PRECISION GRINDING APPARATUS SPECIALLY DEVELOPED FOR MICRO-CYLINDRICAL COMPONENTS

Yeo, S.H., Zhou, M., Tan, B.H, Balon, S.A.P.
Precision Engineering Strategic Research Group
School of Mechanical and Production Engineering
Nanyang Technological University
Nanyang Avenue, Singapore 639798, Singapore
Tel: (65) 790 5539 Fax: (65) 7911859

Abstract
This research work presents the development of a precision grinding apparatus used to manufacture micro-cylindrical components. The different steps of this development from the conceptualisation to the prototyping have been reported. Finally, a test of the precision apparatus has demonstrated that micro-cylindrical components can be ground down to 45µm with an aspect ratio of 4.

Keywords
Precision machine design, micro-grinding, miniature part.

Introduction
The growing needs of micro-mechanical tools are increasing tremendously, for example the micro-milling tools, micro punch, wire bonding capillary, etc. All this micro-components are in common a cylindrical geometry, which is basically a micro-shaft. A micro-shaft has been defined by Friedrich et al.[1] as a cylindrical component with a major diameter of 200µm or less, which is also the border between micro to macro set by Masuzawa and Tönshoff [2].

Manufacturing Process Employed	Minimal Diameter Achieved	Material Used	Conductivity	Aspect Ratio	References
Micro-EDM	2.5µm	Tungsten	Yes	5	[3]
	12µm	HSS	Yes	20	[4]
	4.3µm	Tungsten Carbide	Yes	11	[5]
Turning	10µm	--	--	6	[6]
	25µm	Aluminium (4043-O)	Yes	3	[1] [7]
Grinding	8µm	Tungsten	Yes	8	[8]
	65µm	Ceramic Alumina	No	4	[9]

Table 1: Micro-shaft comparison

Table 1 illustrates some achievements from the fabrication of micro-cylindrical components, using different material removal technology and material. The aspect ratio is defined as the length of the micro-shaft divided by its diameter.

Some micro-cylindrical components have to be made in ceramic because of their specific properties such as the wear resistance, hardness, and non-electrical conductivity. On another hand ceramic micro-components combine two major problems which are the difficult to machine material and the production of miniature components. These two problems can lead to the breakage of the micro-cylindrical component during the machining process. Therefore to produce a ceramic micro-cylindrical components, a precision grinding apparatus has been specially developed to solve simultaneously the two problems reported previously. This paper is to present the different steps of the development (conceptualisation, prototyping) and conclude on the testing of the precision grinding apparatus.

Conceptualisation

The development of the precision grinding apparatus for micro-cylindrical components has started with a theoretical model reported by Balon [10]. This model compared the theoretical grinding force applied and the maximal strength of the micro-component derived from the material mechanical properties. The theoretical grinding force has been approximated using Equation 1 reported by Shaw [11].

$$F_c = \frac{E' v_w \, d \, B}{v_s} \qquad (1)$$

where F_c *is the cutting force (N),* E' *is the specific grinding energy (J/mm*^{3}*),* v_w *is the linear speed of the specimen (m/s),* v_s *is the linear speed of the grinding wheel (m/s), d is the depth of cut (mm), and B is the grinding wheel width (mm)*

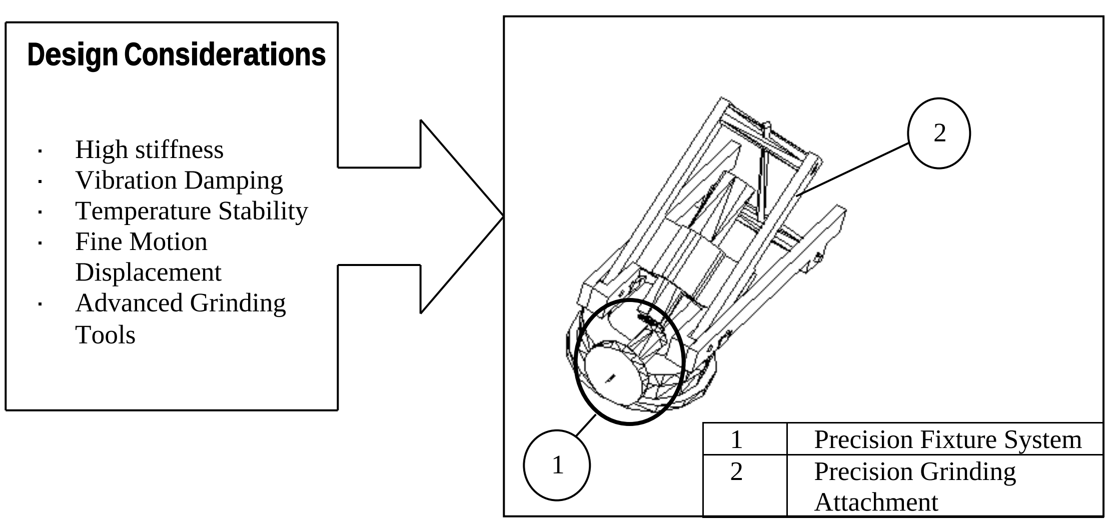

Figure 1: Design considerations and the technical drawing

Balon [10] reported that to reduce down the diameter of the micro-component the grinding force has to be extremely small, below 1mN. Therefore the solutions selected to reduce F_c were to adopt a high rotational speed for the grinding wheel (v_s) and to select a grinding wheel with the minimal width (B). The theoretical model and the design considerations reported by Yeo and Balon [12] has lead to the technical drawing (see Figure 1) of the precision grinding apparatus. The design of the precision grinding apparatus as seen in Figure 1 consists of two main elements namely the Precision Grinding Attachment and the Precision Fixture System.

Prototyping

Figure 2 shows the prototype of the precision grinding apparatus mounted on a commercially available high precision turning machine. A high-speed precision spindle mounted on the precision grinding attachment is used to drive the diamond wheel of few ten of micron width. The raw ceramic rod is clamped by the precision fixture system during the full grinding operation.

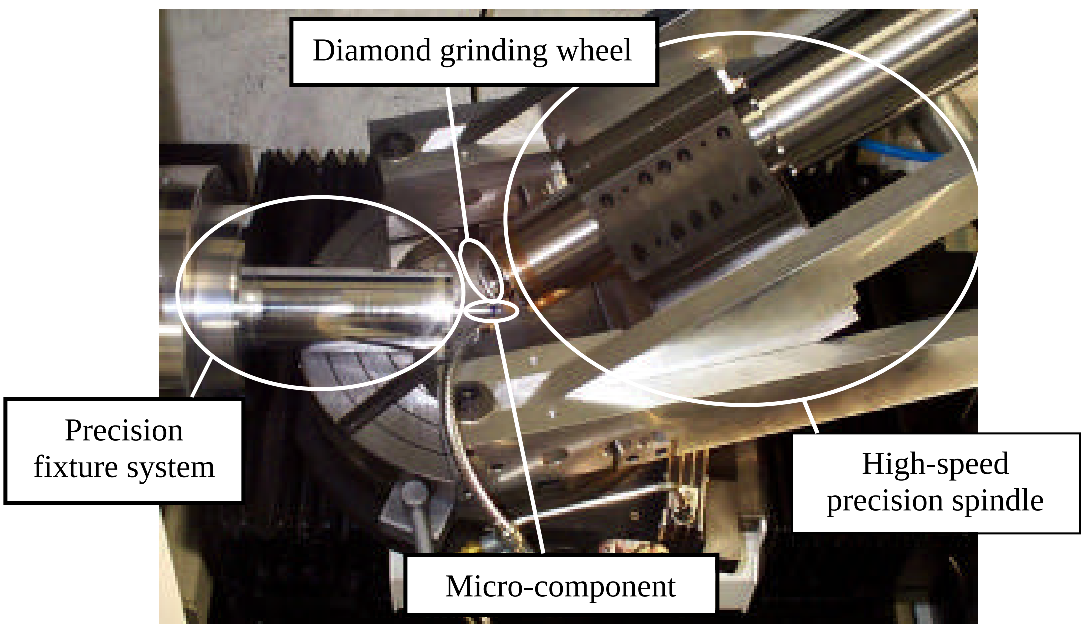

Figure 2: Overview of the precision grinding apparatus

Testing

The precision grinding apparatus has been tested by grinding a micro-cylindrical component made of polycrystal aluminium oxide (99.8%), with a grain size range varying from 2 to 50μm. Figure 3 shows the micro-cylindrical component obtained after grinding. The diameter obtained is 45μm with a length of 184μm. The aspect ratio is then around 4. Yeo and Balon [13] has shown that the material removal occurred in the ductile zone, which means that minimal crack is generated during the grinding process. Therefore the risk of cracks propagation which could lead to the breakage of the micro-cylindrical component is minimised, due to the ductile grinding.

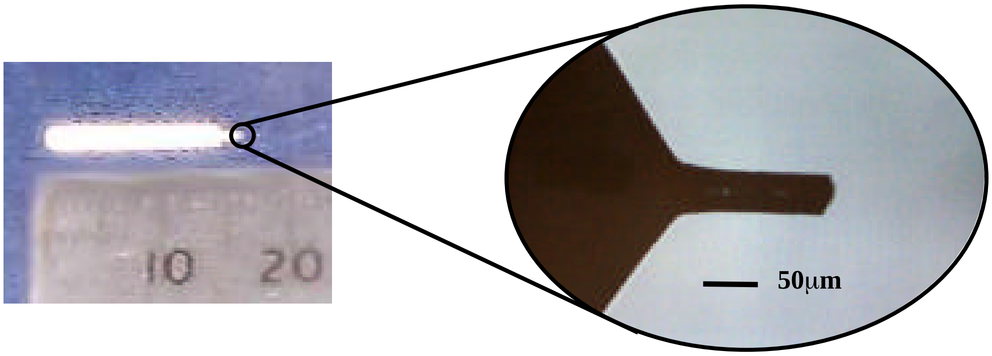

Figure 3: Micro-cylindrical component

Summary

This paper presents the evolution of the precision grinding apparatus from the conceptualisation to the final testing. The precision grinding apparatus has been designed to minimise the breakage of the micro-cylindrical components during the manufacturing process, and has proven experimentally good capability to get it. In the experiment conducted, a micro-cylindrical part made of alumina has been ground successfully to diameter 45μm with an aspect ratio of around 4.

References:

[1] Friedrich, C.R. and Kithiganahalli, B. (1994). *Deflexion compensation model for the machining of microshafts*. Processing of the American Society of Precision Engineering, Annual Meeting, pp. 461-464.

[2] Masuzawa, T. and Tönshoff, H.K. (1997). *Three- dimensional micromachining by machine tools*. Annals of the CIRP, Vol.46, No.2, pp.621-628.

[3] Masuzawa, T. and Fujino, M. (1990). *A process for manufacturing very fine pin tools*. Technical Paper, Internal Manufacturing Technology Conference'90, Chicago Illinois.

[4] Masuzawa, T., Fujino, M., Kobayashi, K. (1985). *Wire electro-discharge grinding for micro-machining*. Annals of the CIRP, Vol.34, No.1, pp.431-434.

[5] Li, H. and Masaki, T. (1991). *Micro-EDM*. Technical Paper, Electrical Discharge Machining Conference, Michigan US.

[6] Yamagata, Y. et al. (1996). *A new fabrication method for microactuators with piezoelectric thin film using precision cutting technique*. Proceeding of IEEE MEMS, San Diego, CA, pp. 307-311.

[7] Frazier, B., Friedrich, C., Warrington, R.O. (1994). *The miniaturisation technologies: Past, Present, and Future*. Proceeding of the 20th Annual Conference of the IEEE Industrial Electronics Society, Bologne Italy, pp.1460-1465.

[8] Kugler Gmbh (1998). Micro Mill Technical Brochure

[9] Mason,F. (1997). *Making Tiny Ceramic Tools*. Manufacturing Engineering, Vol.118, No.1, 3 pp.

[10] Balon, S.A.P. (1999). Development of a Novel Precision Grinding Technique for Micro-Parts. Master thesis, NTU, Singapore.

[11] Shaw, M.C. (1996). Principles of Abrasive Processing. Oxford University Press.

[12] Yeo, S.H. and Balon, S.A.P. (1999). *Development of a New Grinding Set-Up for Micro-cylindrical Parts Fabrication*. 1st International Conference of EUSPEN., Bremen Germany, pp.155-158.

[13] Yeo, S.H. and Balon, S.A.P. (1999). *Fabrication of micro-cylindrical parts based on a novel grinding technique*. Journal of Engineering Manufacture. Accepted for publication