

# Recreating the Skill of an Expert Technician with Force Control Technology

## Precision finishing robot system

In production, automation brings many benefits, such as high productivity and consistent quality. However, the processes called precision finishing rely on an expert technician's skill acquired from many years of experience, and automation has been considered difficult. By combining our robot control and system integration technologies, IHI has completed a robot system able to automate high-precision finishing processes.

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High-precision finishing robot system

## The urgent need for lack of successors and increased production

Finishing refers to the handwork of finalizing the shape and the surface of a workpiece after machining. Finishing includes various processes such as chamfering (shaving off sharp edges), rounding (making edges round), and polishing (making a surface smooth). The finishing process for precision parts such as precision gears and dies are called precision finishing. Even with the latest machining technology, the processes rely heavily on an expert technician's perceptual skills acquired from many years of experience. For example, some processes include instructions that cannot be expressed numerically, such as "smoothly joined," and these skills have been passed down to new technicians.

Thus far, IHI has been engaged with the automation of production processes in order to improve productivity and quality. In order to deal with factors such as the decrease in expert technicians and the increased demand for precision parts, immediate automation has become necessary, even for the precision finishing process which has been difficult to automate so far.

## Hybrid control that recreates the handwork of an expert technician

Conventional robots and machining centers are configured to move a tool along a predetermined path. This configuration is called position control. On the other hand, an expert technician controls the force during finishing work in order to obtain uniform process along the actual shape of each workpiece.

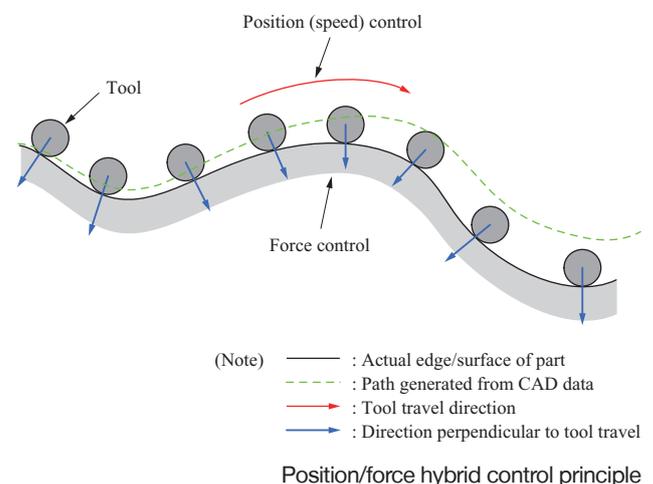
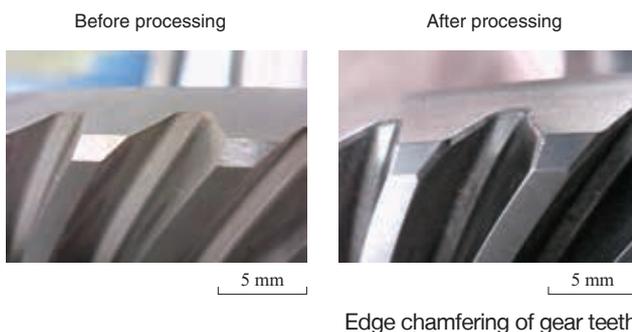
At IHI, we applied a position/force hybrid control which is a combination of position control and force control, and attempted to recreate the work of an expert technician.

The concept for processing using hybrid control is as follows.

- (1) The tool approaches the workpiece, senses the reaction force with a force sensor, and judges when contact is made.
- (2) After the contact is judged, the feed of the tool starts along a process path at constant speed. In this step, the tool is simultaneously controlled by force control in the predetermined direction along the path (typically normal direction of the surface), and by position control in the other direction than the force control direction (see lower-right diagram). The path may be generated from three-dimensional CAD data by CAM.
- (3) At the endpoint of the path, the tool is moved away from the surface in the direction opposite the force direction, and the process ends.

IHI high-precision system additionally implements two other types of control technology. The first is a measurement function to adjust the relative positions of the workpiece and the tool using touch sensing. The function is implemented without additional equipment. To measure the positions, a pin approaches the workpiece until the contact is detected by the force sensor. This is conducted at several points representing the shape of the workpiece to measure the position where the workpiece is installed. Then, the difference between measured and planned position is calculated and robot motion is adjusted. This process enables high-precision processing even if the workpiece is misaligned.

The other control technology is gravity compensation. If the surface of the workpiece is complex, the tool such as the felt abrasive implemented on the spindle motor has to be fed while changing the direction of the tool. The reaction force of the tool from the workpiece must be measured precisely but the force sensor measures reaction force mixed with the gravity of the tool. IHI's gravity compensation technology can separate the reaction force from gravity. This enables the precision force control along the surface of the workpiece with a complex shape.



## Precision finishing robot system to excel in action in production facilities

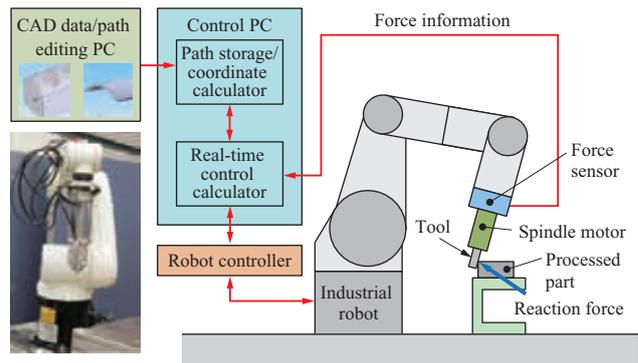
This system has been adopted for the final finishing process of precision gears for aero engines at the IHI Soma No. 2 Works. The system automatically conducts the chamfering and brushing processes after grinding the gear teeth in the diagram below, and is providing results as expected.

The upper-right diagram illustrates the configuration of the adopted system, while the middle-right diagram shows the names of each component attached to the robot arm. Of these components, the measuring pin, the tool, and the spindle motor can be switched automatically. Various pins and tools can be stored in the tool rack. For this reason, by simply selecting a process menu via a touch panel and pressing the start button, the robot conducts the finishing process while switching the tools and the spindles, without requiring involvement from a human worker until the selected process is finished. Additionally, this system applies to abrasive tools used in a finishing process such as grinding stones, brushes and rubber grinding stones. Abrasive tools are easily worn out and their shapes change during the usage. Therefore, by using conventional robots or machining centers, expected finishing quality could not be achieved. Only the IHI High-precision finishing robot system keeps the constant finishing quality even if the size of an abrasive tool gradually changes. The technology of position/force hybrid control is also used in this case and enables the high-precision finishing with a constant applied force.

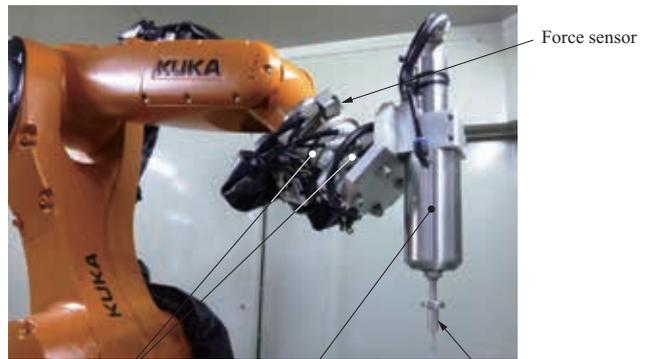
It is no exaggeration to say that the system is like a living expert with the high-precision skillful handwork.

## Aiming for adoption in the polishing process

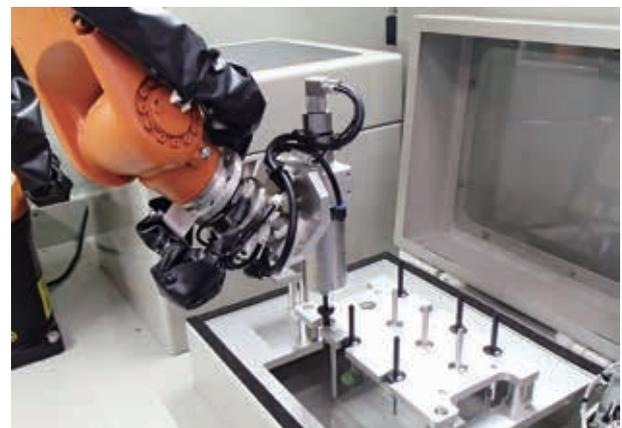
Generally, the process of polishing a rough surface with a complex shape is more time-consuming than edge finishing. Additionally, it is hard to make surface roughness uniform. Therefore, the automation of the polishing process



System configuration

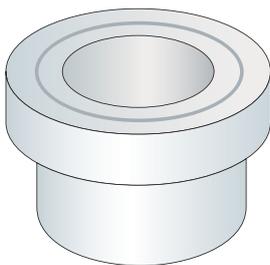


Parts of robot arm

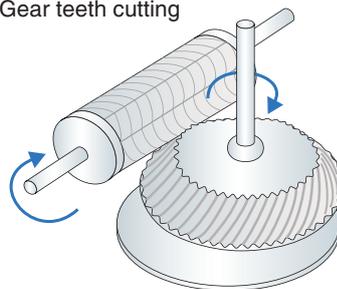


Tool exchange

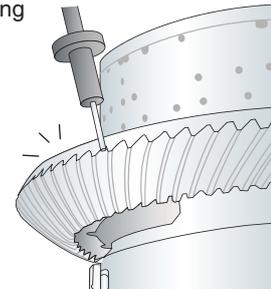
1 Finish turning



2 Gear teeth cutting



3 Deburring



is strongly desired.

Particularly in the case of a die, it is necessary not only to make a rough surface mirror-smooth, but also to satisfy strict precision requirements for the dimension of the shape. The automation of the process is extremely difficult. Because of this, polishing process relies on the highly skilled handwork of expert technicians. The IHI High-precision finishing robot system has potential capability to apply to such process. IHI is developing the technology to automate die polishing process, and successful results were obtained. IHI is constantly working to improve the system in order to reach the skill level of an expert technician.

### A friendly device for anyone who desires automation of high-precision finishing

The IHI High-precision finishing robot system is expected to apply to many kinds of finishing process in other IHI Group plants. Furthermore, IHI has advanced the development to spread the advantages of finishing process automation besides IHI Group companies.

In order to have many users take advantage of the benefits of the automation, it is necessary to simplify the operation. Often in the case of the finishing process, workpieces are produced in a small quantity but with a large variety. Therefore, there is an extremely high demand for adding new types of workpieces or processes. However, compared to conventional position control devices, the operation to add new type of workpiece or process is difficult because there are many complex items such as tool type, force value, approach path/orientation to workpiece, etc. Consequently, at the present time, the operation to add processes needs help from an integration engineer. Accordingly, we are also developing a control interface to add processes easily.

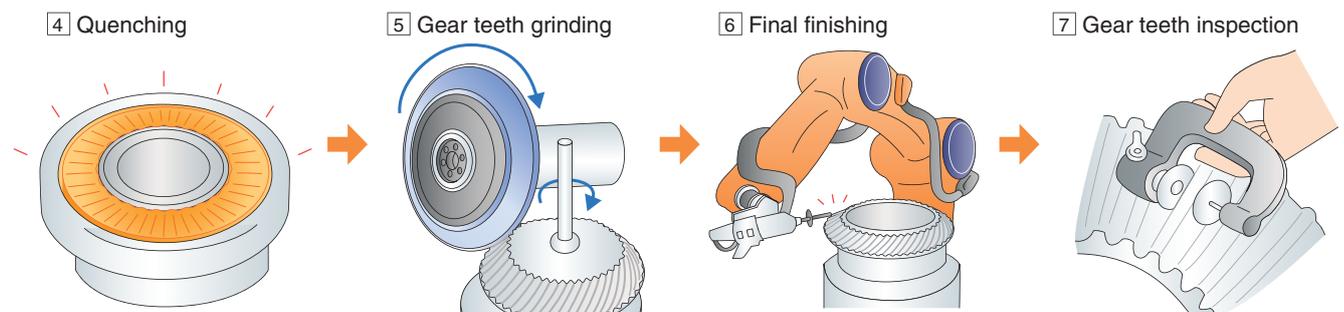
The automation of precision finishing processes brings benefits of reducing workload in addition to ensuring stable reproducibility. The system can reduce worker exposure to dusty environments which can negatively affect worker concentration.

Additionally, the IHI High-precision finishing robot system was also designed with the appearance to fit in to a safe and clean production facility. In the future, we will continue to solve outstanding problems and aim to expand the adoption of this system both inside and outside IHI.

For technical details about this system, please consult “Development of Automation Technology for Precision Finishing Works Employing a Robot Arm,” IHI Engineering Review, Vol. 45 No. 2 (2013), pp. 16-22.

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Gear production process