Technical Update on NC Hobbing Machine
FINISH HOBBING of HARDENED GEARS with CARBIDE HOBS

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Hobbing machine manufacturers have been facing diverse demands from gear industry. Machining at higher speed, producing higher accuracy, lower production cost, and energy saving production are the most common requests from the market. Recently, there has been an increased need for combined gear production processes for higher efficiency. In response to such requests, we are making maximum efforts to design and manufacture our machines in a timely manner.

In 1994, we established the dry hobbing process with carbide hobs in order to develop a high speed dry hobbing machine which does not require coolant oil. Since then, we have continued to develop higher performing and more environmentally friendly hobbing machines. Currently, 80% of our hobbing machines are dry-capable.

There has been a misleading concept that a hobbing machine is simply a roughing machine which does not require high accuracy, as most of the automotive transmission gears further require the shave finish process after hobbing.

In fact, hobbing machines have been used for finishing gears or producing high index accuracy worm wheels where special capabilities of both high accuracy light load and high speed heavy load cuttings are needed.

With the spread of dry hobbing, a new method for gear finishing, Hard Hobbing, was put into practical application in 1998.

Hard hobbing process finishes gear tooth flank which is hardened to HRC 50～60 to high accuracy with carbide hob, while dry hobbing, in general, hobs row blank workpiece with TiAlN coated HSS hob.

Although there exist a few wet hard hobbings, dry hard hobbings are mostly employed in hard hobbing process. These machines, designated to hard hobbing, have been manufactured with continuously updated technologies to produce low cost finished gears.

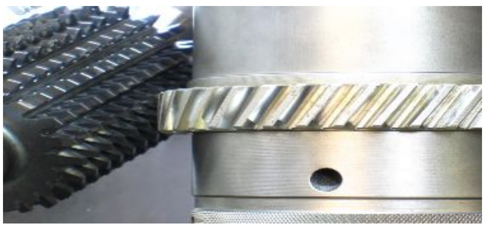
A considerable quantity of the shipped out hard hobbing machines indicate that the hard hobbing process is expected to grow in the future.

● Hard Hobbing and Finishing Process

There are various kinds of finishing methods depending on the usage of finished gears. A grinding method is mostly taken for obtaining high accuracy tooth profile.

Hard hobbing (Refer to Pic.1) has an increasing potential as an application for finishing gears which do not require as much high accuracy as the gears produced by grinding.

A brief summary of the comparison between hard hobbing and gear grinding is shown in Fig.1.



Pic.1 Hob cutter & work gear at hard hobbing

Fig.1 Hard hobbing compared to gear grinding

Item	Hard hobbing	Gear grinding
Tooth profile accuracy	High accuracy but lower than that of gear grinding	Generally, better than hard hobbing
Tooth profile modification	Difficult	Profile modifications such as biased modification possible
Production cost	Low	High
Machine operation	Easy as an extention of hobbing operation	Requires expertise
Surface roughness on flanks	Around 1Rz (Adjustable by changing feed)	1～3Rz
Control on tooth thickness	Easy by giving targeted precision infeed	Requires several trial infeed
Environment	Environment oriented dry operation	Wet operation

As mentioned in Figure 1, the sharp and solid cutting edge of a hard hobbing tool makes it possible to obtain a targeted OBD size with a single infeed. On the other hand, abrasive grinding wheel which does not have cutting edge may not produce the OBD size with a single infeed in some cases.

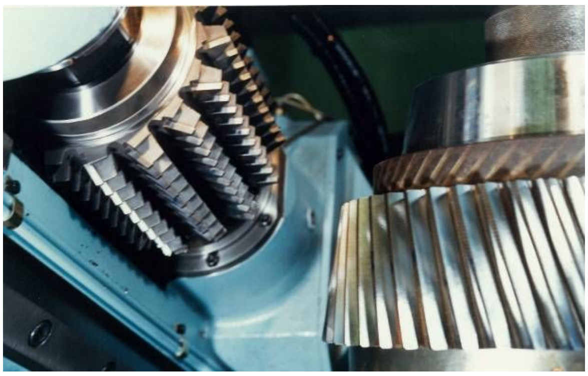
Although there has been no clear definition on hard hobbing, it can be described in relation to carbide skiving finish process as follows.

Both processes finish highly hardened gear tooth flank. The two processes are different in the type of used hob cutters and workpieces to work on.

Skive hobbing cutter: Large module up to m30
with carbide brazed tooth which has about −30° rake angle.

Hard hobbing cutter: Mostly small module carbide solid hob ranging from m0.3 to m2.5
with tooth rake angle near zero degree.

Picture 2 shows skiving of coarse pitched (m5) reduction gear using Kashifuji KB 400 CNC Hobbing Machine.



Pic.2 Skiving hobbing

● Hard hobbing

The application ratio according to the types of gears produced by Kashifuji hard hobbing machines at customers is given in figure 2. As shown, fine pitch gears such as automotive steering pinion and gears used in small reduction gear box have a majority.

Fig.2 Ratio according to application

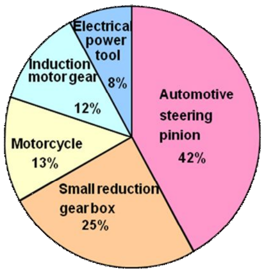
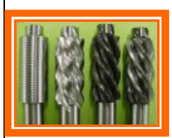
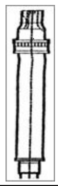


Figure 3 shows a reference case of hard hobbing.

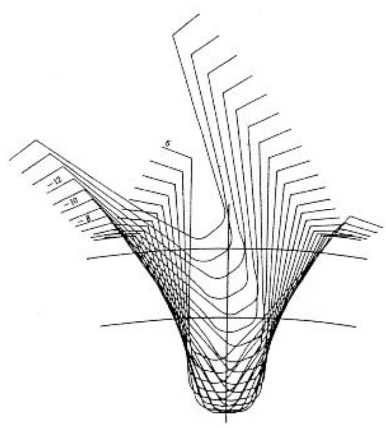
Fig.3 Reference cases of hard hobbing according to the types of gears

Types of gears	**Pinion shaft**		**Fine pitch Pinion & gear**	**Pinion shaft**	**Spur gear**	**Pinion shaft**
	M1.25～M2.5		**M0.5～M2.0**	**M1.25～M2.5**	**M1.25～M2.5**	
Usage	**Electric motor reduction gear box for industrial use**		**Small reduction gear for robot use**	**Automotive steering pinion**	**Motorcycle component**	**Electric power tool reduction gear box**
Picture						
Machine used	**KN150**	**KN151**	**KN80**	**KN80 KN151**	**KN150 KN151**	**P60**
Process detail – Workpiece specs	**m1.25Z8 β15°**	**m1.25Z8 β15°**	**m0.5Z32**	**m2.3Z5 β35°**	**m1.75Z32**	**M0.75 Z5**
	OD ⌀13.9	**OD ø13.9**	**OD ø17**	**OD ø19**	**OD ø61**	**OD ø6.2**
	Tooth width 28	**Tooth width 28**	**Tooth width 7**	**Tooth width 30**	**Tooth width 5.5**	**Tooth width 9**
	SCM440	**SCM415**	**SCM415**	**SCM420**	**SCM420**	**SCM435**
	Induction	**Carburized**	**Carburized**	**Carburized**	**Carburized**	**Induction**
	HRC54	**HRC60**	**HRC60±2**	**HRC55～62**	**HRC55～62**	**HRC50**
Tool specs	**OD ø32** 12 Gashes	**OD ø32** 12 Gashes	**OD ø50** 12 Gashes	**OD ø50** 12 Gashes	**OD ø50** 12 Gashes	**OD ø24** 12 Gashes
	1 Thread	**1 Thread**	**1 Thread**	**1 Thread**	**1 Thread**	**1 Thread**
	Carbide	**Carbide**	**Carbide**	**Carbide**	**Carbide**	**Carbide**
	Coated	**Coated**	**Coated**	**Coated**	**Coated**	**Coated**
Cutting conditions (v.m/min) (f.mm/2f)	**Dry**	**Dry**	**Dry**	**Dry**	**Dry**	**Dry**
	v:60/80	**v:80/100**	**v: 80**	**v: 80**	**v: 80**	**v:200 (2600rpm)**
	F:1.0/0.6	**F:1.5/0.5**	**F:0.8**	**F:0.8**	**F:1.0**	**F:0.4**
	2 cut	**2 cut**	**1 cut**	**1 cut**	**1 cut**	**1 cut**
	Finish from blank	**Finish**	**Finish**	**Finish**	**Finish**	**Finish**
	Cycle time 80″	**Cycle time 67″**	**Cycle time 84″**	**Cycle time 90″**	**Cycle time 53″**	**Cycle time 20″**

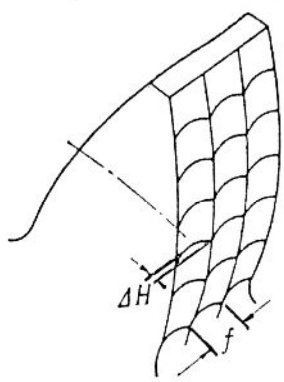
A study on finishing hardened pinion shaft for induction motor gear box inspired Kashifuji to develop hard hobbing process. Since then, this hard hobbing application has become widely used in processing other types of hardened gears which have about HRC 60 hardness. In the early stage, "Hard finish hobbing from blank", finish hobbing hardened cylindrical motor shaft using full depth infeed was developed. This application has also been increasingly used to replace costly grinding. Currently, it is possible to put the application into a large scale production for the gear size up to ml.25.

Hard hobbing produces as good surface roughness of gear flank as that of ground gear, even better one depending on cutting conditions.

Involute variation



Feed mark variation



Surface roughness of a gear tooth flank changes depending on the axial cutter feed amount used. The height of surface asperity is calculated by the following formula.

$$\circ \Delta H = \frac{f^2}{4 \cdot dc} \cdots Root$$

$$\circ \Delta H = \frac{f^2 \cdot \sin \alpha}{4 \cdot d_c} \cdots Flank$$

$\Delta H \cdots$ *Height of surface asperity* (*mm*)

$dc \cdots$ *Hob cutter OD* (mm)

$\alpha \cdots$ Pressure angle (degrees)

f･･･*Feed amount* (mm/rev)

Note:

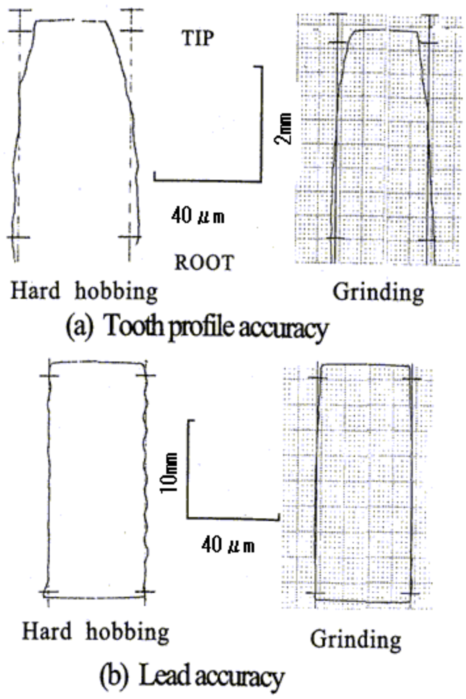
f *for* $f/\cos\beta$

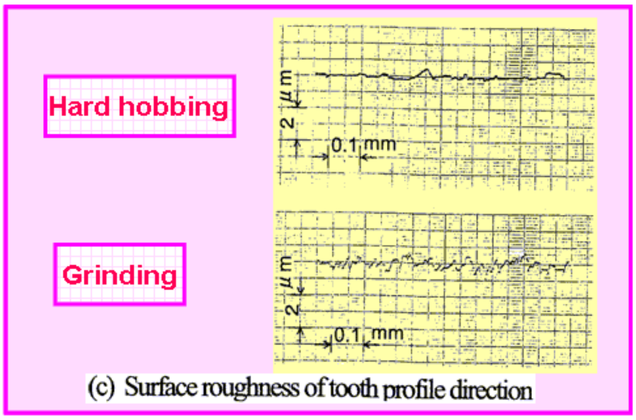
β *for part helix angle*

Fig.4 Involute variation on generated profile & feed mark variation

Figure 4 shows variations caused by gear profile generation and feed mark. The involute form of gear profile is generated by limited number of straight cutter edge lines. Therefore, the generation creates a slight variation between the theoretical involute form and the actual involute generated by straight cutter edge lines, but it is almost negligible. As axial cutter feed per workpiece revolution leaves feed mark on the gear flank at hobbing, it produces feed mark variation. The feed mark made by hobbing is clearly visible, but involute variation is not visible due to its microscopic status. The feed mark height is greatly influenced by the axial cutter feed amount as shown in Figure 4. Surface roughness close to that of gear grinding becomes available when the feed mark variation is kept around 1 micron mm. The 1 micron variation accuracy which does not withhold the practical use of gear is available with 1 mm feed per workpiece revolution.

Comparison data on tooth flank surface roughness between two identical gears is given in Figure 5. The two gears which share the same specification of m2.25 Z49 were processed: one by hard hobbing, the other by grinding.





Gears

Module	2.25
Pressure angle	14.5°
Helix angle	27° (RH)
Number of teeth	49
Whole depth	8.25mm
Face width	24mm
Material	SCM420H
Hardness	63HRC
Hobbing machine	KA220ECNC

Hobs

Number of threads	2(RH)
Outside diameter	85
Rake angle	0°
Number of flutes	16
Coating	Al-Ti-Cr

Conditions

Feed	1.2mm/rev
Cutting depth	0.28mm
Cutting speed	120m/min
Coolant	Air blow

Fig.5 Surface roughness comparison between hard hobbed and ground gears

Figure 5 indicates that hard hobbing produces as high gear quality as grinding does.

In Figure 6, motives and reasons for employing the hard hobbing process are listed.

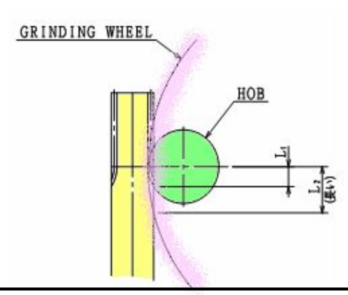
Fig.6 Purpose of employing hard hobbing and its gear production process

	Purpose	Conventional process	Hard hobbing process
1	Higher accuracy	Hobbing→hardening	hobbing→hardening→hard hobbing
		hobbing→shaving→hardening	hobbing→shaving→hardening→ hard hobbing
2	Difficult to grind due to large grinding wheel dia.	Same as above	Same as above
3	Lower cost	hobbing→hardening→grinding	hobbing→hardening→hard hobbing
4	Easier tooth thickness control	Same as above	Same as above
5	Shorter process	turning → hobbing → hardening → grinding or hard hobbing	turning→hardening→hard hobbing

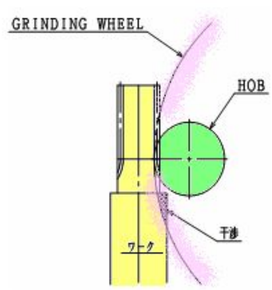
Most of the reasons for choosing hard hobbing fall under item 2 and 3. Details of item 2 are shown in Figure 7. Abrasive grinding wheel of near ϕ400 dia. often causes interference with the workpiece or work holding fixture, making its grinding unable to perform as shown in Figure 7. On the other hand, much smaller dia. hard hobbing cutters (ϕ30～ϕ70) have an advantage of not causing the interference.

Fig. 7 Gear finishing process and its tool

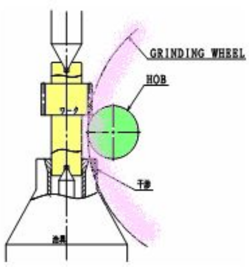
A smaller hob produces shorter overrun that enables to make a shorter component.



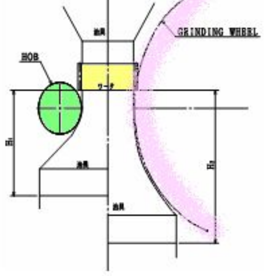
A smaller hob does not interfere with the workpiece shoulder.



A large grinding wheel is likely to interfere with the workpiece holding fixture, reducing the rigidity of the holding fixture.



A smaller hob enables low work clamping position where higher fixture rigidity exists.

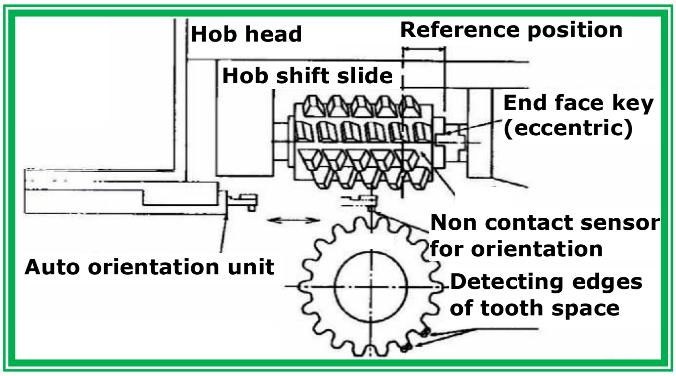


Technical elements required for hard hobbing

A hobbing machine, cutter, mounting cutter, workpiece clamping are important elements. All the elements must be kept at the standard level mentioned in the next items in order to perform proper hard hobbing.

(1) Required hobbing machine specifications

Hob spindle taper and nose end face that hold hob cutter need to have around 1 μm runout accuracy. High runout accuracy of the hob spindle is needed as runout has direct effect on the tooth profile accuracy. Hard hobbing also requires an auto workpiece orientation unit which accurately orientates cutter tooth to tooth space of the workpiece that has been hobbed before hardening. Picture 3 shows this auto orientation unit.



Pic.3 Auto orientation unit

This orientation sensor detects the edges of tooth space on outer diameter of a gear, then plots the position of the tooth space in high speed of 5 seconds.

(2) Required hob cutter specifications

The hob cutter requires a designated carbide material and TiAlN coating for hard hobbing of gears hardened to HrC50～60. The cutter accuracy classification needs to be higher than ISO AAA. Other than those requirements, high accuracy multi threads hob cutters will be needed for faster hard hobbing in the future. A short-pitched cutter tooth design improves hard hobbed gear tooth profile accuracy in some cases. Specifications of the hard hobbed gear and short-pitched hob cutter are given in the next Figure 8 along with the cutting conditions.

Fig.8 Cutting conditions when short-pitched hobis used.

Workpiece specs	: m1.6 PA20° PA16° NT9 HA30°
Cutter specs	: OD ∅40 12 gashes 1 thread
Cutting conditions	: Hob speed 637rpm(80m/min) Feed 0.8mm/rev

Originally, the part was hard hobbed with PA20° cutter, producing considerable amount of profile error. This error was improved with the use of PA16° short-pitched cutter.

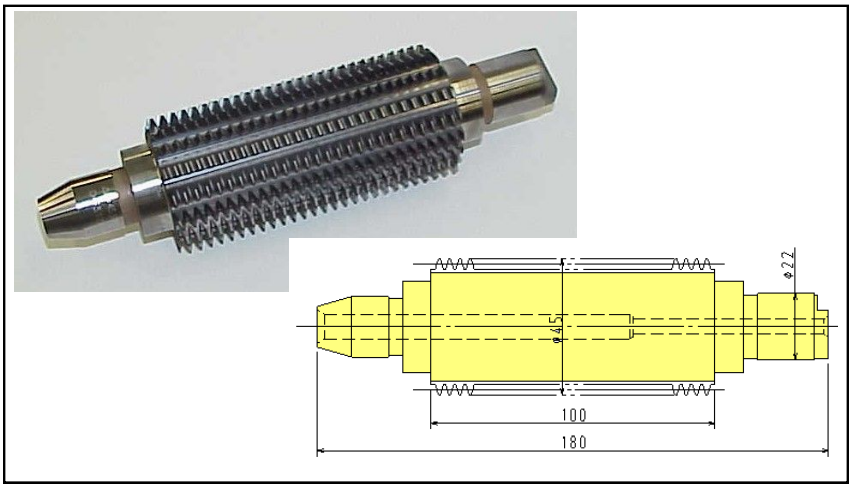
The error was caused by the unbalanced cutting load generated on hob cutting edges (L & R).

When PA20° hob was used for hard hobbing with very small amount of radial infeed, hob left cutting edge was contacting gear tooth flank in 2 points while right cutting edge was contacting in only 1 point. This unbalanced cutting load caused larger stock removal on right edge which is led to the profile error. The short-pitched hob with PA16° enabled a balanced cutting load on both L & R edges, one contact point for each edge, to improve the profile accuracy. The load of force of cutting edge that is put on the gear flank of the workpiece in rotating direction is balanced to improve the profile accuracy. Please note that this use of the short-pitched hob is not applicable to any gears.

(3) Required accuracy for mounting a hob cutter

When it comes to hobbing operation, each of these elements: a hobbing machine, a hob cutter, mounting of a cutter, gear blank , and work holding fixture effect the quality of produced gear. Ideal runout accuracy of a mounted hob cutter is under 3 μm.

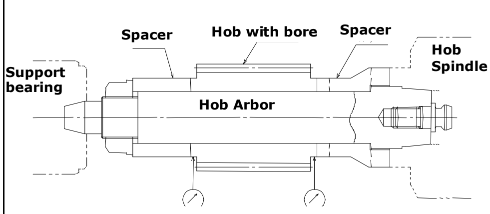
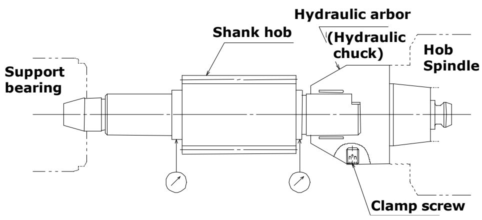
In general, a hob cutter gets assembled on a hob arbor, then it needs to be trued before getting mounted on the machine. This truing is a time-absorbing operation as well as it requires skilled labor. Because of the accumulated elements, such as hob arbor runout, side face runout of hob arbor spacer, clearance between hob bore and arbor, and tightening torque of hob arbor nut, the trued runout accuracy will be around 5 μm at the most. The cutter and arbor need to remain assembled during its regrinding to maintain operation efficiency.



Pic. 4 Shank type hob cutter

Figure 9 is the accuracy comparison chart between conventional and shank type hob mounts.

Fig. 9 Improved hob mounting accuracy with shank type hob

	Conventional mount	High accuracy mount
Mounting method	**Hob with bore ＋ hob arbor**	**Shank hob ＋ hydraulic chuck**
Mounted accuracy	**About 5 μ with a long adjustment**	**1-2 μ with a short setup**
Mounted schematic		
Description	**Preliminary arbor nut tightening produces about 20 μ runout, then time absorbing adjustment comes to obtain about 5 μ runout. It is advised to regrind the hob cutter while hob and arbor are assembled.**	**1 μm runout accuracy is available with just tightening the clamp screw.**

(4) Required accuracy for mounting a workpiece

A workpiece which is mounted incorrectly can exhibit a condition known as runout. The runout has effects on lead accuracy, lead variation and tooth runout of the produced gear. Minimized runout of workpiece end face and high accuracy clamping face of workpiece holding fixture are needed, as the poor perpendicularity of workpiece end face to its bore and work arbor, or the poor runout accuracy of work arbor, can also contribute to the error of gear tooth runout.

Figure 10 shows the trial cuts of an automotive planetary pinion in which two types of workpiece holding fixtures, solid work arbor and hydraulically expanding work arbor, are used. In the case of using the expanding arbor, the following chart indicates an improved lead variation that is attributed to the smaller workpiece runout.

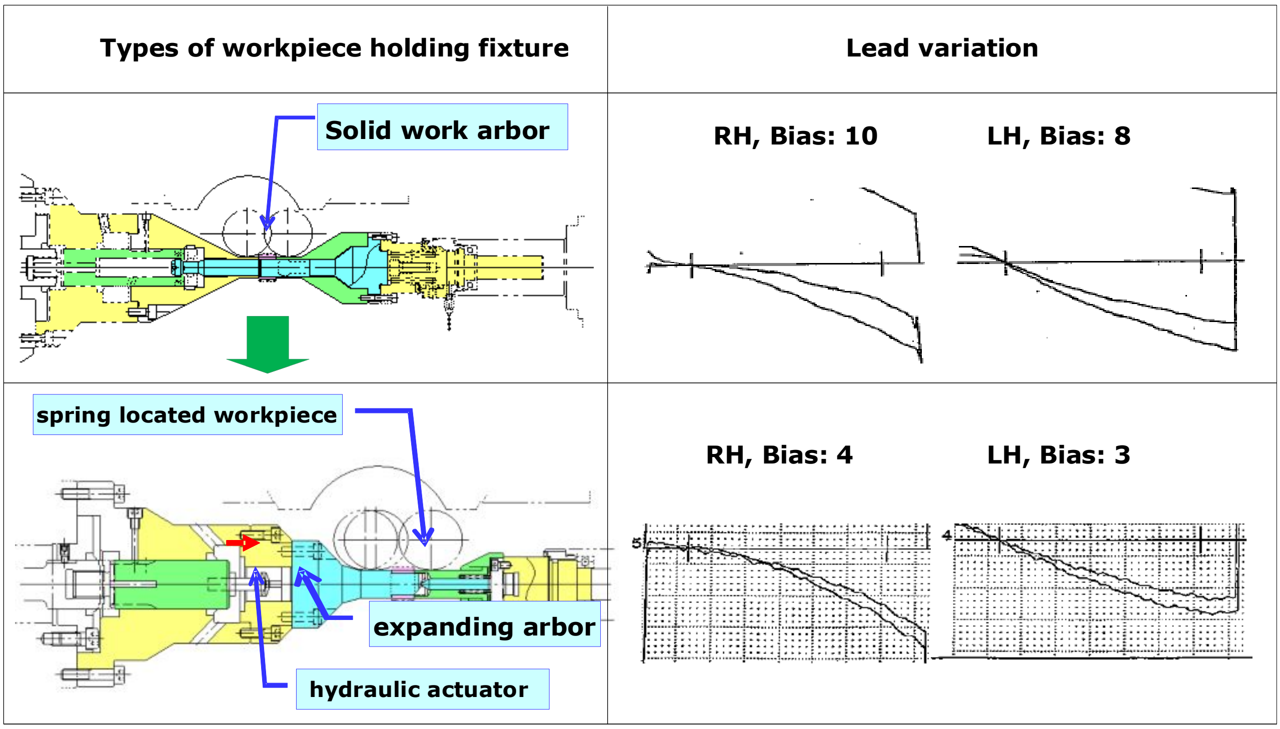
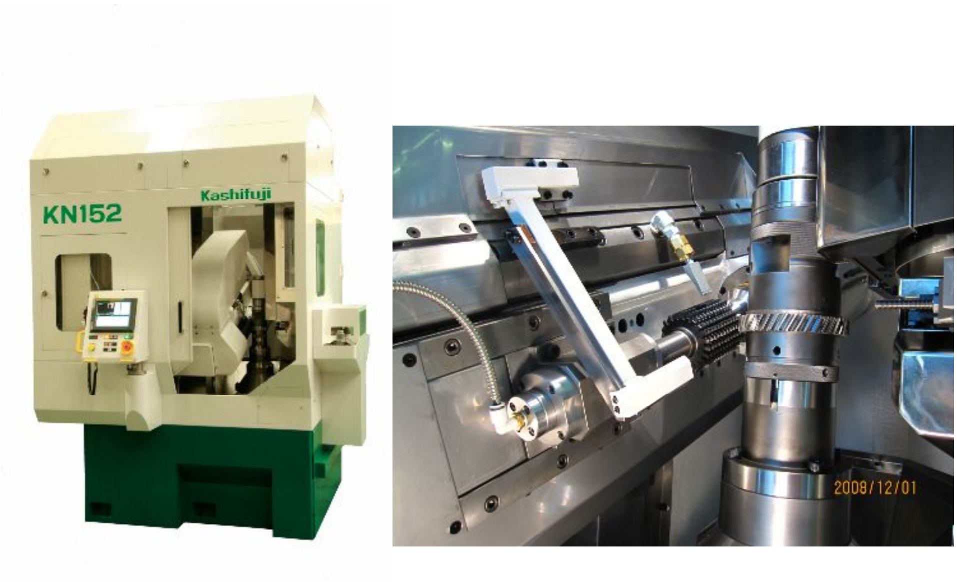


Fig. 10　　Improved workpiece runout accuracy with expanding arbor

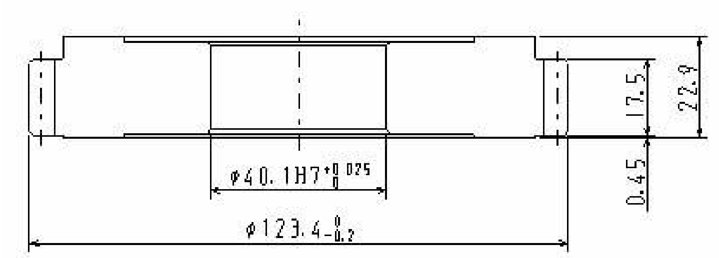
● Hard hobbed gear accuracy

In this chapter, hard hobbing trial cut using newly developed KN152CNC is presented. KN152CNC is the successor machine of KN151CNC. It comes with updated chip evacuation system for dry cut, energy saving capability and hard hobbing cutter head which enables high accuracy hob shift for the finishing process. The KN152CNC machine is shown in Picture 5. Figure 11 and 12 show cutting conditions and gear inspection data respectively when KN152CNC is used.



Pic. 5　Overview of KN152CNC and hard hobbing cutter head for finish process

Fig. 11　　Adopted cutting conditions for the trial



歯車諸元 Gear data		使用ホブ諸元 Hob data		切削条件 Cutting condition	
ピッチ Pitch	M2. 5	メーカー Manufacturer	NACHI	切削方向 Feed direction	クライム climb
歯数 No. of teeth	42	材質 Material	超硬 NF3A1	切削回数 No. of cuts	1
圧力角 Pressure angle	20°			ワーク取付個数 No. of works stacked	1
ねじれ角(方向) Helix angle(Heand)	27. 5° RH	コーティング Coating	AM04	ホブ回転速度 Hob speed	637 min^{-1}
ピッチ円直径 Pitch dia.	118.356 mm	外径 Outer dia.	75mm	切削速度 Cutting speed	150 m/min
外径 Outer dia.	123.4 mm	有効長さ Length	95mm	アキシャル送り Feed rate	1.0 mm/rev
歯幅 Face width	17. 5mm	軸径 Shaft dia.	32mm	ダイヤゴナル量 Diagonal	14.9mm (歯面)
材質 Material	SCM 415	進み角(方向) Lead angle (Hand)	6° 00'RH	切込量 Cutting depth	0.3 mm
硬度 Hardness	HRC 62	条数 No. of starts	3	仕上げ代 Stock removal	0.1 mm
焼入れ Heat treatment	真空浸炭 Vacuum carburizing	すくい角 Rake Face angle	−15°	切削タイム Cutting time	44sec.
		切刃溝数 No. of flutes	18	サイクルタイム(AL仕様) Cycle time (with Auto Loader)	(73sec.)
クラウニング量 Crowning	10μm (歯面)	すくい面コーティング Cutting face coating	無		
				位相合わせ時間 Part orientation time	11sec.

Workpiece specifications are m2.5, 42 teeth and helix angle 27.5° RH. Used hob is 75mm outer dia., 3 starts and TiA1N coated Nachi make. The left diagrams are the inspections charts of before hard hobbing, while the right ones are those of hard hobbed. The charts indicate profile and crowned lead accuracy.

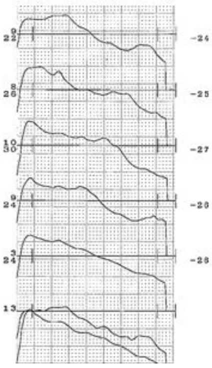
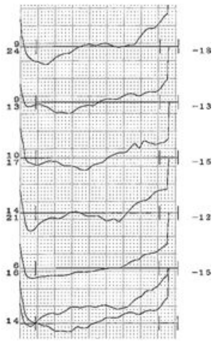
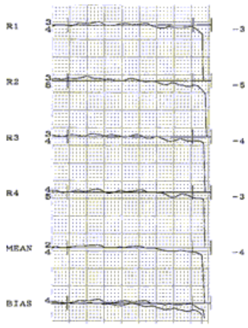
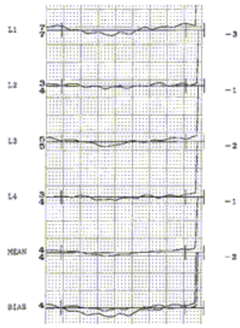
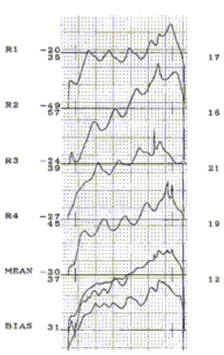
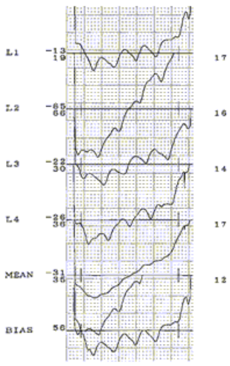
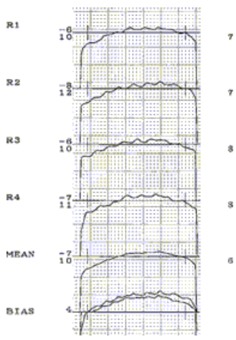
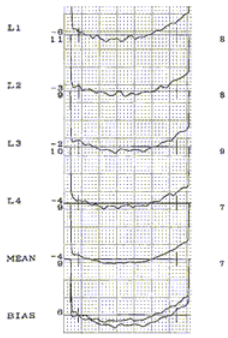
	Before hard hobbing		After hard hobbing	
	right flank 右歯面	left flank 左歯面	right flank 右歯面	left flank 左歯面
Profile error				
	right flank 右歯面	left flank 左歯面	right flank 右歯面	left flank 左歯面
Lead error				

Fig. 12 Accuracy of hard hobbed gear

● Diagonal hard hobbing

The conventional hobbing uses axial feed only. Another hard hobbing, which is called Diagonal Hobbing, was experimented with the simultaneous use of axial (Z axis) and hob shift (Y axis) feed.
Figure 13 shows the schematics of conventional and diagonal hobbings.

Conventional hobbing with axial (Z axis) feed only | **Diagonal hobbing with simultaneous feed of Y & Z axis**

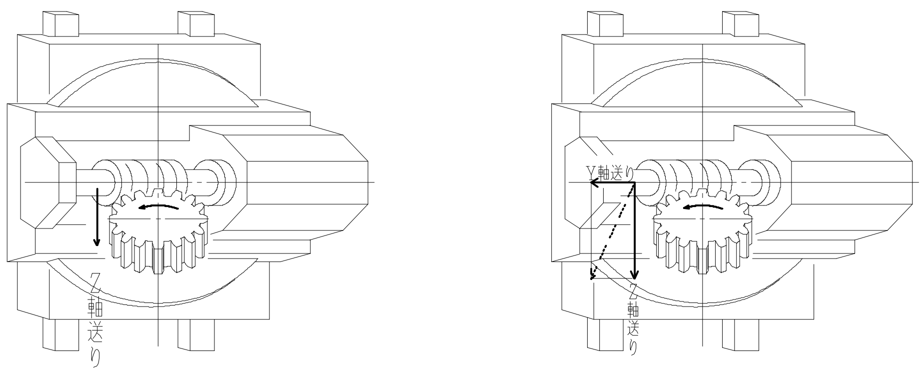


Fig. 13 Diagonal hobbing

As shown in Figure 4, involute variation exists on the hobbed tooth flanks because of the gear profile generation made by limited number of straight hob cutter edge lines.

The heights of this cutter edge lines are generated in succession along gear tooth lead direction. Gear tooth flanks with the involute variation inhibit smooth rotation of a gear pair. Diagonal hobbing is one of the countermeasures which compensate for the variation. The smoother meshing of a diagonal hobbed gear pair can be contributed to the fact that the heights of cutter edge lines (generation marks) lie under a slanted direction as shown in Figure 14.

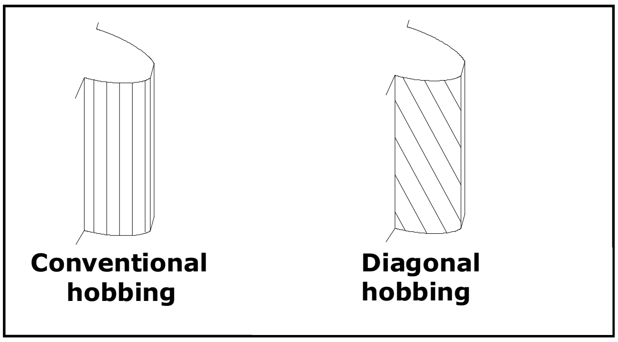


Fig. 14 Generation marks at hobbing

Feed amount of axial and hob shift was calculated in such a way that the waviness of generation marks can be displaced half a pitch per each workpiece rotation. Regularly displaced waviness of generation marks are shown in Picture 6.

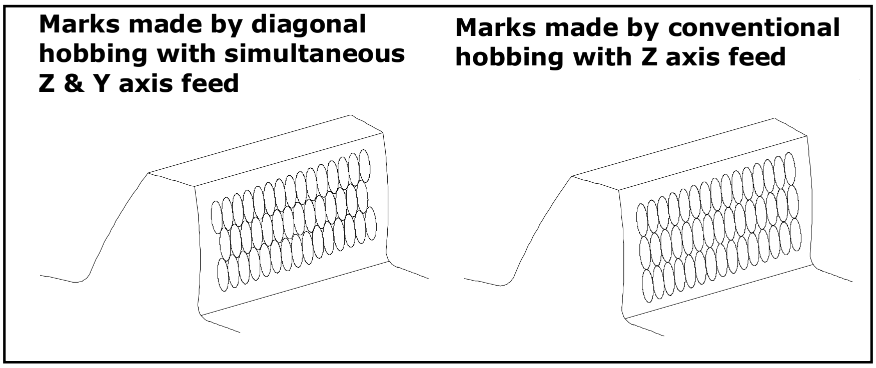
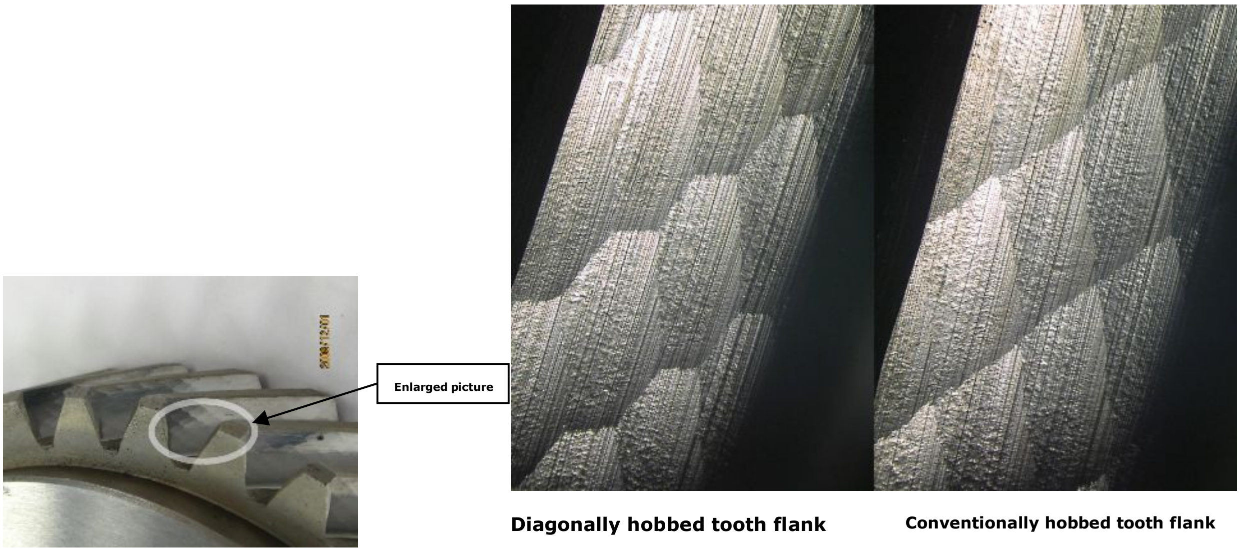


Fig. 15 Generation marks at hobbing



Pic. 6 Enlarged pictures of tooth flank

● Future research subjects of hard hobbing

- Development of high accuracy multi threaded hob cutter for faster cycle time
- Development of workpiece holding fixture which causes minimized workpiece runout for large size gears
- A new process that eliminates feed and cutter marks
- Longer tool life for lower cutter cost
- A noise evaluation test of a gear box in which hard hobbed gears are mounted