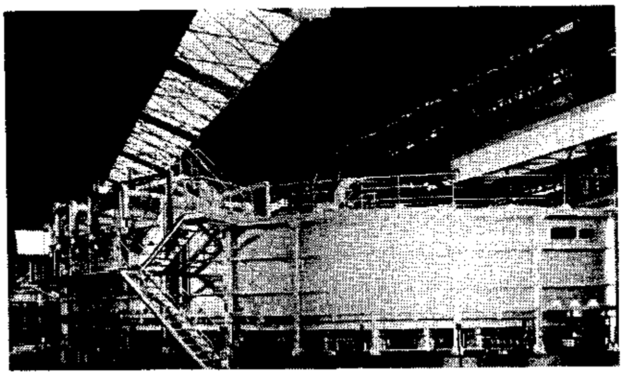

Photo 2 General view of KSR-2 furnace

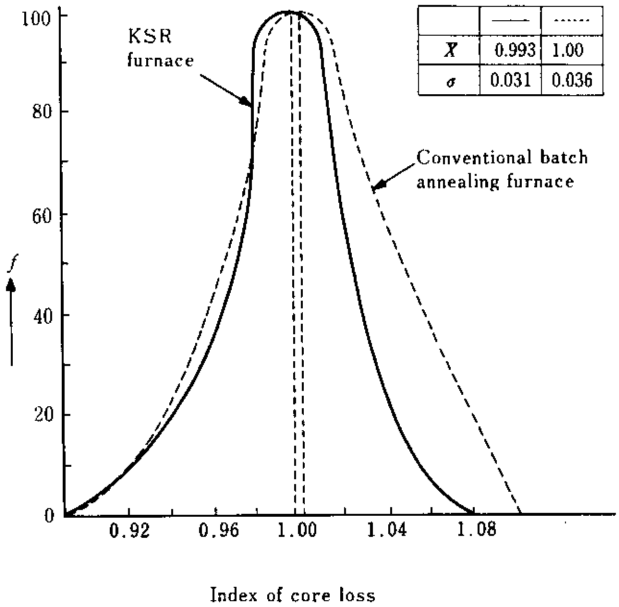

Fig. 7 Magnetic properties of grain oriented silicon steel (thickness 0.35 mm)

4.3 Labor-saving

Streamlining was performed by the continuous process and automation. The installation of the No. 1 KSR furnace resulted in a 20% labor-saving. Furthermore, a 50% labor-saving was achieved in the No. 2 furnace.

4.4 Improvement in Productivity

It is impossible to shorten the heating time and soaking time because they are part of fixed conditions for obtaining magnetic properties. Therefore, productivity was improved by reducing the cooling time.

In the batch annealing furnace, the adoption of cooling devices, i.e., cooling fan, water cooling pipe, air cooling pipe, was almost impossible because the maximum temperature reached as high as 1200°C during heating, and therefore furnace cooling was adopted.

Hence, the shortening of the cooling time in such furnace was unable without cutting down the weight of refractories and increasing a radiation heat loss.

In the KSR furnace, the heating device and cooling device are separate. Therefore, the cooling rate can be freely controlled and the cooling time was substantially able to be shortened. As a result, the time required for cooling was reduced to about 50% of the time conventionally required and the overall annealing cycle was shortened to about 70%.

4.5 Other Effects

Equipment was integrated. As a result, space was effectively utilized and process control became easy.

Furthermore, the concentrated exhaust of furnace exhaust gas improved the working environment substantially.

5 Conclusions

The final annealing process in the manufacture of grain-oriented silicon steel sheets was improved by replacing the batch type furnace with a continuous furnace, and the following results were obtained:

		No. 1 furnace	No. 2 furnace
Reduction in energy consumption	:	20%	50%
Shortening of the annealing cycle	:	30%	30%
Labor-saving	:	20%	50%

This continuous furnace has the following features:

(1) Although annealing is performed using a 100% H_2 atmosphere, safety can be ensured by a method for keeping an oxidizing atmosphere in the furnace. Therefore, it is unnecessary to make the furnace gas-tight.

(2) The atmospheric gas can be continuously fed to the muffles also during the rotation of the hearth.

(3) Coil charging and discharging operations can be carried out in the same place, since the furnace is circular.

The authors would like to extend their sincere thanks to Chugai Ro Co., Ltd. and the persons concerned for their splendid cooperation made available in the development of the KSR furnace beginning with the research stage.

References

1) Allegheny Ludlum Steel Corp.: US Patent No. 3606288
2) Allegheny Ludlum Steel Corp.: US Patent No. 3756868