Experimental Investigation of Hydrodynamic Polishing Machine by Varying Design Parameters

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Abstract

This work is focused on experimental investigation of hydrodynamic polishing (HDP) as a Nano polishing method. The soft rubber tool and the work piece are submerged in slurry during hydrodynamic polishing. An elastohydrodynamic film is formed between the tool and the work piece due to the tool rotation which is responsible for Nano polishing. A HDP experimental setup was fabricated and experiments were conducted on non-shrinking steel 60 HRC with colloidal alumina suspensions of different particle sizes. The experiments study shows the effect of main factors such as spindle speed and constant load at different polishing times. The best surface finish of 0.504 µm was obtained using 75 µm abrasive particle size colloidal suspension at 0.4 N load, 4000 rpm spindle speed and 3 min of polishing time. The change in surface morphology and topography due to polishing also confirm the efficacy of the HDP process.

Keywords: Alumina, Hydrodynamic Polishing, Load, Nano Polishing, Spindle Speed

I. INTRODUCTION

The HDP process is a floating polishing process. The machining system of this process includes a pool of slurry (a mixture of abrasive particles and liquid solvent), a work submerged in the slurry and a rotating spherical tool pressed slightly against the work. In most cases, a constant load is applied to the tool during the machining process. When the tool rotates, owing to the hydrodynamic effect, a slurry film will be formed between tool and work. If the film thickness is much larger than the particle size, the slurry may steadily flow into the gap, which can give the abrasive particles or the shear stress field between tool and work surface a less-random distribution.

Based on the machining mechanism of the HDP process the machining capability of an abrasive particle is decided by its sustained shear stress from slurry flow. Hence, the less-random behaviours in particle and shear stress distributions imply that the machining behaviours of the HDP process may be repeatable. It was shown that the machining behaviour of this process tended to be deterministic if the lubricating condition between tool and work was properly controlled. This deterministic tendency makes this process suitable in implementing the task of form error compensation. The smoothing efficiency of work’s surface irregularities by the hydrodynamic polishing process (abbreviated as the HDP process) is studied. This efficiency is to measure the reduction of work’s surface irregularities due to a unit removal depth of material. A high efficiency may indicate that the reduction of surface irregularities is large when a unit depth of material is removed. It can be also interpreted as that a certain reduction of surface irregularities is achieved by removing a small amount of material. The goal of the study is to examine the possible factors that may influence this efficiency. The previous experimental studies did show that the repeatability of machining rate of this process could be high if the machining parameters related to the lubrication were well controlled. However, the experimental experience also indicated that the machining rate would not be maintained to a fixed value, if the tool was used for a certain period of time, even those parameters related to lubricating condition retained the same values. This time-varying nature of machining behaviour also happened to other type of polishing method and was detrimental to the precision of engineering work, such as the form error compensation process in mould industry and the chemical-mechanical polishing (CMP) process in IC industry. Hence, an understanding of this time-varying characteristic is important to the applications and is worthy of attention. It is known that the major advantages of polishing process, relative to the other machining methods is its ability to obtain a smooth surface. In the smoothing process, the work materials at valleys or peaks of surface irregularities all face the possibility of being removed by abrasive particles. It is expected that the volume removal rate of material at peaks is higher than that at valleys in the probability sense. Hence, the magnitude of surface irregularities can be gradually reduced in the smoothing process. Because both the materials at peaks and valleys are simultaneously removed, it is mostly the case that the average removal depth of material is larger than the reduced size of surface irregularities.
II. METHODOLOGY AND WORKING

A. Principle of Operation:

1) It is a floating polishing process. The machining system of this process includes a pool of slurry (a mixture of abrasive particles and liquid solvent), a work submerged in the slurry and a rotating spherical tool pressed slightly against the work.

2) In most cases, a constant load is applied to the tool during the machining process. When the tool rotates, owing to the hydrodynamic effect, a slurry film will be formed between tool and work.

3) If the film thickness is much larger than the particle size, the slurry may steadily flow into the gap, which can give the abrasive particles or the shear stress field between tool and work surface a less-random distribution. Based on the machining mechanism of the HDP process, the machining capability is depend on abrasive particles size.

![Fig. 1: Principle of Operation of HDP Machine](image1)

B. Working of the Machine:

1) Set the rubber ball 45° to vertical column along with dc motor of (4500 rpm, 3 kg torque and 12 volt). Fill tank with slurry made of Al₂O₃ and distilled water. Initially hardness of work piece was 16 (Rockwell C). So by water quenching process,

2) Hardness increases up to 60 (Rockwell C). Then work piece is placed on the fixture.

3) Start the motor from 1000 rpm that rubber tool touches to the work piece so that it should apply 0.4 N on the work piece.

4) Now place the ball of running condition on the same point up to 3 min. Again move the ball to next point and increase that speed by 1000 rpm and Repeat process for 3 point on each work piece. Same procedure is followed for other there work piece with variable speed from 1000 to 4000 rpm.

![Fig. 2: Working of the Hydrodynamic Machine](image2)
III. Observation and Analysis

A. Observations:

Table – 1
Observations of time, speed and roughness for t = 3 min

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>speed (rpm)</th>
<th>roughness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1000</td>
<td>1.211</td>
</tr>
<tr>
<td>3</td>
<td>2000</td>
<td>1.006</td>
</tr>
<tr>
<td>3</td>
<td>3000</td>
<td>0.835</td>
</tr>
<tr>
<td>3</td>
<td>4000</td>
<td>0.602</td>
</tr>
</tbody>
</table>

Table – 2
Observations of time, speed and roughness for t = 5 min

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>speed (rpm)</th>
<th>roughness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2000</td>
<td>0.9018</td>
</tr>
<tr>
<td>5</td>
<td>2500</td>
<td>0.8102</td>
</tr>
<tr>
<td>5</td>
<td>3000</td>
<td>0.7830</td>
</tr>
<tr>
<td>5</td>
<td>4000</td>
<td>0.5766</td>
</tr>
</tbody>
</table>

Table – 3
Observations of time, speed and roughness for t = 10 min

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>speed (rpm)</th>
<th>roughness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2000</td>
<td>0.8431</td>
</tr>
<tr>
<td>10</td>
<td>2500</td>
<td>0.7992</td>
</tr>
<tr>
<td>10</td>
<td>3000</td>
<td>0.7147</td>
</tr>
<tr>
<td>10</td>
<td>4000</td>
<td>0.5043</td>
</tr>
</tbody>
</table>

B. Analysis and Graph:

Fig. 3: Roughness v/s Speed v/s Time

The graph shows that roughness value decreases with increasing spindle speed and time. Optimum spindle speed is found to be 4000 rpm for early stages of polishing (till 10 min of polishing time). Slurry containing abrasive particles of 75µm gave the best surface finish.
IV. CONCLUSION

The project work was focused on identifying a suitable process for polishing and finding the optimal parameters for polishing of hardened steel plates. However, the smoothing efficiency of work’s surface irregularities by the HDP process was examined in this study. The smoothing efficiency was high when the magnitude of surface irregularities was large. However, the tool speed showed an obvious effect on the value of surface irregularities. The wear rate of tool was always the highest at the beginning of machining. This machining method has the capability to shape an arbitrary profile. The machining rate of this process is sensitive to the surface irregularities of tool. To carve an arbitrary shape, a machining strategy is proposed, this study clearly demonstrates that the HDP process is a promising method for the ultra-precision purpose.

Based on the experimental analysis, following specific conclusions can be drawn from this study.

1) HDP has the capability to produce finished surfaces on hard materials and the best $Ra$ value obtained was 0.5043 µm.
2) Concentration of abrasive particle is the most significant factor controlling the HDP process.
3) Surface finish increases with an increase in speed (From 1000rpm to 4000rpm).
4) Optimum spindle speed is found to be 4000 rpm for early stages of polishing (till 10 min of polishing time). Slurry containing abrasive particles of 75µm gave the best surface finish.
5) Surface finish increases with increase in time (From 3min to 10min).

REFERENCES