Featured Articles

“Monozukuri” Technology for Home Appliances

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OVERVIEW: This article discusses “motor technology” as a core technology behind home appliances, and “inverter technology”, which is used to control motors and electric power, introducing issues and unique technologies by exploring the example of washing machines (front-loading washer dryers). The “cellular manufacturing” method of manufacturing washing machines and vacuum cleaners is also introduced as a production technology that can be used to very efficiently manufacture developed products, along with a new “Monozukuri” (manufacturing) production technology based on using molds fabricated with 3D printers. These monozukuri technologies support the realization of new value in Hitachi’s home appliances, along with a high level of basic performance and unique features.

INTRODUCTION

AS one might expect from the old saying “Hitachi is motors,” one of the core technologies that supports Hitachi’s home appliances is motor technology. Motors have evolved from induction motors into permanent magnet motors, and the inverter circuits and control software used to rotate the motors have become a new type of core technology.

Inverter technology is also a necessary part of the electromagnetic induction heating used in cooking appliances. Power conditioners for residential photovoltaic power generation systems based on this inverter technology have also been commercialized.

On the manufacturing side, Hitachi has been advancing cellular manufacturing year after year, for which it received the Nikkei “Monozukuri” Award in 2008, and has constructed a unique cellular manufacturing system that is ideally suited for the scale and form of Hitachi’s products.

This article discusses washing machine motors as an example of motor technology, inverter technology and control software, cellular manufacturing of washing machines and vacuum cleaners, and mold fabrication that uses the new “Monozukuri” technology of three-dimensional (3D) printers.

MOTOR TECHNOLOGY

Motors in Home Appliances

Many motors are used in home appliances, and the types of motors applied in each product are determined based on the characteristics required for that specific product. For instance, single-phase alternating current commutator motors are generally used in vacuum cleaners because the characteristics specific to these motors are suited to the operating conditions of vacuum cleaners. In the case of refrigerators and washing machines, however, there is a strong demand for energy-saving appliances, and so although permanent magnet motors are mainly used in both cases, due to differences in operating conditions, installation space, and other limiting factors, their motor configurations differ significantly. Therefore, motors of various different types and configurations are adopted based on the application. The next section introduces the configuration of the type of motor used to drive a washing machine tub and the main requirements it must satisfy, taking a front-loading washer dryer as an example.

Motors in Front-loading Washer Dryers

The main requirements of a washing machine motor are high efficiency and low noise. In a front-loading washer dryer, the power of the motor is transferred to the washing machine tub using a direct drive method to reduce noise. Although this method is highly effective in terms of noise reduction due to the lack of parts, such as gears and belts, it also must be bulky, since the motor is directly coupled to the load during washing and spin drying. The motor that drives the washing machine tub is located at the bottom of the washing machine tub, however (see Fig. 1), and so although there is room in the radial direction, it cannot

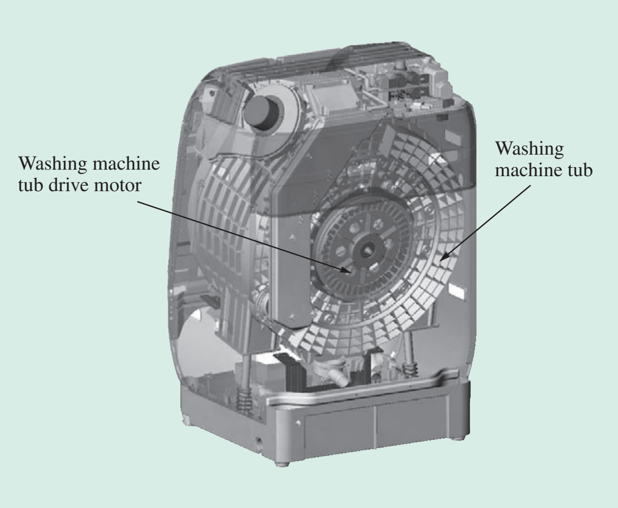

Fig. 1—Structure Image of Front-loading Washer Dryer.
The drive motor is located at the bottom of the washing machine tub.

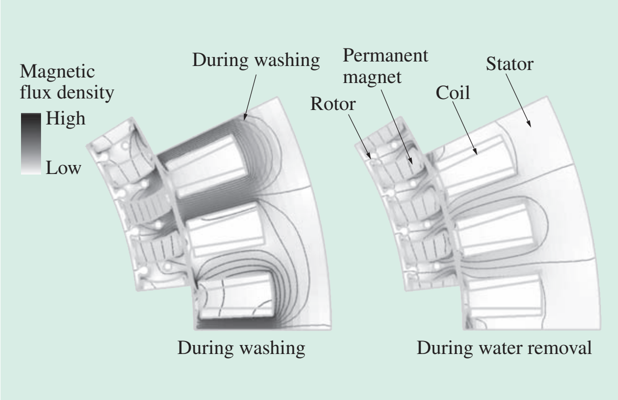

Fig. 2—Magnetic Flux Density Distribution during Washing and Spin Drying.
Magnetic flux density distribution is shown for low-speed, high-torque washing, and for high-speed, low-torque water removal. Field-weakening control is used during water removal to lower the magnetic flux density.

be made large in the axial direction. For this reason, these types of motors are constructed to have a large diameter and a slim, flat shape.

In addition, a single motor using the direct drive method must work well under different operating conditions, because although low speed and high torque are required during washing, high speed and low torque are required during spin drying. Therefore, to adapt a permanent magnet motor to the high torque required for washing, the permanent magnet's flux density must be designed to be high during washing, and also so that the flux density inside the motor can be controlled with field-weakening control when removing water to enable a high rotational speed. For this reason, magnetic field analysis is used to calculate the operating states during both washing and spin drying (see Fig. 2), and the shape is optimized based on the motor characteristics of both operating states. In other words, the permanent magnets are arranged in a spoke layout to facilitate increasing the flux density and controlling the field-weakening, while at the same time, the shapes of the periphery of the rotor core and the stator core's teeth are optimized to reduce the cogging and pulsating torques that cause vibration and noise.

Fig. 3 shows a developed 56-pole, 42-slot permanent magnet motor that uses concentrated winding in the stator's winding wire to shorten the coil end. A segmented core structure is used in the rotor core from the perspective of inhibiting leakage flux in the permanent magnet, and in the stator core from the perspective of the utilization rate of the materials.

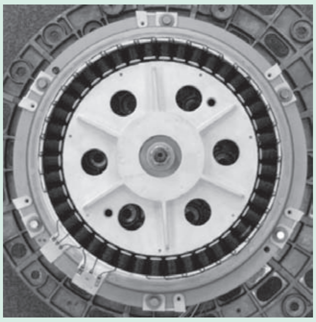

Fig. 3—Washing Machine Tub Drive Motor for Front-loading Washer Dryers.
This motor is a 56-pole, 42-slot permanent magnet motor with concentrated winding.

Because motors for home appliances are designed within limitations such as installation space, while at the same time providing the characteristics required for the product, they differ widely depending on the application. Hitachi will continue pushing forward with developing motors for use in high-performance home applications with a focus on market needs.

INVERTER TECHNOLOGY

Inverter Control Technology Supporting New Functions

Inverter control in home appliances is a core technology that determines product performance in fields such as saving energy. It is also a technology that greatly contributes when it comes to implementing new functions that meet a diverse range of consumer needs.

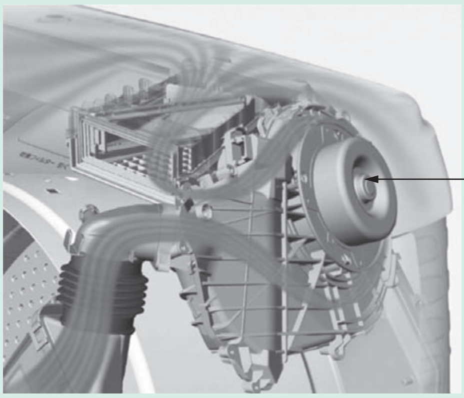

Fig. 4—Turbofan Motor for the "Wind Iron."
This permanent magnet motor is used to create high-speed air flow of approximately 300 kph for use by the "Wind Iron" drying function.

Inverter Control Technology in Front-loading Washer Dryers

Hitachi's front-loading washer dryers use three permanent magnet motors to implement functions that are unique to Hitachi. Each function is controlled by an inverter.

One of the functions of the inverter is to control the motor used to drive the washing machine tub (see Figs. 1 and 3). Vector control for washing machines was developed and adopted for use in implementing three different operating conditions: washing (low speed and high torque), spin drying (high speed and low torque), and braking.

Another is to control the turbofan motor used for drying (see Fig. 4). To enable a maximum motor rotational speed of 14,750 min^{-1} (as of August 2014), the magnetic pole position is estimated with the shunt resistance, which is used for current detection to protect the driver, and control the motor (see Fig. 5).

Water that collects at the bottom of the drum is circulated using a circulation pump motor and control method that can achieve a high washing ability with a low amount of water. This motor can be operated simultaneously with the turbo motor by vector control using single microcomputer.

In addition to motor control in washing machines, Hitachi has also developed unique control methods including induction heating (IH) cooking heaters, and photovoltaic power systems.

Inverter Control Software Development Process

Hitachi uses a control system model-based development environment that incorporates in-house software with commercial tool "MATLAB/Simulink"*1 house in the development of embedded software for inverter control in products released in or after FY2010. This system enables simulation based on designed control models along with automatic source code generation. As a result, not only is human error eliminated during coding, but the readability of the source code is improved as well, leading to increased quality and productivity (see Fig. 6).

Applications are also currently being expanded in fields such as the control of residential photovoltaic power generation systems and induction heating cooking heaters.

CELLULAR MANUFACTURING

"Cellular manufacturing" is a production method that mainly deals with product assembly as a "Monozukuri" technology for home appliances. This production method has dramatically improved productivity.

*1 MATLAB and Simulink are registered trademarks of The MathWorks, Inc.

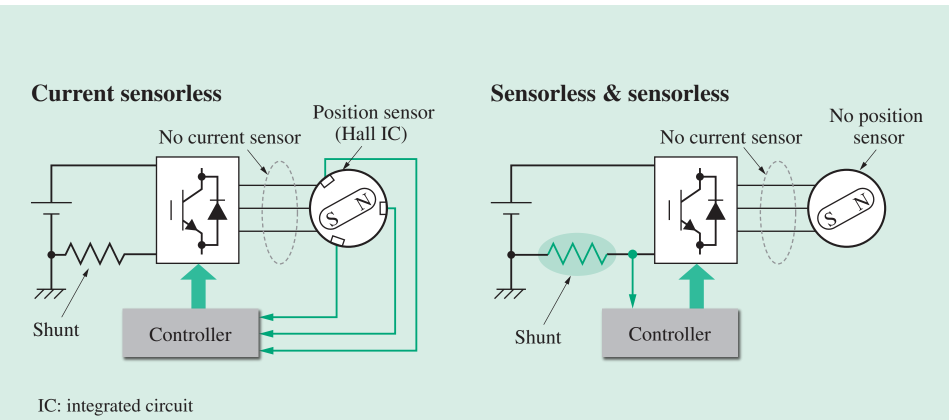

Fig. 5—Sensorless & Sensorless Magnetic Pole Position Detection Method Used for Turbofan.
The current sensorless method previously used for magnetic pole detection (left) is compared to the newly adopted sensorless & sensorless method (right).

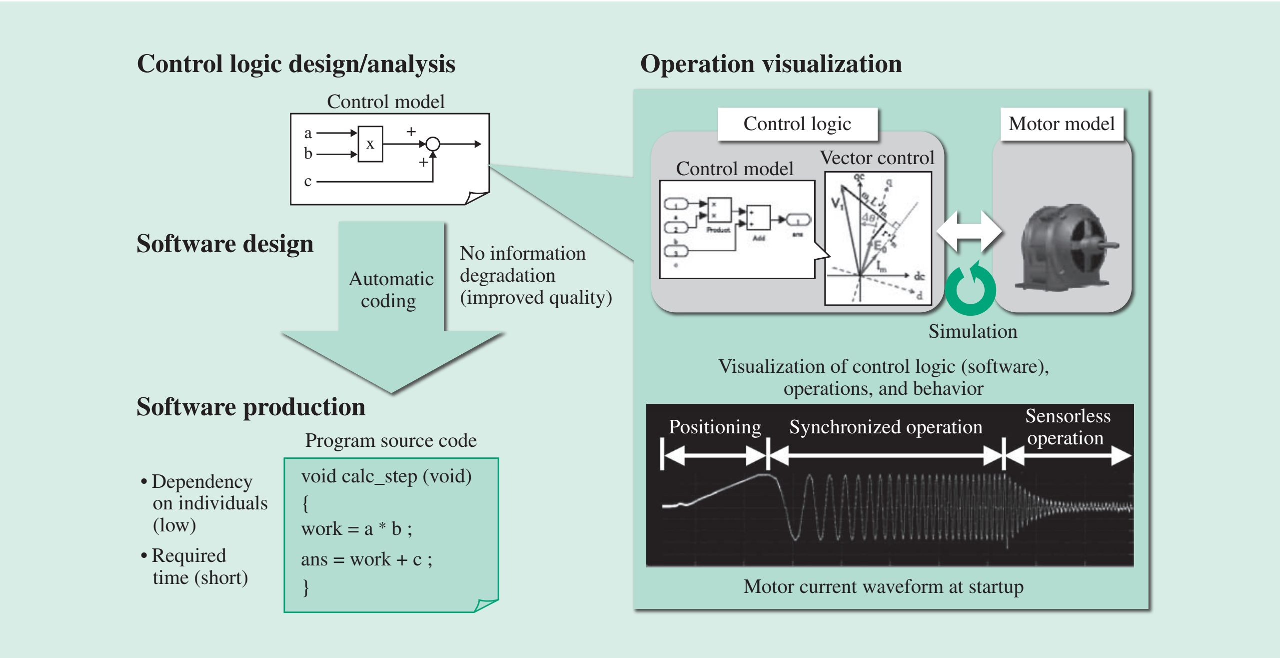

Fig. 6—Development Process Using "MATLAB/Simulink."
Reliability and productivity are improved through an automatic program generation function that works from the control logic, and a simulation function.

"Cellular manufacturing" is a "highly self-contained production method whereby one or several workers are assigned to building the target product or unit assembly all the way until completion," reduces in-progress work between and within processes, eliminates lost time due to switching between production models, and minimizes processing time.

Cellular manufacturing is not limited to a single fixed form, but rather takes a wide range of different forms based on factors such as the product's structure and configuration, the number of parts, the number of production runs, the frequency of model switching, dedicated production and testing facilities, and worker proficiency. Cellular manufacturing can be broadly divided into classifications that include the segmentation cell method, the patrolling cell method, the single person cell method, the inline cell method, and others.

The basic concept is to not have interim works in process based on a fixation with one-by-one production. It is also necessary to eliminate wasted time in everyday work after switching to cellular manufacturing, and important to pursue operational economics based on the traditional industrial engineering approach[*2]. Cells only generate benefits and become usable after mechanisms and automation are included.

*2 Engineering methods aimed at streamlining integrated systems that include people, materials, facilities, and so on.

Front-loading Washer Dryer Cellular Manufacturing (Cell Segmentation Method)

Due to the structure of washing machines, they contain large parts, and the method for supplying these parts has been problematic. To prevent this from interfering with assembly work, it was decided to supply these parts to workers from above (from the second floor).

Product assembly is split into three blocks that are treated as a single team (consisting of one to three cells), with ten teams comprising one line. A number of meticulous improvements were made to thoroughly synchronize the work balance between individual teams (the cycle time for three cells), including the automation of parts supply, a position optimization mechanism for products, measuring work time, and monitoring formation efficiency of each block and all cells. The dynamic production state management of the production management monitor makes it possible to understand the progress of work and the state of the formation in realtime to enable pre-emptive management and generate a "spiraling up" of improvement, with productivity improved by 44% (see Fig. 7).

Vacuum Cleaner Cellular Manufacturing (Single-person Cell Method)

Vacuum cleaners are assembled one at a time by single workers in a single-person cellular manufacturing

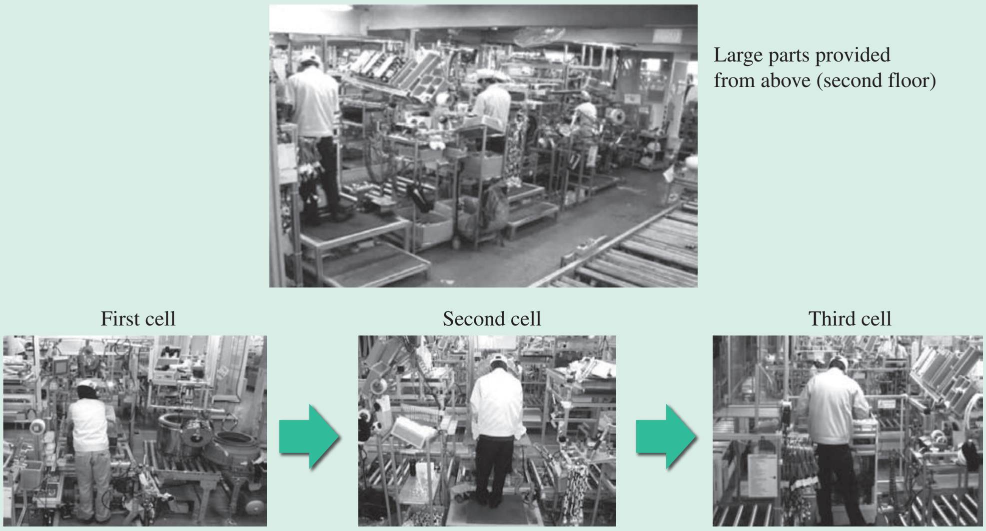

Fig. 7—Front-loading Washer Dryer Assembly Cell.
The three-person group cell segmentation method was used to implement improvements by bringing large parts to hand just in time with an automated mechanism, and by always automatically measuring the assembly takt time.

method. The parts for a single vacuum cleaner are inserted into a special case before they are supplied, and a compact conveyor belt is used to achieve both taking parts in advance and having parts on-hand. The addition of mechanisms such as an automatic removal mechanism for empty parts cases and a mechanism that automatically brings tools to hand (presenting them only when necessary), as well as a device installed to monitor the number of units, all increase the level of completion. To minimize the amount of walking and the number of operations required by parts supply personnel, supplies are consolidated in a single location, and shuttles with part-conveyance mechanisms (two-way dollies with transport mechanisms) travel back and forth between each cell. Efficiency was improved through the adoption of these cellular manufacturing methods, mechanisms, and parts supply improvements, increasing productivity by 40% (see Fig. 8).

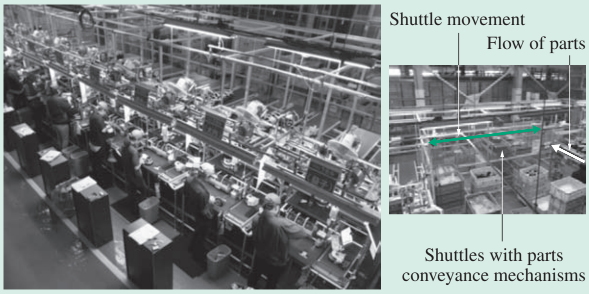

Fig. 8—Vacuum Cleaner Chassis Assembly Cell.
One person per unit completion assembly cells are shown (10 cells). Improvements were implemented by adding mechanisms to cells along with shuttles to supply parts from the back.

MOLD FABRICATION WITH 3D PRINTERS

Internal production of molds through the use of 3D printers in metal optical molding began as part of the development of products for FY2014.

Conventional mold fabrication involves machining parts, assembly, and adjustment, but the introduction of 3D printers has triggered a reformation whereby complicated cooling piping structures can now be fabricated using an "integral molding" method. With this method, metallic powder is hardened using a laser in order to add layers that are 0.05 mm thick, one layer at a time, while gradually forming an intricate 3D mold in a fully automatic fashion (see Fig. 9).

This method reduces the mold fabrication time by approximately 30% over previous methods. Also, a reduction of approximately 20% over previous methods was achieved in the cooling time that occurs during forming by efficient water cooling through a complicated path inside the mold (see Fig. 10).

Progress is also under way in expanding the use of this method to fabricate propeller fan molds for air conditioners, as well as towards application in large air conditioning systems.

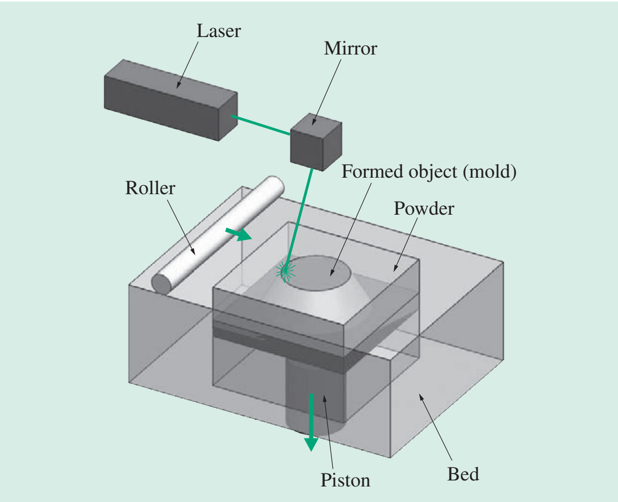

Fig. 9—Processing with 3D Printer.
Uniformly spread metallic powder is sintered into any shape with a laser. Repeated layering is used to enable mold fabrication with an internal structure.

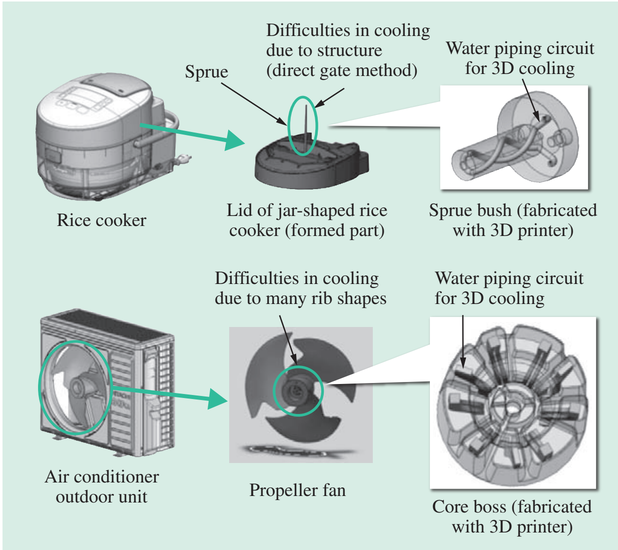

Fig. 10—3D Printer Use Cases.
Cooling time during formation is greatly reduced through the optimal placement of 3D cooling water piping inside the mold part.

CONCLUSIONS

This article introduced "Monozukuri" technologies for supporting and creating a high level of basic performance along with unique functions, including motor technology (washing machine motors), inverter technology (washing machine motor control), cellular manufacturing (front-loading washer dryers and vacuum cleaners), and mold fabrication using 3D printers.

These technologies are being used in the production of other home appliances as well, either in the same manner or with modifications. By developing products while advancing the technologies used to create them on a daily basis at the same time, Hitachi will continue to pursue the "monozukuri" technologies needed to manufacture attractive products.

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