Usually a character line specifically on die and mold can only be done by electrical discharge machining (EDM) in finishing stages, but such process requires two or more setups resulting to have an effect on the accuracy by obtaining setup error, and also lengthening the machining time, thereby causing the cost of the product to increase. The aim of this study is to utilize the 6-axis controlled cutting using bore byte tool with the application of ultrasonic vibration. Experimental results have shown that the sharp character line and grooves can be machined in just one setup by 6-axis controlled machine using bore byte tool. However, this process causes the deterioration of surface quality so that with the application of ultrasonic vibration, the surface quality of the product is improved especially in the machining of malleable or soft material, and the burrs are also eliminated. This proves the potential of 6-axis controlled cutting using bore byte tool with the application of ultrasonic vibration in producing a good quality die and mold product.

**Key Words**: 6-Axis Controlled Milling, Bore Byte Tools, Ultrasonic Vibration, CAD/CAM

1. Introduction

It has been known that the clear character line and grooves on intricate sculptured surfaces is one of the most important elements to make a high quality die and mould product. Traditionally rotational cutting tools such as ball end mills are used in the machining of character lines and grooves but then problem resulted by producing an arc like radius in two adjoining surfaces (Fig.1), thus character lines are not obtained. Basically, character lines are produced by electric discharge machining (Fig.2), however, such process requires two or more setups resulting to affect the efficiency and accuracy of the product. The 6-axis controlled cutting (Fig.3) has been applied to solve this problem, but still, another problem arises - i.e. low surface quality due to low cutting speed.

Ultrasonic vibration has given a great contribution in different fields of application. One of its great uses is that, it has been successfully applied on the scalpel to do a major operation in the major parts of the human body. In machining, ultrasonic vibration has been applied on a small hole tapping of difficult materials, turning of beta-titanium alloys, making the tool electrode of electric discharge machining to vibrate constantly at ultrasonic frequency thus improving the stability and substantially increasing machining rates when drilling a small or micro hole. For this reason, the problem in 6-axis controlled cutting which often causes the deterioration of surface quality (especially on malleable or soft material) due to low cutting speed can be solved by applying ultrasonic vibration during cutting. In addition, the completion of machining in one setting leads to the production with high efficiency, accuracy and quality. This makes possible to reduce the setting error of the workpieces due to transferring of work from one machine to another and also, decreases the actual machining time.

![Fig. 1](image1) 5 axis controlled milling using ball end mill

![Fig. 2](image2) Electrical Discharge Machining (EDM) of character line

![Fig. 3](image3) 6 - axis controlled cutting of character line using bore byte tool

![Fig. 4](image4) Tool geometry of bore byte tool

![Fig. 5](image5) Experiment Setup

![Fig. 6](image6) Vibration direction at 10 degrees and after rolling or correction angle has been applied

2. System and Tool Configuration

2.1 Bore Byte Tool

The bore byte tool (Fig.4) is configured in the exact shape to be ground into the workpiece. The borebyte tool is set at 10 degrees rolling angle from the tangency of the cutting edge to the surface of the workpiece in order to obtain a good and stable ultrasonic vibration.

2.2 Ultrasonic Vibrational Cutting

The tip of the bore byte tool vibrates at a low amplitude and a high frequency. This vibration forces the cutting action to take place. The bore byte tool is oscillated by the booster and sonotrode at a frequency of about 19 kHz with an amplitude of about 30 to 35 um. It forces the the bore byte tool and the workpiece to impact normally and successively on the work surface, thereby machining the workpiece.
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Fig. 7 Tool Orientation

![Diagram showing tool orientation]

In vibration cutting, the cutting edge of the bore byte tool is traveling back and forth along the machined surface while the workpiece is moving towards the tool with continuous velocity. The stresses developed in the subsurface are of critical importance when machining and subsurface flow characteristics influence the resultant stress distributions in the substances. The impact velocity is determined by the frequency and amplitude of the vibrating tool.

2.3 Experiment Setup

The bore byte tool as shown in Fig.5 is attached on the ultrasonic vibration using an adaptor, and this ultrasonic vibration unit is in turn attached on the spindle head of the 6-axis controlled milling machine which allows a variety of machining possibilities on the workpiece. And during machining, with the vibration direction being setup to 10 degrees, the bore byte tool having set also at the required rolling angle or correction angle of 10 degrees (Fig.6), will make the cutting edge of the tool tangent to the workpiece and the vibration direction parallel to the cutting direction.

2.4 CAD/CAM

A drawing or model is drawn using Computer Aided Design (CAD) program namely, DESIGNBASE. These drawings are used as a basis for generating and/or developing a collision-free cutter location (CL) data which is based on the information of the target shape and the tool, using a main processor. The cutter location is defined as the tip of the tool, for a bore byte tool. The diagram of Figure 7, shows a tool traversing a path defined by the edge list tool tip contact points for a given position and orientation.

The CL data generated will then be converted into 6-axis controlled NC data using a post processor on the basis of the workpiece location and some information of the machine tool. This numerical control (NC) data are employed in controlling machining operation.

3. Machining Experiment

The effect of cutting speed on cutting force as well as the effect of depth of cut on cutting force (both with ultrasonic vibration) has been examined in this paper. As shown in Figure 8(a), cutting speed of 100, 200, 400, and 580 mm/s and with a depth of cut of 0.3 mm, it has been observed that a difference of 0.1 to 0.2 Newton has been incurred. As for the effect of depth of cut on cutting force (Fig. 8(b)), a depth of cut of 0.1, 0.2, and 0.3 mm and with a cutting speed of 400 mm/s are tested on the workpiece and it was found that there is a difference of 0.2 to 0.8 Newton. From the results of the above-mentioned experiment, it can be noted that there is not much effects of both the cutting speed and the depth of cut on the cutting force.

Comparison of cutting force between applying an ultrasonic vibration and without ultrasonic vibration on cutting an aluminum testpiece has also been done. As shown in Fig. 9, cutting was done on the same cutting speed (400 mm/s) and with a depth of cut of 0.1, 0.2, and 0.3 mm respectively. It was observed that when ultrasonic vibration is applied while cutting, the cutting force is smaller as compared to machining without ultrasonic vibration. Also, it was noted that there is a small variation encountered in the cutting force with ultrasonic vibration (i.e. from 0.2 to 0.8 Newton), than in the cutting force without ultrasonic vibration, which varies widely ranging from 1.6 to 6.3 Newton.

On machining of intricate groove and character lines (Fig.10), rough machining was done first using different sizes of ball end mill until such time the target shape has been formed and, the groove and character lines were cut using the bore byte tool with the application of ultrasonic vibration. All the machining processes from rough cutting to the 6-axis controlled machining are performed on the same machine.

4. Conclusions

With the experiments we have conducted, we have found out that the 6-axis controlled cutting using bore byte tool with the application of ultrasonic vibration provides capabilities in the machining of grooves and character line in one setup, thus obtaining better accuracy, as well as reducing the machining time.

Likewise, the surface finish of the product has been improved and the burrs are also eliminated. Also, it proves that less cutting resistance has been produced resulting to a good surface appearance.

5. REFERENCES

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