Influence of pocket geometry and tool path strategy in pocket milling of UNS A96063 alloy

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ABSTRACT

2½-Pocketing is a frequent operation in aeronautic and automotive industry. The path that must be followed by the tool during the milling process can be generated using different strategies. In the present paper, the influence of strategy and pocket geometry in parameters as machining time, cutting forces generated and surface roughness is studied. The pocketing tests have been performed on UNS A96063, an increasingly important alloy in such industries.

Keywords: Pocketing, 2½-D shape, tool path generation, cutting forces, machining time.

1. Introduction

More than 80% of all mechanical parts to be machined can be performed using 2½-D milling [1]. This is based on the fact that most of them consist of faces parallel or normal to a single plane, and that free-form objects are usually produced from a raw stock by 2½-D roughing and 3-D or 5D finishing [2]. Roughing represents 50% of the total machining time [3], although it can be 5 to 10 times longer than finishing [4].

2½-D machining which aims to clear out the totally of a pre-defined contour is called “pocketing” and the contour is called a “pocket” [5]. Pocketing is one of the most common operations in aeronautic and automotive industry since it is employed during the roughing stage of moulds and dies manufacturing [6].

There are two main commercial tool path strategies in pocket milling: contour-parallel and direction parallel. The contour parallel path is generated by successive offsets of the input profile. Thus, each successive offset is essential to generate a contour parallel tool path. The direction parallel path uses line segments that are parallel to an initially selected reference line and seems to be simpler than the contour parallel path [7]. The strategy chosen to generate the tool path can influence in important parameters (machining time, cutting forces, length of the tool path, surface roughness).

Recent published works analyse the relationship between these commercial tool path strategies (contour-parallel and direction parallel), technological variables of the process (cutting velocity, feed rate, depth of cut and step over) and surface roughness, in milling [8] and micromilling [9], but keeping fixed the geometry of the pocket.
In the present paper, the technological variables of the process are fixed, but “pocket geometry” is incorporated to the problem (first goal of the work). The influence of pocket geometry and tool path strategy in machining time, cutting forces and surface roughness is studied. There are not similar studies about pocketing of UNS A96063 alloy (second goal of the work), very employed via extrusion in the automotive industry [10], although there is increasing scientific interest in its use via milling [11] (Figure 1).

The experimental procedure (workpiece material and tooling, experimental equipment and set up) is shown in Section 2. The results of the tests are presented in Section 3. Finally, in Section 4, conclusions are exposed.

![Figure 1. Number of works published about milling of UNS A96063 alloy](image)

### 2. Experimental procedure

#### 2.1 Workpiece material and tooling

The workpieces, made up of aluminium alloy UNS A96063 (composition in Table 1), are blocks of 80 mm x 60 mm x 20 mm. As tools, 2-flute GÜHRING 3309 end-flat mills of 6 mm of diameter and a helix angle of 45° are also employed (figure and table 2). Machining tests are conducted under dry conditions at a feed rate of 100 mm/min and a spindle speed of 1500 RPM, under tool manufacturer recommendations (table 3).

### Table 1. UNS A96063 composition

<table>
<thead>
<tr>
<th>%Si</th>
<th>%Fe</th>
<th>%Cu</th>
<th>%Mn</th>
<th>%Mg</th>
<th>%Zn</th>
<th>%Ti</th>
<th>%Cr</th>
<th>%Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20-0.60</td>
<td>0.35</td>
<td>0.10</td>
<td>0.10</td>
<td>0.45-0.90</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.15</td>
</tr>
</tbody>
</table>

### Table 2. Geometry properties of cutting tool

<table>
<thead>
<tr>
<th>d₁</th>
<th>d₂</th>
<th>l₁</th>
<th>l₂</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.000</td>
<td>6.000</td>
<td>57.000</td>
<td>10.000</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 3. Cutting parameters recommended by cutting tool manufacturer

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Material to cut</th>
<th>Cutting speed (m/min)</th>
<th>fₓ (mm/flute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GÜHRING 3309</td>
<td>6 Aluminum and its alloys</td>
<td>297 – 363</td>
<td>0.031</td>
</tr>
</tbody>
</table>

![Figure 2. Cutting tool used in tests](image)
2.2 Experimental equipment and set up

Cutting tests are performed on a vertical prismatic machining centre ALECOP, ODISEA model, with FAGOR control (figure 3). The tool-machine characteristics are shown in table 4.

![Machining centre ALECOP - ODISEA, with FAGOR control](image)

**Table 4. Technical characteristics of ODISEA milling machine**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal travel X</td>
<td>200 mm</td>
</tr>
<tr>
<td>Cross travel Y</td>
<td>200 mm</td>
</tr>
<tr>
<td>Vertical travel Z</td>
<td>200 mm</td>
</tr>
<tr>
<td>Table size (3 tee slots)</td>
<td>450 x 180 mm</td>
</tr>
<tr>
<td>Spindle to table</td>
<td>320 mm</td>
</tr>
<tr>
<td>Spindle taper ISO 30</td>
<td></td>
</tr>
<tr>
<td>Spindle motor Asynchronous three-phase 1.5 kW</td>
<td></td>
</tr>
<tr>
<td>Spindle speed From 100 to 4000 rpm</td>
<td></td>
</tr>
<tr>
<td>Cone head ISO 30</td>
<td></td>
</tr>
<tr>
<td>DC motors 1.44 Nm</td>
<td></td>
</tr>
<tr>
<td>Rapid transverse 5000 mm/min</td>
<td></td>
</tr>
<tr>
<td>Electronic resolution 0.001</td>
<td></td>
</tr>
<tr>
<td>Mains supply 230 V 50/60 Hz</td>
<td></td>
</tr>
<tr>
<td>Dimensions 1470 x 918 x 1855 mm</td>
<td></td>
</tr>
<tr>
<td>Approximate weight 550 kg</td>
<td></td>
</tr>
</tbody>
</table>

All cutting force measurements are carried out using a three-component piezoelectric dynamometer. This has a resonant frequency of 2.3 kHz in the x and y-axes, and 3.5 kHz in z-axis. The dynamometer is connected to a series of charge amplifiers, which in turn are connected to a four-channel oscilloscope with a maximum sampling rate of 200 M samples/s. The whole system is checked and calibrated prior to use. The cutting force data post-process is performed using a software package. A diagram of the whole system is shown in figure 4.

![Diagram of the whole system](image)
In order to characterize the surface profile, a profilometer Marh Perthen M4Pi was used (Figure 5). This equipment measures a number of standard surface roughness parameters. Dependent upon the type of parameter measured, these surface roughness values are calculated from the unfiltered, measured profile, the filtered roughness profile, or the filtered waviness profile. The most standard surface roughness parameter considered was $R_a$. $R_a$ is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. Two measurements with “cut off” 0.8 mm were made for each sample, in order to obtain an average value of all the surface quality parameters.

![Figure 5. Perhometer “Mahr” used to measure the surface roughness](image)

2.3 Experimental procedure

The effect of employing different cutter path orientations when roughing milling aluminium alloy A96063 is investigated in relation to machining time, cutting forces and pocket geometry. Three pocket geometries (Figure 6), extracted from bibliography, are selected. Each geometry is machined twice, using as a contour-parallel as a direction parallel strategy. In every test, cutting forces and machining time are measured for post-processing.

The pocket geometries are chosen according to the following reasons: pocket 1 is a non-symmetric closed convex curve; pocket 2 is a two axes symmetric non-convex curve; pocket 3 is a non-symmetric closed curve with an interior island.

The tool path is generated using the CATIA machining workbench (figure 7). Geometry and dimensions of stock and tool are introduced in the software as well as feed rate (100 mm/min) and spindle speed (1500 RPM). An overlap of 50% of the tool diameter is selected in both strategies. In the case of direction parallel, a final profile contouring operation must be defined for a better finishing in the perimeter.

NC code generated by CATIA is checked and simulated before sending it to machining centre. For this purpose FAGOR’s software “Win-Unisoft” has been employed. Cutter is checked prior to machining to ensure a tool run out lower than 10 µm. This was assessed by a dial indicator with a resolution of 0.001 mm.

After the machining, longitudinal and transversal surface roughness is measured with the perthometer.

![Figure 6. Geometries performed during the tests: pocket 1 (left); pocket 2 (centre); pocket 3 (right)](image)
3. Results

After the machining tests (figure 8), cutting forces data must be post-processed to measure the exact time employed in each pocketing (figure 9). The next stage is the filtering of the cutting forces signals. A Butterworth filter is used to clean the signals. Subsequently, the resultant signal is calculated and plotted as Fx, Fy and Fz (figure 10). The resultant cutting forces mean values for each pocket and strategy is shown in Figure 11. Surface roughness is presented in Figure 12.
Figure 10. Filtered cutting forces measured during milling of pocket 1 with zig-zag strategy

Figure 11. Medium values of resultant cutting forces for each pocket geometry and strategy

Figure 12. Transversal (left) and longitudinal (right) surface roughness for each geometry and strategy
4. Conclusions and future works

In the present paper, a study of the relationship between pocket geometry, cutter path strategy, machining time, cutting forces and surface roughness has been presented. All the pocketing tests have been performed over UNS A96063, an aluminium alloy that arouses increasing interest from the scientific point of view (Figure 1), using a 6 mm diameter 2-flutes end-mill (Figure and table 2). Pockets have been machined in a vertical milling centre equipped with a 3-axes dynamometric platform (Figure 3 and 4), which makes it possible to measure machining time and cutting forces. The transversal and longitudinal surface roughness have been measured via a Mahr Perthometer (Figure 5). Three pocket geometries (Figure 6), selected from bibliography in base of different properties, have been used in the study. Each one has been machined using as contour-parallel as direction-parallel tool path, generated via CATIA machining (Figure 7). Post-processing work has been necessary to extract conclusions from cutting forces data signals recorded during the pocketing tests (Figure 10).

Some conclusions can be obtained from the results:

- Machining time:
  - For all the pocket geometries, contour-parallel strategy achieved lower machining times (Figure 9). This difference is caused by the necessary final contour pass used in zig-zag strategy to avoid the bite shown in Figure 7. This problem is not presented in contour-parallel strategy, besides of the final pass is part of the strategy itself.
  - The difference is more significant in the lobed geometry (Figure 6, pocket 2) than in convex pocket, with or without islands. It is due to zig-zag strategy provides more air-movement, especially in such geometries.

- Cutting forces:
  - For all the pocket geometries, contour-parallel strategy presents upper medium forces results (Figure 11), besides more vibrations. Both phenomenon could be explained by the large number of changes direction during the machining. This situation could origin a premature wear in the tool.
  - An economic study, that takes into account as the economic cost of this premature tool wear in contour-parallel strategy as the save of time in relation to zig-zag strategy, could be interesting as future work.

- Surface Roughness:
  - For pocket 1 and pocket 2, transversal and longitudinal surface roughness is lower for contour-parallel strategy (Figure 12). This trend coincides with the one presented by [8] for steel 1.2738.
  - The differences are lower in pocket 3. It may be due to the presence of islands, which distort the generation of tool paths.

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6. References


