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FABRICATION OF MINIATURE COMPONENTS USING MICROTURNING

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ABSTRACT

Micromachining technology is gaining more importance day by day due to the recent advancement in MEMS technology. One group of micromachining technology is microturning. It has the capability to produce three dimensional features on micro scale. This paper deals with CNC microturning process applied to fabricate a micropin. Basically two types of microturning process are used; straight microturning and taper microturning. Micro machining of a surface involves the production of geometrical lines, whose formative motions generate the required surface. In this regard, various cutting path schemes were applied for generating NC codes. Brass bars of 6mm diameter as the work materials have been machined with cutting tools fixed on tool holder. Work materials are clamped on the spindle which has the facility of three-axis movements. Unlike the conventional processes, the cutting tool has no movements. Different cutting schemes have been applied to form various parts of the micropin.

Keywords: Micromachining, CNCmicroturning, micropin

1. INTRODUCTION

The accelerating trend of miniaturization is increasing day by day and micromachining technology contributes to this trend. Micromachining bridges the gap between MEMS manufacturing and the capabilities of conventional machining. Miniaturization has advantages as it reduces energy consumption and materials requirement for manufacturing.

The term “micromachining” is generally used to define the practice of material removal for the production of parts having dimensions that lie between 1 and 999 μm, although an upper limit of 500μm has recently been considered to set the border between micro-and macro-machining [1]. One group of micromachining technology is microturning. It is a conventional material removal process that has been miniaturized. Microturning has the capability to produce three dimensional features on micro scale.

Cylindrical micropin is widely used as a micro tool for micromachining of 3D mechanical microparts [2]. A cylindrical micropin can be made by grinding, wire electrodischarge grinding (WEDG), electrical discharge machining (EDM), electrochemical etching and micro turning. Each process has its own advantages and disadvantages. Grinding has the problems of grinding force and the wear of the grinding wheel. In EDM, pin shape is limited to straight or stepped [3]. In electrochemical etching, the bottle-neck is in controlling the shape and the diameter. Although WEDG is a powerful method to produce micropin, it has limitation of low productivity [2]. Considering all these, CNC microturning method was conceived to fabricate the micropin of compound shape. Because microturning uses a solid cutting tool, it can clearly define and produce 3D shape following various cutting path.

2. CUTTING PATH IN MICROTURNING

A surface is usually defined as a continuum of consecutive geometrical positions obtained in the motion of one geometrical generating line along a path. The machining of a surface involves the production of the geometrical lines as a result of whose formative motions the required surface is produced [4]. For carrying out the process of cutting, the workpiece and the cutting tool must be moved relative to each other in order to separate the excess layer of material in the form of chips. Hence the motion of cutting tool with respect to workpiece is important. In this respect, cutting path generation has given emphasis.

This paper deals with basically two types of microturning processes; straight microturning and taper microturning.

2.1 Straight Turning

Microshaft with high aspect ratio and micron range diameter can not be machined by parallel cut to the axis of the job as in conventional machining shown in Fig.1 As the machining goes on the shaft tends to deflect because the diameter reduces and the unsupported length of the workpiece increases. Fig.2 describes one possible way of fabrication miniature shafts by step cutting process. Unlike parallel cut method turning is done here in a step wise manner.

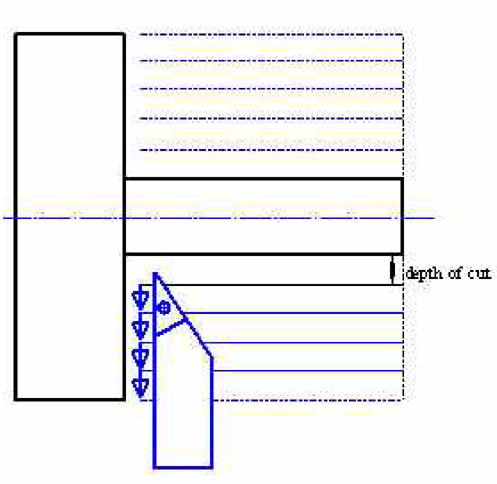


Fig. 1: Turning by parallel cut

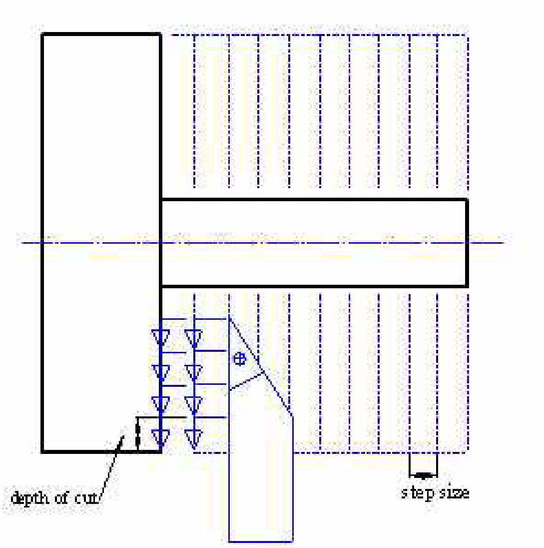


Fig. 2: Turning by step cut

2.2 Taper Turning

Taper turning of a microshaft can be possible as described by the cutting method of Figs. 3 and 4. In parallel cut method, cutting tool motion is parallel to the axis of the job. If t is the depth of cut, α is the taper angle, R and r are the larger and smaller taper radius respectively, total number of cuts(n_p) can be determined.

$$\text{Total number of cuts, } n_p = \frac{R - r}{t} \qquad (1)$$

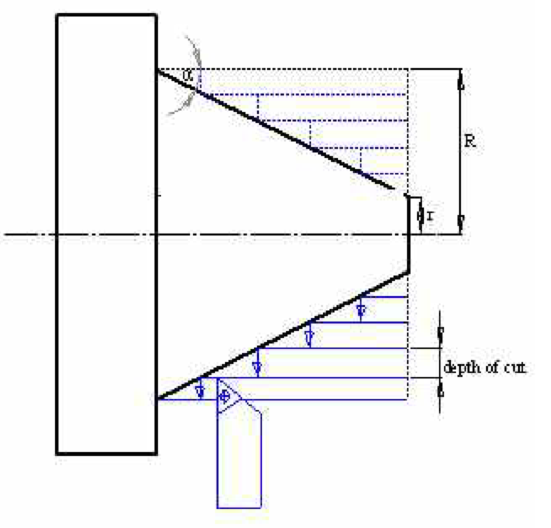


Fig 3.Taper turning by parallel cut to job axis.

Tapered surface can also be generated by machining parallel to the tapered surface as shown in Fig 4. For the same depth of cut (t), the number of cuts (n_t) and the length of the tool path can be given as follows:

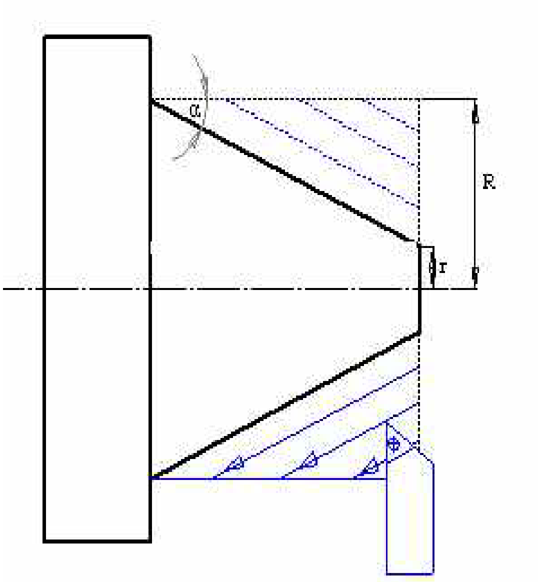


Fig.4: Taper turning by parallel to taper surface.

$$\text{Total number of cuts, } n_t = \frac{(R - r)\cos\alpha}{t} \qquad (2)$$

Considering Equations (1) and (2), it is found that total number of cuts in cutting parallel to taper surface is less than that of cutting parallel to workpiece axis. For saving machining time, cutting parallel to taper surface is preferable.

3. EXPERIMENTAL PROCEDURE

3.1 Machine Tool

Experiments were conducted with a multipurpose miniature machine tool developed in Advanced Manufacturing Laboratory (AML) at NUS for high precision micromachining shown in Fig.5. The machine tool has dimensions of 560-mm W × 600-mm D × 660-mm H, and the maximum travel range is 210-mm X × 110-mm Y × 110-mm Z. Each axis has an optical linear scale with resolution of 0.1 µm, and full close loop feedback control ensures accuracy to submicron dimensions. High- speed, middle-speed, and low-speed spindles are changeable so that µ-milling, µ-turning, µ-grinding, µ-ECM and µ-EDM are possible on the machine. The motion controller can execute the program from the host computer independently.

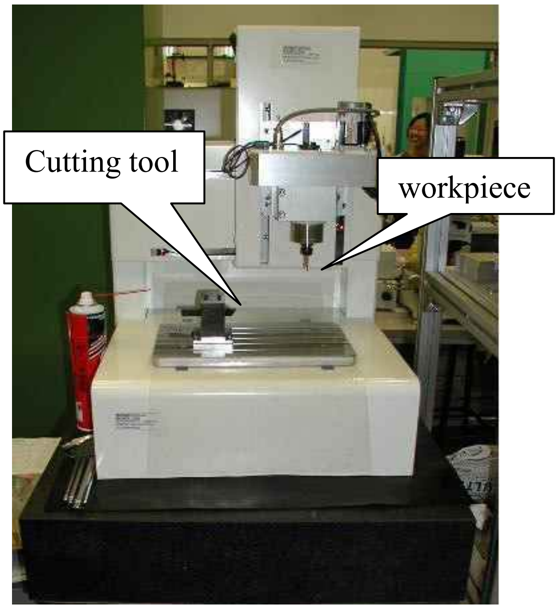


Fig. 5: Machine tool

3.2 NC Code Generation

The machining of microshaft requires hundreds of lines of NC code. Windows based programs were written using Borland C++ Builder 6.0, for generation of NC codes and to visually represent the cutting path to the operator. Such NC code generator facilitates the machining process for taper and cylindrical shaft turning.

3.3 Experimental Set up:

Work materials (6mm diameter brass rod) were clamped on the spindle which has the facility of three-axis movements. Unlike conventional machining, workpiece was vertically oriented. The workpiece is then positioned with respect to the cutting point of the tool. Machining was done using a single point cutting tool according to the cutting paths generated by straight turning and taper turning NC code generator.

3.4 Cutting Force Measurement

During machining, the thrust force tends to deflect the workpiece. However, the workpiece can vibrate freely only in the tangential direction of the tool-workpiece contact region because the vibration along the normal direction is blocked by the cutting tool [5]. As the diameter of the workpiece reduce, the rigidity against the deflection of the work piece by the cutting force decreases. Therefore, control of the reacting force during cutting is one of the important factors in improvement of machining accuracy. The value of the cutting force must be lower than that which causes plastic deflection of the workpiece [6].

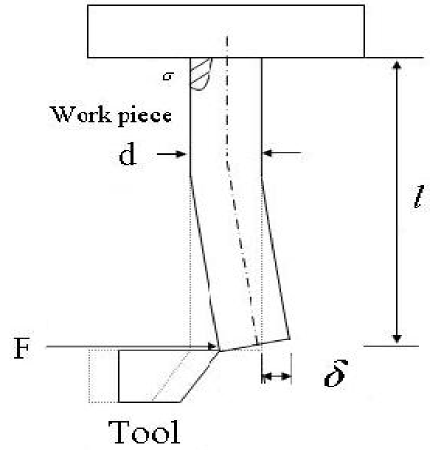


Fig.6: Workpiece deflection in microturning

The step size (*l*), for which the shaft will not deflect plastically, can be determined by applying equations (3) and (4), where F is the radial force at the tip of the circular workpiece with diameter d.

$$\text{Deflection, } \delta = \frac{Fl^3}{3EI} = \frac{64Fl^3}{3\pi Ed^4} \qquad (3)$$

$$\text{Normal stress, } \sigma = \frac{32Fl}{\pi d^3} \qquad (4)$$

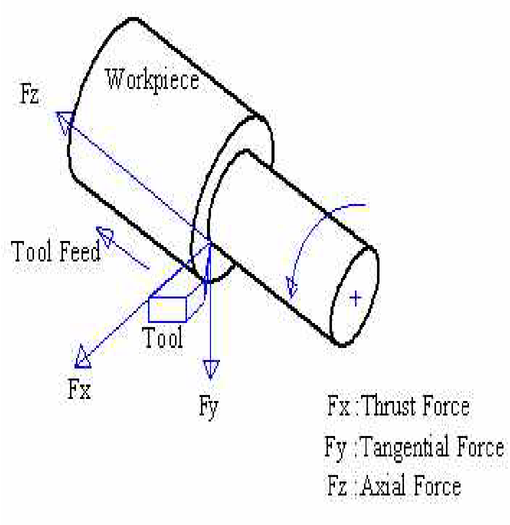
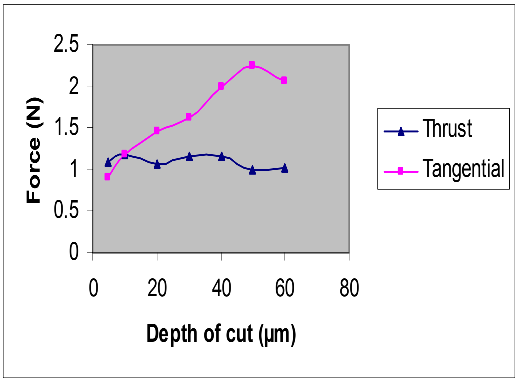


Fig.7: Cutting force components

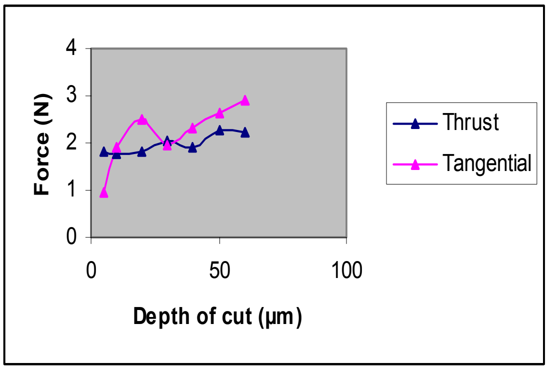
An attempt has been taken to keep the reacting forces as minimum as possible. The cutting forces were measured with a three component dynamometer (KISTLER Type 9256A1), mounted below the tool holder. Three components of cutting force are shown schematically in Fig.7. While machining was performed cutting force data were recorded using a data recorder at a sampling frequency of 24 KHz and these data were analyzed off-line later.

4. RESULTS

Several experiments were carried out to select optimum machining parameters for straight turning using step cut process. Experimental curves for PCD and carbide inserts are shown in Figs. 8, 9 and 10.

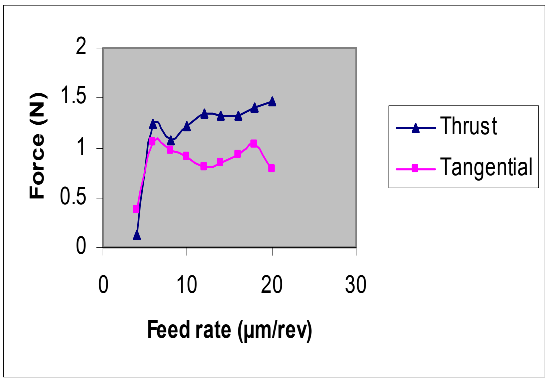


(a)PCD

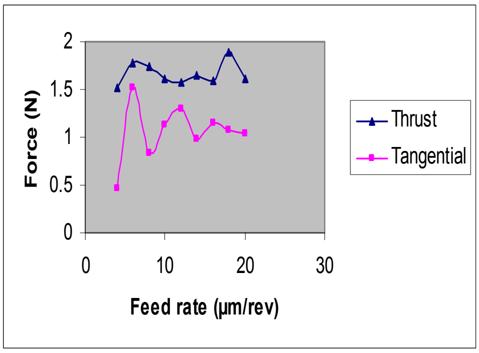


(b) Carbide

Fig.8: Depth of cut vs. Force curve for (a) PCD (b) Carbide inserts

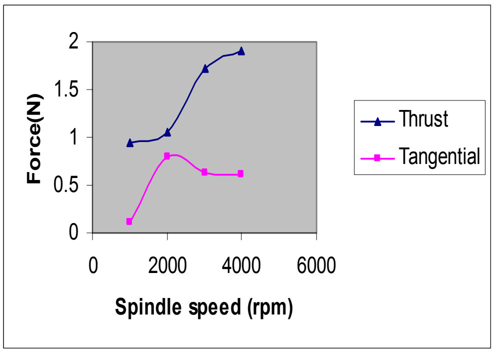


(a)PCD

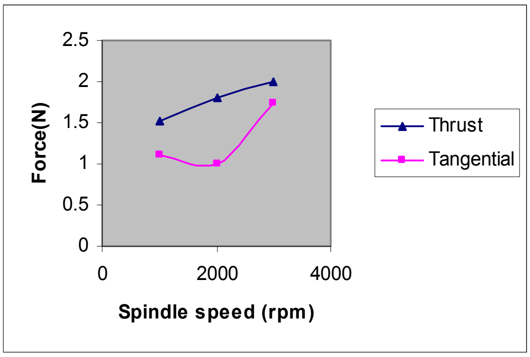


(b) Carbide

Fig.9: Feed rate vs. Force curve for (a) PCD (b) Carbide inserts



(a)PCD



(b) Carbide

Fig.10: Spindle speed vs. Force curve for (a) PCD (b) Carbide inserts

Based on the graphs optimum machining parameters were selected as shown in Table 1.

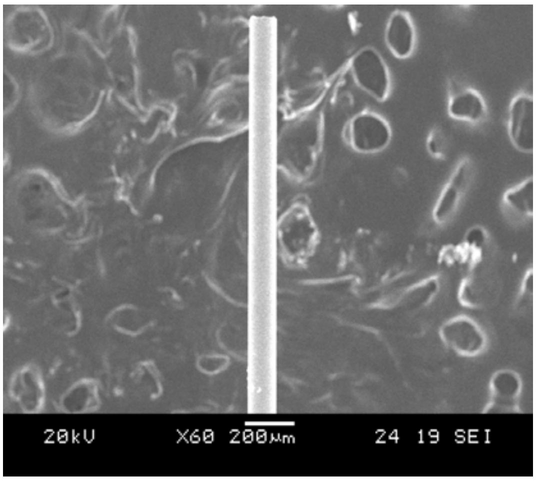
Table 1: Selected optimum machining parameters

Insert type		***Carbide***	***PCD***
Depth of cut (µm)	Rough cut	30	20
	Finish cut	5	5
Feed rate (µm/rev)	Rough cut	12	10
	Finish cut	4	4
Spindle speed (rpm)	Rough cut	1500	1500
	Finish cut	2000	2000

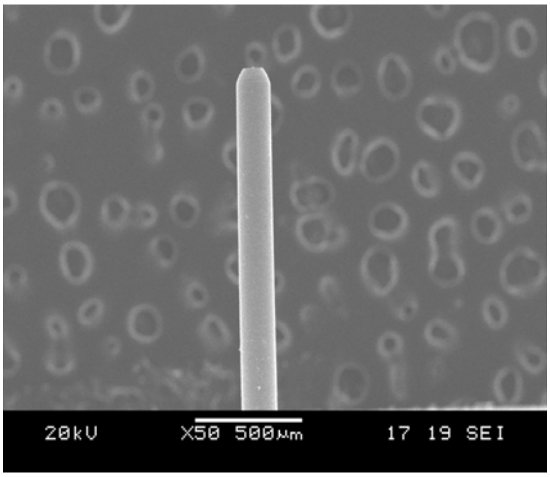
5. MINIATURE COMPONENTS FABRICATION

5.1Micro Shaft Fabrication

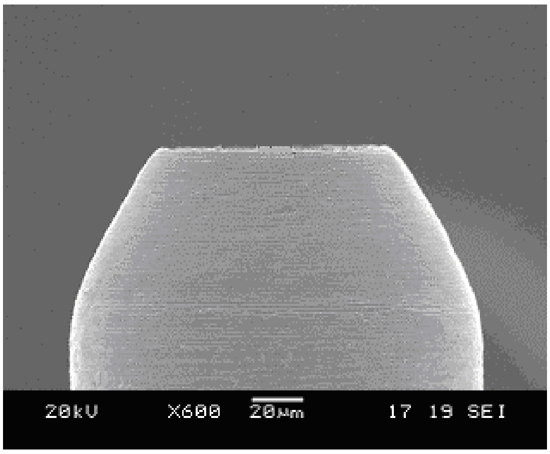
Using optimum machining parameters and step cutting process as described in Figs. 2 and 4, micoshafts were produced. Some SEM pictures of microshaft, microshaft with tapered tip are shown in Fig. 11.



(a) Straight shaft



(b) Tapered shaft



(c) Tapered tip
Fig.11: Microshaft as in SEM

5.2 Micropin Fabrication

Finally an attempt was made to fabricate a micropin using the turning process developed. Fig.12 shows the micropin in SEM with straight and tapered section.

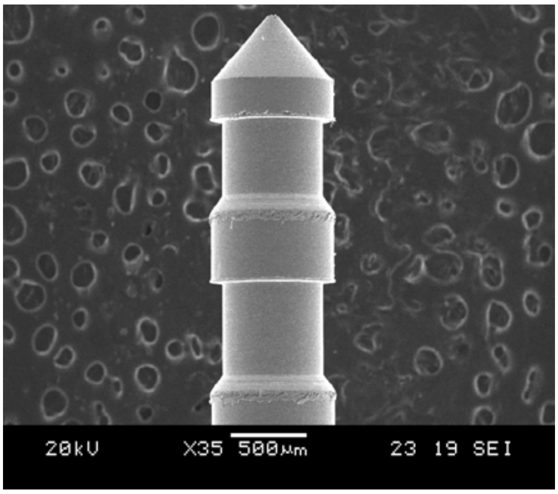


Fig.12: SEM micrograph of the fabricated micropin.

6. CONCLUSION

In this study, a micropin was fabricated using the miniature machine tool. While fabricating, both the straight and taper turning processes were applied. The main drawback of the straight turning is the workpiece deflection which was eliminated by step cutting process. The step size was estimated by applying material strength equations. This attempt can be a useful guide to the industrial manufacturers for miniaturizing the mechanical components with high precision as well as dimensional integrity.

7. REFERENCES

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8. NOMENCLATURE

Symbol	*Meaning*	*Unit*
R	Larger taper radius	(mm)
r	Smaller taper radius	(mm)
α	Taper angle	(degree)
t	Depth of cut	(mm)
F	Force	(N)
l	Step size	(mm)
d	Diameter	(mm)
σ	Normal stress	(Pa)
E	Modulus of elasticity	(GPa)
δ	Deflection	(mm)
$\mathbf{n_p}$	Number of cuts parallel to job axis	
$\mathbf{n_t}$	Number of cuts parallel to taper axis	