Surface Roughness and Machining Accuracy when Micro-Turning Copper

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Abstract— Ever increasing interest in higher precision and miniaturization in manufacturing has led to new requirement in micromachining. Several critical issues involved in micro-machining, expectedly different to the macro level machining, which is, hitherto, not properly established yet. Experiments in micro-turning of brass found that the most suitable cutting style is the reverse cutting style, producing comparatively-best surface roughness, better dimensional accuracy and reduced machining time. Other machining parameters do not really have significant effect on accuracy. However, spindle speed does have some affects, depending on the feed rate and cutting style. The best machining parameters for fabricating micro-pin was found to be 2500 rpm spindle speed, a feed rate of 20mm/min, with the depth of cut 0.20mm.

Keywords— Machining, Micro-machining, Micro-turning Experiment, Design of Experiment, Orthogonal Array.

I. INTRODUCTION

Interest in higher-precision parts production and miniaturization has increased rapidly in recent times. The increased demands on miniaturized parts have also lead into new requirement for the development of high precision manufacturing. This new requirement in machining, especially in micromachining need the current conventional machining method be transformed into high precision micromachining process. Micromachining is one of the key technologies to produce miniature components and microproducts [Chae et. al., 2006]. Many researches in micromachining have been conducted these later years [Özel & Karpat, 2005, Sahin & Motorcu, 2005, Jiao et. al., 2004, Chae et. al., 2006]. All these studies have been carried out in order to find the best technique to fabricate micro functional structures and component.

To create miniaturized components, micro level machining is required. Similar to macro machining process, micro-machining shapes the surface of the work piece by employing cutting tools. Micro-machining, in contrast to conventional macro machining, however employs miniaturized to micro-level cutting tools to produce miniature micro-pin and other miniature devices and components, which range from tens of micrometers to a few millimetres in size [Chae et. al., 2006].

Several critical issues involved in micro-machining, which are different to the macro level machining. The main sources of these issues are the miniaturization of the machine components, the tools used and its machining procedure. In micro-machining, accurate dynamic measurement between the tool and the work piece is extremely challenging. Furthermore, handling, assembling, observing and testing of miniaturized components is also difficult.

The cutting characteristics such as size, accuracy, surface roughness and dimensional repeatability are highly influenced by the capabilities and quality of the machine tool. In micromachining applications, the rotational spindle speed is usually at high speed machining level, ranging from 10,000 rpm up to 200,000 rpm. Since small tool diameter decreases the chip removal rate, a high machining speed is essential in order to maintain acceptable products. Rahman et. al. has indicated that the typical accuracy for precision micro-machine is ± 1 µm [Rahman et. al., 2005].

One micromachining process is micro-turning. The most fabricated micro-turning product is the micro-pin. The huge demands of micro-pin, due to the vast potential application behind it, have given rise to a significant development of micro-turning machine. Typically, micro-pins are required in various industries such as in micromachining (as micro cutting tools), electrochemistry and cell biology [Langen et. al., 1995, Sato, 1995, Sacharoff & Westervelt, 1985]. These thin micro-pins are often very difficult to be fabricated through conventional mechanical methods because it has very small diameter (in the order of micrometer in size) and can be easily bent by the lateral force [Yamagata & Higuchi, 1995, Waida & Okano, 1995]. Additionally, when the materials to be machined are hard and tough, the machining process becomes even more difficult.

A. Micro Machining Parameters

There are several considerations to be deliberated to perform micro-machining efficiently.

1) Spindle speed: Rahman et. al. has noted that an increase in spindle speed results in the reduction of material removal rate. Consequently, the tool force is also reduced due to the shorter work-tool contacts length [Rahman et. al., 2005]. At lower cutting speed, the wear rate is at the minimum. Finally the life of the cutter was seen to be decreased as the cutting speed is increased.
2) **Depth of cut**: Rahman et. al. has observed the increase of cutting force when the depth of cut is increased [Rahman et. al., 2005]. The force generated will, in turn deflect the work-piece and reduces the accuracy of the machined parts. To avoid deflection, depth of cut should always be minimized. It is also recommended for special attention to be given to the length to diameter ratio of machined parts since that when the length to diameter ratio is high, the deflection is also increased.

3) **Effect of feed rate**: Chae et. al has indicated that the feed rate affects cutting forces directly, with excessive forces resulting in a large tool deflection, accelerated tool wear and tool breakage [Chae et. al., 2006]. Rahman et. al. has shown that the increment of feed rate will increase the contact area between tool and work-piece [Rahman et. al., 2005]. As a result, the material removal rate increases which contribute to the increase in cutting forces. Thus, proper selection of feed rate is very important to maintain the desired work piece within the acceptable tolerance limits.

4) **Cutting Parameter selection**: Generally, the use of harder work-piece materials will result in a higher precision product as opposed to softer materials. Significant reasons for this might be due to the presence of fewer burrs and shorter chips in harder materials, resulting in less interference to the cutting action. Ductile materials, on the other hand, will form long continuous chips when machined. It may be necessary to alter the machining conditions, such as depth of cut or surface speed, in order to reduce or to eliminate entirely the long continuous chips. Thus, selection of the machining parameter is very important in order to obtain the best cutting result. Rahman et. al has provided machining parameters as a result of their investigation [Rahman et. al., 2005].

5) **Micro turning results of other researchers**: Liu and Melkote have indicated that the surface roughness is an important feature of practical engineering surfaces because of its influence on the tribological performance of the surface [Liu & Melkote, 2006]. Therefore, accurate prediction of surface roughness produced by a mechanical cutting process carried out at the micron/submicron level can contribute to improvement partly in quality and performance. It is also observed that surface roughness in micro-turning decreases with feed, reaches a minimum, and then tends to increase with further reduction in feed. The surface roughness in turning is also affected by the depth of cut, cutting speed, tool wear, work-piece hardness [Özel & Karpat, 2005, Sahin & Motorcu, 2005, Kohli & Dixit, 2005, Jiao et. al., 2004, Feng & Wang, 2002].

**II. THE EXPERIMENT**

The dimension of micro-pin proposed for the experiment is shown in Figure 1.

![Micro-pin](image1)

**A. Micro-turning Machine**

The Integrated Multi-Process Micro-Machining Tool DT-110, shown Figure 2 is used for the experiment. The machine has an accuracy of 1µm, resolution of 0.1µm and a maximum spindle speed of 5000rpm. The X-axis travel distance is 200mm while Y-axis and Z-axis travel distance is 100mm. This machine is one of the precision micro-machine available in the market. Besides micro-level cutting, DT-110 is also capable in performing micro-EDM, micro-WEDM, micro-EDG, micro-WEDG and micro-ECM.

![Integrated Multi-Process Micro-Machining Tool DT-110](image2)

**B. Machining Parameter**

The unchanged machining parameters are as follows:
- Tool material – cemented carbide tool were used. There is no other tool material tested.
- Number of tool used – There was only one tool used to run all the experiments. New tool will only be used if there is tool breakage.
- Work-piece material – Copper, length 70 mm, 7.5 mm diameter.
The main interest in this study is to define the best cutting parameter to produce micro-pin through micro-machining. The first step in establishing the cutting parameter is to select the depth of cut, followed by feed rate selection, and lastly the spindle speed [ASM, 1989].

1) Depth of Cut: The depth of cut will be limited by the amount of metal that is to be machined from the work-piece, by the power available on the machine tool, by the rigidity of the work-piece and the cutting tool, and by the rigidity of the setup. Based on preliminary tests, the depth of cut chosen were 0.2mm, 0.25mm and 0.3mm.

2) Feed Rate: Due to the small tool diameter, high feed rate must be avoided. After considering the effective cutting time and reviews from literatures, feed rate of 10mm/min, 15mm/min and 20mm/min were selected to run the actual experiments.

Spindle Speed: Spindle speed is varied to 3 levels: 1500 rpm, 2000 rpm and 2500 rpm, which is within the range of the spindle limits.

3) Cutting Style: Three type of cutting style were considered which are reverse cutting (Fig. 3), step cutting (Fig. 4) and forward cutting (Fig. 5). In reverse cutting, the tool moves to the last point and feed the work-piece from rearward using the selected condition of depth of cut. Step cutting style removes the material forwardly starting from the tip. Movement is slower due to minimum value of the length it can move. The forward cutting, even though slightly similar to step cut, removes material with a higher length to diameter ratio.

C. Design of Experiment

There are 4 variable factors (Spindle speed, feed rate, cutting speed, depth of cut, Cutting Style) to be considered. L₉(3⁴) Orthogonal Array, with 3 levels for each factor, shown in Table I, is used in this experiment. Table II shows how the 9 experiments in total for each material were conducted. Cemented carbide tool were used.

<table>
<thead>
<tr>
<th>TABLE I VARIABLE TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = Spindle Speed</td>
</tr>
<tr>
<td>B = Feed Rate</td>
</tr>
<tr>
<td>C = Cutting style</td>
</tr>
<tr>
<td>D = Depth Of cut</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE II L₉ ORTHOGONAL ARRAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
</tr>
<tr>
<td>Experiment</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

D. Machining output and observation

Cutting outputs characteristics that were observed are the surface roughness of finished micro-pin and the dimensional accuracy.

III. RESULTS AND ANALYSIS

All 9 experiments were performed by cutting 9 piece of 7.5mm diameter rod onto the micro-pin.

A. Surface Roughness

From the experiment, 3 readings of surface roughness have been taken, shown in Table III.
### TABLE III
SURFACE ROUGHNESS RESULTS

<table>
<thead>
<tr>
<th>Variables</th>
<th>Experimental Results</th>
<th>Performance measure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A B C D</td>
<td>1 2 3 Target Noise</td>
<td></td>
</tr>
<tr>
<td>1 1 1 1</td>
<td>0.431 0.429 0.431 0.430 7.324</td>
<td></td>
</tr>
<tr>
<td>2 1 2 2</td>
<td>0.352 0.355 0.358 0.355 8.995</td>
<td></td>
</tr>
<tr>
<td>3 1 3 3</td>
<td>0.391 0.387 0.387 0.388 8.216</td>
<td></td>
</tr>
<tr>
<td>4 2 1 2</td>
<td>0.446 0.437 0.443 0.442 7.091</td>
<td></td>
</tr>
<tr>
<td>5 2 2 3</td>
<td>0.353 0.362 0.348 0.354 9.010</td>
<td></td>
</tr>
<tr>
<td>6 2 3 1</td>
<td>0.47 0.477 0.479 0.475 6.460</td>
<td></td>
</tr>
<tr>
<td>7 3 1 3</td>
<td>0.518 0.511 0.506 0.512 5.820</td>
<td></td>
</tr>
<tr>
<td>8 3 2 1</td>
<td>0.306 0.296 0.284 0.295 10.588</td>
<td></td>
</tr>
<tr>
<td>9 3 3 2</td>
<td>0.295 0.295 0.298 0.296 10.574</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE V
ANALYSIS OF VARIANCE (MEAN)

<table>
<thead>
<tr>
<th>Source</th>
<th>Pooled</th>
<th>SSQ</th>
<th>DOF</th>
<th>Variance</th>
<th>F-ratio</th>
<th>Ssq</th>
<th>Rho</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0.014</td>
<td>2</td>
<td>0.007</td>
<td>239.146</td>
<td>0.014</td>
<td>10.192</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0.073</td>
<td>2</td>
<td>0.036</td>
<td>1212.468</td>
<td>0.073</td>
<td>51.850</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0.014</td>
<td>2</td>
<td>0.007</td>
<td>225.205</td>
<td>0.013</td>
<td>9.596</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0.039</td>
<td>2</td>
<td>0.020</td>
<td>650.668</td>
<td>0.039</td>
<td>27.805</td>
</tr>
<tr>
<td>Error</td>
<td>1</td>
<td>0.001</td>
<td>18</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pooled</td>
<td>0.001</td>
<td>18</td>
<td>0.000</td>
<td>0.001</td>
<td>0.556</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St</td>
<td>0.140</td>
<td>26</td>
<td>0.140</td>
<td>100.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sm</td>
<td>4.197</td>
<td>1</td>
<td>4.197</td>
<td>100.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td>4.337</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE VIII
ANALYSIS OF VARIANCE

<table>
<thead>
<tr>
<th>Source</th>
<th>Pooled</th>
<th>SSQ</th>
<th>DOF</th>
<th>Variance</th>
<th>F-ratio</th>
<th>Ssq</th>
<th>Rho</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>3.269</td>
<td>2</td>
<td>1.635</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>11.799</td>
<td>2</td>
<td>5.899</td>
<td>4.291</td>
<td>9.049</td>
<td>38.822</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>2.229</td>
<td>2</td>
<td>1.115</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>6.012</td>
<td>2</td>
<td>3.006</td>
<td>2.187</td>
<td>3.263</td>
<td>13.998</td>
</tr>
<tr>
<td>Error</td>
<td></td>
<td>5.499</td>
<td>4.000</td>
<td>1.375</td>
<td>10.998</td>
<td>47.181</td>
<td></td>
</tr>
<tr>
<td>Pooled</td>
<td>23.310</td>
<td>8</td>
<td>23.310</td>
<td>100.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St</td>
<td>609.709</td>
<td>1</td>
<td>609.709</td>
<td>100.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sm</td>
<td>633.018</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From Table IV (response table), the significant factors were found to be B and D. As rule of thumb, only two factors have been chosen since in L$_9$(3$^4$) orthogonal array, half the degrees of freedom for important factors.

To estimate error, pooling-up technique was used. The pooling up technique starts by regarding the factor with the smallest variance for the error variance. Table V shows the value of each factor before pooling is acquired.

### TABLE IV
RESPONSE TABLE (TPM)

<table>
<thead>
<tr>
<th>Variables</th>
<th>TPM</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td></td>
<td>0.482</td>
<td>0.495</td>
<td>0.483</td>
<td>0.484</td>
</tr>
<tr>
<td>Level 2</td>
<td></td>
<td>0.480</td>
<td>0.479</td>
<td>0.483</td>
<td>0.479</td>
</tr>
<tr>
<td>Level 3</td>
<td></td>
<td>0.486</td>
<td>0.475</td>
<td>0.483</td>
<td>0.486</td>
</tr>
<tr>
<td>SSQ</td>
<td></td>
<td>0.00017</td>
<td>0.00198</td>
<td>0.00000</td>
<td>0.00029</td>
</tr>
<tr>
<td>Rank</td>
<td></td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

### TABLE VI
FACTOR LEVEL TARGET PERFORMANCE MEASUREMENT

<table>
<thead>
<tr>
<th></th>
<th>Value -5%</th>
<th>Result</th>
<th>Value +5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.372</td>
<td>0.391</td>
<td>0.410</td>
</tr>
<tr>
<td>A2</td>
<td>0.403</td>
<td>0.424</td>
<td>0.444</td>
</tr>
<tr>
<td>A3</td>
<td>0.349</td>
<td>0.368</td>
<td>0.385</td>
</tr>
<tr>
<td>B1</td>
<td>0.438</td>
<td>0.461</td>
<td>0.483</td>
</tr>
<tr>
<td>B2</td>
<td>0.318</td>
<td>0.335</td>
<td>0.351</td>
</tr>
</tbody>
</table>
Table VI shows the allowed deviation of +/- 5% from the results obtained. The response graph of the result is plotted in Figure 6. From the response graph, factor C1 (reverse cutting) was found as the most significant factor that contributes to lowest surface roughness values.

![Fig. 6 Surface Roughness Graph](image)

Noise Performance Measurement

Response table for Noise Performance Measurement is shown in Table VII. Significant factor that affect variability are factor B and D. The SN ratio is defined in such a way as the larger value, the better characteristic. Table VII showed that for optimum process, C1 and B3 should be used.

<table>
<thead>
<tr>
<th>Variables</th>
<th>TPM</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Current</td>
<td>8.178</td>
<td>6.745</td>
<td>8.124</td>
<td>8.969</td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td>7.520</td>
<td>9.531</td>
<td>8.887</td>
<td>7.091</td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td>8.994</td>
<td>8.416</td>
<td>7.682</td>
<td>8.632</td>
<td></td>
</tr>
<tr>
<td>SSQ</td>
<td>3.269</td>
<td>11.799</td>
<td>2.279</td>
<td>6.012</td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

The Response graph of the SN Ratio is plotted in Figure 7. From the response graph it is clearly shown that, the most significant factors that contribute to variability were the factor B2 and D1.

![Fig. 7 Noise Performance Measurement Graph](image)

Table X shows the value when 2 significant factors were selected. The value of surface roughness with combination of (A2, B2, C2, and D2) is 1.843 while the optimum condition value is decreased to 0.492.

Table IX

<table>
<thead>
<tr>
<th>Value -5%</th>
<th>Result</th>
<th>Value +5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>-4.035</td>
<td>-4.247</td>
</tr>
<tr>
<td>A3</td>
<td>-2.519</td>
<td>-2.651</td>
</tr>
<tr>
<td>B1</td>
<td>-4.134</td>
<td>-4.351</td>
</tr>
<tr>
<td>B3</td>
<td>-1.700</td>
<td>-1.790</td>
</tr>
<tr>
<td>C1</td>
<td>3.474</td>
<td>3.656</td>
</tr>
<tr>
<td>C2</td>
<td>-5.115</td>
<td>-5.384</td>
</tr>
<tr>
<td>C3</td>
<td>-7.926</td>
<td>-8.343</td>
</tr>
<tr>
<td>D1</td>
<td>-2.650</td>
<td>-2.790</td>
</tr>
<tr>
<td>D2</td>
<td>-2.483</td>
<td>-2.614</td>
</tr>
<tr>
<td>D3</td>
<td>-4.433</td>
<td>-4.666</td>
</tr>
</tbody>
</table>

Based on optimum selection, the best value that can be obtained from optimum experiment is 0.388 which gain ratio is 1.2 from current condition. The comparison graph is plotted in Figure 8.

![Fig. 8 Surface Roughness Comparison](image)

Table XI shows the value when 3 significant factors were selected instead. The surface roughness with combination of (A2, B2, C2, and D2) is 0.418 while the optimum condition value decreases to 0.274.

Based on optimum selection, the best value that could be obtained from optimum experiment is 0.274 with gain ratio is 1.5 from current condition. The comparison graph is plotted in Figure 9.

![Fig. 9 Surface Roughness Comparison](image)
### TABLE XI
**OPTIMUM FACTOR SELECTION (FACTOR SELECTED IS 3)**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>CURRENT TPM</th>
<th>OPT TPM</th>
<th>TPM</th>
<th>OPT TPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>0.424</td>
<td>3</td>
<td>0.368</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>0.335</td>
<td>2</td>
<td>0.335</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>0.447</td>
<td>1</td>
<td>0.360</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>0.418</td>
<td>1</td>
<td>0.274</td>
</tr>
</tbody>
</table>

### Fig. 9 Surface Roughness Comparison

### TABLE XII
**ACCURACY MEASUREMENT RESULTS**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Experimental Results</th>
<th>Performance measure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Target Noise</td>
<td>6.094</td>
</tr>
<tr>
<td></td>
<td>6.486</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.419</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.105</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.418</td>
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</table>

### B. Dimensional Accuracy

Table XII shows the accuracy measurement results. Table XIII shows the ranking of the significant factors, while Table XIV shows the value before pooling the smallest 5% variance range of data distribution.

### TABLE XIII
**RESPONSE TABLE**

<table>
<thead>
<tr>
<th>Variables</th>
<th>TPM</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<td>0.000198</td>
<td>0.00000</td>
<td>0.00029</td>
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<td></td>
<td>Rank</td>
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<td>1</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Range of data distribution for mean is 5% from the exact value, shown in Table XV. The response graph of the result is plotted and shown in Figure 10.
A. Surface Roughness

The Ra values obtained for each experiment range from 0.3301µm to 0.4955µm. Figure 6 showed that the most suitable cutting style is reversed cutting. It might be due to cutting from the edges of the cutting tool. The other significant factor after cutting style is depth of cut and feed rate.

B. Accuracy

To obtain the most accurate micro-pin, the most suitable cutting style is step cutting because the cutting length is the smallest compared to the others. However, step cut is costly because it takes longer cutting time. Reverse cutting style give moderate accuracy and might be suitable to cut different materials.

C. Quality of Finished Product

Reversed cutting style produce better surface roughness values with considerably lower machining time.

V. CONCLUSIONS

Based on the surface roughness results, it was found that the surface roughness of brass is greatly affected by the type of cut. The most suitable cutting style was found to be the reverse cutting style. For accuracy, different machining parameters do not really have significant effect. However, spindle speed does have some affects on the dimensional accuracy, depending on the feed rate and cutting style used.

The following conclusion can be drawn from the experiments conducted:

- Surface roughness, Ra increases in proportion with the selection of cutting style.
- Average surface roughness decreases as the depth of cut decreases.
- Cutting style affects the quality of the machining outputs, with reversed cutting style produce better surface roughness, better dimensional accuracy and reduced machining time.

- The best machining parameters for fabricating micro-pin can be concluded at spindle speed of 2500 rpm, a feed rate of 20mm/min, with the depth of cut 0.20mm.
- By using the best machining parameters obtained from experiments, the micro-pin produced could achieve the desired machining outputs requirements.

ACKNOWLEDGMENT

Additional guide and aid by the departmental technician is greatly appreciated.

REFERENCES