Development of a VGX-100 Super-Large Vertical Grinding Machine

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Conventionally, the grinding of large workpieces has required a significant amount of manual operation. Now, JTEKT has developed a super-large vertical grinding machine that enables high-precision, fully-automatic grinding of large workpieces, from centering to final dimensional finishing.

Key Words: *vertical grinding machine, space saving, large workpieces, TOYODA STAT BEARING®*

1. Introduction

In recent years, European countries have led efforts to reduce fossil fuel consumption by utilizing wind power, an important element in tackling the major environmental issue of global warming. Recently this effort has expanded into other countries such as America and China. As such, there has been a sudden rise in demand for wind generation equipment and machines to make the large workpieces this equipment is configured from at a high productivity and high efficiency. Moreover, to further improve performance of such large workpieces, the demand for high machining precision at a micron level has emerged.

This report introduces a super-large vertical grinding machine developed to satisfy the abovementioned demands.

2. Development Aims

Workpieces machined in vertical grinding machines do not deflect under their own weight in the bending direction, therefore it is possible to obtain high precision and roundness even for large workpieces. Process integration is also possible on vertical grinding machines, by being able to grind the O.D, endface, I.D and so on, in a single-chuck.

However, the height of these machines means they must be transported in a disassembled state and reassembled on site. In some cases it is even necessary to dig out the plant floor and install these machines in pits. This extra work results in high cost and prolonged installation time.

Moreover, the machine configuration of a single-side grip wheel spindle and high column means that strength between the wheel and the workpiece is spread over a long distance, significantly reducing overall system rigidity. The vertical grinding machine also has a disadvantage from a thermal rigidity perspective, as the front and back of the wheel spindle and column are thermally asymmetrical, making the machine tends to be sensitive to machine temperature, ambient temperature and grinding heat. For these reasons, it has been difficult to accomplish high efficiency and high precision machining, which creates load.

With the objective of finding an innovative solution to the abovementioned challenges, we have utilized the advantages of the vertical grinding machine and developed a super-large vertical grinding machine which, while being compact, also offers high rigidity and high precision. By introducing this machine to JTEKT's large bearing manufacturing lines we have achieved synergism between our various operations.

Fig. 1 VGX-100 super-large vertical grinding machine

MACHINE TOOL MECHATRONICS etc.

3. VGX-100 Characteristics

3. 1 Main Machine Specifications

The NC axis of the machine is comprised of a wheelhead traverse feed (X axis), wheelhead vertical feed (Z axis), wheelhead swivel axis (B axis) and turn table axis (C axis) (**Fig. 2**).

Table 1 shows the main machine specifications, while **Fig. 3** shows machine layout.

Table 1 Main specifications

Item			Unit	VGX－100
Wheelhead	No. equipped		–	1
	Wheel size (O.D ×width × I.D)		mm	ϕ355 × 80 × ϕ127
	Wheel max. rpm (forward/reverse rotation)		min^{-1}	3 000
	Output		kW	8
	Wheel spindle vertical stroke		mm	550
	Wheel spindle swivel angle		°	–1/31
	Wheel head traverse stroke	Right from table center	mm	1 180
		Left from table center	mm	700
	Traverse rapid feed rate		mm/min	20 000
	Vertical rapid feed rate		mm/min	10 000
	Min. input increment		mm	0.0001
Table	Max. grinding diameter		mm	ϕ1 000
	Max. grinding height (incl. fixture height)		mm	400
	Max. load (incl. electromagnetic chuck)		kg	2 500
	Table rotational speed		min^{-1}	5～50
	Height to table surface		mm	980 at chuck surface
	Support structure		–	Hydrostatic
Machine space (W×D×H)			mm	4 220×3 435×3 557
CNC			–	GC50
Options	Auto balancer		–	○
	Gap sensor		–	○
	High pressure cleaning		–	○
	Chattering monitoring		–	○
	Full cover		–	○
	Fully automatic centering device		–	○
	On-machine size measuring device w/temperature compensation		–	○
	Electro permanent magnetic chuck		–	○

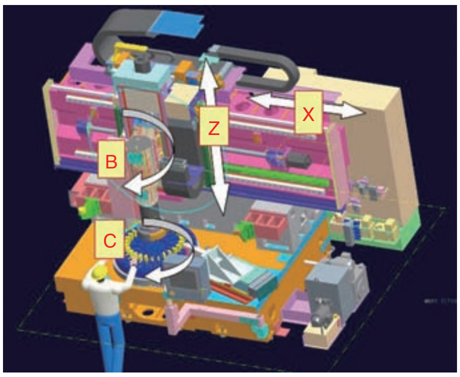

Fig. 2 NC spindle structure

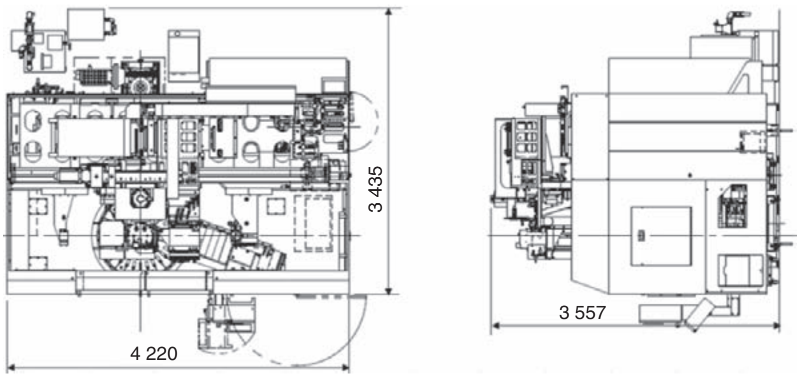

Fig. 3 Machine layout

3. 2 High Precision Hydrostatic Turn Table

The rotational accuracy of the table must be improved in order to improve roundness and cylindricity. Particularly in the case of large turn tables, it is difficult to secure rotational accuracy with rolling bearings as support. Also, bearings would require periodical replacement due to wear and deterioration consistent with age. On this machine, a hydrostatic bearing table has been newly developed, applying the TOYODA STAT BEARING®, a technology which has earned a reputation of being highly reliable on cylindrical grinders.

Figure 4 shows a resurge wave form of this table with a rotational accuracy of 0.47 µm, proving the results to be satisfactory. Furthermore, a cylindrical workpiece (dia. ϕ500) was ground, giving a roundness of 0.72 µm, better than the target value of 1 µm.

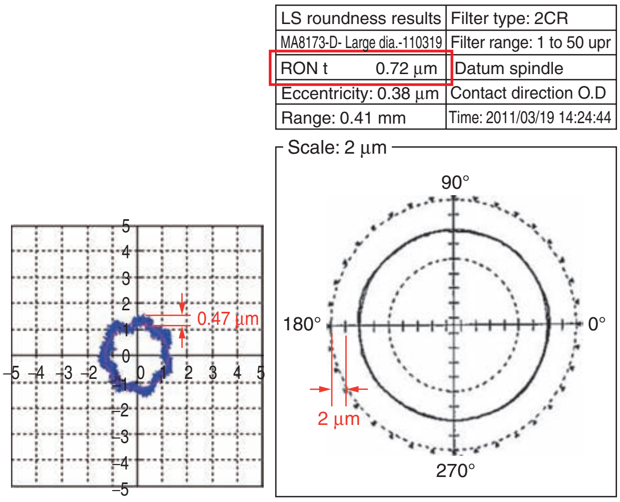

Fig. 4 Rotational accuracy of the hydrostatic table and roundness at processing

3. 3 Highly Rigid Wheel Spindle with Built-in Auto Balancer

It is difficult to secure rigidity for vertical grinding machine wheel spindles, as they must have a large overhang and be single-side grip in order to grind inner diameters of workpieces. Moreover, as **Fig. 5** shows, it is easy for the wheel mounted on the nose of the spindle to become unbalanced and vibration to occur on the spindle overall, creating problems with the surface quality such as chattering. Particularly in order to achieve high efficiency grinding with hard wheels made from ceramic, CBN and so on, the spindle must be sufficiently rigid to support grinding force and the wheel unbalance must be regularly monitored and corrected.

By employing JTEKT's highly rigid, highly precise bearing on the developed machine and experimenting with bearing span and diameter, we have increased wheel spindle rigidity to twice that of our competitors' (conventional). Moreover, by taking measures to achieve the ideal wheel balance, we have been able to install the auto balancer directly below the wheel. These measures have made it possible to achieve high precision automatic balancing and a high quality surface finish free of chattering.

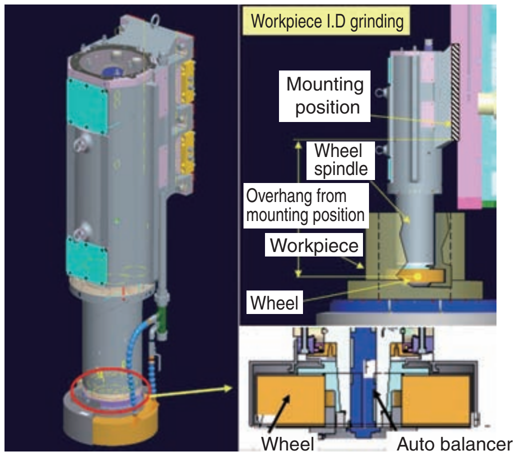

Fig. 5 High-rigidity wheel spindle with built-in auto balancer

3. 4 Feed Spindle Structure

The wheel head traverse feed (X axis) has a long stroke, so a linear guide was adopted to achieve both high rigidity as well as high speed to reduce non-machining time due to spindle travel. Also, through careful positioning of the linear scale and full-closed loop control, high accuracy locating was possible.

The column that supports the wheel head traverse slide is normally of the gantry shape, however, when the wheel head travels to the middle of the column it deflects under its own weight, and the wheel tip posture changes. On the developed machine the coolant outlet has been positioned on the side face and other measures taken to eliminate maintenance performed from the rear of the machine. The column has then been integrated, as an alternative to the gantry type structure. This reduces the amount of wheel posture change due to X axis travel and increases straightness.

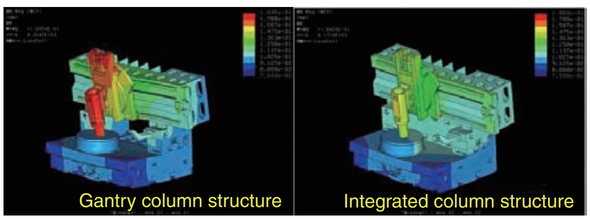

Fig. 6 Advantages of an integrated column structure

For the wheel head vertical feed (Z axis), JTEKT's box slide, with proven performance on high precision machining centers, was adopted. This secured high rigidity and high damping ability. Also, by allowing ample slide length in relation to slide width it became easier to achieve straightness. On top of this, by employing a full-closed loop for the Z axis as well, high accuracy locating was achieved.

High turning accuracy of the wheel head swiveling axis (B axis) is essential to achieve high precision combined grinding such as cylinder grinding and taper grinding in a single chuck. The worm-type swiveling mechanism is commonly used, however this creates accuracy and space issues such as variation caused by backlash at roll over, and the need for a large worm wheel diameter in order to obtain high accuracy. On the developed machine, a link mechanism (full-closed loop) was employed for the ball screw feed as it is backlash free, and the obtainment of a high accuracy angle indexing was made possible by adjusting the radius of the drive portion from the swiveling center to an ample size.

3. 5 Low Thermal Displacement Design

The main components of the developed machine such as the bed and column were arranged carefully to achieve thermal symmetry.

Furthermore, to make the main body of a structure free of bending and warping due to room temperature changes, we repeatedly carried out thermal capacity analysis using CAE, creating a structure with high thermal capacity balance.

Cooling oil was sent to the servo motor mounting portions for each axis, as these are the sources of heat, and insulation couplings were used to prevent heat being transferred to the main body and ball screw. To save on space, the control panel was installed at the bed rear, and to avoid heat transfer, a 10 mm thick insulation panel was used to prevent the control panel and bed coming into direct contact with one another.

In order to isolate the grinding heat, another heat generating source, an isolation cover was installed with air gaps provided so that used coolant did not make direct contact with the bed or column. Grinding heat is transferred from the workpiece and chuck however this does not directly transfer to the bed as the table is floating on the hydrostatic bearing oil controlled at a fixed temperature.

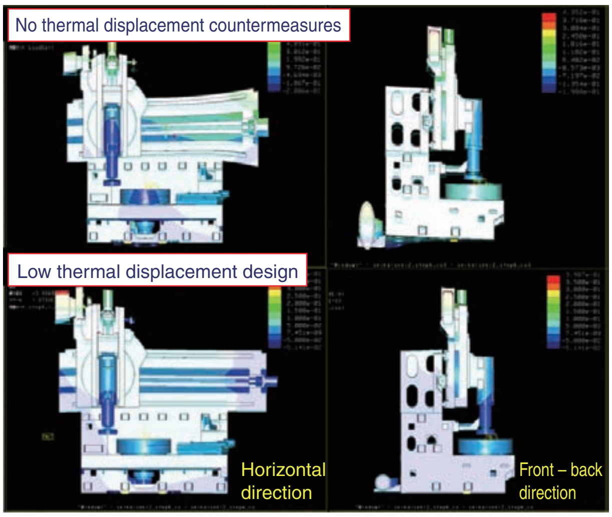

Fig. 7 Advantages of low thermal displacement design

3. 6 On-Machine Size Measuring Device with Temperature Compensation

The expansion caused by grinding heat must be constantly monitored to control the grinding dimensions of large workpieces. Conventionally, the operator measured the temperature of the workpiece mid-way through grinding and manually compensated the finishing dimensions accordingly.

On the developed machine, a temperature sensor is provided on the size measuring device, automating the tasks of mid-way grinding workpiece temperature measurement and compensation. This has made it possible to achieve precision in one go while operating in automatic mode.

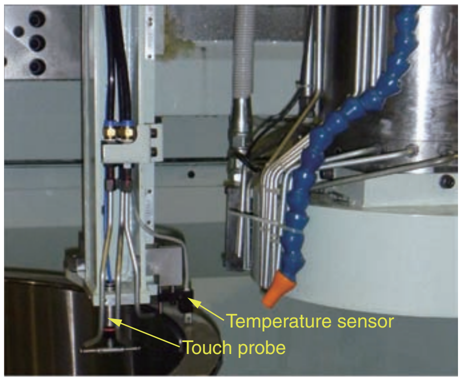

Fig. 8 On-machine size measuring device with temperature compensation

3. 7 Fully Automatic Centering Device (Patent Pending)

In order to reduce the amount of manual work the operator must perform, we have newly developed a device which centers the loaded workpiece automatically at a high accuracy. The workpiece must be moved accurately

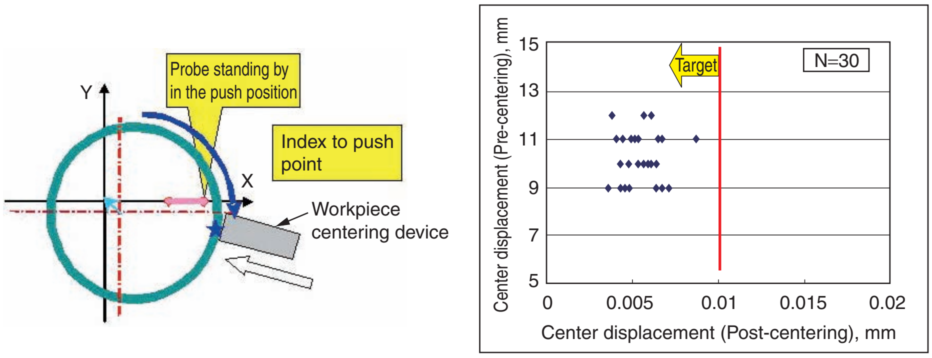

Fig. 9 Automatic centering device for workpieces

at the micron level to ensure accurate centering. However, in the case of workpieces with diameters of 1 m, even a temperature change of a few degrees causes the workpiece outer dimension to change significantly, not to mention, the coordinates at the tip of the centering device itself change due to thermal displacement. Consequently, it was impossible to accurately move workpieces with a centering device which refers to NC coordinates as the datum. On the developed machine, the displacement amount and direction of the workpiece is calculated and a probe is placed on standby opposite the centering device, with the workpiece being moved using the probe as the datum until the ON signal comes on. This makes it possible to move the workpiece in miniscule amounts and with accuracy, achieving fully automatic centering within 10 μm accuracy. This device can center workpieces outer/inner diameters ranging from ϕ700 to ϕ1 000 mm without requiring set-up changeover.

3. 8 Space Saving Design

The higher the machine, the easier it is for shaking and vibration to occur. To prevent this, a high rigidity bed with a large footprint and ample thickness is required. Furthermore, by stacking the table on top of the bed, satisfactory rigidity is secured but machine space and height are both greatly increased. Through structural analysis, the ultimate rib thickness and distribution was identified for this machine and a thin, yet highly rigid, bed structure obtained. Also, by installing the table unit inside the bed, table height was suppressed and overall machine height reduced.

These measures eliminated the need for installing the machine in a pit, as is required with conventional machines. It is also possible to transport this machine without disassembling main components, hence speeding up delivery and installation.

3. 9 Improved Maintainability

As vertical grinding machine axes are located in high positions, service and maintenance such as oil replenishment, adjustments and so on requires danger work at heights and puts a heavy strain on the operator as they must climb up and down.

On the developed machine, oil replenishment for the ball screw, guides, etc., all use the forced lubrication method, with adjustment valves positioned within the operator's reach, improving service and maintainability.

4. Conclusion

The development of this model incorporates technology such as the hydrostatic bearing cultivated by a grinder manufacturer over many years, achieving both high precision and high productivity. Furthermore, the grinding of large workpieces which had relied on manual operation for centering, etc., is now fully automated, realizing a high added value not seen in conventional machines.

We will continue to do our best to keep ahead of market and production shop needs and develop machines which offer our customers satisfaction of use.

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