9th INTERNATIONAL CONFERENCE ON MICROMANUFACTURING

Nanyang Technological University
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25-28 March 2014
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BACK

Machining

26A6-34: An Experimental Guideline to Manufacture Micro-Impeller using Micro-Milling Process
Kiswanto, G.; Zariatin, D.L; Baskoro, A.S; Istiyanto, Jos

26A6-25: Modeling and Simulation of the Fixed Diamond Wire Sliced Wafer Surface
Chung, Chunhui; Nhat, Le Van

26A6-58: Experimental study of the micromachining characteristics of polytetrafluoroethylene (PTFE) Materials for microscale shapes
Kim, Dong Min; Park, Hyung Wook

26A6-59: Force Modeling of Five-Axis Micro Ball End Milling
Zhu, James; Xu, Chi; Kapoor, Shiv G; Rosenbloom, Avery

26B5-74: A Study on Precision Grinding of Thin-wall and Honeycomb Structured Components
Tian, Y.B.; Zhong, Z.W.; Rawat, R.

26B5-99: Surface Evolution Models for Abrasive Slurry Jet Micro-machining ofChannels and Holes in Alumina
Kowsari K; Nouraei H; Papini M; Spelt J.K

26B5-107: Workpiece surface flatness improvement by tool length compensation inmicromilling
Annoni M; Cacciatore F; Davoudinejad A; Rebaioli L; Semeraro Q

26C4-116: Effect on stainless steel surfaces form micro cutting in different grain size
Komatsu, Takafumi; Yoshino, Tomohiro; Torizuka, Shiro; Matsumura, Takashi

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From I2M2 president

From Conference Chairs

Welcome Message - From I2M2 President

Dear colleague,

As President of the International Institution for MicroManufacturing (I2M2), I would like to welcome all the participants and guests of the 9th International Conference on MicroManufacturing (ICOMM2014) at Nanyang Technological University in Singapore. This conference provides a great opportunity to shine a light on all the excellent research activities in micromanufacturing being undertaken around the world. Micromanufacturing has emerged as the major driver of various products development that requires high quality and complex micro-scale features. Its growth has been increasing all over the world and its impact has been demonstrated in many fields.

The I2M2 provides a global platform to promote research, collaborations and dissemination of knowledge in micromanufacturing through conferences, reports, publications, and I2M2 homepage. The past conferences are listed below:

- 8th ICOMM2013, University of Victoria, Victoria, Canada
- 7th ICOMM2012, Northwestern University, Evanston, USA
- 6th ICOMM2011, Tokyo Denki University, Tokyo, Japan
- 5th ICOMM2010, University of Wisconsin, Wisconsin, USA
- 4M/4th ICOMM2009, Forschungszentrum Karlsruhe FTZ), Germany
- 3rd ICOMM2008, Carnegie Mellon university, Pittsburgh, USA
- 2nd ICOMM2007, Clemson University, Clemson, USA
- 1st ICOMM2006, University of Illinois at Urbana-Champaign, Urbana, USA

Through these conferences, we have built a strong and growing global membership.

Hosted by Nanyang Technological University (NTU) and National University of Singapore (NUS), the 9th ICOMM2014 brings together the world's leading experts to share their cutting-edge research and applications. Additionally, the conference serves as a resource for international researchers to discuss their latest achievements and establish possible collaborations. It also offers excellent keynote speeches and technical papers which have been submitted from many countries, such as, Japan, USA, China, Singapore, India, Taiwan, Canada, Germany, Korea, UK, Italy, Malaysia, Denmark, France, Belgium.

I am sure that the 9th ICOMM2014 in Singapore will be a great success and I especially look forward to seeing you all there. Thank you very much for your participation and contribution.

Dr. Kuniaki Dohda, I2M2 President

Northwestern University, USA

An Experimental Guideline to Manufacture Micro-Impeller using Micro-Milling Process

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No.

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Abstract

The objective of this research is to contribute an experimental guideline to manufacture micro-impellers by micro-milling process. This guideline is composed by analyzing and resuming the machining result that performed this research and related findings from other published journals. Numbers of machining process were performed in order to see the feasibility to produce micro-impellers. There are three important aspects that must be considered for manufacturing a micro-impeller, which are the geometric design of the micro-impeller, optimum cutting parameters and machining strategy to manufacture pre-eminent micro-impeller. The capability of available commercial CAD/CAM system to design micro-impeller is found adequate to confirm the design requirement in certain range of dimension. The constraints to manufacture micro-impeller such as dimensional tolerance, burrs occurrence, and work piece deflection must be considered appropriately. Indeed, this paper is an experimental reference to plan manufacturing process for micro-impeller or other micro-product.

Keywords: micro-milling, micro-impeller, cutting parameter.

1. Introduction

The demand of micro technology to produce various micro-products such as micro-impeller is increasing. Micro-impeller consists of number of blades which might have a complex shape. Several methods have been used to produce micro-impeller successfully such as Electro Discard [1], photolithography with ultra-thick photo resist (SU-8 3000) [2], LIGA process for resin material [3], mold Shape Deposition Manufacturing (SDM) for silicon nitride material [4] and micro-milling process [5] [6]. Among these methods, 5-axis micro-milling is a preferable method to produce micro-impeller with complex shape of blades.

Micro-milling is a scaling down technology from macro/conventional milling process; however in some circumstances, it has its own characteristics which differ with macro-milling process due to its size-effect [7] [8] [9] Many researchers investigated the characteristics of micro-milling process and a lot of experiments were done to understand the behavior of micro-milling process. However, the information about micro-milling technology especially to produce a certain product is still scattered. There is no integrated reference or guideline about how to develop a micro-product such as a micro-impeller.

In this paper, a guideline about micro-milling process that related to micro-product is explained in detail, in terms of design feasibility and constraints, planning the machining strategy by using commercial CAD/CAM system, and cutting parameter selection. Several of cutting experiments to produce micro-impeller were performed to investigate and verify the information. This integrated guideline emphasizes the knowledge of micro-milling process. The discussion is presented in three main categories which are the micro-impeller design constraints, machining strategy, and cutting parameter selection.

2. Methods

There are two approaches used to compile the guideline, which are literature review and experimental analysis. The first approach is by resuming important and relevant information from journals or research reports. All information in the journals was classified into three aspects which are the design constraints, machining strategy and cutting parameter selection. The design constraints to produce micro-impeller were investigated throughout the reviewed journals. Journals that discussed about thin wall and its problems were summarized. The practical cutting parameters which applied in the experiment, such as work piece material, tool material, tool geometry and tool coating, cutting speed, feed-rate, the effect of tool ware, surface roughness and burr characteristic are concluded. These practical cutting parameters are tabled and categorized based on work piece material. However, there is a lack of information about the machining strategy for micro-milling process, thus must be further investigated by the second approach which is performing experiments to produce micro-impeller.

The investigation begins from design to the machining process. An integrated available commercial CAD/CAM system is used to design micro-impeller. The capability and reliability of CAD/CAM system to design micro-impeller is analyzed. The machining strategy, such as the type of operation, cutting direction, cutting patterns, engage and retract strategy have to be determined appropriately, since it influence the product quality and effectiveness of the micro-milling process. Furthermore, the cutting parameter must be selected by considering the literatures and the optimum cutting parameter applied in the preliminary experiment of this research. It is necessary to select the optimum cutting parameter for the best result, but machine capability to reach certain cutting parameters such as spindle speed must be considered.

In this research, micro-milling process is performed on a miniaturized micro-milling machine, Hadiia Micromill-5X, as shown in Fig.1.Various tools with diameters of 0.1 and 0.2 mm are used to produce micro-impeller from AA7075 material. The micro-impeller is designed with a diameter of 2 mm and 3 mm, and with a blade thickness of 10 μm and 50 μm.

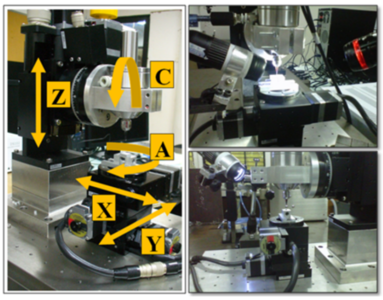


Fig.1. Micro-milling machine, Hadia micromill-5X

3. Design Constraint

Impeller is a main part of a compressor which is designed to transfer energy or increase fluid pressure. Impeller is designed by calculating several parameters such as fluid flow rate, discharge velocity, total head change, etc., to conform the desired working capacity. The result of calculation defines the impeller geometry and dimension. However, due to some shortage of micro technology, it is necessary to acknowledge the capability of micro-milling process on producing micro-impeller.

The most important obstacle in designing micro-impeller is to define the acceptable blade thickness. Blade has the same shape of thin-wall that gather around forming a micro-impeller. Li et al [10] proved that peripheral micro-milling process could produce 8 μm thicknesses of thin-wall, but with inadequate quality. The proper quality of thin-wall with a thickness of 14 μm could be obtained by performing the cutting sequence proposed in the research.

Due to the complexity to design an impeller, CAD software is generally used to assist the design process. Available CAD software is not prepared for design micro-parts exclusively. There are few things need to be considered during the design phase, especially to generate extra complex thin-wall of micro-blades.

Various micro-impellers were designed using an available CAD/CAM system. An integrated CAD/CAM system is chosen, because the simplicity to transfer the part designs into manufacturing process design. Transferring micro-part design from different CAD and CAM system might result in misinterpretation of data points.

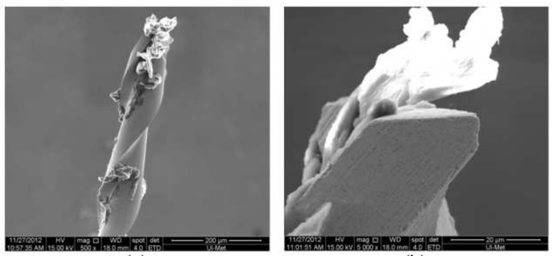
4. Machining Strategy

Complex product such as micro-impeller requires a good planning regarding the tool movement, cutting direction and cutting sequences, known as machining strategy. Machining strategy is identical to tool path generation. Brinksmeier et al [16] stated that commercially available CAM tools was not suitable for tool path generation of ultra-precise micro-milling machine, due to the lack of machine kinematic in commercial CAM software. However, in this research, a kinematic calculation and post-processor was developed to overcome the problem. One of post-processing tasks is to interpret the data point in the CL file and transform it into appropriate command to control the micro-milling machine movement. Thus, the commercial CAM system can be used to generate the micro-part tool path. It is found that, with some considerations, machining strategy developed using commercial CAD/CAM system is satisfying, according to shape and dimension comparison between design and machined micro-impeller.

Despite of a special feature to design impeller is available in an integrated CAD/CAM system, it considers difficult to imposing the micro-impeller design in micro dimension. Therefore, skill to operate the CAD/CAM system to generate a tool path is highly needed. Some parameter such as feed and speed, cut direction, tolerance, smoothing, etc. needs to be justified. To produce minimum burr, conventional or up-milling cutting must be selected. Set the minimum value of intol and outtol in Tolerance. This setting affects the number of data point generate by the CAM system. More data point is produced within minimum tolerance. Although it needs more computing time, the computer capability still can pursue the requisites.

5. Cutting Parameters

Cutting parameter such as depth per-cut, cutting speed, and feed-rate is generally defined based on the work piece material, cutting tool and type of process (i.e. roughing, semi-finishing or finishing). Tool with diameter less than 2 mm is classified as a micro tool. It has a similarity of material, geometry and coating with conventional/macro tool, but in a smaller dimension. The small size of the tool makes it very difficult to inspect with naked eyes. Rejected tool could send to the customer coincidently. Random inspection of available micro-tool was performed using SEM. It is found that one of carbide micro tool with a diameter of 0.1 mm is not in acceptable condition, as shown in Fig. 2. It seems that some substance, whether the tool coating or excessive tool material is covering the cutting tool surface.



(a) (b)

Fig. 2 Unacceptable micro-tool conditions (a) 500X (b) 5,000X

Recommended cutting parameter is commonly provided by the tool manufacturer. However, sometimes the capability of micro-milling machine cannot comply with the manufacturer recommendation. Thus, practical reference of cutting parameters in needed. This practical reference is compiled and tabled from other published experiment reports and journals.

Fig. 3 shows a range of spindle speed and feed-rate that applied to various work piece material, which is collected from journals. It describes that most of the micro-milling processes were performed with spindle speed less than 100,000 RPM, and feed-rate less than 640 mm/min. Meanwhile, Fig. 4 shows the range of depth per-cut that applied in micro-milling process, which are generally smaller than 0.5 mm.

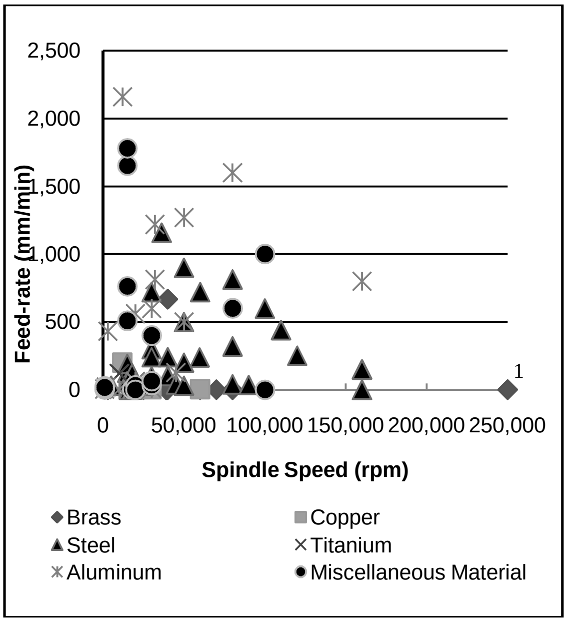


Fig.3.The range of spindle speed and feed-rate for various workpiece materials.

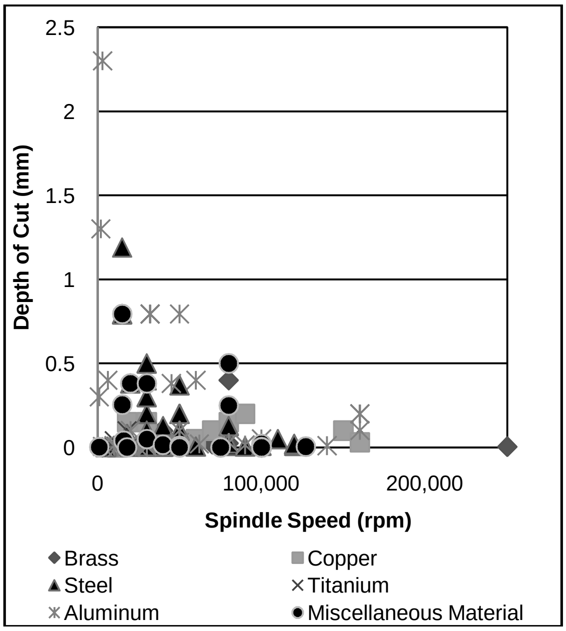


Fig.4.The range of depth per-cut and spindle speed for various workpiece materials.

Several literatures explained that the cutting parameter affects tool wear [11] [12], surface roughness [13] and burr formation [14] [15]. It is true that improper selection of cutting parameter will result in poor quality of the micro-impeller. One of the crucial problems in micro-milling is burr occurrences. Burr is a result of improper cutting parameter selection or tool ware. Micro-burr aggravates the micro-impeller quality. Fig.5. shows a 2 mm diameter of micro-impeller which covers with burr. The micro-impeller was manufactured with 0.1 mm diameter of carbide nACro coated flat end-mill tool which has two flutes. The depth per-cut, spindle speed and feed-rate are 0.01 mm, 80,000 RPM, and 60 mm/min, respectively.

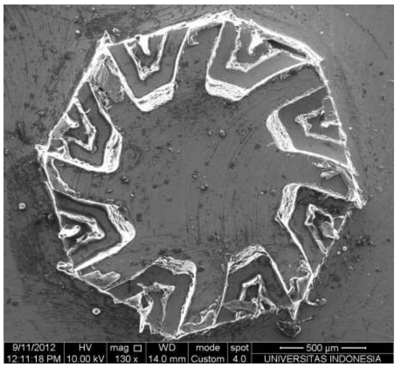


Fig.5. Micro-impeller with diameter of 2 mm developed with depth per-cut, spindle speed and feed-rate of 10 μm, 80,000 RPM, and 60 mm/min, respectively.

In order to find the optimum cutting parameter, cutting experiments was performed to investigate the suitability cutting parameters for AA7075. This data of cutting parameter is used as a reference to perform the following machining process to produce satisfactory micro-impeller. Fig.6. shows an adequate quality of 3 mm diameter micro-impeller. Ball-nose Mega-T coated carbide tools with diameters of 0.2 mm were used.

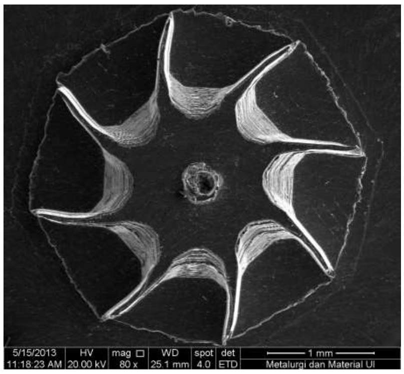


Fig.6. Micro-impeller with diameter of 3 mm developed with depth per-cut, spindle speed and feed-rate of 10 mm, 70,000 RPM and 30 mm/min, respectively.

6. Conclusions

This paper gives comprehensive reference about how to manufacture micro-impeller using micro-milling technology. There are three important aspects must consider while manufacturing micro-impeller, which are the design constrain that related to size and shape of blade, selection of optimum cutting parameter that enhance the quality of the micro-impeller, and determination of machining strategy when using available integrated CAD/CAM system.

The capability of CAD software and working range of micro-milling machine must consider when designing complex shapes of micro-impeller. Despite of there are some constraints in commercially available CAD/CAM system that related to minimum dimension and the complexity of blade, an integrated CAD/CAM system was proven to be an adequate tool to design micro-impeller. Integrated CAD/CAM system is also satisfactory in planning the machining strategy.

Occasionally, recommendation of cutting parameters from the tool manufacturer cannot be applied, due to limitations of the micro-milling machine. Therefore, a collection of practical cutting parameter to produce micro-impeller with a particular quality of surface roughness and minimal burr is needed. The list of practical cutting parameters is proven to be an effective reference and guideline in defining cutting parameter and give an adequate result of the micro-impeller.

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