Vertical Machining Center DCV50 for Die Mold Cutting

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In order to hold advantage over the cheap Chinese products the die mold cutting industry in Japan where vertical machining centers are mainly used has come up with manufacturing complicated high-precision die molds in a short delivery term. The machine tool manufacturers have responded to such demands by introducing machining centers equipped with various complicated functions. However, they have still not been able to satisfy the customers. Paying reconsideration to the machine concept based on the current requirements for die mold cutting, Mitsubishi Heavy Industries, Ltd. (MHI) has successfully developed a Machining Center DCV50 simple in design but capable of stable, high-precision cutting. The outline of the machine is introduced below.

1. Introduction

In response to the upcoming of China, the mold industry and high added-value parts machining industry in Japan are struggling for survival by manufacturing more complicated parts of higher precision in a shorter delivery term. However, the machining precision and short delivery term are the key factors to the capacity of the machining center.

The vertical machining center M-V∑ launched in the market by MHI under the brand name of "Σ Series" is equipped with high-precision and almost all required functions, so that the machine falls short of meeting the high-end requirements of the customers including the cost performance.

MHI has therefore developed a machining center simple in structure but capable of long-term stable, high-precision machining equivalent to VΣ by reviewing the conventional functions in order to respond to the needs of the customers. This paper describes the needs of customers and the corresponding technologies thereof.

1.1 Current demands on die mold cutting

The works in die mold cutting in Japan have generally come to be smaller in size, while the precision and delivery requirements are becoming stricter, so that the industry is corresponding to the demands for high precision and short delivery term through integration of arrangements, execution of machining needing no finishing by using high-speed spindle, automation of work exchange and work control using ID chips, and by introducing various other functions. An increasing number of mold manufacturers are responding to short delivery term by purchasing the rough machined products from overseas and carrying out only finishing machining.

As for the machining, the micro-machining using tools with smaller diameters is increasing, causing the machining time using 1 piece of tool to get longer. Accordingly, higher precision of machining and stability performance for long-term continuous operation has been increasingly demanded.

According to the present trend, the dissatisfaction of the mold users in terms of the quality of machined surface and work shape is mostly attributed to the inadequate stability of the machine against the precision requirement.

1.2 Present trends in machine tool

In order to respond to the aforesaid demand for long-term machining precision stability performance, each manufacturer has adopted correction as a countermeasure against thermal displacement, a method used also in MHI ∑ Series.

The correction here refers to a method of making correction of axial travel using a certain corrective formula, with the temperatures near the heat source, the main cause of thermal displacement, as a parameter. The correction, however, differs according to the factory environment, so that independent adjustment under the environment of each factory is necessary. In addition, the higher the demand for precision is, the larger the number of measuring points becomes, practically making the control more complicated.

There is a limit to the control of correction. The precision including spindle, thermal displacement of the unit is generally limited to +/−5 μ m, falling far short of the actual requirement from users for machining precision: +/−2 to 3 μ m. Further high precision requirement is expected in the future, calling for a solid countermeasure.

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2. Technology for long-term, stable precision

2.1 Key points of high-precision machining

With the controller and ball screw drive system becoming highly accurate, the difference in positioning precision of feed mechanism is becoming less conspicuous among companies, so that the heat restraining technology to maintain the long-term high precision is considered to be a technology for differentiating the company from the other companies.

The technology often uses two types of correction for thermal displacement correction: (1) the correction of change in machine posture (position) due to temperature change in the factory, spindle speed, etc. made in the direction of feeding axis and (2) the correction of the elongation of the spindle itself caused by the heat due to rotation of the spindle.

However, with the machining precision requirement from the users becoming stricter, the manufacturers have still been unable to come up with guaranteed values after thermal displacement correction or the permissible value after the thermal displacement correction is considerably high against the requirement. Thus, an established technology is still to come.

As a provisional countermeasure, therefore, there are many cases where this correction is made invalid at the time of high-precision machining. Instead, high-precision machining is carried out after maintaining the thermal balance of the machine through a long-term warm-up operation.

Although the warm-up operation appears a waste of time and contradictory when viewed from the standpoint of the demand for short-term delivery of molds, in view of long-term machining of molds and taking into consideration the re-machining of the mold due to defective precision at the finishing process inflicting large effect on the delivery term, it can be regarded as an unavoidable option for the users, considering the present levels of technical prowess of each manufacturer. However, improvement to this regard is an imminent need.

In order to ensure stability of machining precision essentially required in long-term machining, MHI has made a re-study on the countermeasure, returning back to the original point and starting mainly with the heat generation.

2.2 Objective of the new function

2.2.1 Restrained heat generation through review of spindle cooling circuit

The stability of spindle against heat during long-term operation is extremely important in die mold cutting where machining is carried out continuously at a high-speed spindle rotation over a long time period. Further, since correction only cannot meet the recent precision requirement, the shortening of the time up to the thermal balance without making any correction plays a key role. Hence, the standard spindle internal cooling circuit has been reviewed in the vertical ∑ Series.

In the Σ Series where attention is focused to the Z-axis that inflicts biggest effect on the machining precision, i.e. the restraint (prevention) of spindle elongation due to heat generation, a constant-temperature coolant is circulated inside the spindle in synchronization with the machine temperature to restrain the spindle elongation caused by heat generation. However, because of the constant-temperature control inside the cooling unit, it is unresponsive to the spindle heat generation, causing follow-up delay to occur.

The new circuit adopts a control system for cooling down only the heat generated in the spindle to restrain the heat generation. The result of pre-verification by using a spindle of 30 000 min^{-1} has clearly shown that the elongation caused by heat generation can be restrained to below a certain level through synchronized control of the coolant discharged from the spindle internal cooling circuit with the main body temperature by using the aforesaid circuit. Further, in order to improve the trackability (follow-up property) against temperature, the temperature controller has been replaced with the inverter control system capable of estimating the cooling capacity from the volume of heat generated in the spindle to follow up. **Fig. 1** shows the spindle cooling circuit diagram.

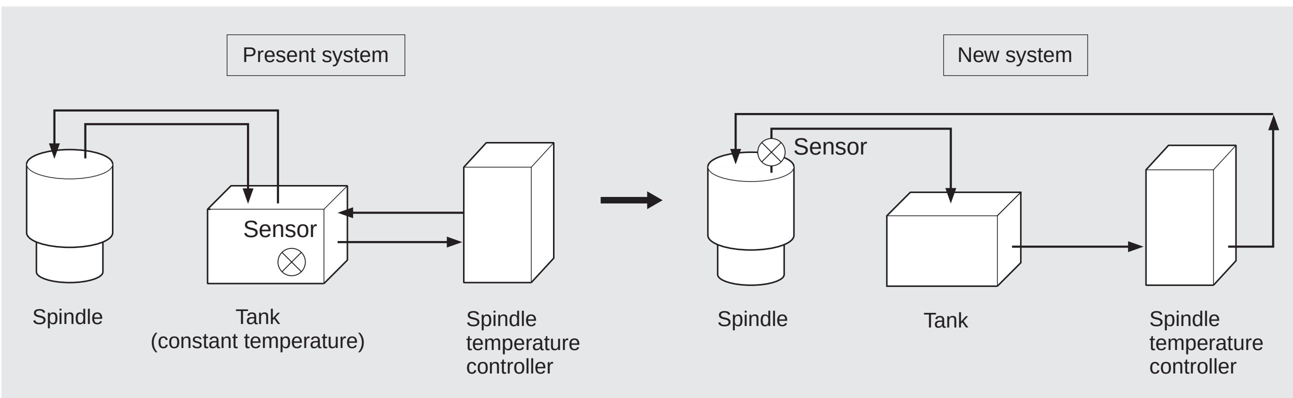

Fig. 1 Main spindle cooling circuit

DCV50 is equipped with a 20000 min^{-1} spindle. The confirmation test for verification using the actual machine shows the elongation along Z-axis due to spindle heat generation gets shortened approximately to one-third: from 65 μm to 20 μm when the spindle is operated at the maximum speed of 20000 min^{-1}.

Furthermore, the time needed for reaching the state of thermal balance by using the new system has been shortened to 20 min. against 60 min. by using the present control system, with the time shortened to one-third. This indicates that a high-precision machining can be obtained by carrying out warm-up operation for only one-third as long (**Fig. 2**).

Further, in the case of the conventional oil cooling unit a surge of +/−2 μm occurs even after the thermal balance because of the effect of the valve switching system of the cooling unit, which is directly linked to the elongation/contraction of the spindle, causing surge to appear on the machined surface. In the new inverter system, the surge has been reduced to +/−1 μm or under, leading to the improved quality level of the machined surface.

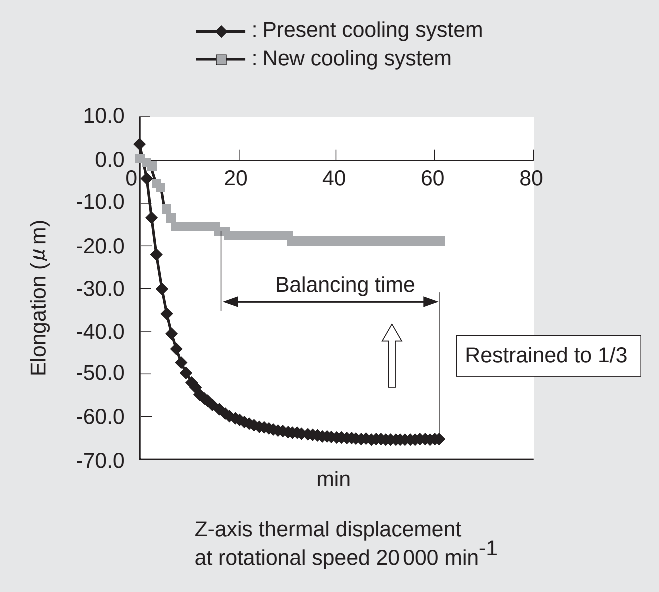

Fig. 2 Thermal displacement of main spindle in Z-axis direction

2.2.2 Restraint of thermal displacement through review of the countermeasure against thermal displacement of the main body

The coolant circulating inside the spindle is simultaneously made to circulate the outer jacketof the spindle, resulting in stable thermal displacement of the main body.

If postural change of the machine main body depends largely on the heat transfer to the main body from bearing, spindle motor, etc. caused by the spindle rotation, the effect is larger when the spindle speed is higher. In the case of Σ Series, therefore, the temperatures at the main points were measured to carry out successive correction of the heat transferred from the spindle.

However, because of the longer time taken due to the heat-transfer delay and correction of spindle thermal balance, it took about 1− 2 hours to reach the state of high-precision thermal balance. In the new control system, however, MHI has been successful not only in restraining the elongation of spindle but also the generation of heat from the spindle.

Further, the thermal displacement of the main body causes postural change depending on environmental change in a factory, heat generation in the machine heat generation at the time of machining, etc., so that it is necessary to minimize the effect of heat in order to prevent the postural change from occurring.

As for the heat generated in the machine itself, it is shielded with insulation board to prevent the effect from the machine control panel at the rear (of the machine), and the machine itself was entirely covered with guard to protect from the environmental effect of the factory.

As a result, the thermal displacement correction of the main body has also been simplified as shown below. Correction has so far been made by means of the corrective formula using the parameter of temperatures obtained from 6 sensors installed to the main body. In the new system, however, because the heat generation from the spindle has been restrained, an equivalent level of correction could be made by measuring temperatures only at 2 points instead of 6 points in the conventional system.

The result is shown in **Fig. 3**. The graph shows the change of spindle end measured for each direction against the table of factory environment change within the range of 8°C for 24 hours. In the conventional system the environmental change range in the factory was assumed to be 4°C, while the 8°C change range in the new system is equivalent to the general change level of a factory, thus realizing high-precision machining in general factories and ensuring enhanced robustness against thermal displacement.

Further, it is highly useful for the end users that a sufficiently high-precision machining can be carried out in a general factory without having to make an expensive temperature-controlled room.

Moreover, from the standpoint of correction, it is better to have 2-point correction than 6-point control if the same level of precision can be obtained since the error-causing factor gets reduced. Thus, the new system has successfully responded to the requirement of end users by maintaining the long-term high-precision through restraint of heat generation.

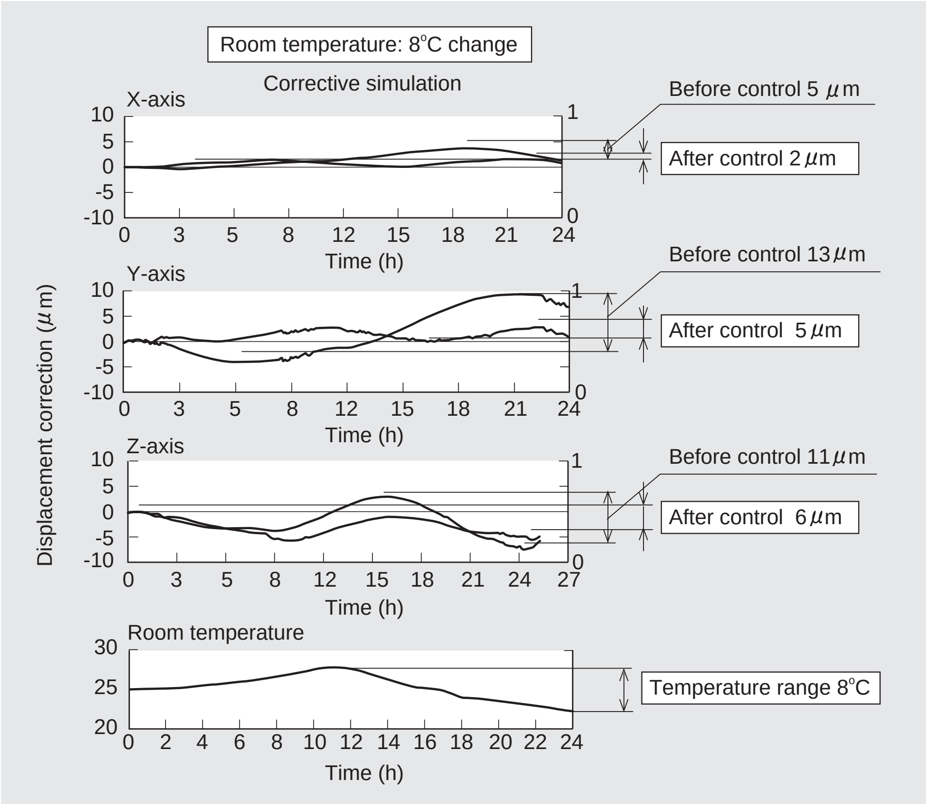

Fig. 3 Correction of main body thermal displacement using 2-point temperature sensor

2.2.3 Improvement of feed axis

In DCV50, improvement is made in the Y-axis feed guide system that carries out back and forth movement of the table in feed axis. In M-V Σ Series, the oil static pressure slide system was adopted for Y-axis feed guide system in order to reduce the effect of feed axis characteristics caused by the change in the weight of the machining work. This system has been replaced with an orthodox type surface slide system. The surface slide system with simple mechanism has been adopted because the maximum weight of work is 700 kgf (equivalent distribution) and the effect of moving spindle characteristics due to change in work weight is within the error range.

Further, as a countermeasure against the rising of table (front-up phenomenon) or the slide surface oil at the time of feeding, regarded as a problem in the conventional surface slide type, the oil pressure has been released by adopting gib, reducing the oil groove width for slide surface oil supply from half size and making oil groove pitch smaller. Consequently, the front-up level at maximum feeding speed = 24 m/min has been reduced from1/5 size decreased.

2.2.4 Evaluation of new function using actual work

Next, the long-term stable machining is confirmed by machining an actual work.

The work in **Fig. 4**, called a "sample of fine level-difference machining," is put to character cutting for machine name using fine-deep machining after machining the wavy sample. The character cutting of the machine name DCV50 is carried out using deep cutting on the surface starting successively from D to the depth of 1 μ m, 2 μ m, 3 μ m, 5 μ m and 10 μ m respectively. The cutting time required for finish cutting is 9 hours 30 minutes, during which time the aforesaid level-difference cutting has to be carried out. Hence, it is quite a hard job. The result follows up to the level-difference of 1 μ m, that the spindle elongation at continuous operation of the spindle is stable and that the main body has stable postural change.

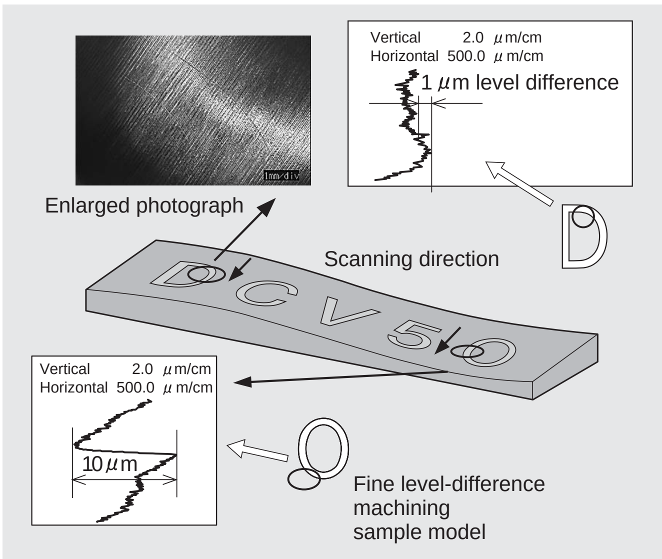

Fig. 4 Micro-machining level-difference sample cutting

Next, evaluation is made by carrying out actual precision die mold cutting. The sample in **Fig. 5** is a mouse-shaped sample cut by using various machines in order to evaluate the general die mold cutting in MHI. Since this work is subjected to continuous machining for more than 2 hours at 20 000 min^{-1} for finishing machining, it can be used for the evaluation of long-term stable machining. The measurement of rough surface after machining has been confirmed to be Ry = 4.1 μm or under.

Fig. 6 shows a model of digital camera, with the copper electrode subjected to electro spark machining using DCV50. In electro spark machining the electrode machining precision gets transcribed, indicating the roughness of the mold surface after machining to be Ry= 4 μm or under, proving that the electrode has been machined uniformly.

The machining of copper electrode of cellular phone in **Fig. 7** is also the same.

The machining of aforesaid 4 samples has proved that the newly developed DCV50 ensures a long-term stable machine precision. The machine also sufficiently conforms to the present precision requirements.

3. Future prospect of the machine

DCV50 ensures the high end precision requirement simply by carrying out warm-up operation for maximum 20 minutes. It is expected that there will be increasing demand for higher precision and shorter delivery term. With the spindle speed likely to get faster, more technique will be needed for restraining the spindle heat generation and control method. The advanced cooling control system based on the estimation made from rotational frequency instead of the simple follow-up type control system and the method of restraining the heat generation near the spindle taper so far not being cooled off are going to be problems.

The important point is that the market demand should be responded by making a new proposal, not only as an extension of the present. The conventionally unnoticed waste time of the user shortened by paying attention to the actual method applied by the user, and the ensured stable precision will certainly help gain the user's satisfaction. MHI is determined to pay heed to customer's stricter demands and to responds accordingly.

4. Conclusion

MHI will be highly honored if the aforesaid technologies applied in the new machine could contribute to higher productivity of our customers.

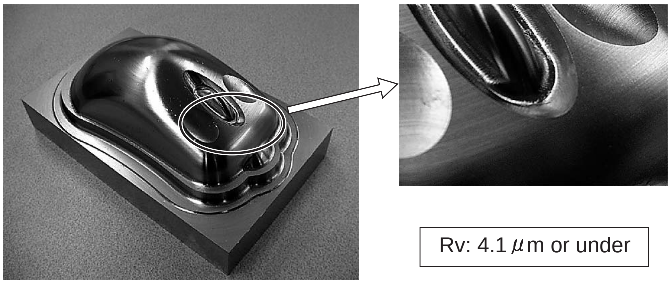

Fig. 5 Mold "Mouse" sample
Roughness of machined surface: Ry = 4.1 μm or under

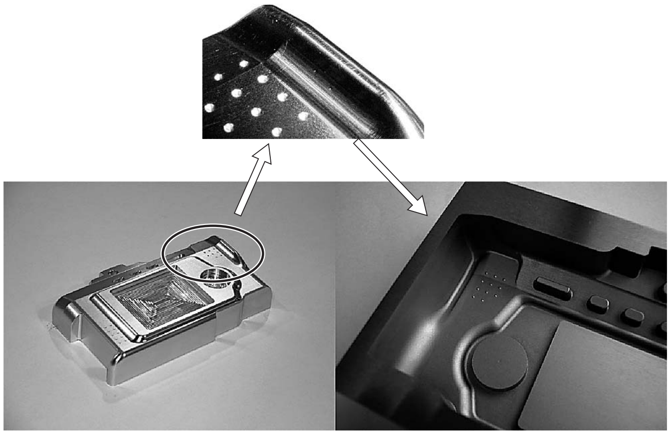

Fig. 6 Digital camera copper electrode and machined surface after electrospark machining
Smooth and continuous shape is transcribed by electrospark machining.

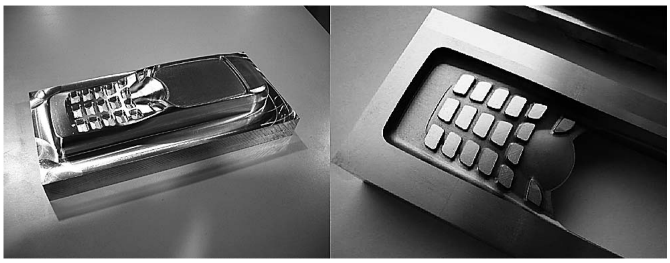

Fig. 7 Copper electrode of cellular phone and machined surface after electrospark machining

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