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Recent Developments of HIP Equipment in JAPAN

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Abstract. Toll services have been increased recently in the Japanese HIP market. This trend leads to larger HIP equipment and shorter cycle times for productivity improvement. In addition, longer life cycle of pressure vessels are demanded to reduce the costs in conformance with the requirements of the relevant laws and regulations of Japan.
To meet such demands, KOBELCO has developed a new rapid cooling system and the first product was delivered in 2016. This new cooling system ensures a rapid cooling rate while achieving the design life cycle by low design temperature of the pressure vessel. At the development stage of the new cooling system, the numerical analysis of the heat flow during rapid cooling was conducted using new techniques including a real gas model and a new model for the thermal insulator. This article will introduce this new rapid cooling system and describe other related topics.

Introduction

Since KOBELCO started the sales of HIP equipment in the 1970s, we have developed many types of equipment for many applications. For example, for cemented carbide parts in 1971, high speed tool steel billets in 1977, and soft ferrite in the 1980s, and so on. There were two very important development challenges. One was “Diversification of the process atmosphere”, and the other was “High productivity.”

Table 1. Typical development accomplished by KOBELCO [1-2]

Small R&D high pressure gas equipment	1964
Production HIP for cemented carbide parts	1971
Production HIP for high speed tool steel billets	1977
Production HIP with bottom loading system	1977
Production HIP for soft ferrite	1978
Nitrogen HIP unit	1981
Modular HIP system for soft ferrite production	1982
Oxygen HIP unit for R&D of ceramics	1986
Oxygen HIP unit for commercial production	2002
Oxygen partial pressure control HIP	2002
Mechanical properties testing equipment in hydrogen	2003
New Rapid cooling method	2015

Development challenges

The first development challenge was “Diversification of the process atmosphere.”

In the beginning, the basic gas atmosphere for HIP has always been argon. In Japan there were many requirements for various gases for various processes.

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What is in production today is:
- Nitrogen gas for silicon nitride used for ceramic ball bearings
- Oxygen + Argon for superconductive electrical wire
- Shroud HIP to prevent damage from gas generated in the product

KOBELCO has always tried to find better way to handle various gases. And these HIPs are still in use today and play an important part in their respective industries.

Another development challenge was “High productivity.”
HIP equipment must have a thick-walled pressure vessel for high pressure. This makes HIP equipment more costly than commonly used heat treatment equipment. Moreover, raising and lowering the temperature takes time, and in very large HIP equipment, one HIP cycle may take a whole day or more to complete. In order to address such issues, productivity improvement was required to reduce the processing cost per workpiece. From the very beginning, KOBECLO has designed the bottom loading system for high productivity. In the 1980s the Modular HIP system was incorporated into HIP equipment. In 2015 a newly developed rapid cooling furnace was installed to a considerable degree of high productivity.

Modular HIP system
In the 1980s, a modular HIP system was incorporated into HIP equipment in order to achieve full density in the production of high quality soft ferrite. A modular HIP system has two or three cooling stations and preheating stations as shown in Fig. 1.

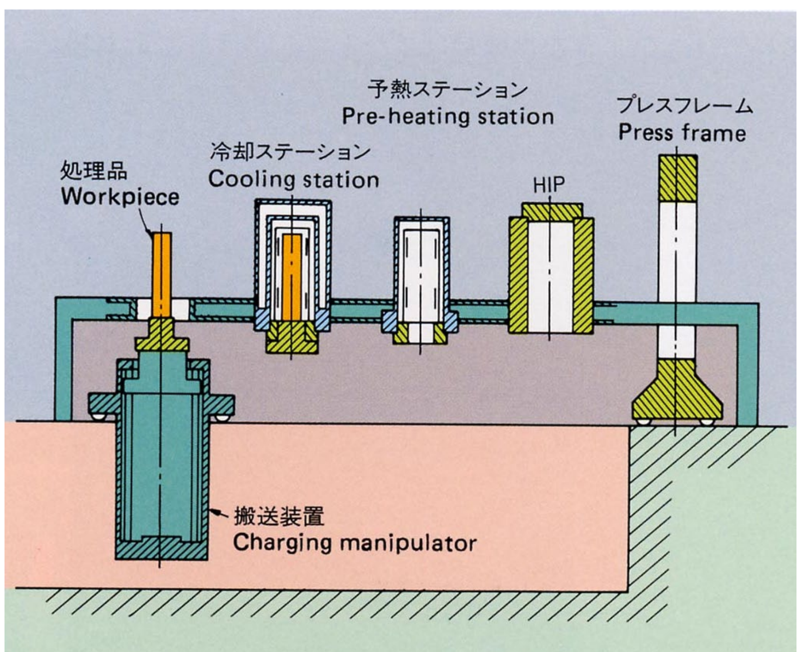

Fig. 1. Modular HIP system

The workpiece can be transferred while it is kept in an inert atmosphere furnace. It allows the preheated workpiece to be inserted into the pressure vessel for HIP treatment, or taken out in a hot state after HIP treatment and transferred to the cooling station to cool down. As a result, only the pressurizing, holding, and depressurizing processes are performed in the HIP pressure vessel, leading to 2 to 2.5 times higher productivity.

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KOBELCO Old Rapid cooling system

In the global market, rapid cooling furnaces that directly cool the high temperature and high pressure hot zone were made commercially available, significantly contributing to the reduction of processing time. KOBELCO also worked on the development of a rapid cooling furnace. In the 1990s, we produced a prototype and conducted a performance verification test. Unfortunately, however, we could not put it into commercial production. At that time, ASEA had a patent on wire-wound, interior cooling vessels which provided the most efficient cooling performance, and competitors including KOBELCO had to use liner type cooling vessels for small and middle size units and mono block vessels incorporating a rapid cooling furnace for large size units. Mono block vessels with a low interior cooling performance allow an excessive temperature rise at the pressure vessel inner surface due to direct rapid cooling gas. To prevent such excessive temperature rise, a heat sink was required inside the pressure vessel to dissipate heat from the hot zone. A mechanism for keeping the hot zone at a uniform temperature in rapid cooling was also needed. Therefore, to install these two systems into the pressure vessel, the very low volumetric efficiency of the pressure vessel impeded cost effective treatment and the full utilization of rapid cooling properties. Consequently, ASEA had a monopoly in the direct, rapid cooling HIP market.

New rapid cooling furnace

To solve the problem, KOBELCO has developed a new rapid cooling furnace. Fig.2 shows the diagrammatic illustration of the new rapid cooling furnace.

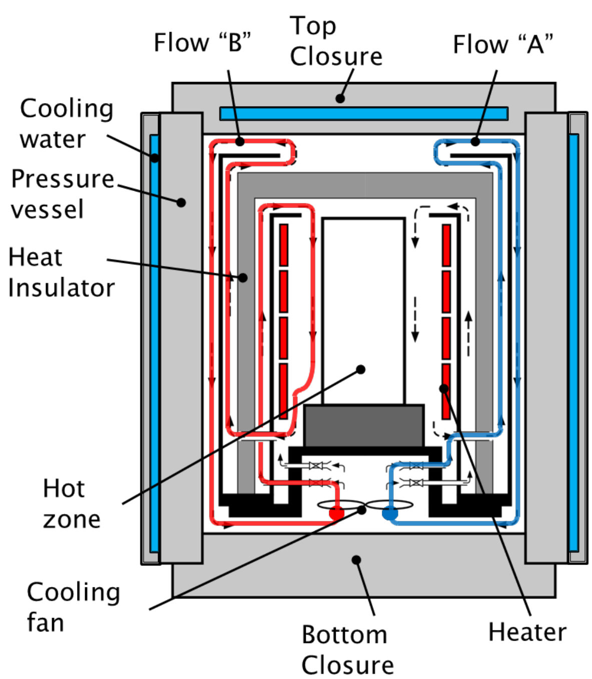

Fig. 2. New rapid cooling furnace

The heat insulator which surrounds the hot zone, blocks heat transfer and provide thermal control when the temperature in the hot zone gets high. The new rapid cooling furnace has vertical cylinders inside and outside of the heat insulator to direct the medium gas upward. These cylinders feature circulation flows which are generated inside and outside of the heat insulator.

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The gas blown by the cooling fan circulates, flowing between the outer cylinder and the heat insulator up to the top of the heat insulator, then between the heat insulator and the pressure vessel down to the cooling fan while being cooled along the pressure vessel inner wall. This is called “first circulation flow,” shown as “Flow A” in Fig.2.

Then the gas blown by the cooling fan flows between the inner cylinder and the heat insulator up to the top of the hot zone: From there, it flows into the hot zone to cool the hot gas, and then merges with the first circulation flow to circulate back to the cooling fan. This is called “second circulation flow,” shown as “Flow B” in Fig.2.

Rapid cooling by using these two circulation flows is the one of the biggest features of the new furnace.

As you may know if you are familiar with fluid mechanics, the higher the gas flow rate, the higher the heat exchange rate between the gas and metal on the metal surface. The commonly used rapid cooling furnace roughly uses the second circulation flow only to perform rapid cooling. In this case, the cooling rate in the hot zone depends on the amount of the cooling gas in the hot zone.

The hot gas passing through the hot zone is directed to the pressure vessel inner surface, thus it is necessary to reduce the gas flow rate to a certain level or lower in order to prevent an excessive temperature rise at the pressure vessel inner surface. That means the maximum gas flow rate is limited. On the other hand, in the new rapid cooling furnace, the first circulation flow does not pass through the hot zone, enabling an increase of the gas flow rate regardless of the cooling rate. The second circulation flow is cooled while merging with the first circulation flow that prevents an excessive temperature rise at the pressure vessel inner surface and allows an increase of the first circulation flow rate. As a result, a heat exchange is performed between the relatively cool mass flow of gas and the pressure vessel inner surface.

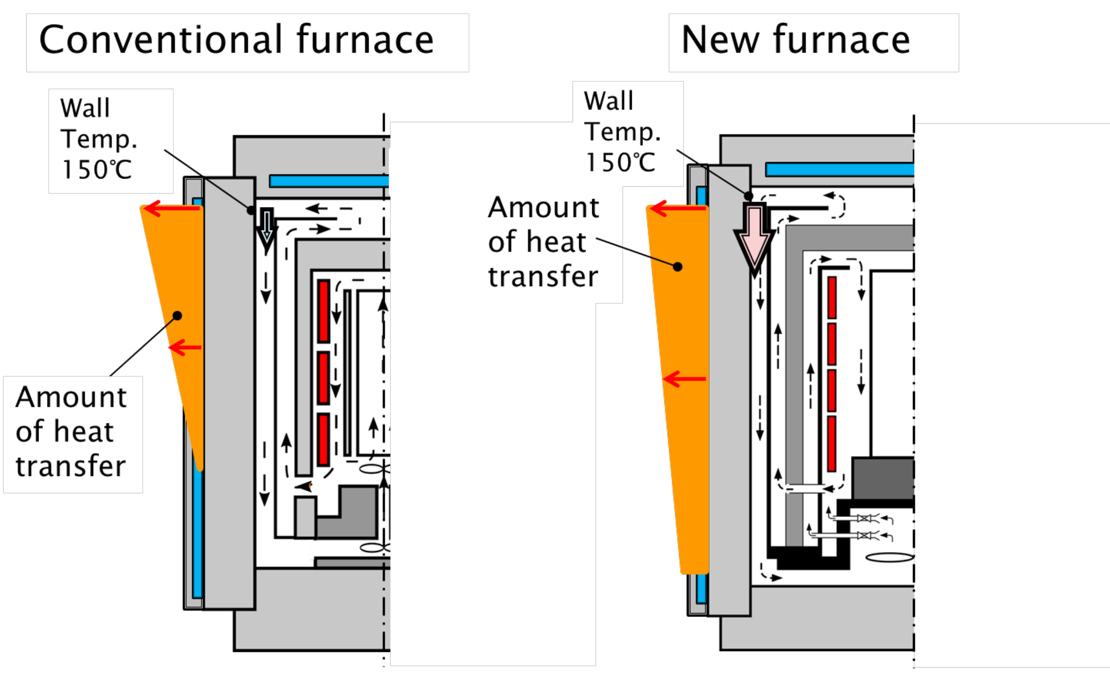

Fig. 3. Comparison of two different furnaces

The sufficiently increased heat exchange rate between the gas and the pressure vessel inner surface, allows effective use of the entire pressure vessel inner surface for heat exchange to

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prevent an excessive temperature rise at the pressure vessel inner surface, and makes best use of the heat extraction capability of the pressure vessel. Another feature of this new rapid cooling furnace is that the hot zone does not require any additional devices such as a circulation fan since the temperature in the hot zone can be kept constant. This is made possible by introducing the second circulation flow from the top of the hot zone.

Fig.3. shows a comparison of two different furnaces. The design of the wire-wound interior cooling vessel is the same in both cases. The left drawing shows a typical conventional rapid cooling furnace with only the second circulation flow. The right drawing shows the new rapid cooling furnace with the first and second circulation flows. The orange area shows the calculated amount of heat transfer. In either case, the gas flow rate is set so that the inner wall temperature of the vessel is uniform (150 °C). The gas is argon and the temperature of the hot zone is 1100 °C. As Fig.3 shows, the rapid cooling with the first and second circulation flows on the right side can absorb more heat than the rapid cooling with only the second circulation flow on the left side. It is necessary to discharge more heat from the hot zone through the pressure vessel to rapidly lower the temperature in the hot zone. This new rapid cooling furnace can discharge more heat from the pressure chamber to achieve faster cooling of the hot zone, compared to a conventional cooling furnace.

As a result of calculating the cooling rate of the hot zone inside HIP according to previous drawings, the new rapid cooling furnace is 1.5 times faster than conventional furnaces. In this case, a comparison was made with the same temperature on the inner surface of the pressure vessel. However, if the cooling rate is fixed, the new rapid cooling furnace can achieve rapid cooling with a relatively low temperature of the pressure vessel.

The life of the pressure vessel depends on the design conditions such as the thickness of the vessel, the design temperature, the conditions of the wire winding, etc. In Japan, in particular, since it is necessary to use the maximum value of the inner surface temperature as the design temperature of the pressure vessel, designing a lower temperature can ensure a longer vessel life. The same can be said about design pressure. Therefore, with the new rapid cooling furnace, the vessel life can be designed to be longer, or the design pressure can be higher.

The first commercial unit of new rapid cooling furnace

In 2016, the first commercial HIP equipment employing this new rapid cooling furnace was delivered to the customer. Table 2. shows the main specifications of this HIP equipment – among the largest scale in our product line. We have developed wire-wound, interior cooling vessels in parallel to the development of the rapid cooling furnace. This large HIP equipment has our largest interior cooling vessel with piano wire wound around the cylindrical core using a spacer. A heater has been designed and developed by incorporating the new rapid cooling furnace to meet the specifications shown in Table.2. and installed in this HIP equipment.

Table 2. Main specifications of the first commercial unit.

Hot zone diameter	850mm
Hot zone height	2,500mm
Maximum temperature	1400 °C
Maximum pressure	147MPa
Maximum weight of work load	4,500kg
Cooling rate with no load	40 to 60°C/min
Cooling rate 2ton load	15 to 25°C/min

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Fig.4. shows the results of the rapid cooling performed at the cooling rate of 15°C/min with approximately 2-ton load using this HIP equipment. As shown in this graph, the rapid cooling was performed smoothly in the range of 1,150°C down to about 400°C at the cooling rate of an approximately 15°C/min. And also we have achieved enough temperature uniformity during cooling even without the installation of a stirring fan in this furnace.

The temperature of the pressure vessel inner surface was raised to 120°C, and then stabilized at about 110°C. This clearly demonstrates the benefits of the new rapid cooling method – “prevention of excessive temperature rise at the pressure vessel inner surface, and best use of heat extraction capability of the pressure vessel.” The design temperature of the pressure vessel inner surface is 150°C that allows for the heat extraction capability of the pressure vessel. Therefore, faster cooling can be achieved by increasing the rapid cooling gas flow rate.

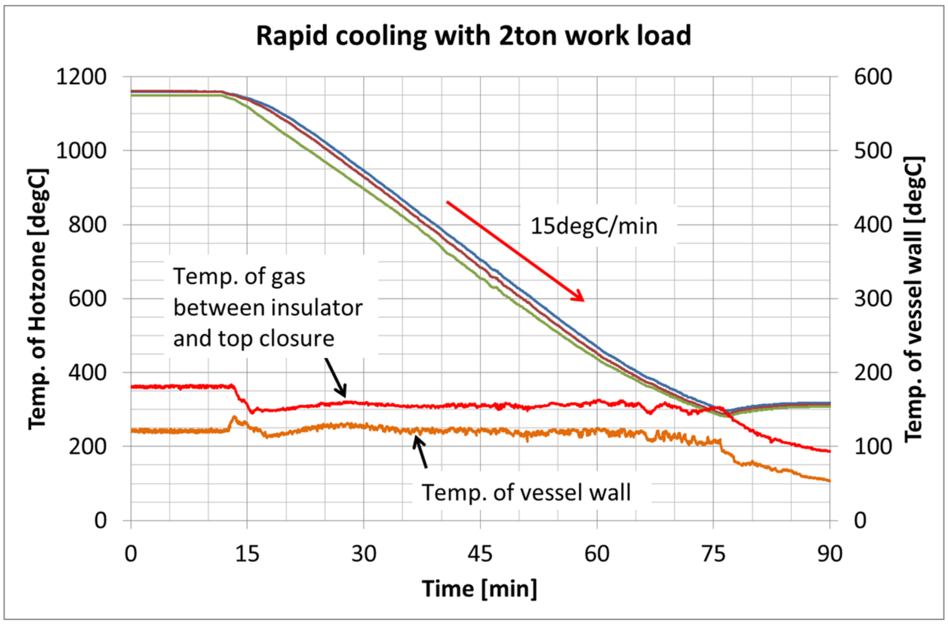

Fig. 4. Results of the rapid cooling controlled in 15°C/min

Other topics

A Tungsten heater is now under development. With a Tungsten heater it is possible to have a cleaner HIP atmosphere at higher temperatures. This will increase the possibility of developing new materials. For example, materials for electronic components, certain kinds of ceramics which need contamination control, etc.

Summary

KOBELCO has developed a new rapid cooling system as previously described. But some other related developments are in progress. With these results we expect they will expand the HIP field. We sincerely hope that our HIP technologies will contribute to the development of the global industry.

References

[1] US Patent 4,582,681: Method and Apparatus for Hot Isostatic Pressing

[2] US Patent 7,008,210 B2: Hot Isostatic Pressing Apparutus