Development of Process Integration Using a Gear Skiving Center
—A Case Study Focusing on the Development of a Synchro-sleeve Gear—

L. ZHANG K. NATSUDA

Due to the pursuit of automobiles that generate less noise and are more fuel efficient, there has been an increasing demand for the gears used in automotive transmissions to have higher accuracy, higher efficiency, and be manufactured through integrated processing. The gear production lines currently operating in the automobile industry are comprised of many specialized machines (hobbing machines, broaching machines, etc.) which require a high investment cost. The workpieces produced need to be transferred between different specialized machines and even between different processes which could lead to positioning and assembly errors. This paper introduces the Gear Skiving Center, as well as a case study of integrated processing of the synchro-sleeve gear using the Gear Skiving Center.

In the past, the processing of synchro-sleeve gears required multiple machines such as a lathe machine and hobbing machine, however now, the Gear Skiving Center is the sole piece of equipment required to complete all the necessary manufacturing processes, not to mention offers the added benefits of 1.5 times machining accuracy, 0.5 times processing time, and 0.25 times the number of necessary machines.

Key Words: *gear skiving, high accuracy, process integration*

1. Introduction

Currently, gear shaping, broaching and hobbing are the machining methods adopted for gears. Gear shaping is the typical machining method used to shape gears, and is the comparatively mature method used broadly for mass production lines such as auto parts. Broaching offers merits such as high efficiency, easy operation, and minimal variation in machining precision, and is considered indispensable to mass production lines. Hobbing has high productivity and excellent precision, therefore is widely adopted in the machining of external gears. However, these machining methods are not versatile, and in actual production sites, there exist various issues relating to productivity, production cost, etc.[1] (**Table 1**). In contrast, skiving is drawing attention as a new machining method for both external and internal gears. Details of this machining method are given below.

2. Skiving Method

Skiving is a tool cutting method performed using a gear-shaping tool such as a gear shaper. As **Fig. 1** shows, the principle of skiving is to tilt the tool and workpiece relative to each other and simultaneously rotate them to generate relative speed, which is utilized to machine gears.

The principle of skiving was proposed in Europe in the 1960s, however skiving could not be put into practical application due to rigidity and control issues of the machine tools at the time. In recent years, the practical application of skiving has become possible due to technological advancements relating to tools, control and machinery, therefore it is drawing attention as a new machining method.

While gear shaping is a method whereby the reciprocating motion of a tool in the axial direction is

Table 1 Characteristics of gear machining methods

Machining method	Shaping	Broaching	Hobbing	Skiving
Precision (new JIS)	Grade N7-N12	Grade N7-N12	Grade N6-N12	Grade N6-N12
Tool cost	Low cost	High cost	Low cost	Low cost
Cycle time	Long	Short	Short	Short
Supported workpiece	External gear, internal gear	Internal gear	External gear	External gear, internal gear

applied to cut teeth, skiving involves rotating a tilted tool and workpiece to generate cutting force and cut teeth. Because skiving does not use reciprocating motion, there is no need for idling and its machining time can be significantly reduced.

As **Fig. 2** shows, unlike gear shaping, skiving does not require a recess, therefore it offers the merits of compact and higher-strength products[1).

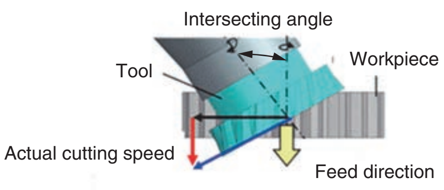

Fig. 1 Skiving method

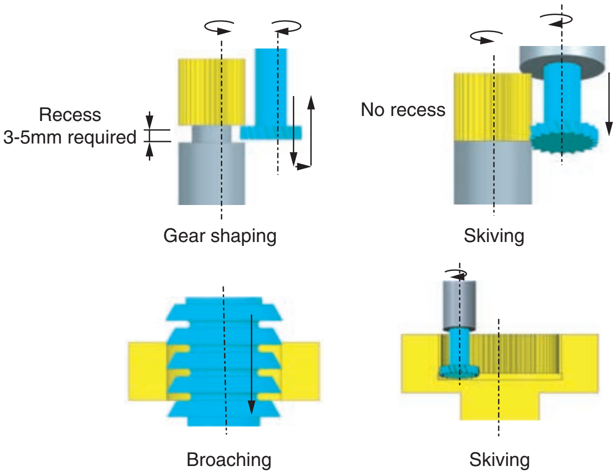

Fig. 2 Skiving method merits

Moreover, compared to broaching, skiving offers low tool and equipment costs, in addition to making it possible to perform integrated machining of the internal gear. Also, by controlling the tool's gear profile and machining trajectory, it is also possible to easily adjust gear profile correction, such as crowning[1)].

Compared to hobbing, skiving offers the merits of allowing machining of both external and internal gears, and reduced workpiece assembly and positioning errors through the single-chuck machining of compound gears.

3. Gear Skiving Centers GS200H, GS300H, GS700H

In November 2013, JTEKT equipped a machining center with the technologies of high-precision synchronized control, high-speed, high-rigidity turning table and skiving tool to develop GS300H, a gear skiving center capable of performing all processes from lathing to gear machining and drilling. This made it possible to machine gears of ϕ300mm or less. GS300H was primarily developed for the machining of auto parts.

Moreover, in 2015, to respond to a variety of customer products and needs, such as construction and farming machinery, we newly developed GS700H, a gear skiving center. This made it possible to machine large gears such as module 6 and those sized ϕ700mm or less (**Fig. 3**).

Finally, in 2016, we developed GS200H as a gear skiving center achieving high productivity and stable precision in a size suitable for mass production lines of auto parts. By adopting a machine structure and devices capable of withstanding the high load necessary for high-efficiency gear skiving, we realized high productivity by increasing the rigidity of the machining devices and each axis (**Fig. 4**). **Table 2** shows the main specifications.

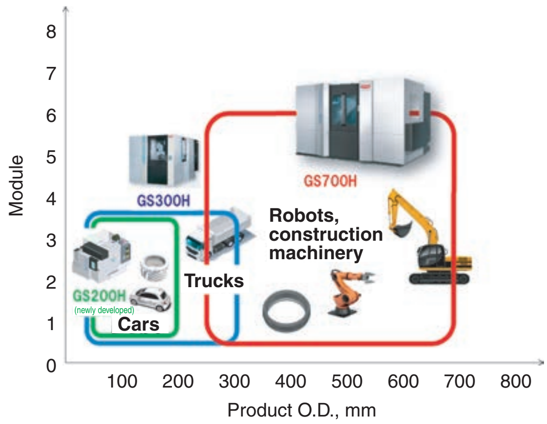

Fig. 3 Scope of gear skiving center

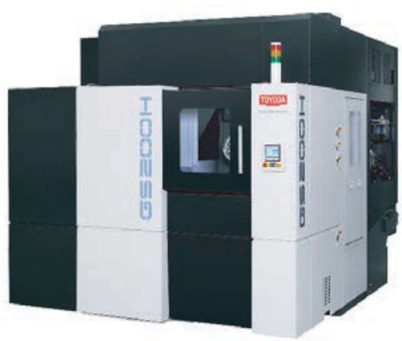

Fig. 4 Gear skiving center-GS200H

Table 2 GS200H specifications

Item			Specifications
Feed unit	Travel (X, Y, Z)	mm	470, 360, 620
	Rapid feed rate	m/min	48
Spindle	Spindle end profile	–	BT No. 50
	Spindle RPM	min^{-1}	12 000
ATC	Tool holding capacity	pcs	8 [OP : 20]
C axis	RPM	min^{-1}	3 000
	Max. workpiece dia.	mm	ϕ220
Control	CNC	–	TOYOPUC-GC70
Required surface area	Width × depth	mm	2 400 × 3 000

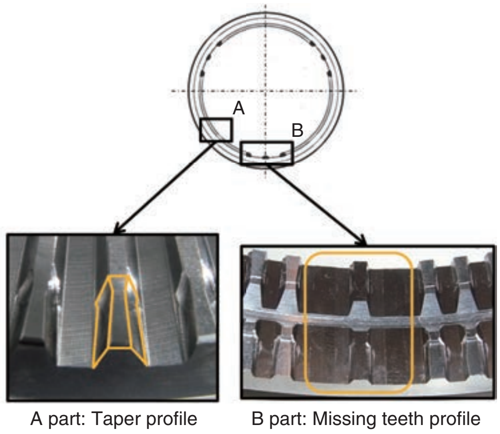

Fig. 6 Special gear profile

4. Initiative for the Process Integration of Synchro-sleeve Gears

The synchro-sleeve gear is used in manual transmissions and works in sync with the shift lever to switch the gear ratio (**Fig. 5**).

To change gears smoothly while the gears are mutually rotating, the synchro-sleeve gear has a special gear profile; namely taper and missing teeth (**Fig. 6**).

High-precision machining of special gear profiles is necessary as poor precision could lead to shift change problems and slipping.

Currently, rolling is used to create the taper profile of synchro-sleeve gears, while broaching is used for the missing teeth profile (**Fig. 7**). This process/machining method creates positional errors due to machining precision problems and workpiece assembly errors and it leads to the problem of a high defective rate.

Here, we will introduce an example of replacing rolling and broaching with skiving and achieving process integration and high precision in a single gear skiving center, including rolling of the inner diameter and teeth cutting.

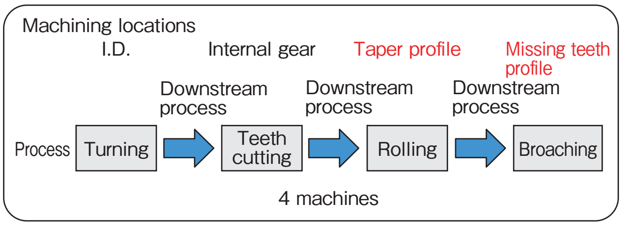

Fig. 7 Conventional machining process

4. 1 Workpiece Specifications

Table 3 below shows the gear specifications, including size (ϕ115×25mm) and material (chromium steel - SCR420H).

Table 3 Gear specifications

O.D., mm	ϕ115
I.D., mm	ϕ93
Module	ml. 86
No. of teeth	51
Angle of torsion, °	30 (RH)
Tooth width, mm	25
Tooth depth, mm	2

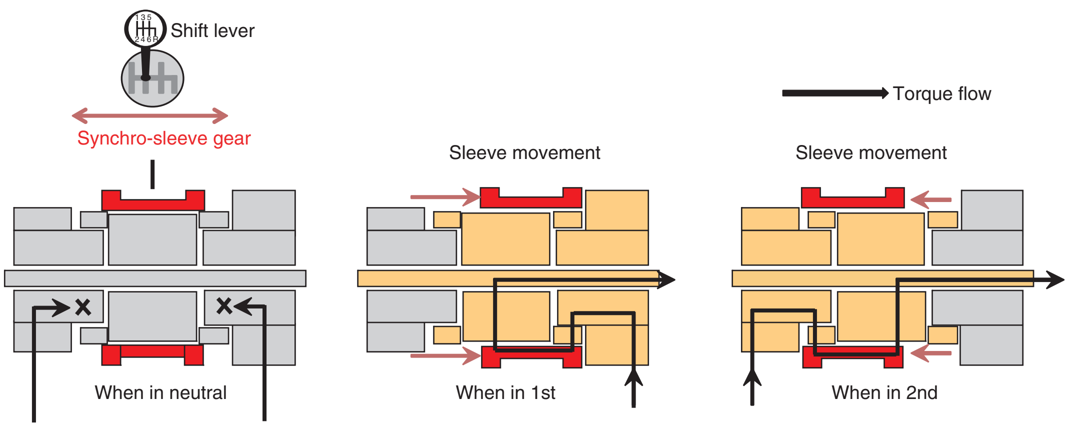

Fig. 5 Synchro sleeve

4. 2 Target Value

Regarding taper angle and phase error, in order to achieve high precision, we set the target value of precision at half or less of the conventional results.

<Target value of precision>

Taper (angle error): 0.5° or less

Phase error: 0.01° or less

Gear precision: JIS grade N7

4. 3 Details of the Development

In order to machine special gear profiles using the skiving method, we divided up the individual processes and extracted the necessary development requirements. The following section introduces the tools and machining method to machine the taper and missing teeth profile.

1) Machining of the taper profile

The taper portion comprises the three elements of the taper profile, symmetrical recesses and double-end profiles. **Figure 8** shows the machining method developed by JTEKT in order to satisfy these.

In regards to the taper angle, we adopted a machining method whereby the taper angle is replaced with a helical gear's angle of torsion, and the tool and workpiece are synchronously rotated to machine an arbitrary taper angle.

For the symmetrical profile, we devised a method to machine the left and right tooth flank respectively. In the case of skiving, the tool trajectory differs depending on the rotational direction and tool torsion at the time of machining, and the cutting zone varies, therefore differences arise in the contact of the left and right tooth flanks and there is asymmetry in the recess portion. As such, we designed a special tool and developed a machining method to control the rotational direction.

Both ends of the workpiece are given a taper profile, therefore we designed tooling to enable machining in a single chuck. We devised a machining method of mounting the rake face of the tool around the opposite way and feeding it in the reverse direction to the conventional method.

2) Missing teeth profile machining

There are three missing teeth profiles on the circumference of the workpiece. As such, we adopted one tool and a synchronization ratio of 1:3, as shown in **Fig. 9**. The removal zone was considered as a profile and the tool's cutting edge was designed to suit this shape.

When a machining method with varying synchronization ratio is used, it can be assumed that the meshing status of the tool and workpiece will be uneven, thus creating large load variance and resulting in chipping. As such, we performed FEM analysis and dynamic rigidity analysis to create a high-rigidity shape whereby there is as little displacement of the tool as possible due to load during machining.

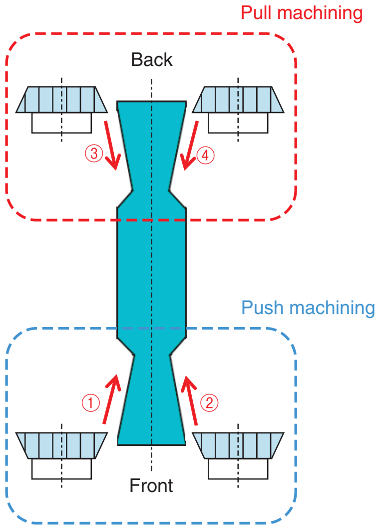

Fig. 8 Taper machining process

To design the tool's cutting edge, we developed design simulation software of arbitrary gear profiles. Commonly, the gear profile is designed in accordance with an involute generation theory. As such, conventional tool development involved generating motion of the tool cutting edge profile, then calculation and optimization of the workpiece gear profile. However, there is no missing teeth generation theory that can be applied to the missing teeth profile used on this occasion, therefore we were unable to settle on a profile for the cutting edge.

As such, we developed a new simulation software to reverse calculation of the tool profile from the workpiece's missing teeth profile. By entering the missing teeth profile of the workpiece and tool specifications, the optimal tool cutting edge profile is outputted, and this makes it possible to design tools of all non-involute profiles, such as reduction gears and pulleys (**Fig. 10**).

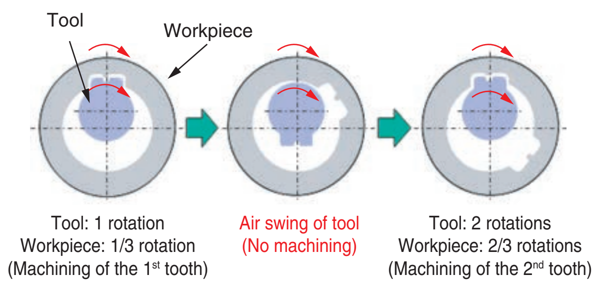

Fig. 9 Image of missing teeth machining process

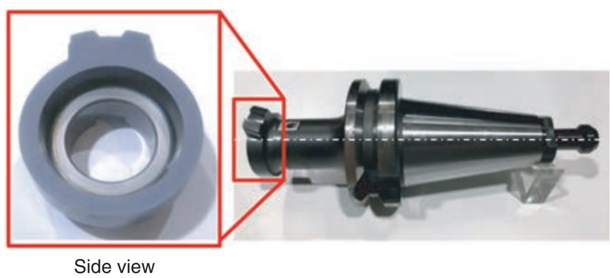

Fig. 10 Tool for missing teeth

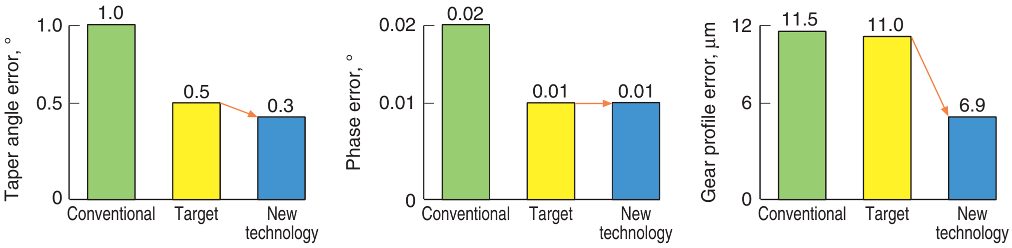

Fig. 11 Processing results

4. 4 Machining Results

We performed a machining evaluation for the taper portion using a skiving tool with 29 blades, as well as a machining evaluation of the missing teeth portion using a 2-blade skiving tool with a torsion of 20°.

The machining evaluation results were a taper angle error of 0.3°, missing teeth (profile error) angle of 0.05mm and a phase error of 0.01° or less, meaning that gear precision was equivalent to the target value of JIS grade N7 (**Fig. 11**). **Figure 12** is a post-processing photograph.

Consequently, as **Fig. 13** shows, a machine adopting the skiving method of machining integrates processes to effectively perform the tasks of four machines in one, in addition to halving tool costs.

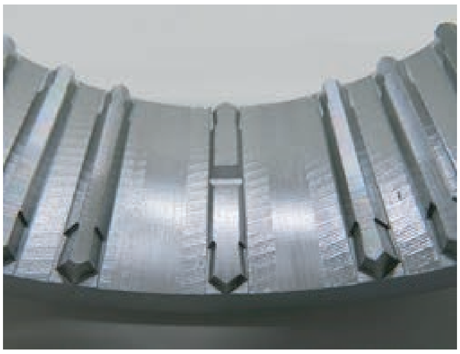

Fig. 12 Post-processing workpiece

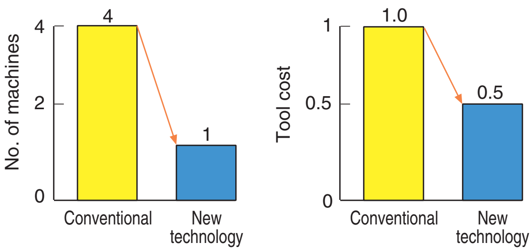

Fig. 13 Effects

5. Conclusion

In regards to the machining of synchro-sleeve gears for manual transmissions, we successfully achieved high precision, high efficiency combined machining by using the GS200H and adopting the skiving method. This has enabled the reduction of the number of machines and achieved a space-saving, flexible machining line capable of swiftly responding to changes in manufacturing processes and production volume.

Moreover, by utilizing the technologies and skiving centers developed on this occasion, it is possible to support a wide-range of profiles other than gears, such as the non-involute profiles of pulleys, tapers and chamfers. JTEKT will continue engaging in the development of gear machining technologies and contributing to the technological innovation of gear manufacturing.

*1 TOYOPUC-GC70 is a registered trademark of JTEKT Corporation.

References

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L. ZHANG*

K. NATSUDA*

* *Machine Tools & Mechatronics Engineering Dept., Machine Tools & Mechatronics Operations Headquarters*