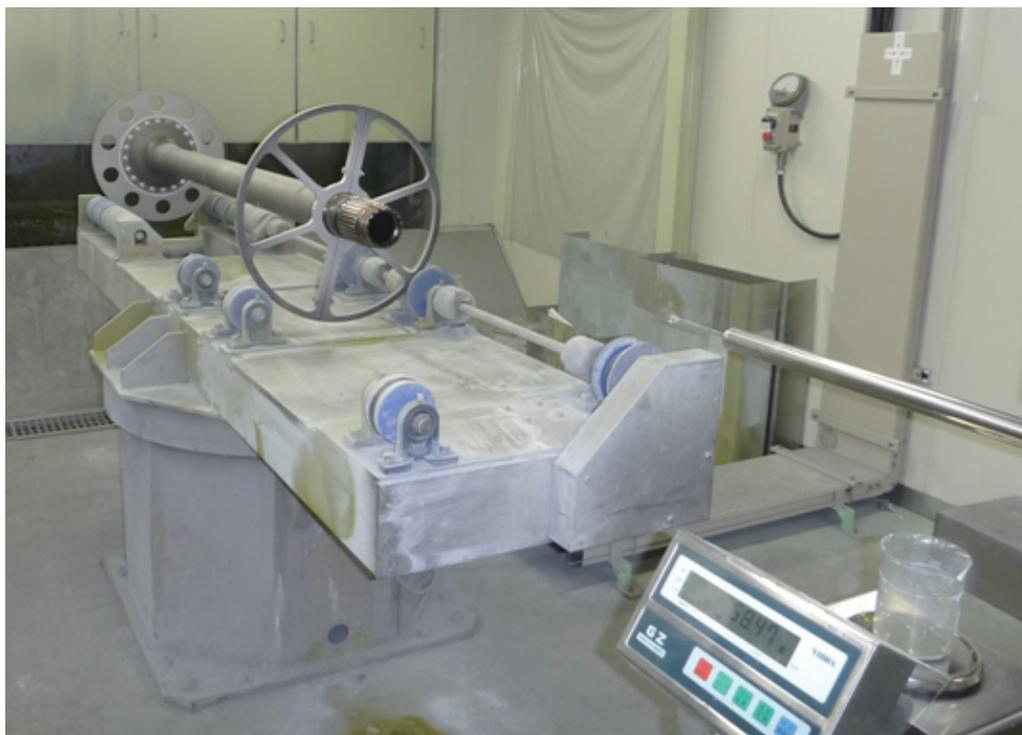


# IHI's Unique Technology Behind Jet Engines

## Automated shaft coating

In the past, jet engine shafts have been manually coated by skilled workers. In the midst of the current situation in which it is difficult to secure skilled workers, we have put an automated coating system for engine shafts into practical use for the first time in the world. The result has been improved coating quality as well as the establishment of a system to cope with a future increase in demand.

Mechanical Technology Department,  
Electrical System Department,  
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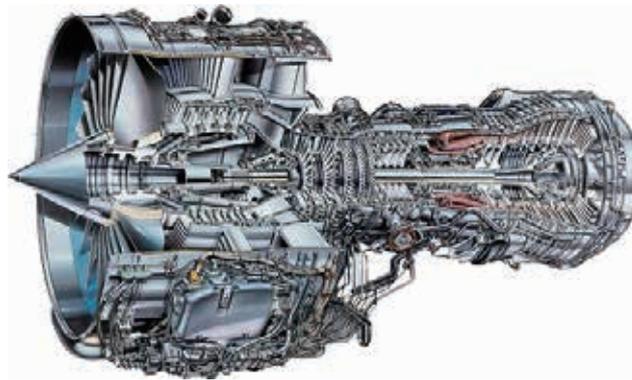


Automated engine shaft coating system

### Coating process developed based on “craftsmanship”

A civil aircraft engine is produced by assembling various parts such as a fan, compressor, combustor, turbine, and shaft that are supplied from respective expert manufactures

around the world. IHI manufactures and supplies parts such as fans, fan cases, compressors, turbines, and shafts to companies around the world. Among such parts, our supply of engine shafts, especially long shafts, accounts for more than 70% of the world-wide supply.



Cross sectional view of V2500 engine  
(Image credit : Japanese Aero Engines Corporation)



Engine shaft

As illustrated in the above view, an engine shaft is not a simple rod-shaped part. They have the important function of transmitting the torque generated by the turbine to the fan and other parts. In aircrafts for which drastic weight reduction is required, reducing the weight of not only airframes but also engines is a major challenge. As can be seen from the cross sectional view, an engine shaft has a hollow structure, and also has a complicated shape, the outer and inner diameters of which are set according to necessary functions and strength, and the wall thickness varies along the axial direction. Since an engine shaft rotates at high speed at temperatures varying from low to high according to the axial position in relation to each section of the jet engine, many special processes such as precision machining, thermal treatment, and surface treatment are used. A coating process for rust-proofing and improving heat resistance is one such process. After being subjected to the various manufacturing processes including the high precision machining, the engine shaft is coated with a special coating material, baked, adjusted to final balance, and then delivered as a product.

In the past, the only way to perform this coating process was manually by a skilled worker. In particular, the inner surface of the shaft is coated by a skilled worker, who carefully performs a subtle feeding operation using a coating spray gun mounted on the tip of a thin tube supplied with the coating material through a hose. The thickness of a coating film must be tens of  $\mu\text{m}$  on average and fall within a given variation limit.

Meanwhile, the coating material contains aluminum powder, and it very easily precipitates, and therefore liquid dripping and clogging are apt to occur. In addition, in a situation where the inside of the engine shaft has complicated changes in shape along the axial direction, it is

difficult to realize a coating film with the required quality.

Such problems have been solved by the “craftsmanship” of skilled workers. Engine shafts have various shapes. Among them, even a short and relatively simple-shaped shaft requires 2 to 3 years’ experience before a worker can coat the shaft by themselves. Indeed, a three-meter long shaft called a “long shaft” for a large engine is said to require more than 10 years’ experience before a worker can coat the shaft. This is because a longer shaft makes it difficult to visually examine the state of the middle of the inside of the shaft, which increases the amount of work relying on experience and intuition.

In the case of manually coating long shafts, which requires the longest working time, even a skilled worker could only coat about two shafts a day. In order to cope with an increase in the production of engine shafts, skilled workers need to be trained; however, it takes a long time to train them. To solve this problem, we started developing an automated engine shaft coating system, something that no one in the world had ever done before at that time.

### **The goal is not the reproduction of “craftsmanship”**

Specifically what is the “craftsmanship” of skilled workers? When a coating spray gun ejects the coating material inside an engine shaft, the volume of the ejection varies depending on the direction. The volume of the ejection also slightly varies depending on temperature, humidity, etc. Furthermore, it is necessary to sometimes vibrate the hose to prevent the coating material from precipitating somewhere in the pressure-feeding process en route from the coating material tank through the hose to the coating spray gun. “Craftsmanship” is compensating for defects in a conventional coating system by human expertise to

achieve the necessary thickness of the coating film.

However, as a result of various studies, we found it difficult to replicate this craftsmanship in order to automate the process. Therefore, we let go of the idea of duplicating human expertise, and decided to invent and introduce a machine system designed for automation. Then, we combined the machine system with a controller based on the up-to-date control method, and replaced a conventional coating system with the new combination, which led to our success in the development of an automated coating system for engine shafts.

The image on the right schematically illustrates the automated engine shaft coating system that has been put into practical use. The factory has an air-conditioned area dedicated to the system to improve the work environment and avoid the influences of temperature and humidity on the coating.

In the past, a procedure was required in which the coating spray gun is moved axially, which ejects the coating material radially in all directions, and then the shaft is rotated by 180 degrees to obtain a radially uniform thickness of the coating film inside the shaft. To achieve automation, an automated coating system was configured such that the coating spray gun is fixed so that the coating material is ejected in one direction (vertically upward), and the shaft is made to continuously rotate instead. This eliminates the disadvantage of the conventional system where the volume of ejection of the coating material varies depending on ejecting direction, and it also eliminates the need to rotate the shaft 180 degrees.

A change in the method of supplying the coating material is also an important point. Since the coating material contains aluminum powder it has abrasive properties, so an ordinary pump cannot be used. For this reason, various methods were tested to search for a mechanism and system that were able to stably pressure-feed the coating material without precipitation, and finally a new tube pump

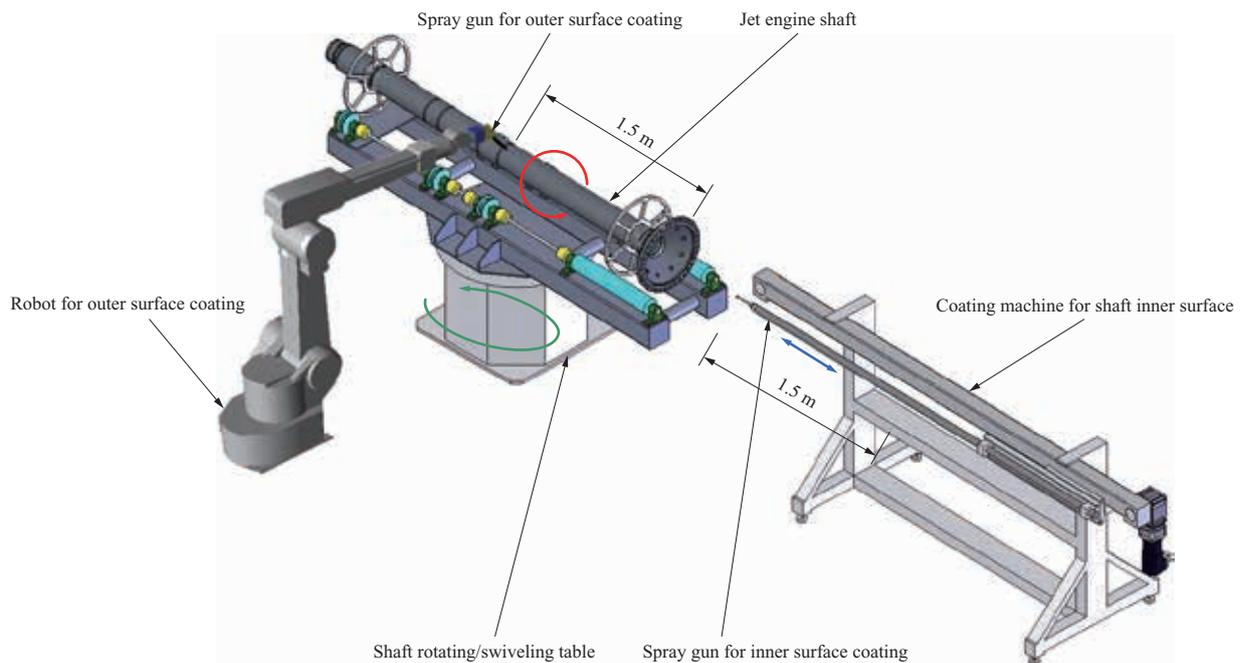
pressure-feeding method was devised and adopted. In the tube pump method, a roller rotates to squeeze an elastic tube to extrude the coating material inside. One rotation of the roller extrudes a constant volume, which enables accurate volumetric supply, and therefore the tube pump method is also used for artificial hearts, etc. Advantages of this method are that the rotational speed of the roller can control the volume of the supply, and in addition to this, the flow speed can be increased by decreasing the diameter of the tube for transport, which can prevent the coating material from precipitating even when the flow rate is small.

The part that required the most creative thinking in this development was the adjustment of a control system. The coating spray gun is axially moved in the rotating engine shaft, which means that the coating is applied in a spiral. The thickness of the coating film is determined by the rotational speed of the engine shaft, the moving speed of the coating spray gun, and the ejection rate of the coating material. However, the greatest challenge was how to realize suitable coating conditions for areas where the inner diameter varies axially, and thereby make the thickness of the coating film fall within the required range. In the past, the coating of such an area has relied on the “craftsmanship” of a skilled worker.

To overcome this challenge, a flat plate was used as a test piece to obtain basic data on the thickness of the coating film under parameter conditions including the rotational speed of the engine shaft, the moving speed of the coating spray gun, the rate of ejection of the coating material, etc. On the basis of this data, coating conditions for an actual engine shaft were set, and a control system that carries out the operations according to these coating conditions was designed. Then, the control system was applied to an actual engine shaft, after which it was adjusted and improved. Overcoming difficulties in adjustment and improvement, we finally succeeded in achieving the desired thickness for



Coating work done by skilled worker



Schematic view of automated engine shaft coating system

the coating film.

Engine shafts are also coated on their outer surfaces, but this coating is simply conducted by commercially available industrial robots.

### **Aiming at further quality improvement to cope with increase in demand**

Development of the automated engine shaft coating system has significantly increased productivity, especially in coating process of long shafts. In the past, the maximum number of long shafts that could be coated in one day has been two. However, after the introduction of this automated system, the time necessary for coating one long shaft has been decreased to about two hours.

Our automated coating system has another advantage: improved quality, specifically referring to the improvement in accuracy and uniformity of the coating film thickness. Automation opens up the possibility of achieving a level of accuracy that exceeds “craftsmanship.” This will probably eliminate the need for balance adjustment processing after the coating has been applied. Balance adjustment refers to the fine adjustment of mass distribution of an engine shaft. If the mass distribution is not symmetrical about the rotational axis, vibration due to centrifugal force occurs while it rotates.

Although the coating work has been automated, the role of skilled workers is still important. In addition to long shafts there are other types of engine shafts, and therefore, to automate the coating work for all of them, the optimum settings need to be identified for each type of shaft. For high-mix low-volume production, skilled workers are

in charge as before, whereas for mass production, the automated coating systems is used, and this allows flexible production plans to be realized.

In addition, in order to produce high-quality engine shafts, IHI employs various advanced technologies for improvement of machining accuracy, special surface treatment, etc. including the automated engine shaft coating system. Such efforts are highly praised, and we have received the “Supplier Gold Award,” which is presented by Pratt & Whitney Corporation, one of our engine shaft customers, to excellent parts manufacturers.

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