The Configuration of a Machining Centre and its Influence on Accuracy

Gilles Dessein, Pierre Lagarrigue and Walter Rubio
Laboratoire de Génie Mécanique de Toulouse, Université Paul Sabatier, Toulouse Cedex, France

The aim of the paper is to provide an experimental method for revealing systematic defects in a machining centre. The problem is first analysed by comparing results from two different machining operations carried out on the same unit. The machining unit as a whole is then studied in order to obtain maximum precision on each axis, and to determine the influence of machine layout on accuracy. Finally, the best possible layout is chosen in terms of optimum precision.

Keywords: Experimental design; Machining scattering; Numerically controlled machine tools; Production optimising

1. Introduction

Quality in production engineering is based on knowledge and control of the manufacturing process. All machine tools have a certain degree of accuracy depending on machine tool variations [1,2], machine set-up and design and state of the material. Lack of knowledge of machine capacity alters manufacturing quality. If we limit our attention to machine variations, the use of the same tool, the same machining set-up and the same procedure for different configurations will reveal these defects, i.e. machining unit scattering.

Using an identical machine in several different configurations can verify this scattering.

During the machining of a series of identical workpieces on a numerically controlled machining centre (4-axis horizontal spindle machine), the machined dimensions vary according to the configuration used, even though the settings are correct (Fig. 1).

In order to list the machine dispersion, machine behaviour has to be analysed in all configurations (direction of travel, pallet change, etc.). In view of the number of tests to be carried out, and the number of parameters to be considered, it is necessary to use an experimental design method (amount of time in operation, cost of materials, difficulty in analysing a large number of tests).

Following on from this study, our initial plan was to discover machine parameters likely to influence machining quality, and then to experiment on one axis for two similar machines, in order to compare the possible behaviour of several machining centres. Analysis of experimental results has subsequently enabled us to quantify the effects of different parameters, to determine which factors really have an influence, and to identify the origin of the defects in a machine.

A secondary study on the three machine axes has enabled us to quantify potential scattering, and to quantify the axes in terms of machine configuration. To conclude, we offer an experimental behavioural model of a machine in operation with a view to using the machine in its optimum configuration.

2. Test procedure

2.1 Choice of Parameters

An initial static verification of the geometry of the machine according to the French standard NF60-117 is inconclusive. In
fact, the defects in the pallet's inherent flatness are less than 10 μm, which creates, in our example, machining defects of less than 1 μm. We have therefore chosen to study the machine during the machining cycle. Following a process analysis [3], we have decided to study the influence of the parameters shown in Table 1 during the machining of a groove [4].

The rigidity of the machining assembly and the bending of the tool have not been taken into account since the machine uses the same tool and the same machining assembly for all the configurations tested.

Similarly, the machining of a reference surface before each test groove enables us to avoid errors in measuring tool length. The tool wears during the experiment, but the degree of wear observable between two experiments is negligible.

### 2.2 Experimental Method

Because of the complexity of the system, and the large number of parameters selected, we have decided to use an experimental design based on Taguchi's method [5], in particular on his research into extreme limits. As our goal is to find the level of different factors consistent with minimum scatter, interactions between factors have been ignored [6,7], and only two levels have been assigned to the factors. Through trial and error, we can make an initial approach to discovering the origin of scatter.

Relevant factors are either continuous (D, E, G, I) or discrete (A, B, C, F, H) (Table 1). The choice of two factor levels enables two factor types to be studied in the same experimental design [8]. Taguchi's table as modified to suit our model can be calculated using the criterion of the number of degrees of freedom (Ndf = 10), and by the criterion of orthogonality (Sisson and Vigier's method which gives us the lowest common multiple \( L_{cm} = 4 \) ) [9].

<table>
<thead>
<tr>
<th>Parameters chosen</th>
<th>Defect observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: DAT1*</td>
<td>Error in point perception</td>
</tr>
<tr>
<td>B: MOS*</td>
<td>Positional error on the appropriate machine axis</td>
</tr>
<tr>
<td>C: pallet change</td>
<td>Repositioning or damping defect</td>
</tr>
<tr>
<td>D: distance of approach</td>
<td>Different machining stresses on the machine</td>
</tr>
<tr>
<td>E: depth of cut</td>
<td>Different behaviour depending on direction of movement</td>
</tr>
<tr>
<td>F: direction of approach</td>
<td>Response time and sticking of guideways</td>
</tr>
<tr>
<td>G: waiting time (time-out)</td>
<td>Taking up of clearance</td>
</tr>
<tr>
<td>H: down or up-milling</td>
<td>Different machining effort on the machine</td>
</tr>
<tr>
<td>I: width of cut</td>
<td>-</td>
</tr>
</tbody>
</table>

DAT1*: part datum shift represents the vector from measurement origin to part origin.
MOS*: represents the homing procedure.

Applying these conditions, the smallest orthogonal plan for the model consists of 12 experiments. We have assumed that no interactions take place, but if they do, their effect is mixed in with the factor effect. In table L12, the effect of each interaction is scattered over the columns as a whole, thus noticeably weakening any possible interaction effect. For safety, we have thus chosen table L12.

If interactions between influencing factors need to be studied further, an L8 table (after simplification) or an L16 table can subsequently be chosen. A numerical control programme divides the experimental design into 12 experiments for both machining centres.

### 3. Results

Precise analysis of results brings to light those factors which are significant, and an experimental model of the machine behaviour can thus be constructed. The groove depth response has been measured on a 3D measuring machine. The mean effects for each parameter are calculated, and the residue and variance values enable the results to be verified and the theoretical response to be calculated.

The factor behaviour is determined by analysing the results, and the mean effects graph indicates the precise influence (Fig. 2).

### 4. Discussion

What is immediately noticeable is the homogeneity of results on the mean effects graph. All the factors influence the machining in the same direction, regardless of the machine. A large depth of cut influences the system in the same way as the lack of pallet clamping, and the depth of groove tends to be reduced. This leads us to think that the workpiece tends to retreat during machining, i.e. the clamping of the machining assembly is incorrect. The fact that a pallet change, and thus a recent clamping of the plate improves the quality leads one to suppose that the plate clamping pressure decreases over time, and that the stability of the unit as a whole is affected.