e500H-GS: Gear Cutting Development by Skiving Method

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Gear cutting machines are special purpose machines that require costly equipment investment, and for which high volume production is expected. However, a new production formula is being sought in order to respond to the various changes in the surrounding environment.

To respond to these demands, the skiving method has been developed, along with a machining center capable of achieving this new method, the "e500H-GS Skiving Machine", which contains every type of function for the rotating table, controls, and tools. This machine is introduced in the following paragraphs.

***Key Words**: gear, skiving, machining center, process integration*

1. Introduction

Gears are an important machine element and used in many products in every field. Cars are manufactured on special purpose machines, and high volume production that requires heavy equipment investment is presupposed. Due to various environmental changes and globalization, however, there is a demand for a new competitive production system that can respond flexibly to market changes.

2. Current situation of the gear industry

Gears are an important machine element that supports industries and serve as an important functional component of drive units and control mechanisms of equipment.

Gears have been used since times of old and continue to be used today in many products ranging across transport machinery such as automobiles and airplanes, industrial machinery including wind power generation, and electrical equipment like printers.

Monozukuri in Japan including the automobile industry has experienced the Lehman Brothers crisis, Thailand floods, super-strong yen, etc. in the midst of globalization. A transition is occurring from the conventional large-scale production system to a compact and flexible production system that allows gradual overseas investment and withstands market environment changes, and the gear industry is no exception.

The current gear cutting line, however, consists of many special purpose machines such as hobbing and broaching machines, presupposing high volume production. For example, manufacturing a product requires various special purpose machines and equipment investment. Other problems include the long setup change time of special purpose machines, making high variety production difficult.

3. Functions sought after in gears

A gear is defined as a toothed part designed to have teeth that mesh with the teeth of another part in sequence, transmitting motion to, and receiving motion from, other parts. Gears include spur gears consisting of two parallel shafts, helical gears, bevel gears consisting of two, single-point intersecting shafts, spiral gears consisting of two, non-parallel, non-intersecting skew shafts, worm gears, and hypoid gears. The role of these gears is to change the angle of rotation and speed with high efficiency, and the direction of rotating shafts. Main mechanical features are expressed in torque and rotation speed, and improving efficiency is important as there are some mechanical losses.

For instance, in automobiles, gears are used in devices such as epicyclic gear trains that divide the power of a motor and engine of an automatic transmission or hybrid vehicle, while in airplanes, gears are used in devices such as GTF (Geared Turbo Fan) devices that change the turbine of a turbo fan engine on a jet aircraft.

In recent years, as various devices of automobiles and airplanes become highly efficient and consume less energy, gears, an element part, also need to be more compact, quieter, more efficient, accurate and rigid, and possess higher added value. In order to respond to these needs, new technology development is required for gear cutting methods.

4. Introduction of the skiving method

Various methods are available for cutting gears such as a milling process that progressively cuts the tooth surface using an end mill and a generating method that transfers the tool tooth profile to a workpiece.

Since the milling process progressively cuts a workpiece using a small diameter tool, cutting resistance is small, and high precision machining is possible, but resulting in a long machining time and low productivity. On the other hand, as the generating method transfers the tool tooth profile to a workpiece utilizing the rotary motion of a workpiece or tool, machining load is relatively large, but results in high machining efficiency. Examples of the generating method include a hob that cuts external teeth and a gear shaper that cuts internal teeth. These methods are common and widely used in mass production lines for automotive parts, etc., making them relatively mature technologies. They are not versatile, however, and actual production sites face various issues.

The skiving method is introduced here as a latest gear cutting technology. The principle of the cutting method has existed through the ages, proposed in Europe in the 1960s, but it was not practically used in those days. Recent technological advancements in fields including tools, controls, and machines enable this method to be practically used, drawing attention as a new method.

The skiving method is a gear generating method in which a tool is inclined with respect to a workpiece and moved along the workpiece axis while in high speed synchronous rotation, as shown in **Fig. 1**. While on a gear shaper a tool is moved in a reciprocating motion to machine a workpiece, in this method the rotation of an inclined tool and workpiece generates a cutting force, allowing the workpiece to be machined. The required rotation speed of the tool and workpiece is a few thousand rotations per minute. This is more than 10 times faster than general hobbing, in which a tool and workpiece rotate a few hundred times per minute.

For example, when steel is machined, the optimal cutting speed is approximately 150 m/min, and for this speed to be achieved, a workpiece of ϕ100mm needs to rotate 1 500 times per minute.

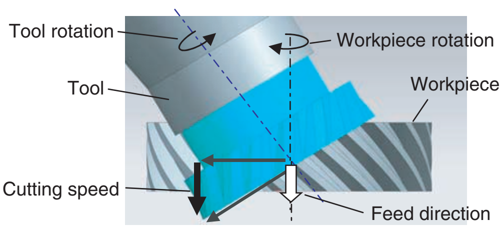

Fig. 1 Skiving method

While the feed amount for hobbing is approximately 2mm per rotation of a workpiece, it is smaller for the skiving method, which is approximately 0.2mm.

As shown in **Fig. 2** and **3**, one advantage of this method is that, unlike the conventional gear shaper, a reciprocating motion is not necessary, eliminating dry cutting and substantially reducing machining time. Another advantage is that workpieces can be machined at the optimal cutting speed, increasing the tool service life. Advantages over hobbing include better accessibility and a shorter incomplete gear-shaped portion, making products compact. Furthermore, tooth surface correction, such as the crowning of internal teeth, can be easily adjusted by controlling the tool tooth profile and machining trajectory.

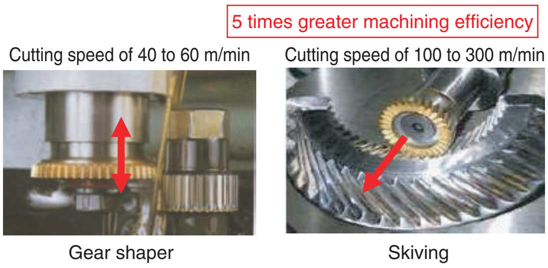

Fig. 2 Comparison of gear shaper with skiving method

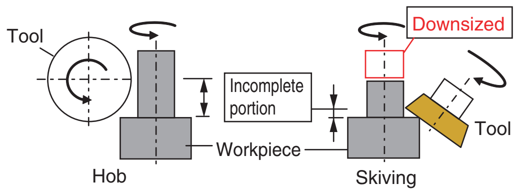

Fig. 3 Comparison of hob with skiving

Due to the advantages mentioned above, this method not only reduces machining time and improves productivity, but also can produce a shape unachievable using the conventional method as a result of the increased machining flexibility, enabling the creation of new high value added products.

Technologies required to achieve this method are mainly related to tools, controls, and machines. Tool technology in which the tooth profile is designed and produced based on the generation theory of creating tooth surface shape, control technology in which highly accurate synchronous control rotates a tool and workpiece synchronously a few thousand times per minute within 1 μm, and machine technology in which a highly rigid table and spindle can rotate at a high speed are required.

5. Skiving machine “e500H-GS”

In November 2013, JTEKT developed e500H-GS, an all-in-one skiving machine that can perform turning, gear cutting, and boring. As shown in **Fig. 4**, this machine uses a machining center for its base and is equipped with three technologies required for the skiving method: high-speed high-precision synchronous control, a high-speed high-rigidity rotating table, and tools for skiving.

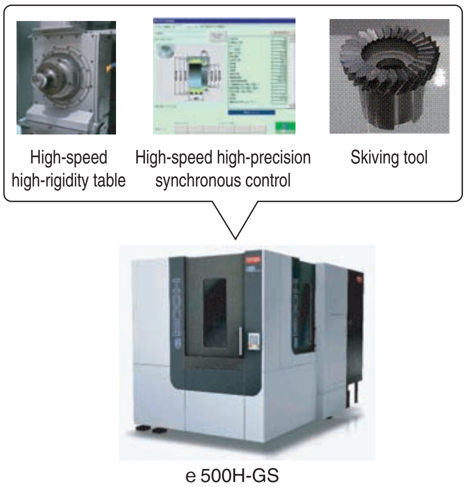

Fig. 4 Elemental technologies to support skiving machine

The base machine is a horizontal machining center with a pallet size of 500mm. This machining center was developed under the three concepts of e, “evolutional”, “efficient”, and “easy”, and consists of a compact machine body that did not exist in the past, an elemental technology that balances high productivity and reliability, and a JTEKT-made CNC unit that allows customers to easily operate and maintain the machine, making it suitable for universal cell lines.

For instance, regarding the machine body size, small devices are used and optimally arranged to cut down on the installation area and secure a wide workpiece range. Compared with the conventional line consisting of cell lines, the installation area has been reduced by 51%, enabling the machine to be installed in the smallest space in its class.

The machine structure consists of a center trough that has excellent chip disposal, a lightweight and highly rigid FCD450 column with high speed and heavy duty cutting capabilities, and a highly rigid cylindrical roller slide that can withstand high speed and high acceleration/deceleration while maintaining rigidity. The JTEKT-made CNC unit used for control is equipped with a visualization function that allows even beginners to instantly see equipment operation status. Functions necessary for the skiving method are added to this base machine. The main specifications are shown in **Table 1**. The three functions developed for the skiving method are described below.

Table 1 Machine specifications

Item			Specification
Feed unit	Stroke (X, Y, Z)	mm	730, 630, 800
	Rapid feed rate	m/min	60
Spindle	Spindle nose shape	–	BT No. 40
	Spindle speed	min^{-1}	12 000
ATC	Tool holding capacity	piece	20 [40]
C-axis	Rotation speed	min^{-1}	3 000
	Max. workpiece diameter	mm	ϕ220
Control	CNC	–	TOYOPUC-MC70
Required area	Width × epth	mm	2 200 × 3 650

5. 1 Rotating table

The rotating table is compact with a loading range of ϕ800mm or less, has a highly rigid structure, and can rotate at a high speed up to 3 000 min^{-1}, making it able to handle various workpiece sizes and modules. In order to ensure the rigidity of workpieces, a hydraulic cylinder for chucking is built into the table, preventing the mounting position from widely overhanging the table top. This facilitates automatic attachment and detachment by a robot, etc.

5. 2 Gear cutting control

The JTEKT-made CNC “TOYOPUC-MC70” used for control enables high-speed high-precision synchronous control that is suitable for skiving, and is compatible with the shape of both spur gears and helical gears. Moreover, an easy programming function is equipped to allow gear cutting programs to be created just by entering gear specifications and tool data, so that even beginners can operate the machine.

5. 3 Gear cutting tool

Since a tool is inclined with respect to a workpiece, its tooth profile differs from that of a pinion cutter normally used for a gear shaper. Therefore, the generation theory was analyzed to establish the optimal design method. In consideration of tool cost, a tooth profile with many regrindings and long tool service life can also be designed. For tool material, low friction coating is applied to the high hardness base material that provides long service life even at high surface speed.

6. Machining examples

In order to verify the effect of this machine, the gear portion of a side gear was machined through integrated processes from turning, to cutting, to boring in one chucking as shown in **Fig. 5**, and compared with a gear that was machined through the conventional process using five special purpose machines including hobbing and broaching machines. The situation in which an external gear is machined using the skiving method is shown in **Fig. 6**.

Coaxiality between gears has been improved when gears are machined in one chucking, achieving a machining accuracy of less than 10 μm, which is 1/3 of the conventional process. The machining accuracy for the external tooth module 2.4 portion is shown in **Fig. 7**.

When a gear is machined, the time required to cut external teeth using the skiving method is the same as using a hobbing machine, and for the stepped external tooth portion, the cutting time has been reduced by 1/5 of the cutting time using the conventional gear shaper. Based on these results, the equipment cost and processing cost required to machine a product have been reduced by 60% compared with our conventional line (**Fig. 8**).

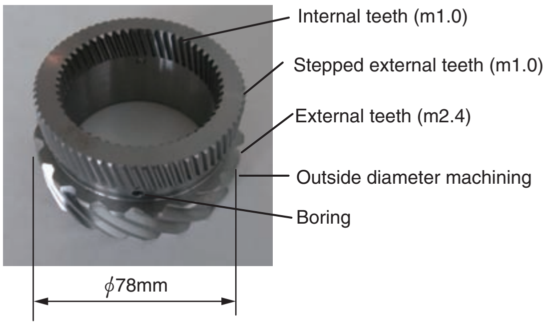

Fig. 5 Side gear

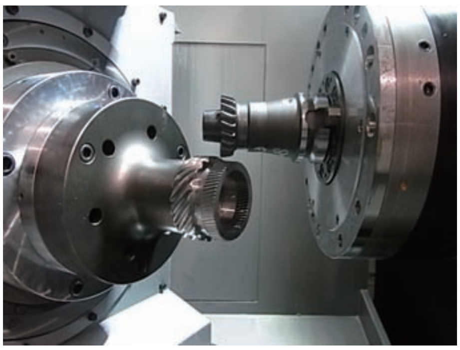

Fig. 6 Skiving

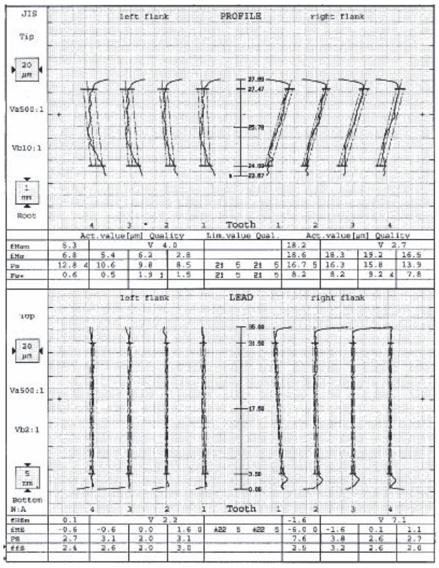

Fig. 7 Gear accuracy module 2.4

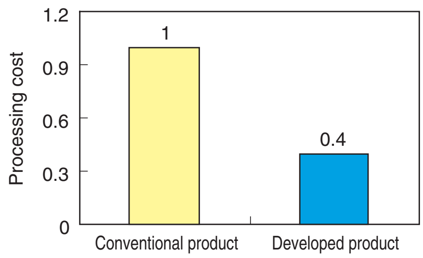

Fig. 8 Processing cost comparison

Such large effects are gained from not only the reduced investment cost as a result of using less equipment, but also machining in one chucking that reduces the wait time between processes and increases the ratio of the time to generate chips, improving the net ratio.

This machine offers various advantages in addition to the reduced product processing cost. For instance, when setup change is necessary due to design change, large modification is required for in the case of conventional lines consisting of special-purpose machines. This machine, however, is a general-purpose machining center with a tool change function, offering flexibility and easy setup change, allowing lower cost and fewer man-hours for handling such change.

Other advantages include efficient development through the shorter startup time when developing a new product.

7. Conclusion

We will endeavor to promote technology development that responds to various needs so that we can continue to offer customers attractive products.

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