

# FABRICATION OF PROTRUDING FEATURES IN A MICRO-MOLD: A PLANNING REPORT

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## ABSTRACT

There exists an opportunity to study the manufacturing process of protruding features for the purpose of polymer mold fabrication at the micro-scale. An experiment is planned using Taguchi DOE methods to fabricate micro-scale positive features by varying size, spindle speed and spindle direction. Data will be collected on feature accuracy, and used to further refine the experiment in an effort to produce a precise, accurate, micro feature. Results and knowledge gained herein will be extended to features of greater complexity, requiring increasing degrees of precision.

**Keywords:** micro-machining, micro-mold.

## INTRODUCTION

The field of micro-machining is an area of modern manufacturing that demands attention from a wide array of groups. Micro-machining is loosely characterized as fabrication of features with overall dimensions in the sub-millimeter range. Tools used for this type of fabrication will also have defining dimensions less than 1 mm. Micro-machining characteristics are typically thought to vary from conventional machining once the ratio of driving tool dimension to part size to be produced becomes a single digit.

The application of such machining methods spans a gamut of industries, from micro-electronics to pharmaceuticals, making micro-

machining a technology deserving of study to further refine machining techniques and practices. The goal being to produce higher quality, cleaner finished products, in a clean and efficient manner. Finished products can be composed of a variety of materials. Polymers make up by far the broadest and most diverse class because they are available in a wide variety of compositions, properties and forms, and can be fabricated readily into complex shapes and structures (Zhao, 2003).

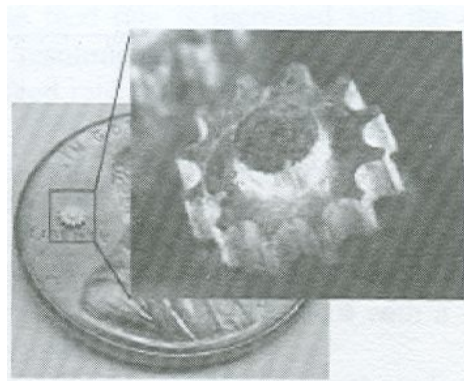


FIGURE 1: A PRACTICAL EXAMPLE OF THE TYPICAL SCALE SEEN IN MICRO-MACHINED FEATURES (DeVor, 2004).

The use of micro-machining as a technique to create micro-molds for the fabrication of components is of particular interest. The trend towards miniaturization in these industries has brought about a demand for increasingly precise molded plastic components. Major suppliers of

injection molding equipment are gearing up for growth in injection molding equipment, capable of making parts weighing one thousandth of a gram and even less (Zhao, 2003; Mapleston, 1998). The optimization of the micro-mold manufacturing process and practice will be paramount for the efficient production of complex miniature finished products.

## EXPERIMENT

### Purpose

The fabrication of a micro-mold will inevitably include features of various shapes, contours, and sizes. Features such as holes, pockets, and troughs can be assembled in various geometric configurations to produce a recess in a mold.

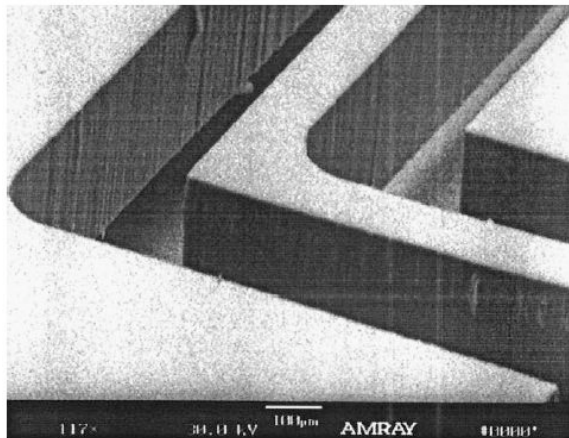


FIGURE 2: TRENCH FEATURES IN A MICRO-MOLD; SCALE BAR = 100  $\mu\text{m}$  (FRIEDRICH, 1998).

A feature unique to the fabrication of micro-molds is a protrusion, or positive feature, that would be left after machining away adjacent material. The fabrication of these protrusions represents a significant challenge when machining at the micro-scale, and will be the focus of this experiment.

### Feature Design

The feature we will attempt to manufacture at the micro-scale is a simple rectangular protrusion. Due to the limited practical knowledge of the behavior of the feature,

material, and tool on the accuracy of the finished part, preliminary experiments will need to be completed on simple shapes. Knowledge derived from these preliminary experiments should lead to work on features of increasing complexity.

### Equipment

Machining will be performed on a Mori-Seiki NV1500DCG vertical milling center. The machine has the capability to computer-numerically-control machining in 3-axes.



FIGURE 3: MORISEIKI NV1500DCG VERTICAL MILLING CENTER.

The movement along the vertical (Z) and front-back (Y) axes is driven by twin linear motor driven screws. The screw-motor pairs are located on each side of the spindle in the Z-axis, and on either side of the worktable in the Y-axis. The twin drive reports a resolution of  $\pm 0.5 \mu\text{m}$ , while reducing vibration by 84% from a conventional single screw driven axis (Mori Seiki, 2005). The air-bearing spindle has a maximum speed of 24,000 rpm. Temperature is regulated via cooling ducts routed throughout the machine, specifically to the linear motor mounts, and spindle, then to an oil cooler.

### Experiment Design

In order to consider all the process parameters involved in machining a simple feature, the experiment is designed using Design of Experiment techniques outlined by Taguchi

(Ealey, 1994). A two-level factorial design method is used for this experiment. Each process parameter will be tested at a designated high (+) and low (-) level. The goal of the experiment is to minimize the difference between the prescribed feature size and the actual feature size. There exist many possible machining parameters that will influence the outcome. The factors chosen are feature height and width (tested in terms of a width to height ratio ( $w_d/h_d$ )), tool rotation direction, and spindle speed. An additional process parameter that deserves attention is the tool path. The particular parameter is difficult to characterize due to the wide range of possible cutting paths. Therefore, a traditional profile-milling path will be used for the preliminary experiment, with the notion to closely review and consider the impact of the tool path for future trials. The DOE matrix, Table 1, shows the number of experimental trials in terms of the process parameters and their levels. Table 2 shows the values for each chosen process parameter. Each trial will be run a total of three times. All other process parameters will be held at nominal values. The material to be fabricated is 4041 grade aluminum. Two tools will be used for rough and final machining. The first is a 5mm diameter, 4-flute, HSS end mill. The final cut will be performed by a 50  $\mu$ m diameter, 2-flute, HSS end mill.

Trial	Width/Depth Ratio	Spindle Direction	Spindle Speed
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

TABLE 1: DOE MATRIX.

Parameter	Low Value (-)	High Value (+)
width/depth ratio (mm/mm)	0.1	0.5
spindle direction	counter clock-wise	clock-wise
spindle speed (rpm)	12,000	18,000

TABLE 2: PARAMETER VALUES.

### Data

Geometric data for each feature will be collected using precise metrological equipment. Feature width will be measured using an optical coordinate measurement machine. Feature

height will be collected using a profilometer with a mechanical stylus.

### Result Interpretation

Using the two level factorial experiment design leads to the characterization of the effects of each parameter on the final part. These main effects will be considered, as well as interactions between the parameters. From the results we should be able to note the impact of the chosen process parameters, and their interactions in an effort to further refine the experiment. If necessary, additional runs can be performed at different parameter levels to produce higher quality finished features. Due to the preliminary nature of the experiment we fully expect to further refine not only parameter levels, and also the tool path used for fabrication.

### CONCLUSIONS

Results and knowledge gained herein will be used to further refine the experiment in an effort to produce an accurate and precision micro-feature, and ultimately a highly accurate micro-mold.

After completion of these goals for a simple feature, experimentation can be extended to features of increasing complexity. Ideally, results will be used in the creation of a practical set of guidelines for fabrication of micro-molds.

### REFERENCES

Devor, R.E., Kapoor, S.G., Ehmann, K.F. (2004), "The Mechanics of Machining at the Microscale: Assessment of the Current State of the Science", *Journal of Manufacturing Science of Engineering, Transactions of the ASME*, Vol. 126, No. 4, pp. 666-678.

Ealey, L. (1994), *Quality by Design; Taguchi Method and US Industry*, ASI Press, Burr Ridge IL.

Friedrich, C., Coane, P., Goettert, J., Gopinathin, N. (1998), "Direct Fabrication of Deep X-ray Lithography Masks by Micromechanical Milling", *Precision Engineering*, Vol 22, pp. 164-173.

Friedrich, C., Coane, P., Goettert, J., Gopinathin, N. (1997), "Metrology and Quantification of Micromilled X-ray Masks and Exposures", *SPIE*, pp. 3048.

Mapleston, P. (1998), *Modern Plastics*, Vol. 75, Iss. 9, No. 27.

Mori Seiki Co. (2005), "Vertical Machining Centers / D Series", *Mori Seiki Official Website*, <http://www.moriseiki.co.jp/english/index.html>.

Zhao, J., Mayes, R.H., Chen, G., Xie, H., Chan, P.S. (2003), "Effects of Process Parameters on the Micro Molding Process", *Polymer Engineering and Science*, Vol. 43, No. 9, pp. 1542-1554.