Development of the GS200H5 Gear Skiving Center

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Production sites for the manufacture of small gear parts require processing machines with high productivity that are flexible to various kinds of production. To meet these requirements, we have developed the Gear Skiving Center GS200H5. The features of this developed machine include a compact machine size suitable for small-size gear production lines, the achievement of high accuracy and high productivity through a design with high rigidity and low thermal displacement, and the ability to conduct machining such as turning and cutting on a gear cutting machine. The details of these features are described in this paper.

***Key Words**: gear, skiving, gear skiving center, compact machine size, high rigidity, process integration*

1. Introduction

An important theme for mankind at present in reducing environmental load at the same time as achieving sustainable development is reducing greenhouse gases. To this end, a variety of initiatives are being promoted in each industry. The automotive industry in particular is deeply involved with this theme and as such, is pushing ahead with the development and sale of vehicles that contribute to energy-saving, best represented by electric vehicles (EV), hybrid vehicles (HV) and plug-in hybrid vehicles (PHV). These vehicles are required to have a high level of quietness and stability when being driven, therefore the small gear parts that make up the planetary gear reducer equipped on vehicles are required to have high strength and accuracy in order to suppress noise and vibration during operation. Moreover, various initiatives are being promoted to improve energy efficiency, such as the downsizing and weight reduction of equipment through the integration and combination of small gear parts.

2. Skiving Machining Method and its Merits

Generally speaking, the current mainstream forms of gear machining used in the manufacturing industry require special-purpose equipment such as a hobbing machine or gear shaper for outer teeth and a gear shaper or broaching machine for inner teeth. However, in recent years, a style of machining known as “skiving” is attracting a great deal of attention. Skiving enables cutting of both inner and outer teeth on a compound processing machine that performs both turning and drilling. The principle behind skiving was first proposed in Germany in 1912. In the 1970s, a technical study was also conducted in Japan but at the time it was not developed to the point of practical application. However, thanks to technological advancements in recent years relating to the fields of tools, control and processing machines, the various issues standing in the way of realizing the skiving method were solved and practical application was achieved. As **Fig. 1** shows, skiving involves a tool tilted relative to a workpiece, whereby both the workpiece and tool are rotated at high speeds synchronously so that the tool follows the workpiece axis to form gear teeth. As such, skiving means the tool has better proximity to the workpiece than the current gear cutting method performed on a hobbing machine as **Fig. 2** shows, therefore the incomplete tooth portion of the product can be designed short. Moreover, as **Fig. 3** shows, the gear shaper based on the back and forth movement of a tool requires its tool relief shape to be made in the product itself. With skiving, however, this is not necessary, therefore product dimensions can be shortened and better product strength is achieved. Considering the abovementioned merits, by engaging in product design assuming skiving as the machining method, it is possible to make parts lighter and more compact than previously.

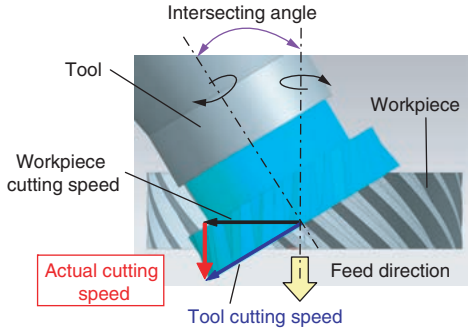

Fig. 1 Skiving method

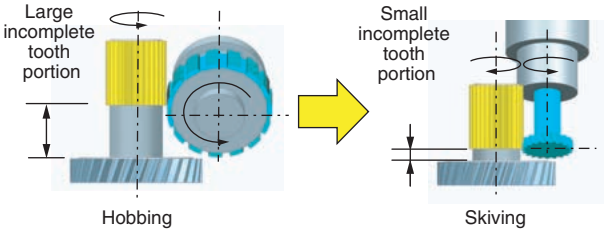

Fig. 2 Comparison of hobbing with skiving

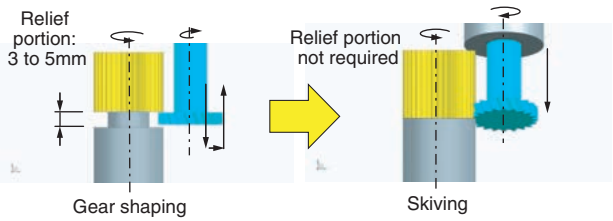

Fig. 3 Comparison of gear shaper with skiving

3. Development Aims

In 2014, JTEKT launched the GS300H, a gear skiving center for manufacturers of small and mid-sized gear parts, then created a series in 2016 with the development of GS700H, which is optimal for machining large gear parts. As gear processing machines supporting not only gear cutting, but also turning, cutting, drilling and so on, these two products contributed to the improvement of productivity through process integration and weight reduction of gear products.

The aim of this development was to focus on the mass production market for small gear parts and develop a processing machine with a machine size suited to incorporation in a mass production manufacturing line at the same time as offering high production capability. Consequently, we developed GS200H5 – a gear skiving center inheriting the process integration capacity that is a feature of the current gear skiving center series, at the same time as being a compact machine securing high productivity and stable accuracy.

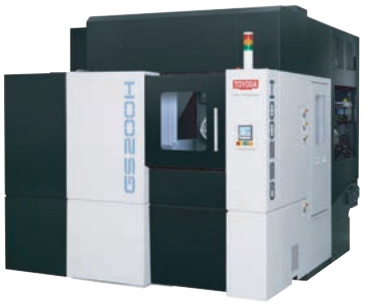

Fig. 4 GS200H5 Gear Skiving Center

4. GS200H5 Specifications

Table 1 shows the specifications for GS200H5 (hereinafter "the developed machine"). **Figure 5** shows the developed machine's overall layout.

Table 1 Main specifications

				GS200H
Travel	X axis		mm	470
	Y axis		mm	360
	Z axis		mm	520
	B axis		°	−220.0～0.0
	Distance between spindle center and workpiece axis center		mm	−120～240
	Distance between spindle end and workpiece axis end		mm	185～805
	Height from floor to workpiece axis center		mm	1 350
Feed rate	Rapid feed rate	X, Y, Z axes	m/min	48
		B axis	°/min	11 520
	Cutting feed rate	X, Y, Z axes	m/min	30
	Rapid acceleration rate	X, Y, Z axes	m/s^2 (G)	6.86 (0.7)
Tool spindle	Rotation speed		min^{-1}	6 000
	Output (15 min/continuous)		kW	30/25
Workpiece axis	Rotation speed		min^{-1}	3 000
	Output (15 min/continuous)		kW	32/19.5 (OP：33.5/28.3)
	Max. workpiece dia.		mm	ϕ220
	Max. workpiece width		mm	150
	A axis end-face max. moment		N・m	82.2
Tool	Tool holding capacity		tools	8 (OP：20)
	Max. length		mm	300
	Max. dia.		mm	160
	Max. weight		kg	27
	Tool change time	tool to tool (～7 kg)	sec	2.4

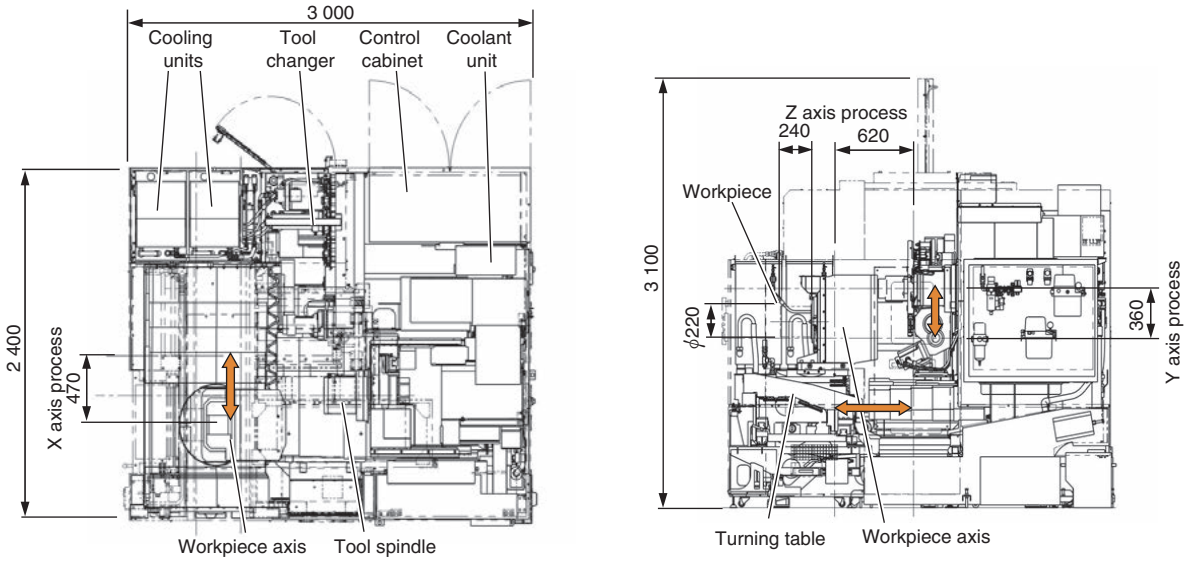

Fig. 5 Machine layout

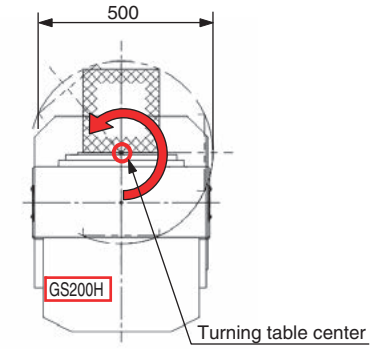

Fig. 6 Minimizes work-swing

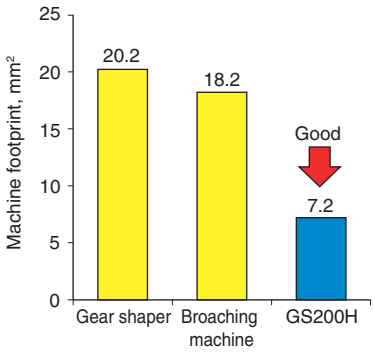

Fig. 7 Comparison of floor space

5. A Machine Size Suiting Workpiece Size

In recent years, in order to increase production efficiency per a set surface area of a production line, a demand has emerged for small equipment suited to workpiece size. To meet such a demand, in order to keep the developed machine compact, the maximum fixture workpiece installed on the workpiece axis (220mm dia. × 240mm height) has been brought closer to the center of the turning table rotation in order to minimize workpiece swing (**Fig. 6**) and this has kept the corresponding drive axes (XYZ) processes to the bare minimum. This design point made it possible for the developed machines to have the dimensions of 2 400mm in width, 3 000mm in depth and 3 100mm in height, therefore giving it a smaller footprint than gear-cutting special-purpose machines such as gear shapers and broaching machines that handle workpieces of the same size (**Fig. 7**).

6. High Productivity and Stable Accuracy

In order to achieve high productivity, the layout of the various units adopted by the developed machine was designed to enable high-efficiency gear skiving. The following describes the features of the units.

6. 1 High Rigidity Tool Spindle Unit and High Rigidity Workpiece Axis Unit

The tool spindle plays an important role in securing machining performance. With this in mind, we adopted a JTEKT-made double-row cylindrical roller bearing that offers both high damping ability and high rigidity, which are required for the intermittent cutting that skiving involves, and consequently improved machining performance. Furthermore, in regards to the workpiece axis, we adopted a JTEKT-made angular ball bearing with the ability to rotate at high speeds (e.g. 3 000 min^{-1}) which is necessary for gear skiving, as well as a high rigidity able to withstand intermittent cutting.

6. 2 High Performance Feed Unit

For the feed unit, we adopted a cylindrical roller slide that is able to achieve high-speed drive while having high

rigidity and damping performance. The features of the cylindrical roller slide are its minimal elastic deformation and displacement relative to repetitive variable load. It is also known for its outstanding damping ability. By adopting the cylindrical roller slide, the feed unit undergoes minimal position change at sudden acceleration or sudden stopping and swift positioning is possible.

6. 3 High Rigidity/Low Thermal Deformation Platform

When designing the bed and columns that support the moving elements of a machine tool, we performed a simulation of force transmission by utilizing FEM analysis technology in an attempt to find the layout with the smallest amount of part deformation due to machining load. Moreover, to achieve stable machining accuracy even in installation environments with varying room temperature, we carried out repeated irregular thermal analysis to optimize the shape and rib arrangement and find a design which secured the appropriate heat capacity and heat release balance. As a result, we succeeded in a design that is able to reduce the bending and warping of the machine's material caused by temperature change and minimize any reductions in machining accuracy. In addition to these efforts, by manufacturing the bed and columns with JTEKT's sophisticated casting technology, we created a highly rigid platform with high damping performance and low thermal displacement.

6. 4 Control Technology Supporting Skiving

Skiving requires the high-speed, high-accuracy synchronous control of tool spindle and workpiece axis rotation. As such, the developed machine is equipped with a high accuracy, high resolution encoder in its tool spindle and workpiece units, as well as adopts a JTEKT-made CNC unit, TOYOPUC-GC70, with a track record in gear skiving control, for its controller. By adding the functions necessary for skiving to the TOYOPUC-GC70, it has become possible to achieve high speed, high accuracy synchronous control. Moreover, creating an NC program for skiving is extremely difficult due to the need for synchronous control of three axes or more. As such, this CNC unit was given a simple programming feature to enable users to create gear skiving programs simply through entering data such as gear specifications, tool specifications and cutting conditions.

7. Process Integration with a Gear Skiving Center

Generally speaking, gear cutting machines such as broaching machines and hobbing machines do not have magazines or tool changers. In contrast, the unit layout of the developed machine is based on that of a machining center but designed as a compound processing machine with both a tool changing function and gear machining function, therefore it is capable of supporting processes other than gear cutting. **Figure 8** explains using workpiece and process examples. Conventionally, machining of this part comprised the five processes of ①turning, ②hobbing, ③gear shaping, ④chamfering and ⑤drilling. Then, in order to achieve these processes, equipment or special-purpose machines for each process were required. Meanwhile, the developed machine accomplishes all five processes in a single machine. This makes it possible to complete several processes on a workpiece in just one operation of the chuck, thus eliminating the machining error created when the workpiece is loaded and unloaded

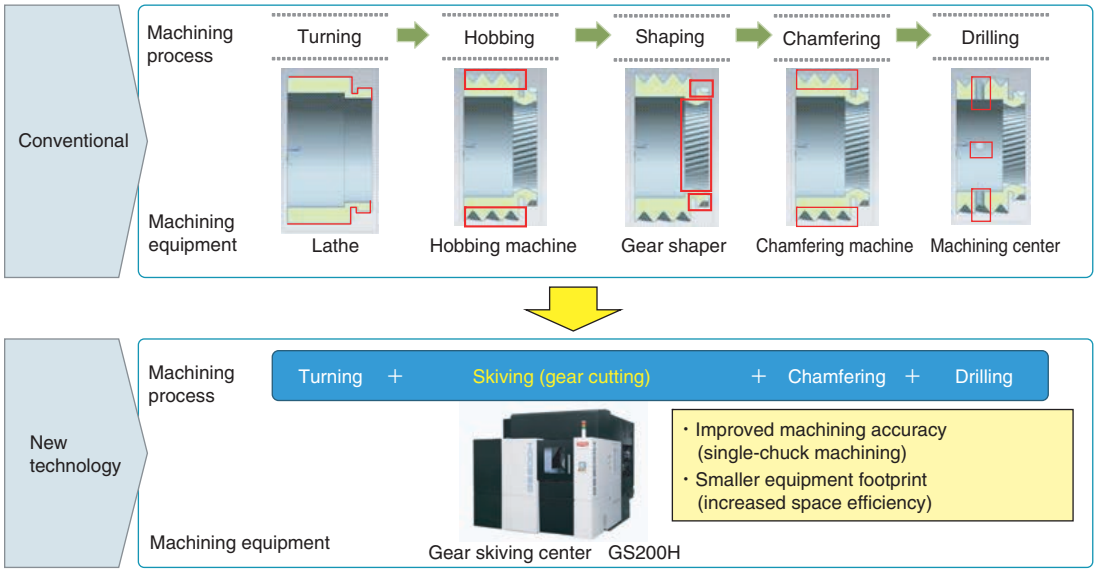

Fig. 8 Example of process integration

Processing conditions

Workpiece (ring gear)	Size	mm	ϕ149×24
	Material	—	SCM415
Module		—	1.5
Intersecting angle		°	20
Spindle rotation speed		min^{-1}	2 159
Workpiece axis rotation speed		min^{-1}	1 666
Feed rate	Roughing	mm/min	416
	Finishing	mm/min	283

Result

Process time	sec	19
Tooth profile accuracy	μm	5.5
Tooth trace accuracy	μm	6

Fig. 9 Example of machining ring gear

between processes and postural changes, and ultimately securing stable machining accuracy. Moreover, by integrating the processes, the standby time between each process is eliminated, thus the net machining rate in the product manufacturing cycle is improved. The time taken for the gear cutting process has been shortened due to replacing ②hobbing and ③gear shaping with skiving. In addition to the above-mentioned merits, the developed machine also offers a smaller footprint and reduced initial investment due to a smaller number of equipment being required. In this way, promotion of process integration will make it possible to reduce the scale of production lines and enable a transformation to flexible production equipment.

8. Machining Examples

As an example of the machining capable by the developed machine, **Fig. 9** shows the results of machining a module 1.5 ring gear. This machining result gives an accuracy equal to or less than Level 7 in the accuracy level scale defined in JIS B 1702: 1998 (with 0 being highest accuracy and 12 being the lowest accuracy) commonly necessary in the roughing process of gear cutting in mass production lines.

9. Conclusion

The developed GS200H5 fulfills the needs of many customers by maintaining the process integration ability characteristic of gear skiving centers at the same time as offering high accuracy, high productivity and space-saving merits. Moving forward, JTEKT will constantly stay on top of market trends so that we may continue offering our customers attractive products.

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