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Cutting Performance of Digital Controlled Milling A·M·B spindle

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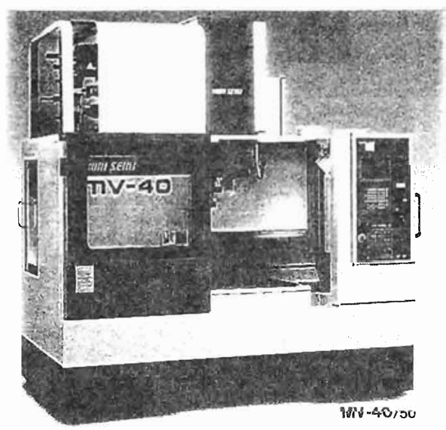
ABSTRACT

Recentry, The Active Magnetic Bearings are used for high speed machine tool spindle, because of its remarkable advantage such as maintenance free, high speed, and process monitoring possibility during operation. Furthemore, the high stiffness and high speed milling A. M. B. spindles have already available on the market, for example, HF200MA40A manufactured by IBAG zurich AG with maximumspeed of 40,000rpm, 40kW maximum power, and HSK-50E as the tooling interface with integral drawbar system for ATC operation. By the way, it is possible to measure the Dynamic Stiffnass or the Compliance of the spindle with the several tools, by means of hammering as the most traditional way. Disturbance signal injection to A. M. B. system is another possibility to estimate the Dynamic Stiffness at tool suspended by A. M. B. system.
Furthemore, It is possible to measure the Cutting Force of tools by means of Digital controlled Active Magnetic Bearings. In this paper, we are reported the Cutting Force of tools on A. M. B. spindle at the several cutting condition.

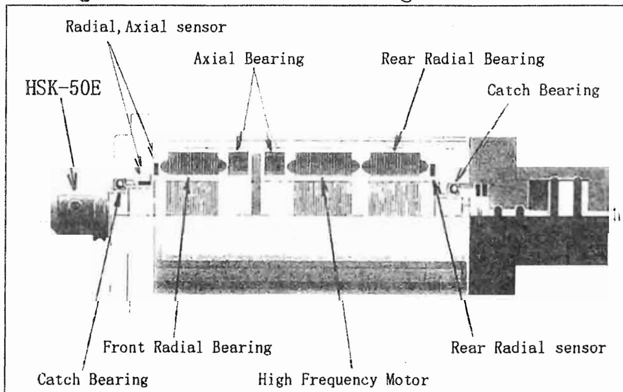
1. INTRODUCTION

The A. M. B. spindle named "HF200MA40A" manufactured by IBAG zurich AG is realized at maximum speed: 40,000rpm, maximum power:40kW, and spindle diameter: ϕ90, is already on the market. Furethemore, it has integrated ATC drawbar system, HSK-50E tooling interface having taper and shoulder contact is studying on DIN standard. This spindle was shown on International Machine trade fair held in Italy "'95 of May", built in the Machinning Center called MV-40B manufactured by MORI SEIKI co., Ltd., MV-40B demonstrated its performance to cut the Cast Iron FC-25 with CBN toolings. The controller of A. M. B. spindle HF200MA40A is Digitaliy controlled by DSP and PWM Power Amplifire. In this paper, we measured the Cutting Force at tools on several cutting conditions, calculated by Personal Computer using DSP signal directly.
As the result, we made special presentation for High Speed cutting information such as the relationship between the Cutting Force and the Cutting conditions.
The Machinning Center MV-40B which having the A. M. B. spindle is shown in Fig. 1. The structure and spec. of A. M. B. spindle HF200MA40A is shown in Fig. 2.



Positioning accuracy	0.005mm(Full stroke)
Repeatability	±0.001mm
Rapid feed rate	20m/min(X, Y) 15m/min(Z)

Fig. 1 MORI SEIKI Machinning center:MV-40B



Max rot. Speed	40,000rpm
Max peak power	40kW
Continuous power	30kW
Taper size	HSK-50E
Max axial load	1500N/μm
Max radial load	front 1400, rear 700N/μm

Fig. 2 IBAG A. M. B. spindle : HF200MA40A

2. CONDITION OF PROCESSING AND ESTIMATION

2.1 Setting up

The measurment of Cutting Force at tools, during actual cutting are calculated on PC by direct communication with DSP, which controlling the A.M.B. And the Cutting Forces are obtained by integral output signal from DSP. Before the measurment of Cutting Forces, we calibrated the Cutting Forces at the Tool Holder, by adding the corresponding force to the tool. A communication method between the PC and DSP is shown in Fig.3

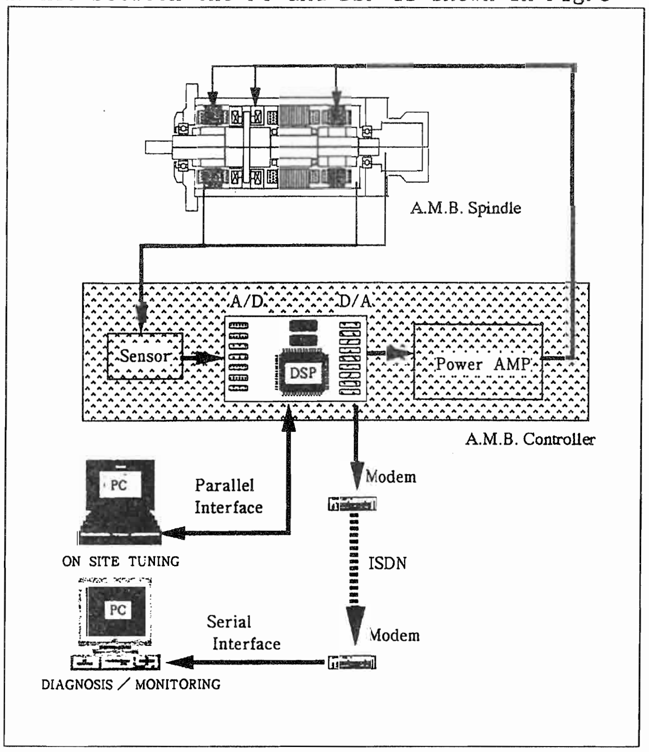


Fig.3 Measurment of DSP signal

2.2 Estimation of Radial(axial) Compliance

Before the several cutting test was started, the spindle rotational speed were decided. At first, the Radial and Axial Compliance of A.M.B. spindle at 0 rpm with planed Cutting tool ϕ20 carbide End Mill cutter installed into Weldon tool Holder (Side lock type) was measured by disturbance signal injection to DSP by means of communication software from the PC.

These kind of procedure is quite useful for first total system start up and to optimize the actual cutting condition.

In the first stage of this procedure, we checked the mentioned compliance and confirmed that there was no strange peak appearing in the measured data. Next, we also measured the compliance of the spindle with planed tools during rotation. The measured compliance of YA(Rear side radial bearing axis) at 40,000rpm and 35,000rpm are shown in Fig.4. The measured compliance of 40,000rpm has high component at 650Hz, but on the other hand, in case of the compliance of 35,000rpm, there is no remarkable peak around rotational speed.

Therefore, we decided to carry out most of our cutting test with this spindle at 35,000rpm.

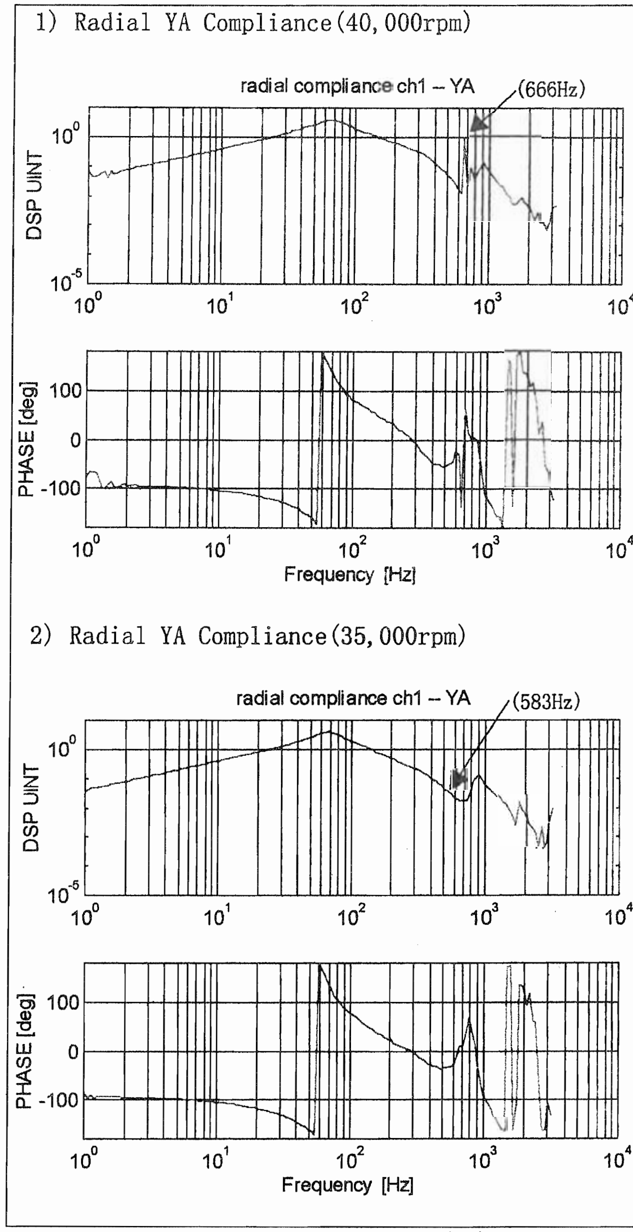


Fig.4 Radial Compliance(YA)

2.3 Cutting Condition

All cutting conditions are shown in Table.1. The cutting direction and the cutting outline are shown in Fig.5. We vary the cutting condition listed below.

1) Cutting Tool : ϕ20 solid carbide End Mill (2 Flute type)
2) Cutting Width : · 8mm (Side Cut)
   · 16mm(Side Cut)
   · 20mm(Groove Cut)
3) Cutting Depth : 2, 4, 6, 8, 10 mm
4) Feed Rate : 4, 6, 8, 10, 12 m/min
5) Material : A6061-T6 (155×155×80mm)

N (rpm)	ae (mm)	ap (mm)	F (m/min)	Remark
40000	16	2, 4, 6, 8, 10	4	Side Cut
35000	8	2, 4, 6, 8, 10	4	↑
35000	8	2, 4, 6, 8, 10	6	↑
35000	8	2, 4, 6, 8, 10	8	↑
35000	8	2, 4, 6, 8, 10	10	↑
35000	8	2, 4, 6, 8, 10	12	↑
35000	16	2, 4, 6, 8, 10	4	↑
35000	16	2, 4, 6, 8, 10	6	↑
35000	16	2, 4, 6, 8, 10	8	↑
35000	16	2, 4, 6, 8, 10	10	↑
35000	16	2, 4, 6, 8, 10	12	↑
35000	20	2, 4, 6, 8, 10	4	Full Cut
35000	20	2, 4, 6, 8, 10	6	(Groove)
35000	20	2, 4, 6, 8	8	↑
35000	20	2, 4, 6	10	↑
35000	20	2, 4, 6	12	↑

Table. 1 Cutting Condition

3. A RESULT OF MEASUREMENT

3.1 Cutting Force

The Cutting Force(Fx, Fy, Fz) of tool head which direction is X, Y, Z perpendiculer to each other were measured for the several cutting condition. During this cutting test, Cutting depth:ap of 2mm to 10mm with Cutting width:ae of 8mm and 16mm so-called Side Cut was able to be finished for planed Feed rate ranging from 4m/sec to 12m/sec.

But, for so-called Groove Cutting, Cutting width= Cutting dia., Cutting depth was restricted by Feed rate. For Groove cutting, it is very difficult to make coolant liquid to reach the Cutting tool head and is also quite bad condition for removing the cutting chip from the Cutting head. This means, chip load will increse remarkably and the chip is easy to welded to the cutter itself which increase the chip load more and more.

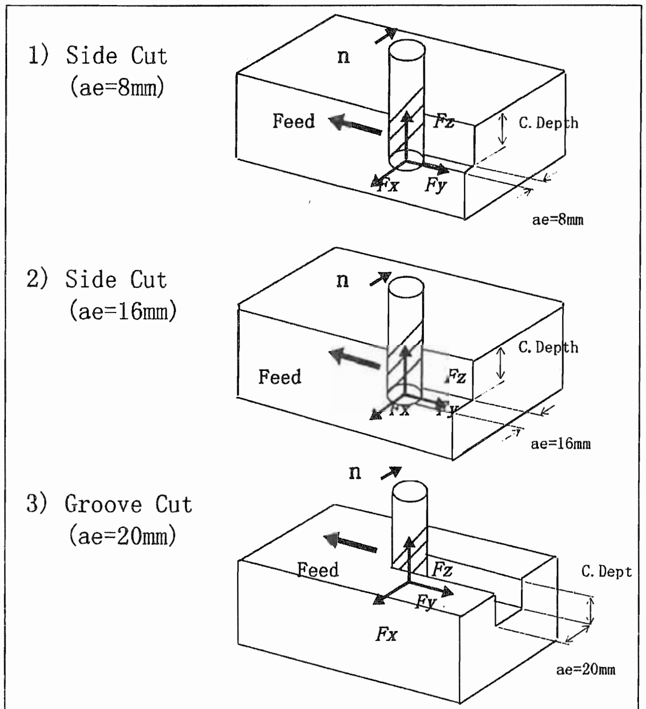
As the result with this bad cutting condition, as soon as the chip load will reach the A. M. B. spindle load capacity, the DSP will transfer the warning signal to the MC, and driving converter for emergency fail-safe stop of total system.

Additionally, for Cutting depth of 10mm with selected cutting tool 20mm End Mill, the cutting result were always terrible that the spindle displacement reached to un tlerable. This limitation is not caused by the limit of the performance of the A. M. B. spindle, but is brought about the absolute limit of tool itself.

Then, each detail Cutting Forces component are mentioned in the following sentences. And a result of measurement at the Cutting Forces are shown in Fig. 6.

1) Fz : Cutting Force of Axial direction

Fz is proportional to the Feed rate, Cutting depth and Cutting width as shown in Fig. 6(3). After all, it is simply proportional to Stock Removal.



- Cutting Length : 155mm
- Taper Size : HSK-50E, Weldon holder
- Tool Size : φ20 End Mill(2 flute type)
- Material : A6061-T6

Fig. 5 Cutting View

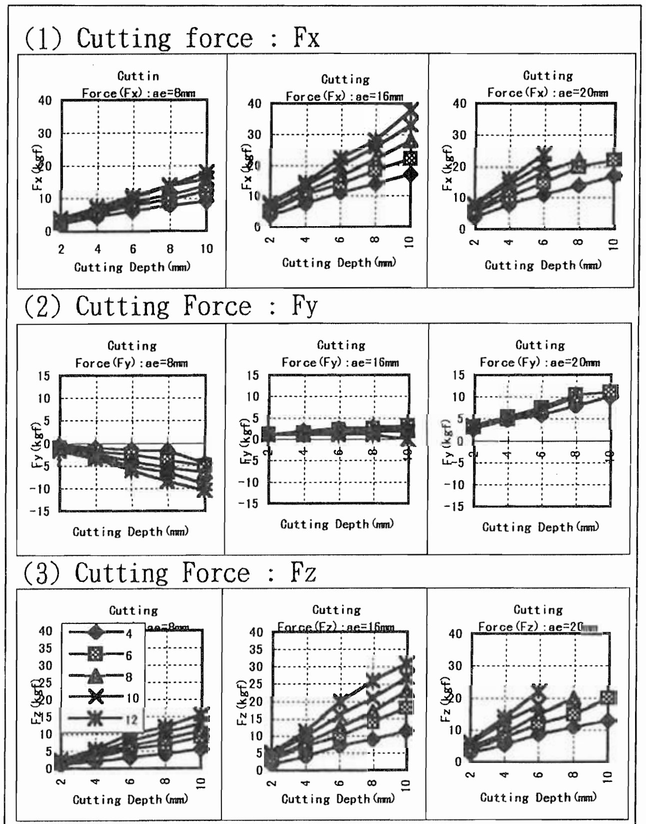


Fig. 6 Cutting Force

2) Fx : Cutting Force of Radial direction
Fx is proportional to Cutting depth, Cutting width as shown in Fig. 6(1). But this Cutting force is proportional to the approximately 0.7 powered value of Feed rate.

3) Fy : Cutting Force of another Radial direction
Most interesting characteristics was found in the behavior of Fy. As shown in Fig. 6(2), the direction of Fy changed depend upon the value of the 'ae'.

In a word, in case of it is lower than a certain persentage of the Cutting width(ae) against the tool diameter(cd), Fy is pulling to the Feed direction. On the other hand, in the case of it is higher, Fy is pushing force.

But, these cutting test were Down Cutting, so in another cutting condition, for example, Climb Cutting or another number of flute, it can be imaged to get a different result, easily.

This direction change of Fy(t) can be explained by detail consideration of the Cutting force compornent in one rotation by means of quite simple model shown in Fig. 7.

As we detected the Cutting force compornent by the integral output of DSP, corresponding each Cutting force compornent can be obtained by integration of the each Cutting force compornent function in time domain.

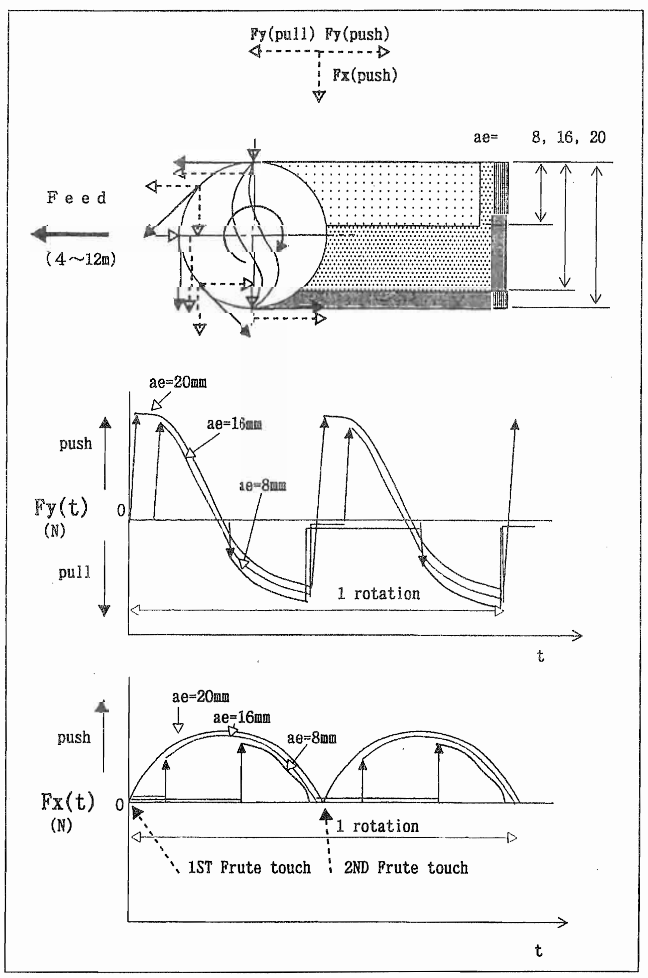


Fig. 7 Cutting Force at the tool

The integrated results of Fx(t) is always positive value results for any ae/cd. This means Fx(t) is always pushing force. On the other hand, the value of integration for Fy(t) can take either positive or negative value depend on ae/cd. This leads to next quite useful critica, a certainvalue of ae/cd (70~80%) offer almost zero force of Fy.

3.2 Experimental Cutting Force Equation

The Cutting Force are influenced by each Cutting coditions. Cutting Forces can be discribed by the following experimental formula.

$$Fx = \alpha \cdot ae \cdot ap \cdot f^{0.7} \quad [N] \quad (1)$$

$$Fy = \beta \cdot ae \cdot ap \cdot f \quad [N] \quad (2)$$

$$Fz = \gamma \cdot ae \cdot ap \cdot f \quad [N] \quad (3)$$

(remark)
- $\alpha \fallingdotseq 1/24$ · $\beta \fallingdotseq$ (a constant of influensed ae/cd)
- $\gamma \fallingdotseq 1/60$
- *ae:Cutting Width(mm)* ·*ap:Cutting Depth(mm)*
- *f :Feed Rate(m/min)* ·*cd:Cutting Diameter(mm)*

Each constant of α, β, γ, in this Cutting conditions is only valid for ϕ20 carbide End Mill, and Down Cutting. But, in another Cutting condition, such as Climb cutting, another cutting tool, these parameters are expected different values.

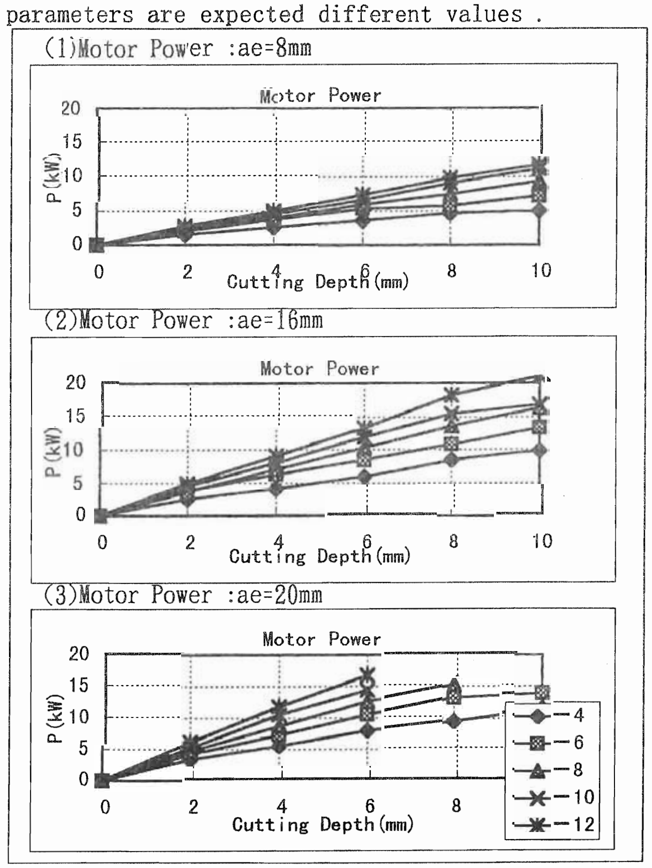


Fig. 8 Motor Power

3.3 Motor power and Stock Removal

The Motor output Power for several Cutting conditions is shown in Fig. 8. Motor Power of actual cutting is proportioned to the Stock Removal. (cm^3/min)

Power estimation for Cutting conditions is represented by following reference formura.

$$Vc = n \cdot \pi \cdot d / 1000 \quad (4)$$

$$Vf = fz \cdot n \cdot Z \quad (5)$$

$$P = Vf \cdot s / Q_{kW} = Q / Q_{kW} \quad (6)$$

(remark)

- *fz : Cutting Feed 1 rev. 1Flute* (mm)
- *n : Spindle Rotational Speed* (min^{-1})
- *d : Cutter Dia.* (mm)
- *Vc : Cutter velocity* (m/min)
- *Z : Number of Flute*
- *Vf : Feed rate* (mm/min)
- *Q_{kW} : Available Stock Removal per 1kW* (cm^3/min·kW)
- *P : Spindle Output Power* (kW)
- *Q : Stock Removal per Min.* (cm^3/min)
- *S : Project Area* (mm^2)

4. SURFACE ROUGHNESS

The Surface Roughness as the quality of cut material is measured for each Cutting conditions, at the Bottom and Side faces. However, the measurment point was decided at about the 40mm point from Cutting start point, and measured length is 4mm respectively. For the Bottom face, measured point is the center of Cutting width, and for the Side face the measured point was set about 2mm height from the Bottom surface. The all results of measurement Surface Roughness is indicated by Ra(μm), as shown in Fig. 9.

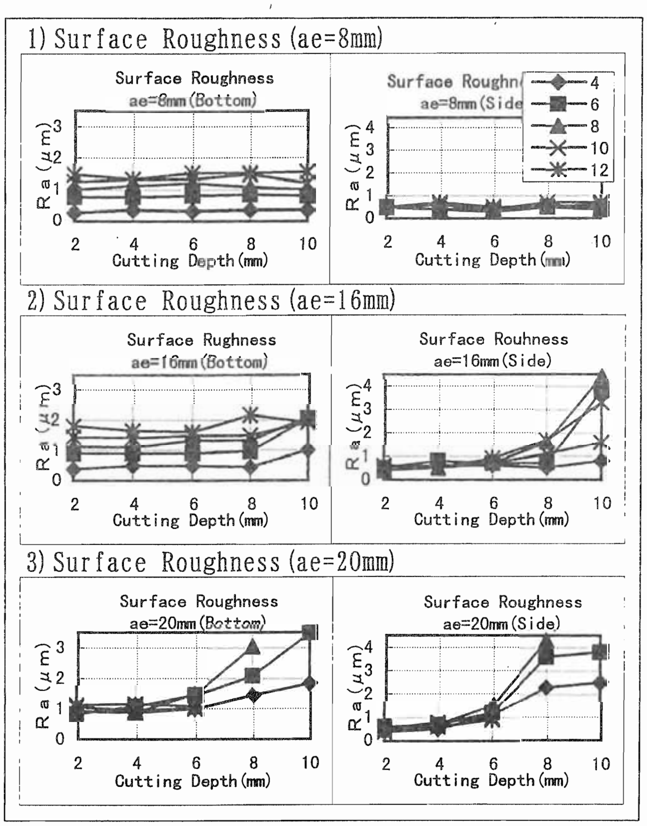


Fig. 9 Surface Roughness

In case of the Cutting forces under about 200N (20kgf), the Surface Roughness of Side face of 0.5μm can be obtained indipendently upon the Cutting condition such as Feed rate, Cutting depth and Cutting width.

5. FUTURE TECHNOLOGY

With the Digital Controlled A.M.B, it is possible to get the every controll signal for A.M.B., by direct communication with a DSP from the PC. For example, we can monitor the Compliance, Cutting Force and Displacement of the spindle, which allow us to save the startup time to reach the optimum Cutting condition.

Recentry, thanks to, for example, Linear Motor direct drive technology, the very High Speed Feed Rate machines are already available on the market. In the near future, the Digital Controlled A.M.B. milling spindle combined with mentioned High Feed Rate machine including communication interface between each other will bring us the quite high possivility to the future High Speed Cutting technology.

REFERENCES

1. MORI SEIKI Co., LTD. A technical catalog of MV-40B (Vertical Machining Center)
2. IBAG Zurich AG, A technical catalog of High Frequency Motor Spindles with Active Magnetic Bearings for Milling, Drilling, and Grinding