２００５ｔｈ　JSME Medal for New Technology

- High Speed and High Gas Barrier Rotary DLC Plasma Coating System for PET Bottles
- Development of 1010 m/min. ultra high-speed elevator with atmospheric pressure control, active mass damper etc.
- Long-term reliable creep test in excess of 100,000 hours and issue of Creep Data Sheet
- Development of High Performance Room Air Conditioner Using Two-Stage Compression Cycle with Gas Injection
- Semi-active Suspension for Railway Vehicle
- Development of an Induction-heated Rice Cooker Using Ultrasonic Waves
- Development of the refurbishment and reuse technology of gas turbine buckets
- Sophisticated Function-Integrated Mother Machine
  (Vertical CNC Cylindrical/Internal Grinding Machine for Facilitating Process Innovation)

JSME

The Japan Society of Mechanical Engineers

High Speed and High Gas Barrier Rotary DLC Plasma Coating System for PET Bottles

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1. Introduction

Beverage and food containers have been rapidly replaced by polyethylene terephthalate (PET) bottles because of their advantages such as lightweight, designability, physical toughness and economy. As a result, 60% or more of the total number of such containers are now PET bottles.

However, a disadvantage of PET bottles compared with metallic containers and glass bottles is its lower gas barrier capability such that sensitive contents tends to deteriorated by permeation of gases such as the ingress of oxygen and the loss of carbon dioxide gas. Various gas barrier enhancing technologies have been developed to solve the problem.

Mitsubishi Heavy Industries, Ltd. (MHI) has developed a DLC plasma coating system which has the world's highest levels of productivity and gas barrier performance. This coating system is capable of forming a extremely thin but quite high gas barrier DLC (Diamond Like Carbon: carbon similar in physical properties to diamond) film on the inner surface of the bottle using plasma CVD (chemical vapor deposition). This report gives a brief introduction to the system.

2. DLC coating technology

The DLC film, which is deposited on the inner surface of the bottle via the plasma CVD provides remarkable high gas barrier performance against the inflow and the outflow of gases such as oxygen and carbon dioxide (Fig.1).

Compared with other film-forming methods, the plasma CVD process employed in the present system can form a dense DLC film utilizing its high energy ions, which strike the DLC surface during the deposition process, and therefore provides quite high gas-barrier performance compared with multi-layer PET bottles that have been appearing in ever-increasing quantities as a high gas barrier package for the sensitive contents.

The process for forming the DLC film on the inner surface of the PET bottle is as shown in Fig. 2 .

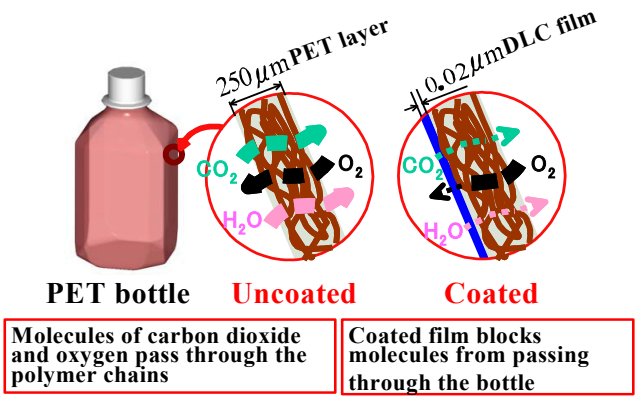

Fig.1 Mechanism of gas barrier

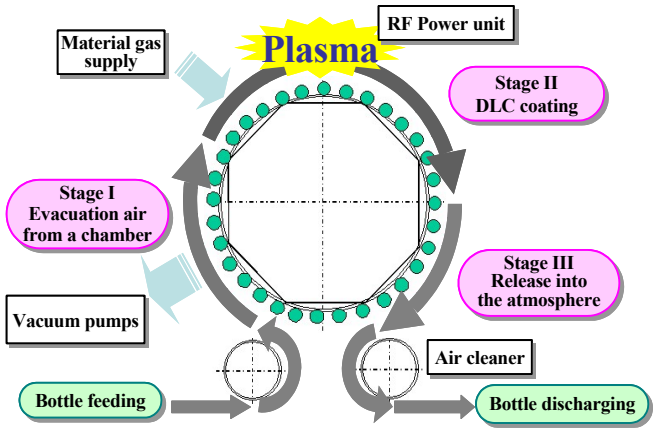

Fig.2 DLC plasma coating process

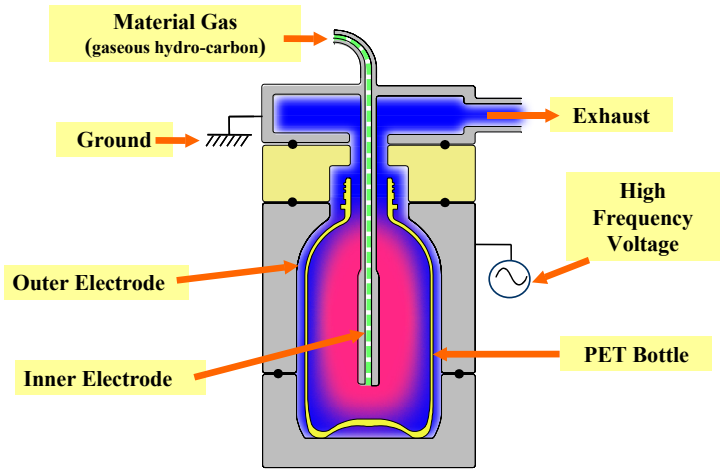

Fig.3 Configuration of DLC coating electrodes

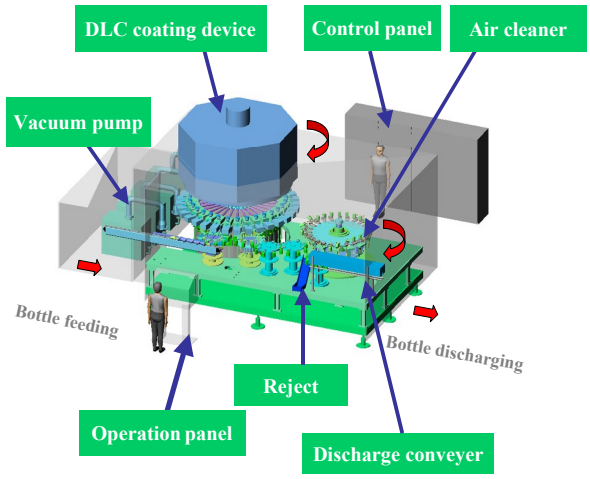

Fig.4 Outline of DLC coating system

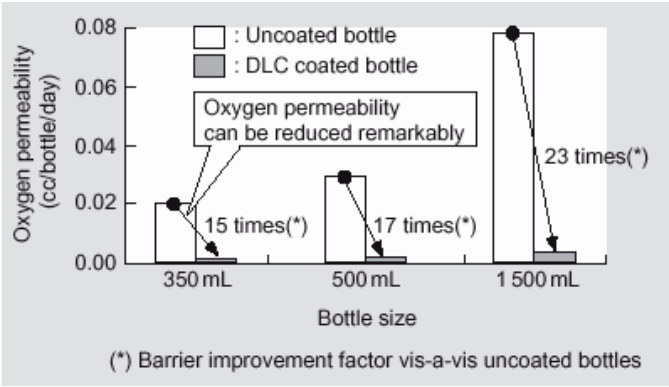

Fig.5 Oxygen barrier performance

DLC coated bottles have oxygen barrier performance for each bottle size that are 15 times greater or higher than those of uncoated bottles.

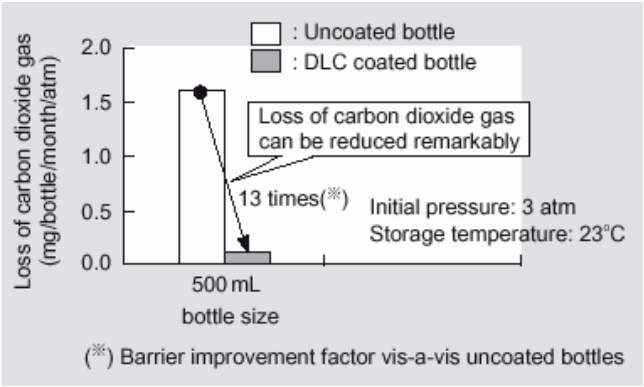

Fig.6 Carbon-dioxide barrier performance

DLC coated bottles have carbon dioxide gas barrier performance that are 10 times greater or higher than those of uncoated bottles.

This process essentially consists of five steps.

(1) A bottle is set into a vacuum chamber (external electrode).

(2) The chamber is pumped down to the vacuum.

(3) Acetylene (source gas of the film) is supplied into the bottle.

(4) Plasma is generated by RF (Radio Frequency: 13.56MHz) discharge and the acetylene gas is decomposed and deposited on the inner surface of the bottle to form a thin film of 10 to 30 nm.

(5) The chamber is opened to the atmosphere, and then the bottle is picked up from the chamber.

The steps outlined above are repeated on a rotating rotary table to enable high-speed production of the coated bottles. The configuration of the electrodes is shown in Fig.3 .

MHI's advanced expertise, such as thin film plasma deposition, high-frequency circuit, rotary vacuum seal and pumping system, which are cultivated in various MHI's products, as well as the bottle handling technologies in beverage filling machines, has been utilized to the development of this system.

MHI's DLC coating system has been commercialized based on four commodity concepts described in items (1) to (4) below. Fig.4 shows an outline of the system for large bottles.

(1) High gas barrier performance

As can be seen from Fig. 5, DLC coated bottles provide the world's highest level of barrier performance with levels as much as 15 times higher than those of uncoated bottles. Also, as shown in

Fig. 6, it is confirmed that the DLC bottles have barrier performance that are as high as 10 times those of uncoated bottles against carbon dioxide.

(2) High productivity

MHI's plasma coating system has a bottle production rate of 18,000 bottles per hour (for 0.5-litter bottle) and 12,000 bottles per hour (for 1.5-litter bottle), which is the highest rate in the world for this kind of bottle coating.

(3) Measures for safety and the environment

It has been confirmed that the DLC-coated PET bottles satisfy the voluntary guidelines of the Japanese Council for PET Bottle Recycling and there is no problem in the recycling process of the bottles. In addition, the U.S. Food and Drug Administration (FDA) has certified the safety of the DLC-coated PET bottles as food containers.

(4) Availability of wide range of bottle sizes

The coating system is readily applicable to a wide range of bottle sizes from 0.3 to 1.5-litters. In addition, since the DLC-coated PET bottles are used mainly for beverages and foods, the reliability of the bottle quality is important from the viewpoint of safety. To ensure it, a process monitoring system checks all the histories of the film-forming process parameters (pressure in the chamber, RF power, and source gas flow rate etc.) for each bottle and can store those as traceable data for future reference.

3. Conclusion

The commercialization of this system will expand the application of PET bottles for various beverages, such as sensitive soft drinks like green tea drinks and carbonated drinks, and alcoholic beverages, for which high barrier for oxygen and carbon dioxide permeation are essential to preserving good product quality. In addition, the use of the DLC coated PET bottles may be expand to a variety of non-beverage contents such as seasonings and cosmetics, as well.

It is anticipated that the PET container market will continue to grow rapidly all over the world in the future. MHI is dedicated to developing and delivering products to the customer that are high performance and reliable as well as environmentally friendly and safe.

Development of 1010 m/min. ultra high-speed elevator with atmospheric pressure control, active mass damper etc.

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1. Abstract

Super high speed elevator of 1010 m/min.s was installed within TAIPEI101 built in Taipei in Taiwan, and it was now commercialized.

Fig. 1 shows an overview of TAIPEI101.

This elevator can go up from the 1st floor to the 89th observatory floor in 39 seconds. The challenging development items are the following new technology.

A powerful traction machine and a twin-drive control system

An atmospheric pressure regulation and an active vibration-eliminating control for comfort riding on a car

A safety device and an oil buffer for ensuring the safety of passengers

Fig. 2 shows main development items.

Fig. 1 Overview of TAIPEI101

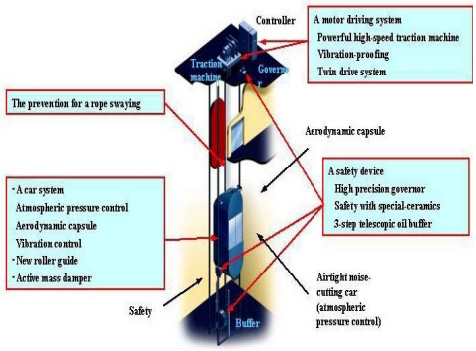

Fig. 2 Development items for 1010m/min. ultra high speed elevator

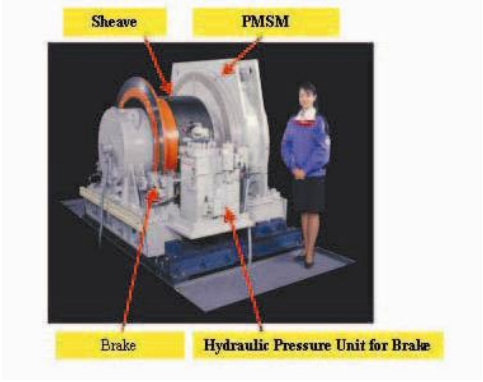

Fig. 3 Permanent Magnet Synchronous Motor (PMSM)

2. Technology

Fig. 3 shows a powerful traction machine of PMSM (permanent magnet synchronous motor). The machine has maximum-output 1186Kw and rated-output 168Kw. This machine with two winding lines, so called twin-drive control, is connected to two parallel independent converter/inverter units. It has a special frame for avoiding a vibration caused by an electromagnetic force. Moreover, It is installed with the double multi-step vibration-eliminating construction for shut down of effect to the tower.

A new type roller-guide unit of rolling along a guide rail for guiding a car was developed. This unit decreases lateral vibration. A balance weight is loaded in the lever bottom of a guide roller, and an interference spring undertakes all the forces of working from a guide roller. A force does not work on the rocking shaft (bearing) of a lever by inertia of a balance weight. Moreover, an active mass damper (AMD) that was actively controlled lateral vibration was attached to a car.

We developed a streamlined aerodynamic capsule for reduction of a wind noise. The top spoiler of the wedge

configuration attached in the end of an upper and lower capsule improved the turbulent flow on the surface of a car (Fig. 4). It was contributed to reduce the noise within a car.

Furthermore, the configuration of a car has an air-tightness, and atmospheric pressure regulating system, that is, suction and discharge blower, located in car bottom as shown in Fig.5. It realized atmospheric pressure rate of change by making it constant from starting to run to stop that may ease passengers' ears to pop which feels very uncomfortably.

We also developed a safety device as safety measures. In emergency, a safety device activates brakes perfectly for slowing down and finally stopping of a car by catching a guide rail, when a car drops by over speed in case of the main rope cutting etc. The surface temperature of the braking shoe of the safety device exceeds 1000°C. Therefore, we applied processing grooves to the surface with a special type of silicon nitride ceramic, which has excellent heat resistant and wear-resistant characteristics. We confirmed of high reliability of this device through 60 times or more car-dropping test. Moreover, we also evaluated the characteristic of traction rope sway by means of simulation. The result was applied to design a device for preventing to twine to the apparatus in a hoist-way.

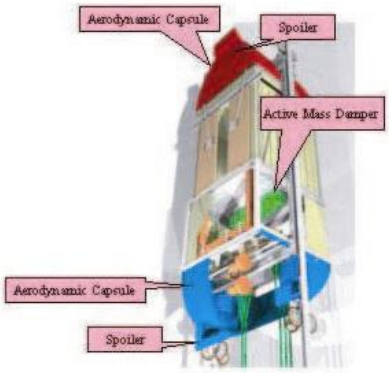

Fig. 4 Car Configuration & Active Mass Damper (AMD)

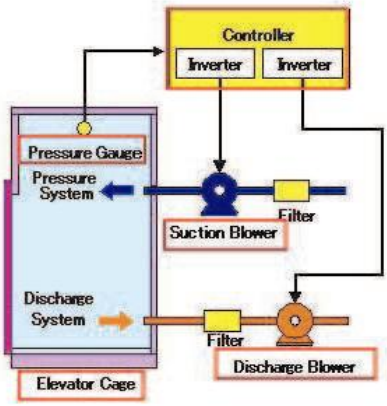

Fig. 5 Atmospheric Pressure Regulating System

3. Conclusion

High-grade perfect elevator system has accomplished by newly developing components or units in spite of challengeable high barrier of breaking 1000 m/min. Furthermore, we focused on the installation technique at site. Authorized excellent experts of installation set up higher precisely processed guide rails. They also confirmed the linearity of all passage of the guide rail by a laser detector. These were contributed to very high precise installation. Ultra high speed and comfortable riding elevator with perfectly safely operation of safety devices was realized.

One year or more has past since TAIPEI101 was opened, and so many customers use this elevator safely and comfortably.

Long-term reliable creep test in excess of 100,000 hours and issue of Creep Data Sheet

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National Institute for Materials Science

1. Introduction

The NRIM/NIMS Creep Data Sheet(CDS) project to produce long-term experimental creep and creep rupture data in excess of 100,000 hours and to publish CDS has been started in 1966 at National Research Institute for Metals (NRIM), and it has been succeeded by into National Institute for Materials Science (NIMS) since 2001. The CDS project intends to contribute for proper application and development of high temperature materials and improvement of safety and reliability of high temperature equipments. First edition of CDS includes creep test data up to about 10,000 hours and revised edition describes those up to about 30,000 to 50,000 hours. Since 1986, final edition of CDS has been published after acquisition of long-term creep test data up to about 100,000 hours, and original CDS program on 44 kind materials has concluded in 2004. The CDS project has been carrying on 22 kind of newly developed high strength materials sampled since 1988.

2. Technology

World largest creep testing facility was established for the CDS project. Total number of creep testing machine was 1,068 which consists of single lever type (878), multiple type (144), large scale type whose maximum load capacity was 50 metric ton (10), and so on (Figure 1). Long-term creep test data on 66 type creep resistant steels and alloys has been produced (Figure 2). Allowable tensile stress for high temperature equipments such as boiler and pressure vessels is generally determined on the basis of 100,000 hours creep rupture strength. Consequently, the CDS project is designed to produce reliable long-term creep test data by way of experiment.

To maintain accurate test temperature is most important technical problem to obtain reliable creep test data. Creep testing laboratory has been air conditioned and constant room temperature is kept throughout the year. Private electric generator allowed continuous creep testing for 40 years without accidental failure of power supply, and made it possible to obtain high-quality long-term continuous creep data. It has been paid full attention to temperature measurement with B-grade accuracy specified in JIS Z8704-1993 (Temperature measurement - Electrical methods) and creep test temperature has been controlled within a half of allowable temperature fluctuation specified in JIS Z2271-1999 (Method of creep and creep rupture test for metallic materials). About 4,000 pairs of all the type R thermocouples used for creep test have been calibrated with the use of standard thermocouples which have been officially approved by the Japan Electric Meters Inspection Corporation (JEMIC), and degradation behaviour after long-term service at the elevated temperatures has been also monitored. Information about production lot, calibration result, service condition, degradation after service and so on have been recorded on each thermocouples and it enable the traceability of the creep test. Huge quantities of information about degradation behaviour of type R thermocouples accumulated in the CDS project has been quoted in JIS Z2271-1999 as background information. Total number of creep rupture data obtained during 40 years is about 10,500 points including more than 700 points of long-term creep rupture data beyond 100,000 hours and total creep testing time of those is over 26,000 years. Very long-term creep test data in excess of 300,000 hours that corresponds to about 34.2 years has been also obtained and the number of it is eight as of March 31, 2006 (Figure 3).

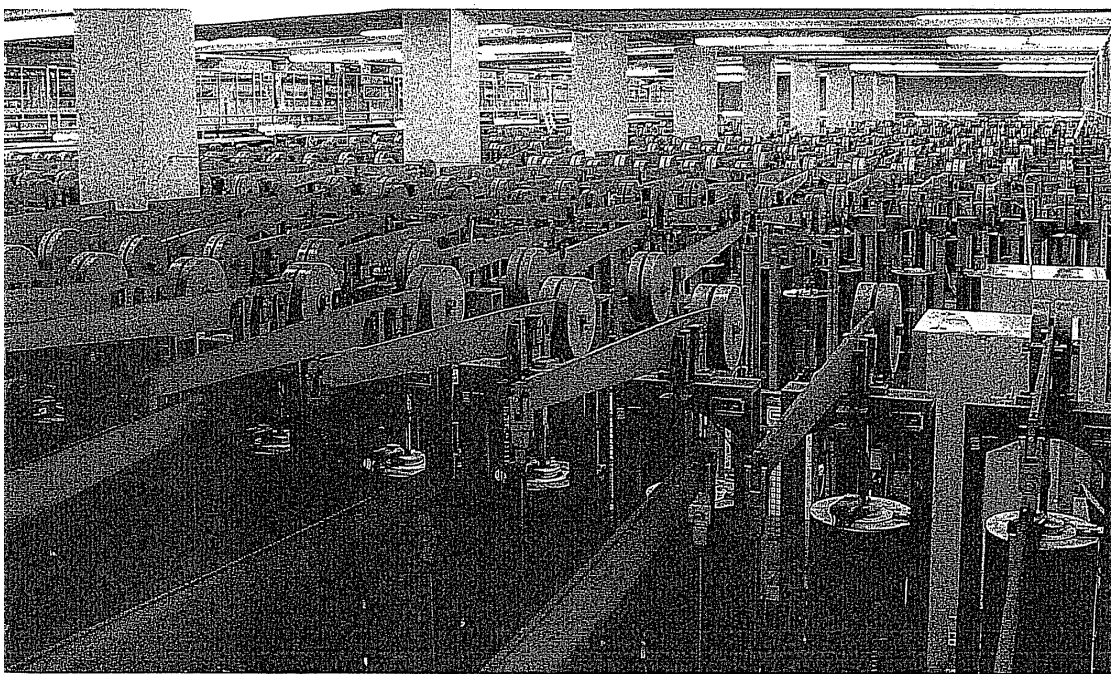

Figure 1 Single lever type creep testing laboratory in Meguro campus of National Institute for Materials Science.

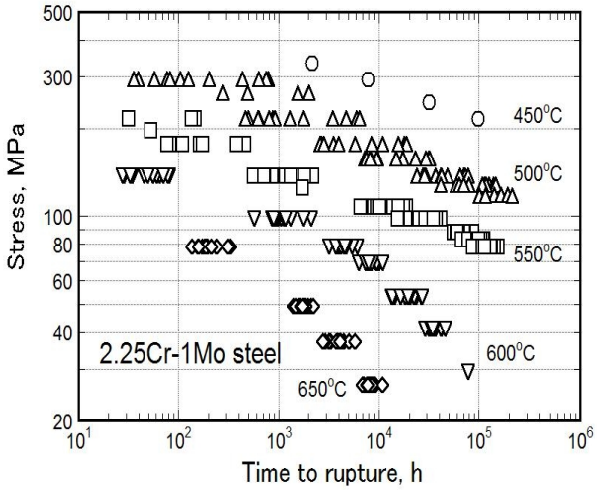

Figure 2 Stress versus time to rupture data of 2.25Cr-1Mo steel

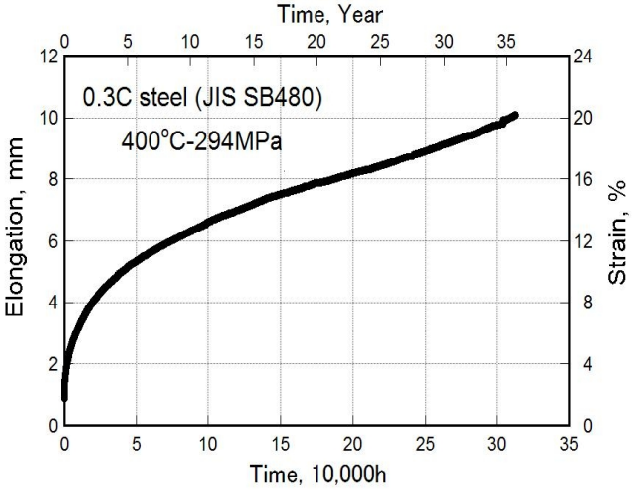

Figure 3 Long-term creep curve of 0.3C steel in excess of 300,000 hours.

3. Conclusion

NRIM/NIMS Creep Data Sheet published until March 2006 amounts to 130 volumes and those have been distributing to about 700 of companies, universities, public research organizations and so on. Contents of CDS have already been released also from the web-site of NIMS as a part of NIMS Materials Database (http://mits.nims.go.jp/db_top_eng.htm), since 2003. The result of NRIM/NIMS CDS project has been widely used for remaining life assessment and soundness evaluation of aged high temperature plant, investigation of the cause of damage and failure, and reference data for development of new materials and so on. It has been also applied for fundamental research on creep deformation and creep data analysis. Issue of the NRIM/NIMS CDS project has been reflected in regulation of allowable tensile stress and contributed to improvement of safety and reliability of high temperature equipments.

Development of High Performance Room Air Conditioner Using Two-Stage Compression Cycle with Gas Injection

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1. Abstract

Recent demands for improved efficiency of room air conditioners have arisen from concerns over global warming. Improvements in cycle performance are difficult because each component is performing at its optimal level. Therefore, we developed a two-stage compression cycle with gas injection to reduce expansion loss, which is an important loss in conventional cycles. The gas refrigerant in the cycle we developed does not absorb heat from air that bypasses an evaporator and is directly injected into a compression chamber. The main devices developed are a "two-stage rotary compressor" that enables a desired gas injection by connecting two compression chambers in series, an "injection component" that includes a separator, a "cycle control" that optimizes gas injection rate by sensing the temperature difference between the separator and the compressor, an "inverter control", "high efficiency heat exchangers", and "high efficiency fans". Using the developed system, we obtained a coefficient of performance (COP) of 6.50 for a room air conditioner with a cooling capacity of 2.8 kW. The obtained value is the highest in the market.

2. Technology

Figure 1 shows an overview of the high performance room air conditioner we developed. A two-stage compression cycle with gas injection was used in an outdoor unit to reduce expansion loss in the conventional cycles.

Figures 2 and 3 show the developed cycle and a pressure-enthalpy diagram under a cooling condition. The two-stage rotary compressor consists of first- and second-stage compression chambers. The injection component consists of two expansion valves between a condenser and an evaporator, and a separator located between the two expansion valves that separated the two-phase refrigerant into gas and liquid. After separation, the liquid refrigerant is reexpanded to lower the pressure by the second expansion valve and then it flows into the evaporator. On the other hand, the gas refrigerant bypasses the evaporator and is then injected into the second-stage compression chamber at an intermediate pressure. This mechanism reduces expansion loss by decreasing the quality of the inlet refrigerant of the evaporator. Refrigerant mass flow rate in the evaporator and in the first-stage compression chamber decreased dramatically. As a result, this mechanism reduces pressure loss in the evaporator and compression power in the two-stage rotary compressor. Furthermore, we have developed cycle control unit to optimize gas injection rate by sensing the temperature difference between the inlet of the separator and the suction port of the second-stage compression chamber. This control unit improves cycle performance under varying operating conditions, such as cooling, normal heating, and low outdoor temperature heating.

The two-stage rotary compressor as shown in figure 4 is the most important component in the developed cycle and consists of two compression chambers connected in series using a connecting pipe that is outside the compressor. This compressor achieves a stable gas injection because the injected part is connected to an intermediate connecting pipe where the pressure fluctuation is small. By compressing

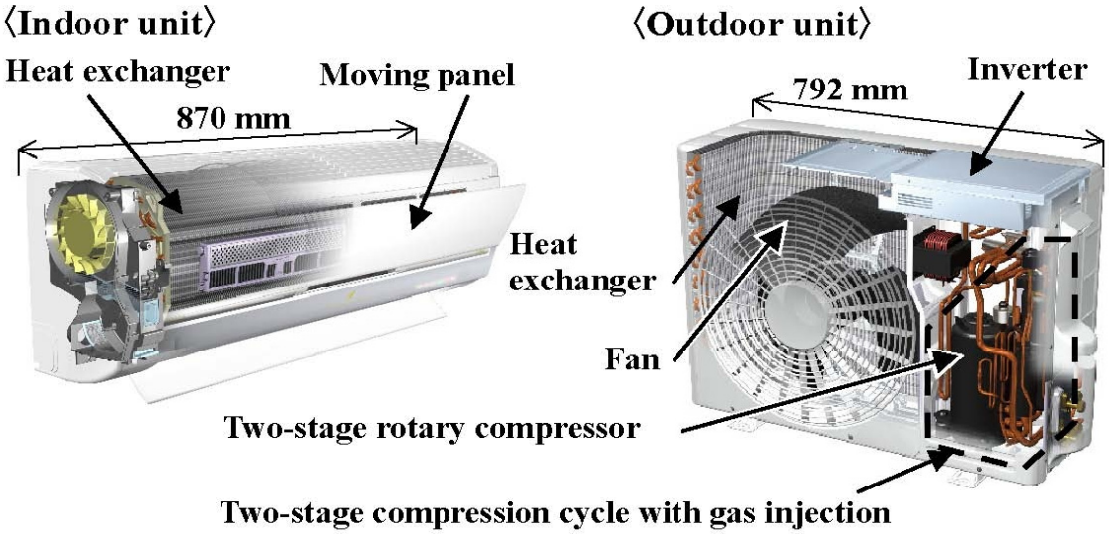

Fig. 1　Overview of developed high performance room air conditioner

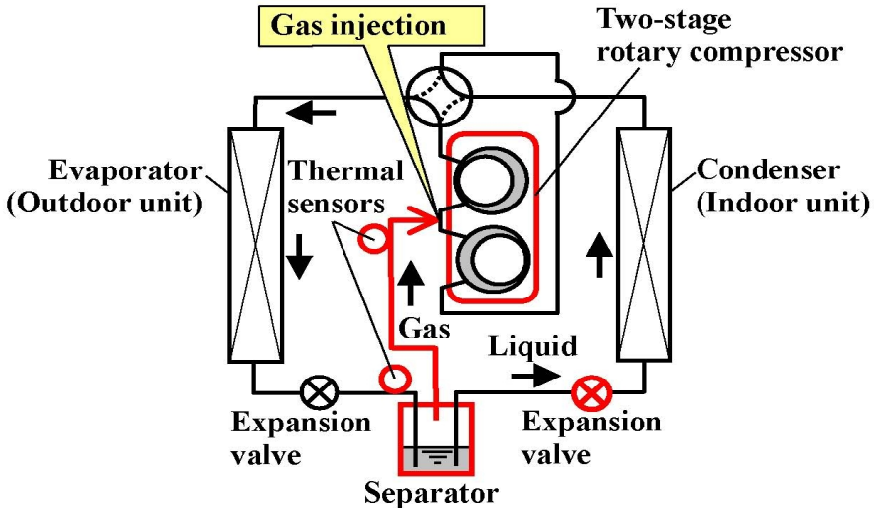

Fig. 2　Structure of developed cycle (Under cooling operation)

the refrigerant in two stages, the refrigerant leakage in each compression chamber is reduced thus leading to improved compression efficiency. We optimized the dimensions of compressor elements such as the volumetric ratio of each compression chamber, the aspect ratio of the compression chambers, and the discharge port diameter, by numerical and experimental analysis to achieve an effective gas injection and high compressor efficiency. In addition, we developed a novel inverter control that minimizes compressor motor input by altering input current wave against various torque fluctuation of the two-stage compressor.

We also optimized the refrigerant path of heat exchangers and the shape of fan blades based on the developed cycle.

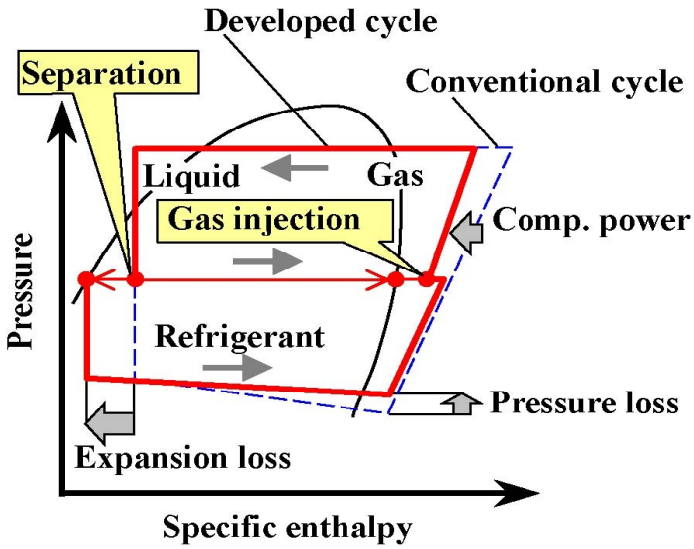

Fig. 3　Pressure－enthalpy diagram (Under cooling operation)

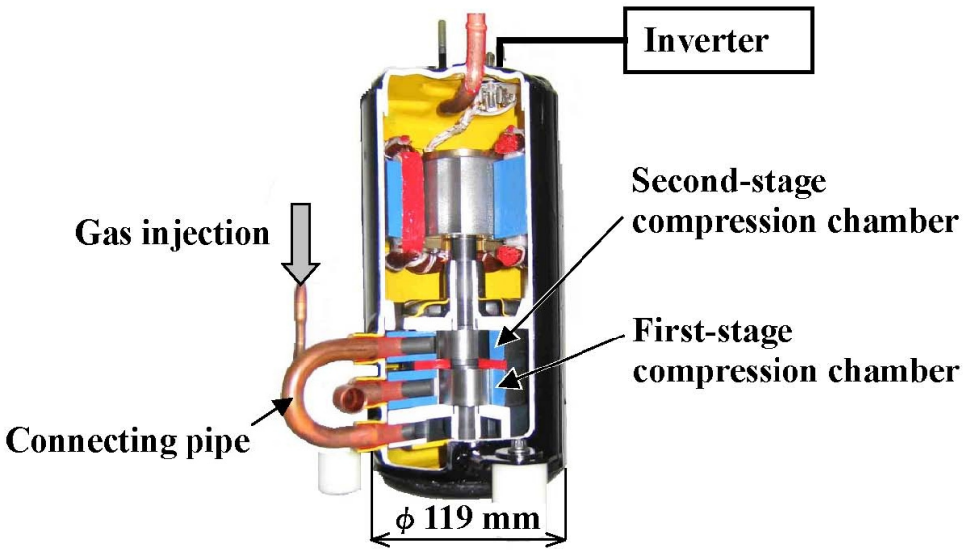

Fig. 4　Two-stage rotary compressor

3.Conclusion

Room air conditioners that use the developed cycle are named “double accelerator system”. This system was first launched in 2004 for the Japanese market and the total number of units being produced is increasing. A 2.8 kW room air conditioner that operated using the developed cycle achieved a COP of 6.50 and a maximum heating capacity of 8.3 kW. The obtained values are the highest values in the market.

Semi-active Suspension for Railway Vehicle

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Haruhiko KAWASAKI KYB corporarion

1. Abstract

A semi-active suspension system for railway vehicles has been developed. High-speed operation causes a large lateral vibration to railway vehicles. Mainly, it is caused by transmission from bogie vibration running on the truck, and aero-dynamical forces which work on carbody directly. Traditional passive suspensions are not enough to reduce the both vibrations because each vibration has a different pass of transmission.

To improve riding comfort of high-speed trains, a lateral semi-active suspension system, which reduces the both vibrations, has been developed. The performance and security of the system were confirmed in running tests. As the result, this system was installed to the Shikansen train since 1996, as the first vibration control system of commercial trains. In this system, the damping forces are switched through selecting a combination of working orifices by high cycle solenoid valves.

As the second generation of the semi-active suspension, a low-cost and upgrading performance system, which uses a proportional relief valve, has been developed. This system is used in various types of trains, such as older series of Shinkansen trains before 1996, or new high speed trains.

2. Technology

Fig.1 shows the construction of the semi-active suspension. The damping forces of lateral dampers, which are installed between the truck and the carbody, are controlled according to absolute velocity of the carbody. This control method is called sky-hook control.

The damping force of semi-active suspension depends on the direction of piston velocity of the damper. Therefore, semi-active suspension can not generate complete proportioning damping force against the absolute velocity of carbody. As the second best, the system makes the damping force to the minimum, when the piston velocity direction disagrees with the direction of damping force calculated by the sky-hook control. This is called "Karnopp's switching low".

The hydraulic circuit of changeable damper (proportional relief valve type) is shown in Fig.2. This damper has two solenoid valves, which select the direction of damping force. These valves make possible to realize the Karnopp's switching low without finding truck velocity. There are two ways to change the damping force amplitude. The first way, the damper, which is shown in Fig.2, changes the damping force by changing drive current of proportional relief valve as shown in Fig.3. In another way, the damper changes its damping coefficient by switching combination of orifices by more than one of solenoid valves instead of the proportional relief valve. This type of damper is used in the early versions of semi-active suspensions.

When the system is down, the both type dampers behave as a traditional passive damper. Thus, the train safety is kept.

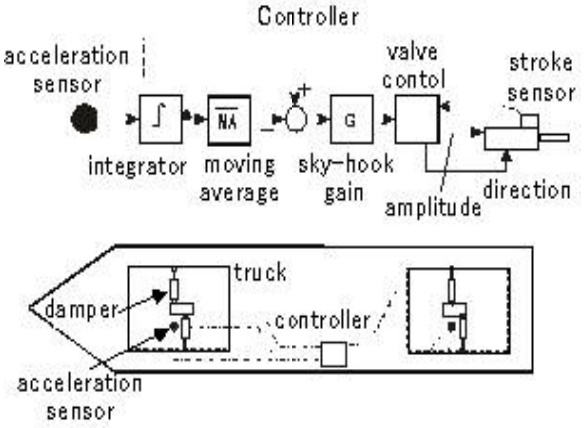

Fig.1 Construction of Semi-active Suspension

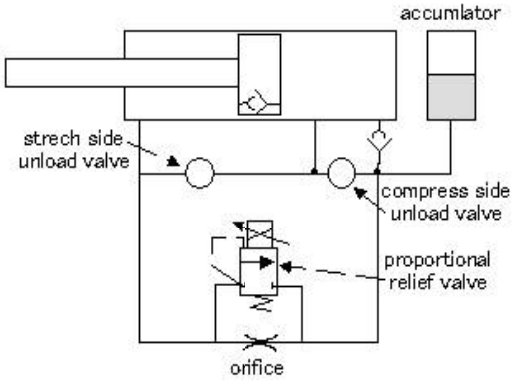

Fig.2 Hydraulic Circuit of Changeable Damper (Proportional Relief Valve Type)

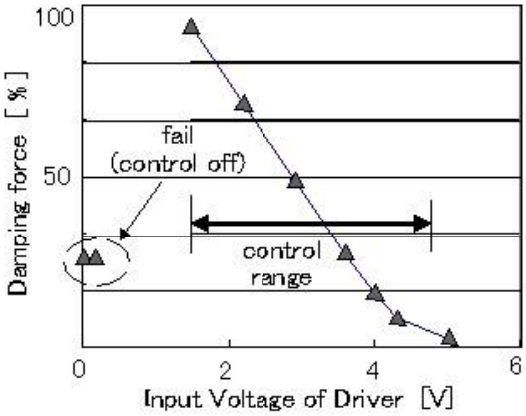

Fig.3 Damping Force of Proportional Relief Valve Type Damper

3. Conclusions

The system developed has been used in practical use since 1996, and has contributed to upgrading the riding comfort in about 1100 cars of trains. The cars equipped with semi-active suspension are increasing. It is thought that this system has been accepted as an effective way to improve the riding comfort of high speed trains.

Development of an Induction-heated Rice Cooker Using Ultrasonic Waves

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Takuya Suganami : Mitsubishi Electric Corporation in the past
Cyoji Nagamine : Mitsubishi Electric Corporation
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1. Abstract

The great majority of Japanese people prefer soft and sticky rice. Ultrasonic vibrations promote water absorption resulting in soft cooked rice. The surface layer of the rice peels appropriately and heating the rice turns it into a thin gruel. Since the gruel sticks to the external layer of rice and increases it stickiness, the rice becomes soft and sticky. In addition, ultrasonic vibrations are also expected to make rice sweeter by accelerating starch decomposition and increasing the amount of dextrose. One idea has been to attach an oscillating element to a rice cooker in order to improve the taste of the rice. This idea, however, has not been realized yet because the high cost of the oscillating element and drive circuit and unification of the pot and oscillating element makes cleaning and handling difficult.

In this context, we developed a completely new technology. Without using a special oscillating element, this method excites longitudinal oscillations in the inner pot using an induction-heating coil to produce an exciting force in the form of an electromagnetic force acting on the inner pot. The longitudinal oscillation generates ultrasonic vibrations in water. This technological development resulted in the first commercialized induction-heated rice cooker using ultrasonic waves in the industry. The rice cooker received high praise for its good performance in cooking tasty rice.

2. Contents of Technology

Figure 1 shows the basic structure of the induction-heated rice cooker. The inner pot, which is used for rice cooking, has two circular induction coils, an inner and outer one, arranged concentrically at the base of the inner pot. For cooking, the control circuit supplies an AC current at a frequency of about 20 kHz to generate eddy currents in the inner pot via electromagnetic induction. Since the inner pot is made from a material having an electrical resistance, the currents generate Joule heating. Thus, the rice is cooked by induction heating.

What is noteworthy about this technology is the finding that inserting a non-magnetic copper ring (Figure 1) between the inner induction coil and the inner pot generates weak ultrasonic vibrations. As Figure 2 shows, the ultrasonic vibration has a periodicity that has a frequency of 11 kHz. The maximum frequency matches the 8^{th} harmonic (88 kHz) of the natural longitudinal oscillation frequency of the inner pot. This gives rise to resonance between the electromagnetic force and the longitudinal oscillation of the inner pot. Figure 3 shows the results of analyzing the 8^{th} harmonic of the natural mode of the longitudinal oscillation of the inner pot. Based on this analysis, the size and arrangement of the copper rings and the dimensions and shape of the inner pot were optimized to increase the mode excitation force of the 8^{th} harmonic of the natural mode of the pot so as to produce strong and stable ultrasonic vibrations. This technological development enables the generation of ultrasonic vibrations without using an oscillating element.

Next, the effects of ultrasonic waves on cooking performance are explained. Since Japanese people prefer soft and sticky rice, the ratio of stickiness to hardness was employed as an index for tastiness. Figure 4 shows the measurement results. Ultrasonic vibrations raised the index of tastiness by 18 points

from 87 to 105 by promoting water absorption. As Figure 5 shows, ultrasonic vibrations also increased the sugar content and made the rice sweeter.

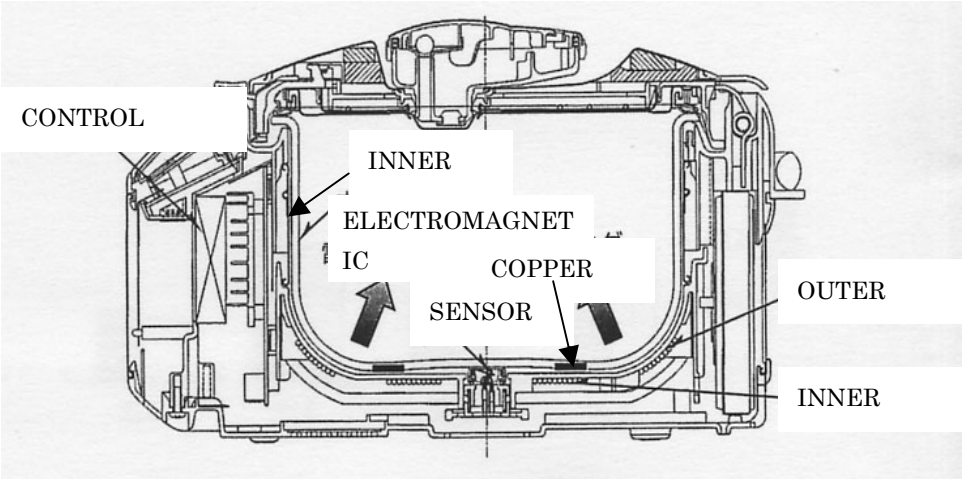

Figure 1　Structure of induction-heated Rice Cooker

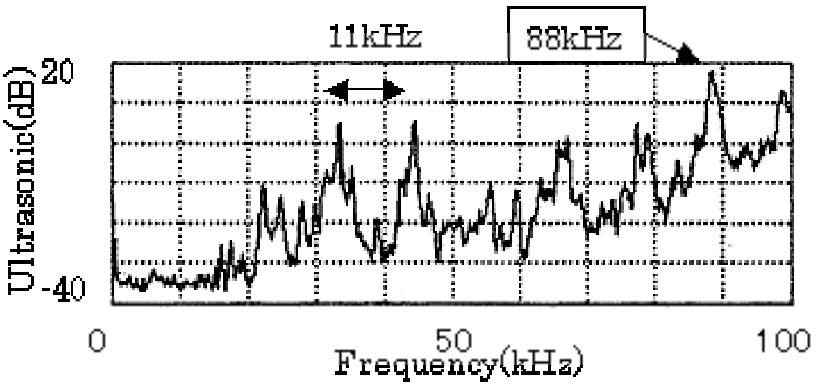

Figure 2　Ultrasonic Vibration Characteristics

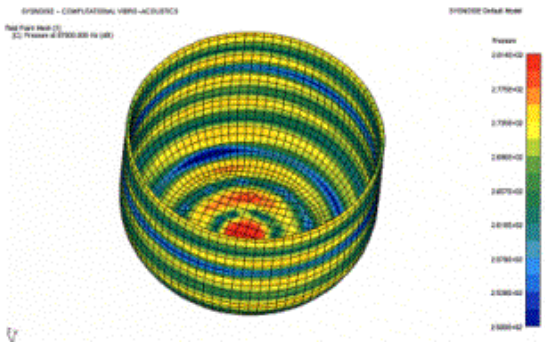

Figure 3　The 8th Natural Mode

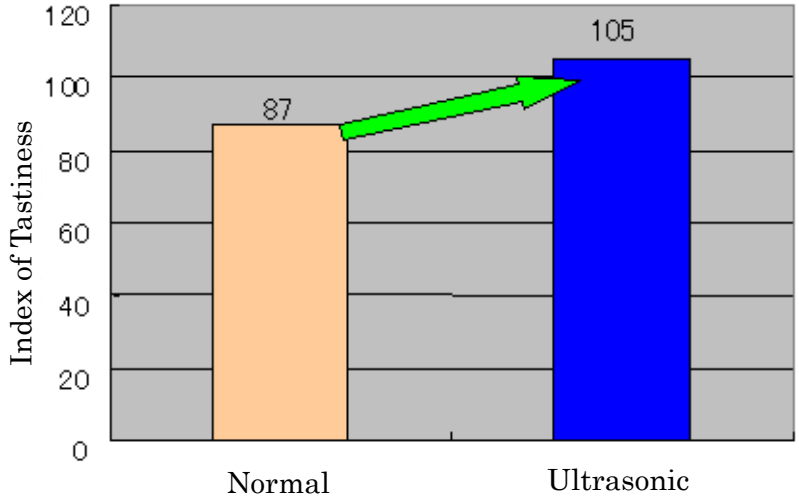

Figure 4　Comparison of Index of Tastiness

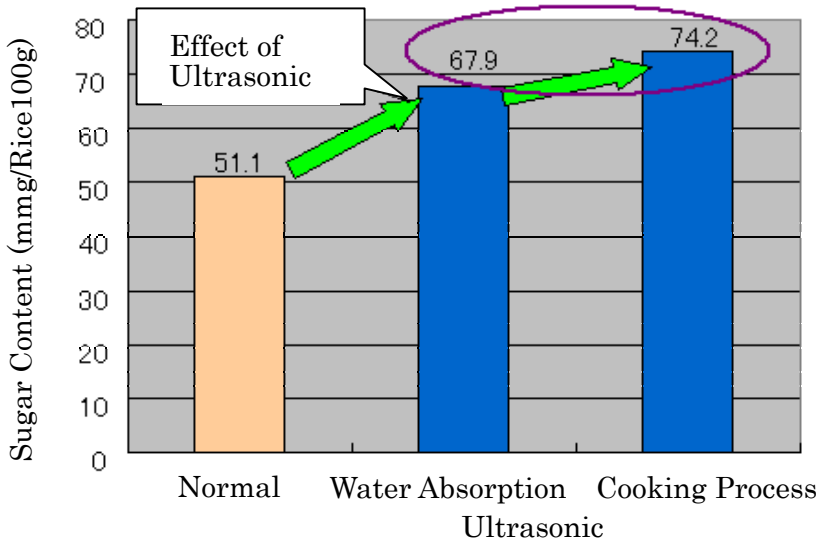

Figure 5　Sugar Content Increased by Ultrasonic Vibration

3. Conclusion

Without using a special oscillating element, this technology generates ultrasonic waves in the inner pot by tuning the electromagnetic induction phenomenon to the longitudinal oscillation characteristics of the pot. This technological development led to a commercialized the Induction-heated rice cooker that uses ultrasonic vibrations. This technology can be expected to contribute to the creation of home cooking appliances and changes of diet in the future.

Development of the refurbishment and reuse technology of gas turbine buckets

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1. Abstract

The refurbishment and reuse technology of gas turbine buckets is a technology which enables to regenerate a retired bucket and to reuse with equivalent to or better reliability and life than a new bucket. According to the investigation results of serviced buckets, life determinants for the buckets were microstructure degradation and creep deformation. Three technical developments were, therefore, conducted, which were (1) microstructure regeneration, (2) reformation, and (3) life assessment technology for refurbished buckets. (1) used a hot iso-static pressing (HIP) to solve the problem of the incipient melting due to segregation of low melting point elements in this kind of buckets. (2) is a technology to enable to reform configuration of a bucket in a mass-production base at ambient temperature even if the bucket materials are low ductility materials of around 3% in tensile elongation. (3) is a development of the life assessment technology based on the coarsening theory of the γ' phases precipitation strengthened nickel base superalloys. Those three technologies enable to refurbish and reuse the retired buckets, which resulted in life extension.

2. Technical Contents

Fig. 1 shows the creep life of a refurbished bucket with that of new, retired, re-heat-treated ones. The reheat-treated treatment used the standard heat treatment of this material. The microstructure observation results are also shown in this figure. Those results show the microstructure and the creep life of the refurbished one is equivalent to or better than the new one. Since there are observed to be closed relationship between the coarsening of γ' phases and remaining creep life, the development of this refurbishment technology is aimed to regenerate the microstructure. It is necessary to once solute this coarsened γ' phase to make smaller. However, since typical cast nickel-base γ' phase precipitation strengthened superalloys used for gas turbine buckets contain low melting point elements, such as boron and carbon, as grain boundary strengthened elements, incipient melting due to segregation of these elements is most concerned and partial-solution heat treatment is applied other than full-solution heat treatment. The partial-solution heat treatment is performed at a temperature lower than the solution temperature of a γ' phase, which means the standard heat treatment is not able to regenerate the microstructure. To increase the solution temperature without incipient melting, HIP technology was used. The HIP technology was developed for the purpose of dense forming of a powder article, crush of casting defects and bonding of dissimilar materials, but here is used to increase incipient melting temperature

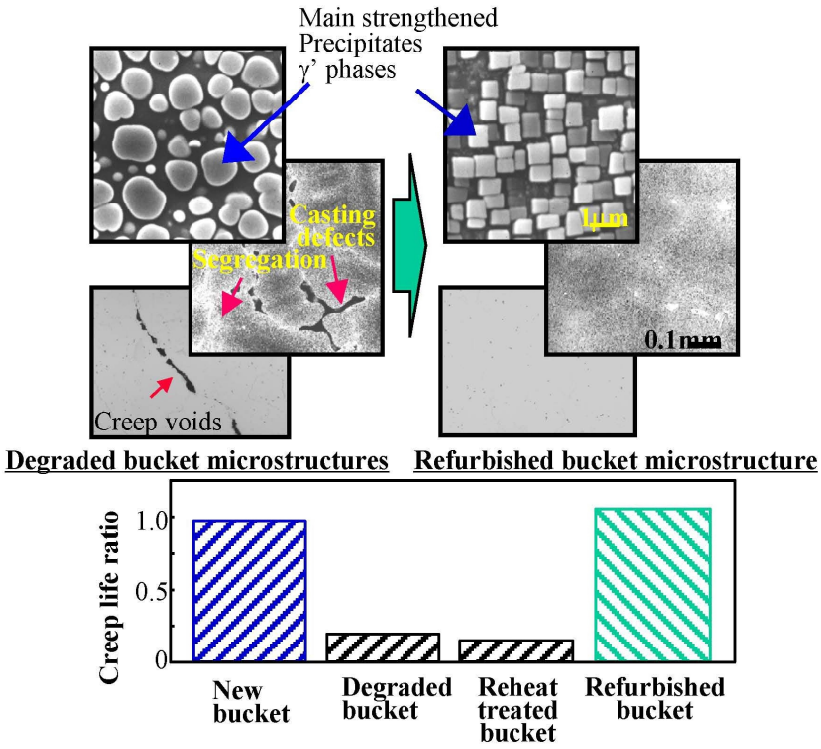


Fig.1 Comparison of microstructures and creep lives in the new, degraded, reheat-treated and refurbished buckets

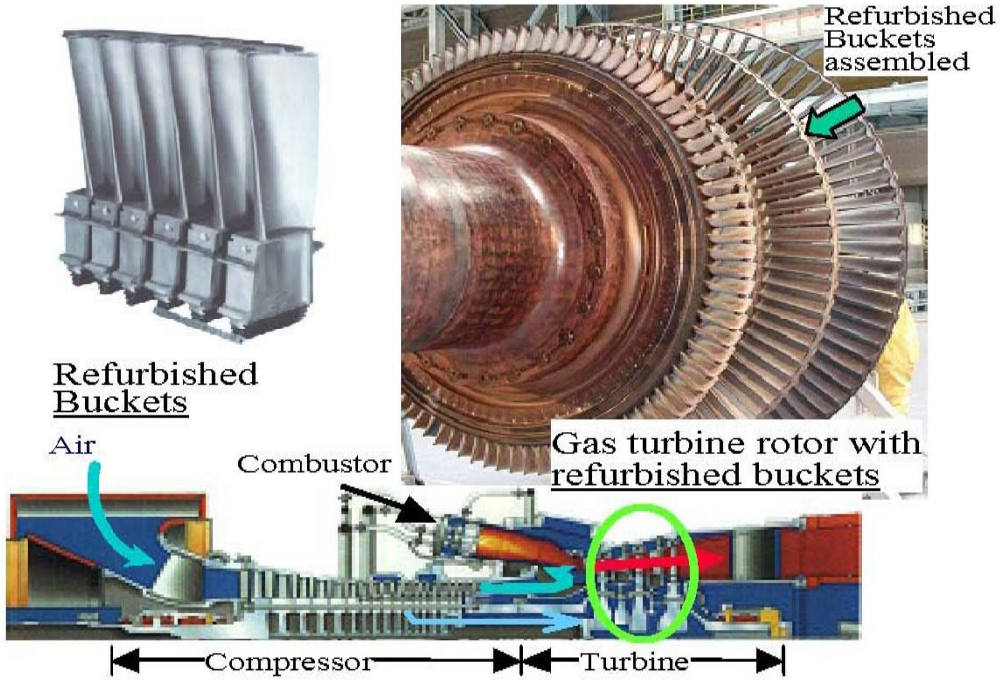


Fig.2 Gas turbine rotor with refurbished stage 2 buckets

and activate diffusion of the segregated elements under the high pressure. Moreover, casting defects, creep voids, etc. are crushed, and recovering aging damages is also expectable, which offer of a refurbished bucket with high reliability more than a new bucket.

To keep the reliability of a refurbished bucket about the same as a new one, the configuration of the bucket should be reformed to an original one. Although 2nd and 3rd stage buckets has a tip-shroud which protects the airfoil distortion by contacting with the neighbored bucket ones, creep deformation occurs during operations and the phenomenon which is unable to secure sufficient contact area. The technology which fixes a bucket tip shroud configuration in an ambient temperature using a hydraulic press was developed. While the buckets material was low ductility of around 3% in tensile elongation at ambient temperature, the amount of press should be carefully controlled. The relation of the amount of press with that of spring backs and the limitation of press to cracking are developed beforehand. Here the fulcrum is moving during pressing not to always press at the same point.

As for the life assessment of a bucket, microstructure methods by using the changes of a γ' diameter and an inter-particle distance have been developed to estimate the metal temperatures and creep lives. The analyses-base life assessment method was modified by using those microstructure estimation results and has been establish. The life consumption diagram for the new buckets was developed as a base line. Life assessments of refurbished buckets were performed and the method for a refurbished one has been also established.

3. Summary

The refurbishment and reuse technology of gas turbine bucket which is registered as a trademark of "BLE Process™" has already applied to 12 gas turbine machines, about 1000 buckets (Fig. 2), and the number of machines is being expanded one by one to the timing out of which the buckets reached a management life come out. Since large life extension is expectable by applying it repeatedly to the same bucket, the economic effect is large, and since it can refurbish without melting and refinement, it is also expectable from the viewpoint of LCA and the amount curtailment of CO_2 discharge.

SOPHISTICATED FUNCTION-INTEGRATED MOTHER MACHINE

(VERTICAL CNC CYLINDRICAL/INTERNAL GRINDING MACHINE FOR FACILITATING PROCESS INNOVATION)

Noboru Watanabe, Taiyo Koki., LTD

1. OVERVIEW

On a machine tool, the form-generating function can be achieved by the combination of linear and rotational movements, and the bedway grinder has been used since 1960's to machine the structural body component that provides the reference surface for linear movement. In closer relation to the rotational movement, however, there have been none equivalent to the bedway grinder so far across the whole world. The machine developed and having been merchandized is thus that of vertical CNC cylindrical/internal grinding machine to machine the reference surface of the structural body component relevant to the rotational movement , such as the headstock of CNC turning machine and spindle housing of machining center, accurately and efficiently. In short, the machine has been developed as a mother machine for machine tool manufacturers, dare to say "an innovative mother machine for mother machines".

The reference surface for rotational movement has been so far machined by the conventional horizontal grinding machine, and as can be readily seen, the conventional machine can not be accommodated to machine simultaneously the outer, inner and shoulder face. To enable satisfactory results in grinding operations, we changed the engineering approach by discarding the conventional machine tool concept and duly adopted the vertical structural configuration. Based on our challenging concept, we have succeeded in developing a new grinding machine that has more excellent functional and performance specifications than those of conventional grinding machines. In fact, the machine has several new features like the one-chucking grinding function that makes wheel changes and setup changes unnecessary, compact structure and higher usability and flexibility. Figs.1 and 2 show the machine developed. In addition, this new machine makes a great contribution to the innovation of the production processes of the machine tool that is at the core of production systems.

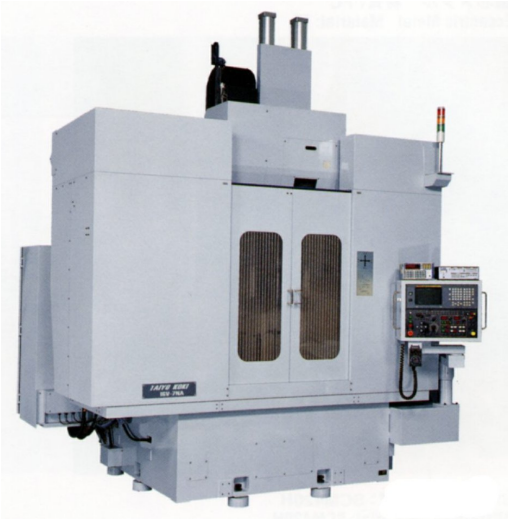


Fig. 1 Vertical CNC Cylindrical/Internal Grinding Machine of New Structural Configuration

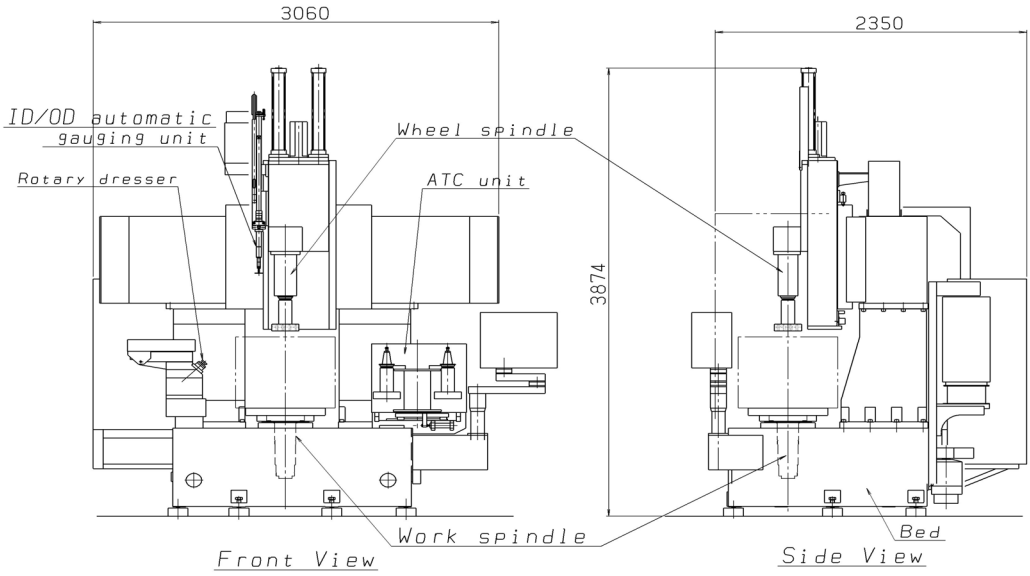


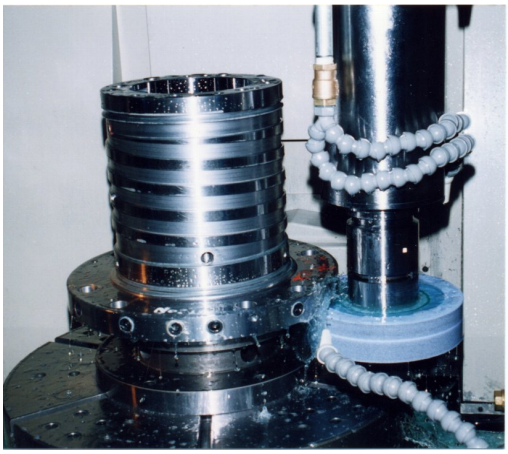
Fig.2 Schematic View of Machine

2. DETAILS OF TECHNOLOGY

Within a grinding machine context, the horizontal grinding machine has been in leading position. In contrast, the machine developed can be characterized by the vertical allocation of its work spindle and wheel spindle. The wheelhead, in which the wheel spindle is mounted, is numerically controlled both horizontally and vertically in the simultaneous 2-axis control mode. Adopting the vertical structural configuration can simplify the centering of medium to large-sized workpieces for grinding. It has also realized drastic reductions in setup time and enabled highly accurate grinding. In addition to these advantages, we have adopted new but essential ideas for designing the machine from the standpoint of functions and structural configuration to achieve highly accurate and efficient machining.

(1) Vertical work spindle and rigid wheel spindle

In the horizontal grinding machines, the work spindle is liable to deform due to the self-weight of the workpiece, resulting in the difficulty of improving markedly the grinding accuracy. The concept of vertical spindle can minimize the influencing magnitude of various causal factors for the deterioration of the grinding accuracy together with successfully stabilizing the machine. An example of highly accurate roundness obtained in grinding by this machine is shown in Fig.3. The vertical structure has also a beneficial aspect to be able to increase the work spindle diameter.



Roundness
- ϕ120 mm Internal(ID) : 0.65 μm
- ϕ170 mm External(OD) : 0.55 μm

Cylindricity
- ϕ120 mm Internal(ID) : 1.5 μm
- ϕ170 mm External(OD) : 1.5 μm

Concentricity
- ϕ120 mm and ϕ170 mm : 0.85 μm

Surface roughness
- ϕ120 mm Internal(ID) : 1.16 μm Rz
- ϕ170 mm External(OD) : 1.80 μm Rz

Fig. 3 Grinding Example – Spindle housing of machining center

(2) Multiple-process grinding with one-chucking

A cup-type wheel, generally used in surface grinding, is applied to the efficient multiple-process grinding,e.g.,cylindrical,internal and shoulder face grinding by contriving some new grinding technologies.

(3) Rigid structure and its remedies for thermal deformation enabling highly accurate and efficient grinding

The rigidity of the structural body component such as the bed and column is enhanced by ribs and partition. Comprehensive means for reducing the thermal deformation are adopted in regard to the heat sources in the machine structure : isolation of heat sources by separating the motor from the machine body and by providing air gaps, cooling by ventilation, forced circulation of temperature-controlled oil using oil jacket, thermal displacement control by scale feedback, and so on.

(4) Compact configuration and higher accessibility to machine and workpiece

Making the most of the advantage of the vertical spindle construction, the floor space and machine width can be minimized resulting in the compact machine to be reality. At the same time, due consideration has been given to the usability of the machine by ensuring the accessibility to the workpiece and machine.

(5) Integration of system functions for automatization

The machine can be characterized by its expandability to the flexible grinding cell by providing various system functions ranging from the automatic wheel changer, and tool magazine, through on-machine automatic measurement and wheel dresser to the automatic pallet changer.

3. SUMMARY

The machine developed and having been merchandized promotes the process innovation in the industrial sector especially in the machine tool industry, which has the world's largest production yield. It can be considered that the machine makes great contributions to the global competitiveness reinforcement in the market, rationalization in the production and further development of production technologies. In addition, a variant of smaller-size has a turret mechanism to index the grinding spindle, enabling it to meet the needs of finish grinding of mass-produced parts. As a result, the machine can satisfy the demands in the automobile related industries, such as growing importance of compactness, increasing flexibility and accommodating general purpose-oriented function. In fact, our machine is now becoming popular and widely accepted even by automobile manufacturers. Therefore, the machine is expected to expand its range of application into the medium to large-volume manufacturing markets.