Development of Energy-saving One-piece-flow Induction Hardening Machine

A. MATSUDA T. TAKAMI

To achieve carbon neutrality by 2050, it is required to reduce CO_2 emission because JTEKT uses large amounts of energy. A lot of energy was wasted in the heat treatment process, especially in atmospheric gas furnaces. therefore, the countermeasures are urgently needed. Because the current heat treatment process is intensive, CO_2 emission from logistics in the pre- and post-processes was also an issue. Aiming to move away from atmospheric gas furnaces and reducing logistics processes, a one-piece-flow heat treatment process for ball bearings using induction heating has been developed.

Key Words: *CO_2 emissions carbon neutrality, energy conservation, one-piece-flow, induction heating*

1. Introduction

As global warming progresses, the government of Japan has set the high target of reducing CO_2 emissions by 46% from 2013 levels by 2030, working towards achieving carbon neutrality in 2050. At JTEKT, we have moved the year for achieving carbon neutrality forward from 2050 to 2035, and are aiming to achieve the target at an early stage (**Fig. 1**).

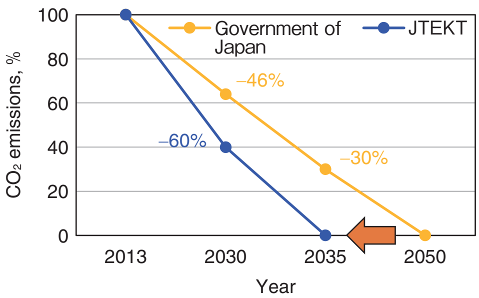


Fig. 1 CO_2 emission reduction targets

A breakdown of JTEKT CO_2 emissions shows that heat treatment accounts for 22% of emissions from manufacturing processes, and the production of bearings accounts for the largest percentage of JTEKT products that involve a heat treatment process (**Fig. 2**). With bearings, products with larger outer diameters mean a larger CO_2 emission intensity (**Fig. 3**). This report will introduce an initiative for reducing CO_2 in the heat treatment process, using large single ball bearings as a representative example.

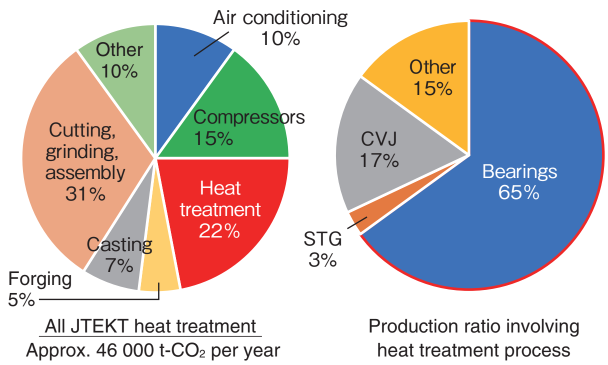


Fig. 2 CO_2 emissions at JTEKT domestic plants[1)]

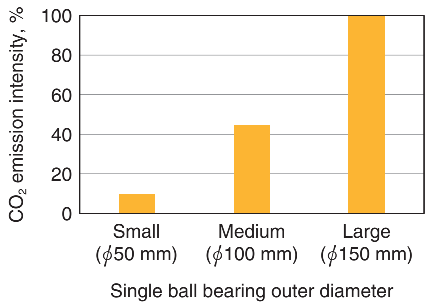


Fig. 3 Comparison of CO_2 emissions by bearing outer diameter

2. Development Objectives

The manufacturing process for large single ball bearings is shown in **Fig. 4**. At the heat treatment process, quenching to harden the workpiece and increases its strength, sizing to correct heat treatment deformation, and tempering to increase toughness are performed.

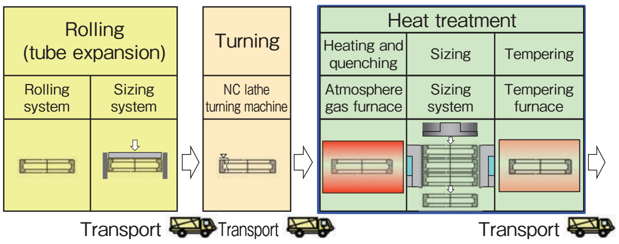


Fig. 4 Single ball bearing process flow

Conventionally, quenching is performed using an atmosphere gas furnace, and the energy used to heat and transport the workpiece is only around 20% of the total. The remaining 80% is discarded as waste, leading to higher CO_2 emissions (**Fig. 5**). Because an atmosphere gas furnace performs large-scale centralized production, CO_2 emissions produced in the logistics between the pre- and post-heat treatment processes are also an issue.

In order to reduce this energy, here we report on the development of a heat treatment that aims to transition away from the use of atmosphere gas furnaces, and also to eliminate logistics by synchronizing the lead time of the preceding process.

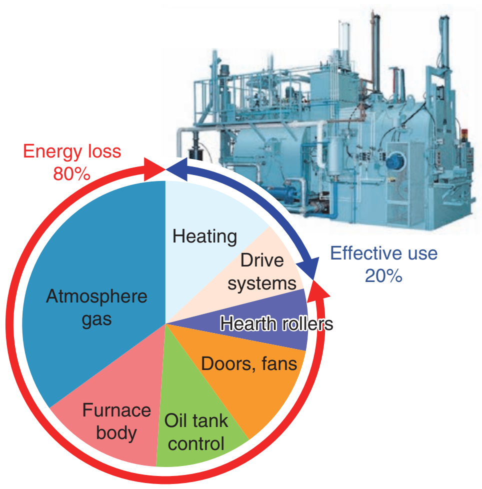


Fig. 5 Atmosphere gas furnace energy consumption[1)]

3. Technical Issues

3. 1 Transition Away from Atmosphere Gas Furnaces

Atmosphere gas furnaces are systems composed of a heat source that heats the workpiece to high temperature, and a system that supplies atmosphere gas to prevent decarburization of the workpiece surface. Because the workpiece is heated by indirect heating from the heat source via the atmosphere gas, the energy efficiency is poor, and the need for the atmosphere gas also produces a large energy loss. Therefore, when developing a heat treatment process, a change to induction heating, which can heat the workpiece directly, was considered in order to improve energy efficiency.

First, in order to coordinate with the lead time of the turning process that is extremely short compared to the heat treatment process, it is necessary to reduce the quenching heating time and increase the temperature. However, higher temperatures increase deformation of the workpiece after quenching, and there are concerns of a tradeoff with worsening dimensional accuracy after sizing. Therefore, in contrast with the conventional batch processing, a one-piece-flow heat treatment method was developed to increase dimensional accuracy by individually controlling the conditions. The manufacturing process developed here is shown in **Fig. 6**.

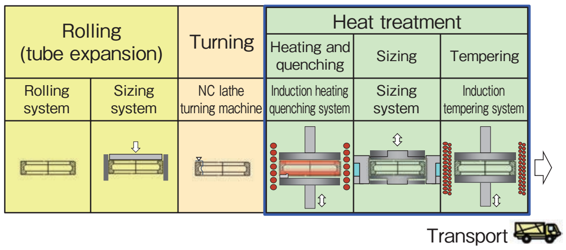


Fig. 6 Developing process flow

3. 2 Initiative for Shortening the Induction Heating Time

This section explains the approach to quenching temperature following a shortening of the time. As shown in **Fig. 7**, when the quenching temperature is raised too much, hardness decreases and the amount of retained austenite increases. It has been reported that the relationship between the time when carbides form a solid solution in austenite and the absolute temperature satisfies the Arrhenius diffusion equation. For this reason, a long heating time is set for atmosphere gas furnace quenching conditions which can satisfy the requirements for hardness and retained austenite.

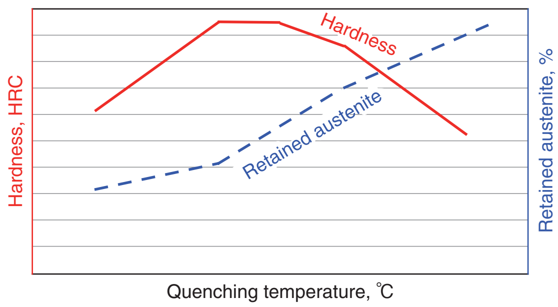


Fig. 7 Relationship of heating temperature hardness and retained austenite[2)]

Shortening the heating time and causing carbides to form a solid solution in austenite requires increasing the heating temperature. However, there are concerns that increasing the temperature will reduce hardness and increase the amount of retained austenite. Because the entire workpiece is quenched, consideration must also be given to the temperature difference between the surface and interior. For this purpose, it is important to create a heating coil and holding jig design and set conditions based on an understanding of the induction heating characteristics.

3. 3 Initiative for Change to One-piece-flow Sizing

Next, the sizing process that is performed after heat treatment is explained. Sizing is a manufacturing method which utilizes the transformation expansion that occurs during cooling after workpiece heating to reduce heat treatment deformation. As shown in **Fig. 8**, the workpiece is rapidly cooled from the austenitizing temperature in the atmosphere gas furnace. Cooling is stopped directly above the martensite transformation temperature (Ms point) and the workpiece is loaded into a die. The workpiece is cooled by heat transfer to the die as it passes the Ms point, utilizing the transformation expansion to improve dimensional accuracy as the workpiece conforms to the die.

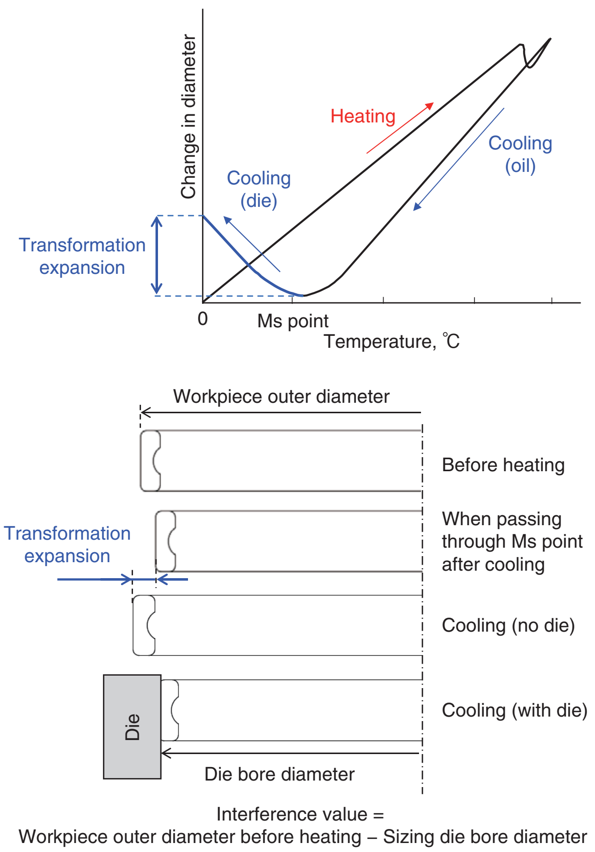


Fig. 8 Sizing process

Because conventional sizing is a batch treatment, it is easy to synchronize with the atmosphere gas furnace. However, with the change to one-piece-flow processing described above, synchronization with induction heating is necessary, and it is necessary to shorten the time in the same way as the heating system. With heat transfer to the workpiece only, there are concerns of insufficient cooling and temperature variation, and a mechanism for even cooling in a short time is necessary. It is also necessary to set the optimal die dimensions and interference value according to changes in the heating and sizing conditions.

4. Development Contents and Results

4. 1 Optimal Design of the Induction Coil

Figure 9 shoes the results from CAE analysis for uniform heating of the entire workpiece. By optimizing the coil gap and the number of coil winds, temperature uniformity was improved by 50% compared to before optimization.

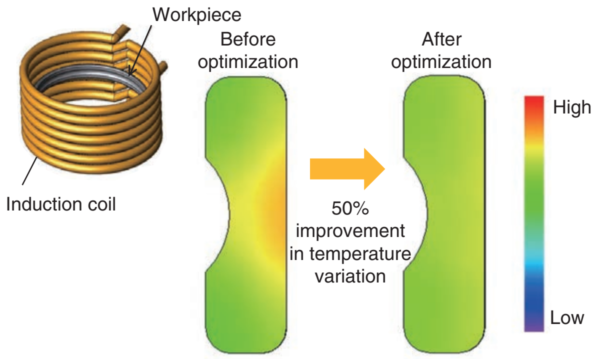


Fig. 9 CAE simulation result

4. 2 Optimization of Induction Heating Conditions

It is necessary to fasten the workpiece inside the induction coil during heating. Because parts that contact the holding jig cause localized variation in workpiece temperature, a material shape with low heat conductivity that is not affected by induction were selected (**Fig. 10**).

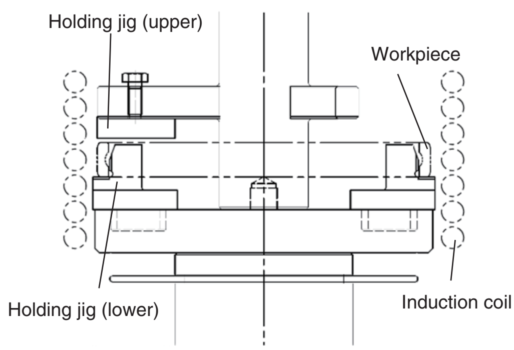


Fig. 10 Work holding jig

Figure 11 shows the evaluation results obtained using the optimized induction coil and holding jig with temperature variation countermeasures. A control range for treatment temperature was confirmed which satisfies the required quality for quenching hardness and retained austenite. As shown in **Fig. 12**, there is no difference in hardness, retained austenite, or internal microstructure between the conventional products and newly developed products, and it was confirmed that the heat treatment quality is the same.

This newly developed machine performs quenching in quenching oil in order to prevent heat treatment cracking at high temperatures and improve dimensional accuracy at the sizing following this process.

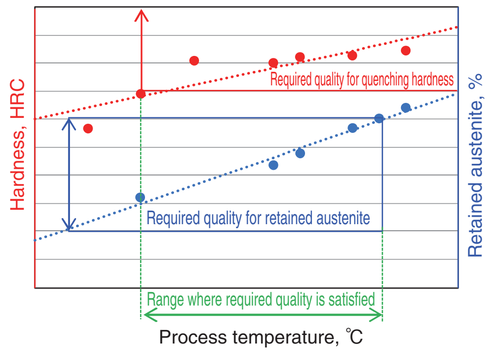


Fig. 11 Result of heating temperature hardness and retained austenite

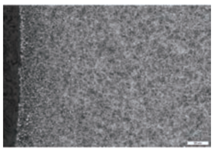
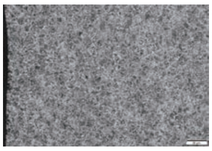
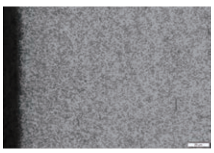
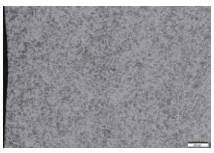
		Conventional product	Newly developed product
Hardness	Surface	○	○
	Interior	○	○
Retained austenite		○	○
Microstructure	Martensite		
		○	○
	Carbides		
		○	○

Fig. 12 Comparison of quality with conventional products and newly developed products

4. 3 Optimization of Sizing Conditions

The measure for shortening the time are shown in **Fig. 13**. When the workpiece is loaded into the die, this mechanism directly cools the workpiece by spraying cooling water at the designated temperature from the upper punch.

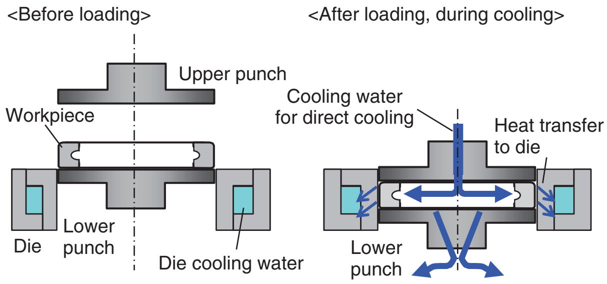


Fig. 13 Direct cooling mechanism

As a result of this measure, workpiece temperature after sizing was reduced by 53%, and temperature variation around the workpiece periphery was improved by 75% (**Fig. 14**).

The results for the interference value and dimensional accuracy after heat treatment following the adoption of this measure are shown in **Fig. 15**. The control range for the interference value to produce the required accuracy was identified. By appropriately controlling the interference value, it is possible to improve dimensional accuracy.

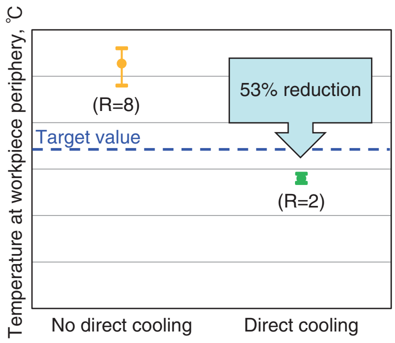


Fig. 14 Effect of direct cooling

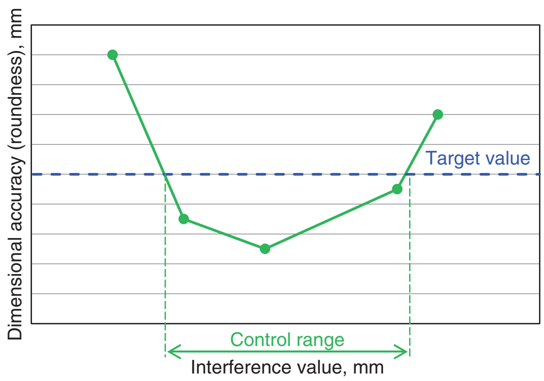


Fig. 15 Result of interference value and dimensional accuracy

Figure 16 shows the results from a comparison of dimensional accuracy for the outer diameter with the conventional process and newly developed process. Dimensional accuracy was improved by 40% with the newly developed process compared to the conventional process.

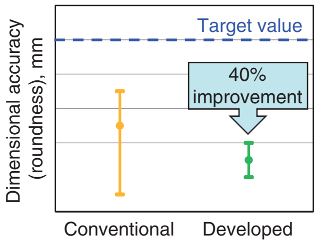


Fig. 16 Comparison of dimensional accuracy with conventional products and newly developed products

5. Development Results

5. 1 Reduction of CO_2 Emissions in Heat Treatment Process and Logistics

Compared to the conventional process, the newly developed process reduces CO_2 emissions by 45% as a result of reducing heating energy by changing to induction heating, and of discontinuing the atmosphere gas furnace. The CO_2 emissions reduction effect is shown in **Fig. 17**.

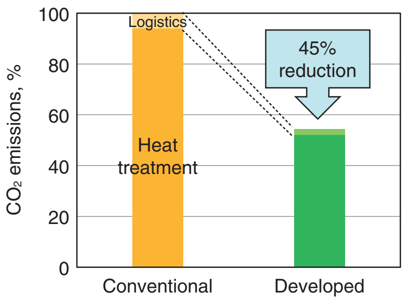


Fig. 17 CO_2 emission reduction

5. 2 Shortening the Lead Time

Compared to the conventional process, the newly developed process reduces the time due to the adoption of induction heating, and reduces lead time by 96%. The lead time reduction effect is shown in **Fig. 18**.

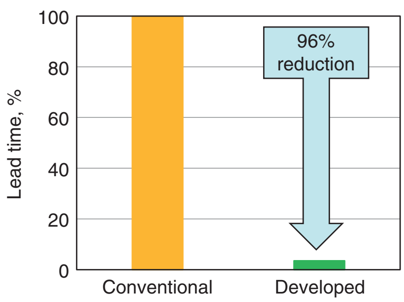


Fig. 18 Lead time reduction

5. 3 Reduction of Installation Space

Compared to the conventional process, the newly developed process reduces the installation space by 40% as a result of adopting induction heating and replacing the large atmosphere gas furnace. The installation space reduction effect is shown in **Fig. 19**. The machine appearance is shown in **Fig. 20**.

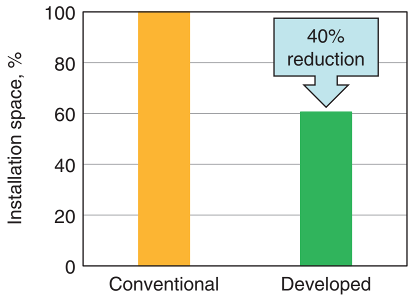


Fig. 19 Installed area reduction

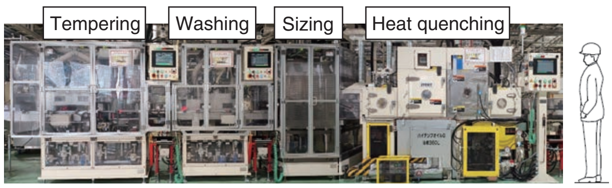


Fig. 20 Newly developed machine appearance

6. Conclusion

As a result of development for adoption of induction heating and changing to one-piece-flow processing in the heat treatment process, we were able to reduce CO_2 emissions by 45% and reduce heat treatment lead time by 96%. In particular, because CO_2 emission from a heat treatment furnace are extremely large, utilizing the newly developed process described in this report can achieve a large reduction in CO_2 emissions.

In the future, we intend to apply the technology in this report to other part numbers, and develop new heat treatment processes to contribute to achieving carbon neutrality not only at JTEKT but in all of Japan.

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A. MATSUDA* T. TAKAMI*

* Heat Treatment Production Engineering Dept., Production Engineering Division