

Development of Energy-Saving High-Performance Continuous Carburizing Furnace

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Koyo Thermo Systems Co., Ltd. and JTEKT Corporation have jointly developed an energy-saving high-performance continuous carburizing furnace with the aim of achieving energy conservation and high functionality. To reduce energy consumption, measures were taken to reduce the amount of heat energy dispersed from various furnace areas (frame surface, inner passageways). To improve functionality, variations in in-furnace temperature and gas uniformity were reduced. This was accomplished by optimizing the inner structure utilizing a 3D fluid simulator to improve flow speed within the furnace and by adopting a new temperature control method (multi-control). By these measures, the developed furnace exhibits advantages over conventional furnaces in energy costs, surface carbon concentration consistency, and heat treatment cycle time.

Key Words: carburizing, continuous carburizing furnace, energy saving, productivity improvement, high performance

1. Introduction

Recently worldwide attention has been attracted to environmental energy issues. The development of China, India, and other emerging countries and global warming were the main themes of the recent global energy summit. Under these circumstances, JTEKT's and other manufacturers' mission is to develop clean energy alternatives to conventional fossil fuels and to reduce energy consumption.

To further cope with these circumstances, JTEKT has been exploring alternative approaches in all manufacturing processes. Among these, heat treatment carburizing processes account for a large portion of energy consumption. The carburizing process is a general surface-hardening heat treatment method. It is also one of the most mature heat treatment processes and is commonly used domestically and globally. However, carburizing has significant potential for improvement due to the large energy consumption associated with long cycle time high-temperature heat treatment.

This report introduces an energy-saving high-performance continuous carburizing furnace which Koyo Thermo Systems and JTEKT have jointly developed with the aim of realizing substantial energy savings, high functionality and reduction of heat treatment cycle time.

2. Overview of Developed Furnace

The energy consumption in a continuous type gas carburizing furnace, the most common type used in carburizing heat treatment, is the largest energy saving or reduction of cycle time opportunity for improvement. We have developed an energy-saving and high-performance continuous gas carburizing furnace as an improvement over this continuous gas carburizing furnace. **Figure 1, 2** and **Table 3** show the appearance of the developed furnace, its general construction and basic specifications respectively.



Fig. 1 Appearance of energy-saving high-performance continuous carburizing furnace

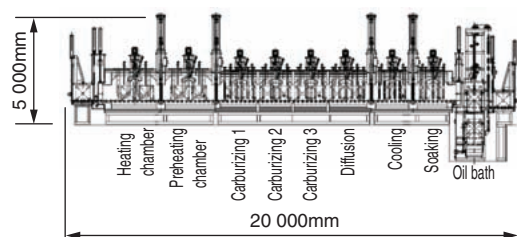


Fig. 2 Outline of energy-saving high-performance continuous carburizing furnace

Table 1 Basic specifications

Effective dimensions	W 610mm × L 8 540mm × H 610mm	
Heating source	Heating chamber	W-type regeneration gas burner
	Carburizing chamber	Electric resistance heating (Max. use temperature 980°C)
Conveyance type	Rollers	
Max. mass of charge	250kg/Tray	

3. Description of Development

3.1 Energy Saving

Energy consumed in the carburizing treatment is classified into: 1 - furnace body radiation heat (energy consumed by radiation heat losses from the furnace to its surroundings and initial heating of the heat treatment furnace structure); 2 - energy for heating product, jigs and atmosphere gas up to carburizing temperature; and 3 - heating of the atmosphere gas for protecting product from the air. **Figure 3** shows each energy consumption ratio in a conventional furnace.

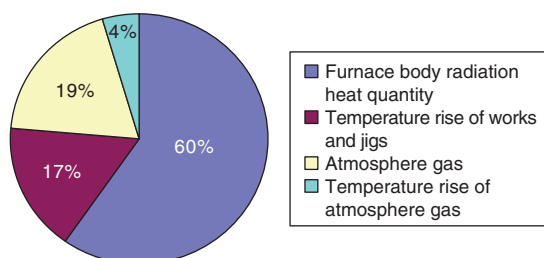


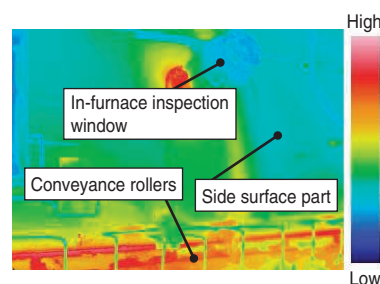
Fig. 3 Energy consumption ratio

Among them, the energy consumption ratio of furnace body radiation heat is the largest, 60% of the total. Furnace body radiation heat does not contribute to carburizing of product at all, so it is wasted energy. Reducing this energy is key opportunity.

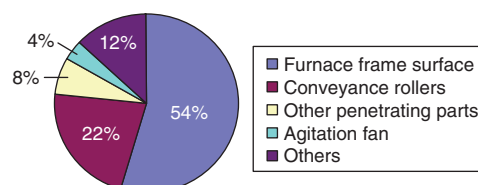
3.1.1 Investigation of Present State and Choice of Study Direction

First, furnace body radiation heat of the developed

furnace and a conventional furnace of the same type was investigated to understand the present state. Power consumption and gas consumption during furnace operation were measured, and the total energy consumption was calculated. The surface temperature of each part of the furnace body was measured with a contact thermometer and a radiation thermometer to calculate the furnace body radiation heat quantity of each furnace part (**Fig. 4**).



(a) Measurement result of radiation temperature (at furnace body-side surface, for example)



(b) Details of furnace body radiation heat quantity

Fig. 4 Temperature measurement result of conventional furnace body

This result shows that radiation heat from the furnace frame surface and conveyance rollers are particularly large. Therefore we have taken measures focusing on these parts.

3.1.2 Countermeasures

Countermeasures for reducing the radiation heat quantity from the furnace frame surface and the conveyance rollers are introduced as follows;

1) Furnace frame surface

Reduction of the radiation heat quantity from the furnace frame surface requires reduction of radiation heat quantity passing through in-furnace insulation layers. **Figure 5** shows the comparison of heat insulation structures of the developed furnace and the conventional one.

The key feature of the heat insulation structure of the developed furnace is the adoption of Moldertherm (ceramic fiber) block produced in Koyo Thermo Systems Co., Ltd. Moldertherm has high temperature capability, light weight, low thermal capacitance, and improved insulating properties (low thermal conductivity). The addition of Moldertherm reduced the radiation heat

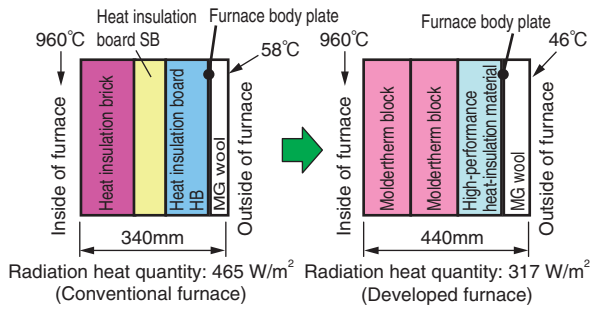


Fig. 5 Comparison of heat insulation structure and radiation heat quantity between developed and conventional furnaces

quantity 30% as compared with the conventional block structure. Additional design features were reviewed. One concept was reducing the number of studs used to affix the insulation materials to the interior furnace walls in order to minimize the heat conduction to the furnace exterior surface. In addition to such reviews, energy loss through the furnace frame surface was reduced by the addition of conventionally used MG wool heat insulation material.

2) Conveyance rollers

The second largest contributor to radiation heat energy losses is the conveyance roller (Fig. 4). In the case of the conveyance rollers, the problem is heat radiation to the outside through the conveyance roller shafts. To address this, the structure of the developed furnace has been designed to prevent heat radiation through shaft ends by selecting materials with lower thermal conductivity than those used in conventional furnaces. Additionally, insulation around the conveyance roller shaft bearing was enhanced.

Figure 6 shows the developed structure of conveyance rollers. Figure 7 shows thermal analysis results which illustrate the improvement resulting from these changes.

This structure yields lower shaft end temperature in the developed furnace as compared to a conventional furnace.

3. 1. 3 Effect of Furnace Body Heat Radiation Reduction

The previous section shows an example of measures taken to reduce furnace body radiation heat. We have also implemented additional countermeasures including changing cooling of in-furnace agitation fan bearings (air cooled type) and insulation enhancement of in-furnace passageways.

Figure 8 shows the results obtained from these reduction measures.

The developed furnace demonstrated a substantial energy saving: 34% reduction of the furnace body radiation heat losses and 37% reduction of CO₂ emissions.

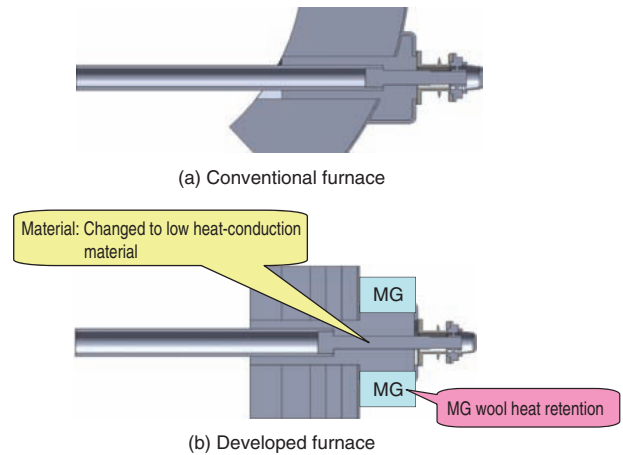


Fig. 6 Summary of heat insulation measures applied to conveyance rollers in energy-saving high-performance continuous carburizing furnace

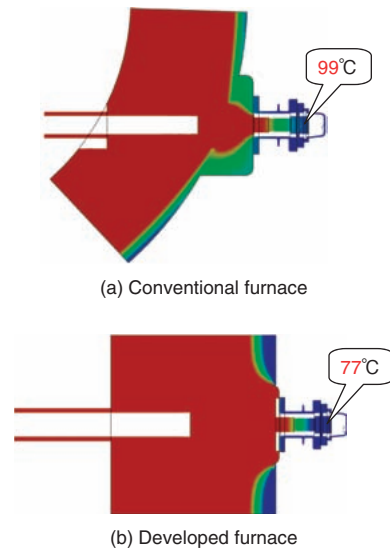


Fig. 7 Comparison of temperature distribution around conveyance roller shaft ends by thermal analysis

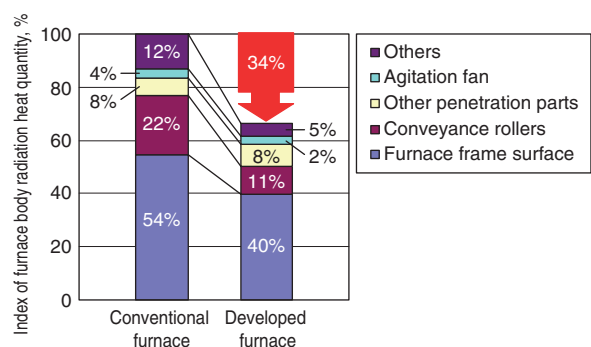


Fig. 8 Comparison of furnace body radiation heat losses between energy-saving high-performance continuous carburizing furnace and conventional furnace

3. 2 Reduction of Heat Treatment Cycle Time

JTEKT has investigated various approaches to reduce the heat treatment cycle time. We have already obtained substantial improvements in high temperature carburizing furnaces currently being used in mass production and in high-speed carburizing that use high-concentration CO gas. These improvements have contributed to heat treatment cycle time reduction and cost reduction. Furthermore, we have focused on variations in temperature and the gas concentration uniformity in the furnace. The carburizing process is generally a batch process in which product mounted in jigs is treated as a lot. Variations in temperature and gas concentration in a furnace for each lot influence heat treatment attributes such as surface carbon concentration and effective case depth. Consequently, if variations in temperature and gas concentration in a furnace are made smaller, on-target effective case depth can be set and heat treatment cycle time can be reduced (Fig. 9).

3. 2. 1 Analysis of In-Furnace Structure

To reduce variation of in-furnace temperature and gas concentration uniformity, increasing the gas flow velocity and homogenizing the gas concentration must be addressed. Three-dimensional fluid simulation was

applied to evaluate conventional countermeasures like increasing the speed of the in-furnace agitation fan, and to determine the optimum in-furnace structure. Figure 10 shows the gas flow velocity distribution comparison of the developed furnace and the conventional one. The analysis shows that the developed furnace circulates the in-furnace gas more actively than the conventional one.

Further results obtained from the three-dimensional analysis are:

- (1) Gas flow in the square shape furnace frame is better than that in the round shape one.
- (2) Gas flow is interrupted when parts such as a skid rail or chain block are located on furnace hearth.
- (3) Attachment of current plate to the furnace ceiling greatly increases the in-furnace gas flow velocity.
- (4) Selection of an optimum furnace shape and utilizing a larger size and higher rotational speed in-furnace agitation fan are effective for increasing gas flow velocity.

The furnace gas flow velocity of the developed furnace was measured to validate these results (Fig. 11).

Figure 11 also shows the result measured with the same type conventional furnace (with different shape furnace frame and fan), for reference. Actual measurement results confirm that with the same rotational speed, the average

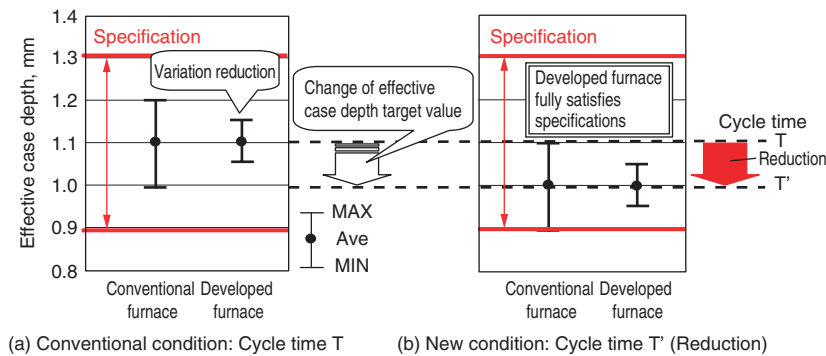


Fig. 9 Reduction of heat treatment cycle time by changing effective case depth target

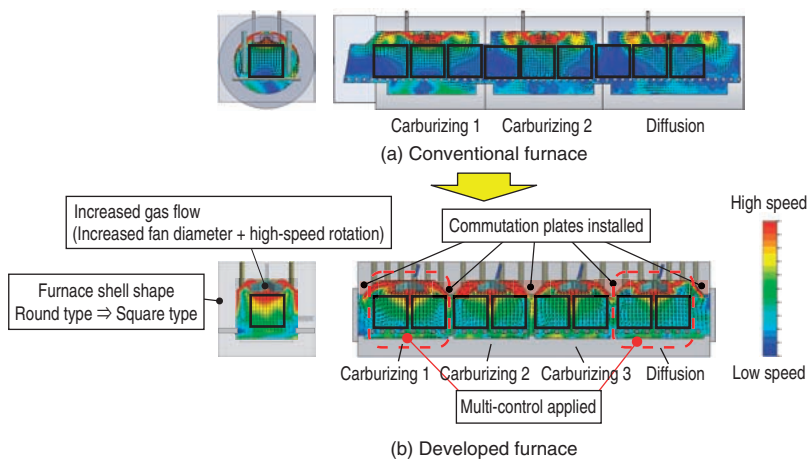


Fig. 10 Three dimensional fluid analysis of gas flow velocity distribution in each furnace

gas flow velocity of the developed furnace is increased to twice that of the conventional furnace, and when the fan rotational speed is increased to 1 000 min⁻¹, the velocity is increased four times relative to the conventional furnace.

3. 2. 2 Improvement in Temperature Control

In the previous section, gas flow has been improved through optimization of in-furnace structure. Then, temperature control has been also studied to further reduce temperature variations. In these continuous type gas carburizing furnaces, the existence of large temperature variations between adjacent zones (preheating chamber / carburizing 1, diffusion chamber / cooling chamber and cooling chamber / soaking chamber) has been already confirmed. The addition of doors between zones has minimized zone-to-zone interference, however this has not been sufficient for reducing the temperature variations. A multi-control system has been developed and applied to the developed furnace that uses two systems to control each chamber. This is an improvement over conventional control systems which use a single system to control each chamber. This system is applied to the carburizing 1 chamber, the diffusion chamber and the soaking chamber in the developed furnace, where zone temperature variations are likely to occur. **Figure 12**

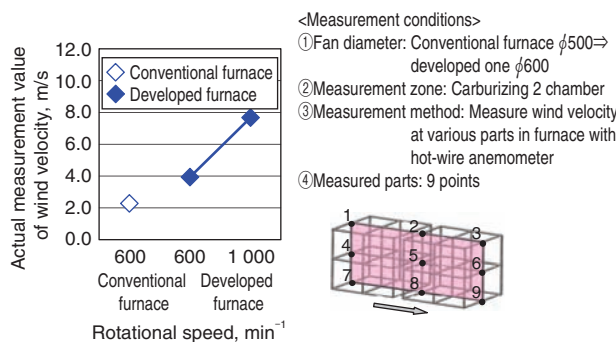


Fig. 11 Average wind velocity when rotational speed of in-furnace agitation fan is changed (In vacant furnace)

shows the results which validate that temperature control is significantly different between the multi-control and the conventional control.

Temperatures were measured at nine locations for one lot to compare the temperature variations (R). It has been confirmed that, in any treatment chamber, the multi-control can reduce the temperature variations, though the effect for each chamber is different.

3. 2. 3 Result of Temperature Distribution Measurement in Furnace

The optimum in-furnace structure and the temperature control, which were obtained from 3. 2. 1 and 3. 2. 2, have been adopted for the newly developed furnace, and the in-furnace temperature distribution has been measured in a working furnace. The result is shown in **Fig. 13**.

Figure 13 shows the comparison of the in-furnace temperature distribution from the carburizing 1 chamber to the diffusion chamber in the developed furnace with that in the conventional furnace. While maximum temperature variation in the carburizing chamber of the conventional furnace is ±6.5°C, the variation in the developed furnace is ±2.4°C, which confirms that variation has been reduced to less than half.

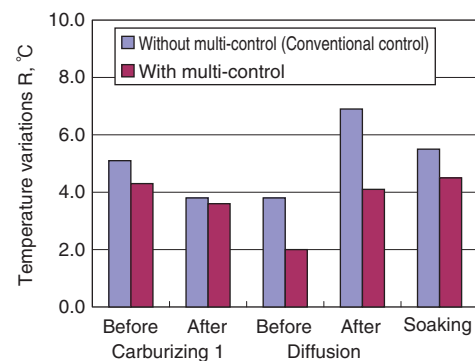


Fig. 12 Comparison of temperature variations at each zone between furnaces with and without temperature multi-control

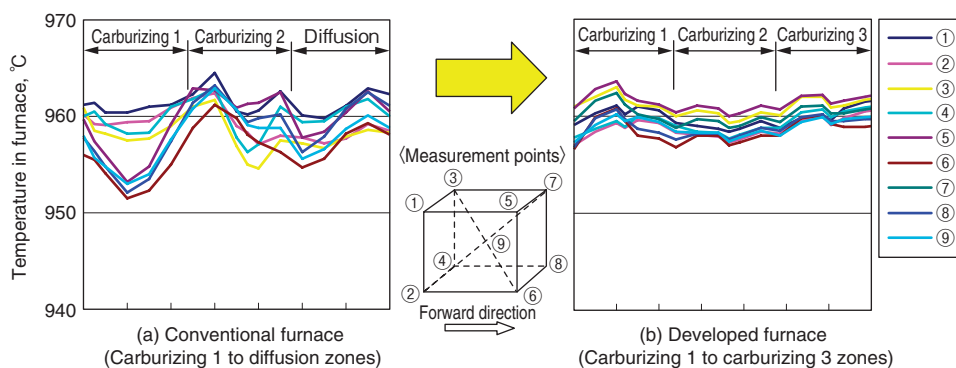


Fig. 13 Temperature distribution comparison at carburizing chamber between energy-saving high-performance continuous carburizing furnace and conventional one

4. Mass Production Effect with Developed Furnace

The developed furnace has already been put to use in mass-production and has demonstrated a 26% energy cost reduction compared with that of the conventional one (Fig. 14).

With respect to heat treatment quality, variation in surface carbon concentration is $\pm 0.10\%$ with the conventional furnace. With the developed furnace, the variation is $\pm 0.04\%$, a reduction of less than one half, comparable to the in-furnace temperature variation improvement. The variation of effective case depth is under evaluation. However, measurable variation reduction has been already obtained (Fig. 15). In addition, reduction of heat treatment cycle time of 5 to 10% can be achieved.

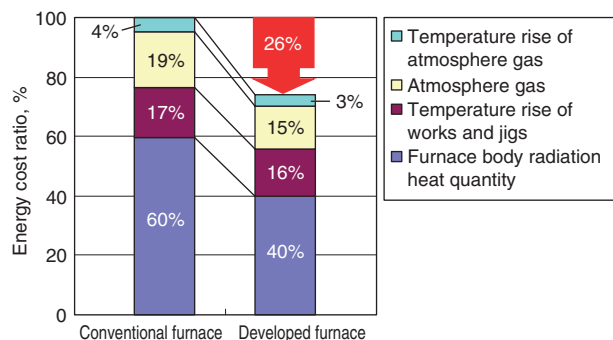


Fig. 14 Energy cost comparison between energy-saving high-performance continuous carburizing furnace and conventional one

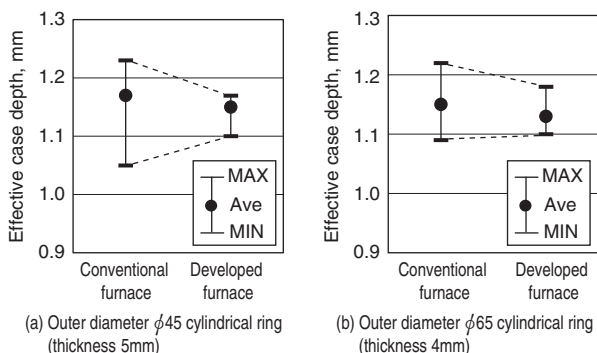


Fig. 15 Comparison of effective case depth variations between energy-saving high-performance continuous carburizing furnace and conventional one

A CO₂ monitor system (Fig. 16) has been introduced to confirm that these improvements are present in mass production operation.

This system monitors gas and power consumption of production equipment, and this data can be automatically converted to daily emissions for instantaneous visualization. It is expected that, by controlling the daily CO₂ emissions, this monitor system helps confirm effective operation and identify equipment problems.

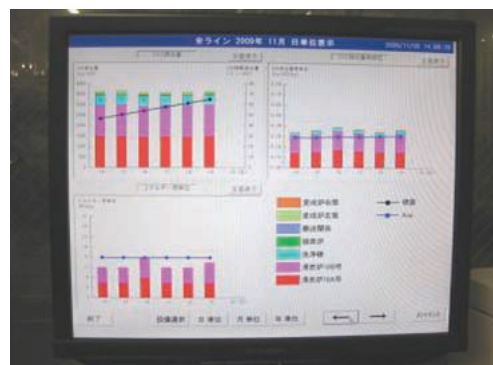


Fig. 16 CO₂ monitor system

5. Conclusion

This report demonstrates our approach to energy saving and productivity improvements. The energy-saving high-performance continuous carburizing furnace which Koyo Thermo Systems Co., Ltd. and JTEKT have jointly developed has been introduced. As described in the previous section, significant improvement has been obtained by introducing the developed furnace in actual mass production lines. We expect that the developed furnace will become the standard for continuous carburizing furnaces. The findings of this development project not only can be applied to conventional equipment but also can be the basis for further development of innovative equipment and process innovation. We will contribute to the protection of the global environment and improvement in heat treatment technology through application of these findings.

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