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Use of Magnetorheological Fluids for Vibration Reduction on the Milling of Thin Floor Parts

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Abstract

Nowadays, aluminum manufacturing companies are required to improve the manufacturing process of components with complex geometric details. This improvement requires an optimization of the process, resulting on higher cutting parameters. In thin floor parts, being low rigidity structures, the increase of cutting parameters brings as a conclusion the emergence of instabilities during machining.

The main objective of this paper is to analyze the stability of thin floor parts, defining what cutting parameters make chatter appear and proposing one solution to instability problem based on Magnetorheological (MR) Fluid shock absorber.

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Keywords: Smart Materials; Magnetorheological Fluids; thin floor parts; chatter.

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1. Introduction

Aviation civil manufacturers have marked two important goals to achieve in a short time. The first is to reduce the operating cost per passenger to offset the high price of oil, resulting on a more attractive offer to airlines. The

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other one, related to ecological scope, aims to contribute in the improvement of the environment, both reducing pollution and accomplishing environmental protection laws, as they are more severe day by day.

With this all, major companies, such as Airbus and Boeing, have had to restructure their designs, working on planes dimensions and the materials used for their fabrication.

In order to improve efficiency, Boeing builds 787 Dreamliner with almost 50% of the weight in composite materials at the expense of aluminum, 20%, as it can be seen in Fig. 1. The bet of Boeing in composites has been so strong, that it is the first company to build an airplane fuselage entirely of reinforced plastic with carbon fibers.

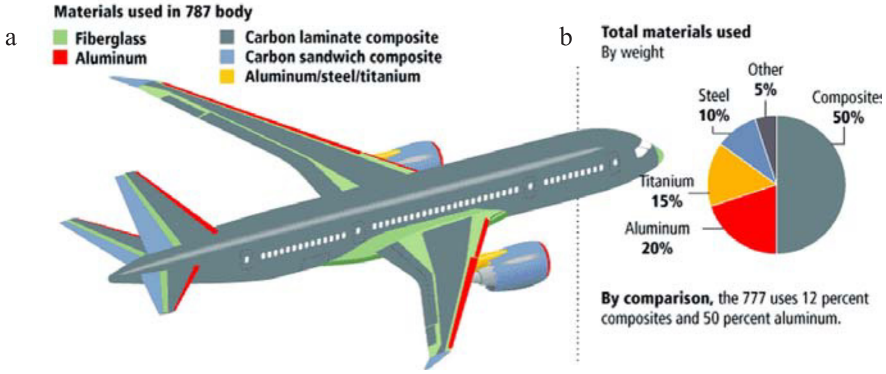

Fig. 1. (a) Materials and their distribution in 787 Dreamliner; (b) Increase of composite materials in 787 Dreamliner. Source: Boeing official web page.

In a near future, civil aviation manufacturers will demand composite components more and more. But it has to be taken into account that the manufacturing of composites does not belong to the world of machining operations, except for routing and drilling operations. As the aluminium market is changing, machining companies have to base their survival improving their processes deeply. For these companies it is essential to design efficient production processes and to obtain a final product which satisfies the final accuracy, quality and dimensions required by the customer. Increase quality and reduce the cost, is the only way for these companies to fight against competence.

Mainly, the improvement named before is related to the optimization of the process, being commonly connected to more aggressive cutting conditions. This optimization is also based on the reduction of downtime or even on the reduction of maintenance time. The increase of cutting parameters such as cutting velocity and axial or radial depth of cut makes the appearance of instabilities during machining, commonly known as ‘chatter’. Chatter is always undesirable as it affects negatively both productivity and components quality. That is why it has to be avoided or reduced.

After the boom of monolithic components in the 90s, instabilities appearance increased during machining due to the low rigidity of this type of components and high machining conditions that they are machined (speeds around 40.000 rpm and feed of 0.2 mm/teeth). Furthermore, to obtain a certain curvature between floor and wall, complex geometry tools have to be used, such as spherical or bull-nose tools. Even for avoiding collisions between tool holder and machine head against the workpiece, tools are usually placed with long overhang, which possibly leads to low flection rigidity. All of this is a source of instability.

The key factor that determines the appearance of instability is the initial excess of mass of the component. With a diagram similar to Fig. 2, is possible to determine the optimum value of the excess of mass during machining in order to avoid chatter. This diagram is obtained by the previous modelling of the cutting process and understanding the behaviour of the workpiece. But this process is so complex that most companies usually do not use it.

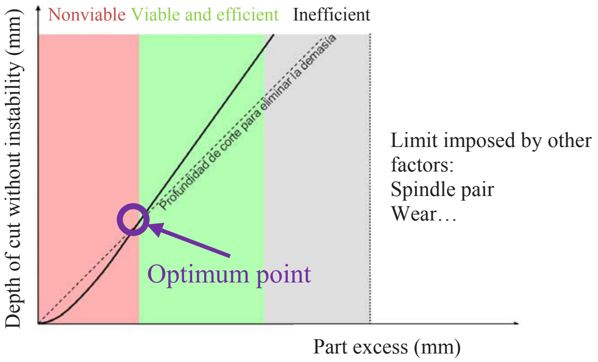

Fig. 2. Diagram obtained by the modeling of the cutting process.

When chatter appears, workshops manufacturers try to avoid it reducing feed rates, varying cutting speed, rigidifying parts, choosing the cutting conditions previously by trial and error test, or even eliminating chatter marks by manual finishing. But obviously, all these solutions make the goal of optimizing break away.

This research wants to find a new solution to the suppression of chatter in thin floor parts by the use of Magnetorheological Fluids so as to obtain an optimal process in the machining of aluminium.

2. State of the art

For several years the chatter has been studied from various viewpoints in order to be avoided: Winfough (1995) studied the effect of the increase of the initial thickness of the part, Sims and Zhang (2004) used actuators to compensate the deformation and vibration of the workpiece and Zatarain et al. (2008) varied spindle speed to more stable speeds. Some other researches, such as, Segalman and Redmond (1996), Wang and Fei (1999), Mei et al. (2009) or Çeşmesi and Engin (2010) made use of Smart Materials for chatter avoidance. Due to the complexity of the study of thin floor parts, so far not much research has been made about this topic. The studies of Smith and Dvorak (1998), Fleischer and Denkena (2006) and Campa (2009) could be some examples.

Campa (2009) experienced the dynamic variables of thin floor parts assuming the vibration in the direction of the tool axis. In this study, 3D stability lobes diagram was obtained for bull-nose tools, defining stable speeds depending on the position of the tool in the workpiece (see Fig. 3). In this way, it was possible to improve the workpiece surface quality varying spindle speed during the machining process. Campa (2009) also analyzed the influence of cutting parameters on chatter, concluding that the amount of material to remove could have a great influence on cutting stability.

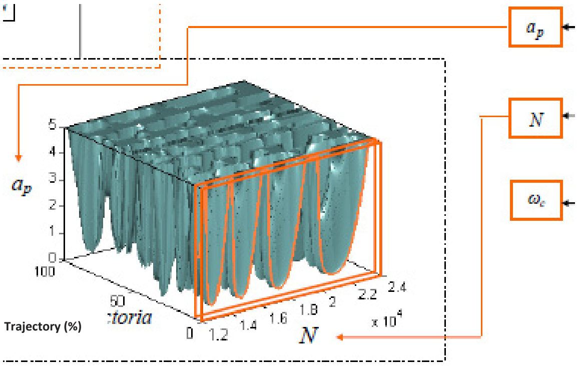

Fig. 3. 3D stability lobes diagram for bull-nose tools studied by Campa (2009)

3. Material and equipment. Methodology

The most suitable material in aerospace industry is 7075-T6 aluminum alloy. So, workpieces of 7075-T6 aluminum alloy were tested in this research. Specimens of 200 mm diameter and 10 mm thickness were prepared. The specimens were tied to the table of the machining center (Kondia HS1000) using a holding device designed specifically for this work, which allows free vibration on vertical axis (Fig. 4).

Bull-nose endmilling tools made of hard metal were used for the test, with a 16 mm of diameter and a corner tool tip of 2.5 mm to achieve the required fillet radii.

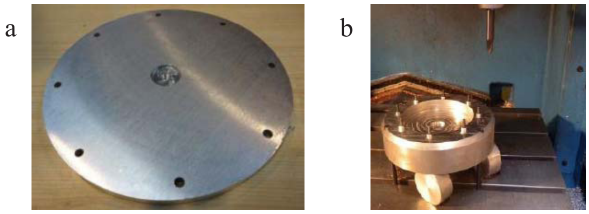

Fig. 4. (a) Workpiece used in the study; (b) Workpiece tied to the table of the machining center.

For modal testing, a hammer PCB086C03 PCB Piezotronics was used to excite the system, and to measure the response to the external force a unidirectional ultraligth accelerometer PCB35C22 Piezotronics was used.

In terms of methodology, as a first approach to the case of study, a series of test were made in order to determine under what cutting conditions instability appeared. After that, the variation of modal parameters such as damping, rigidity and frequency of the workpiece were analyzed along the tool trajectory. Then, 3D stability lobes diagram was obtained according to the methodology used in Campa (2009), detecting stable and unstable areas during machining thereby.

Finally, the problem of chatter appearance was solved through the use of a shock absorber bed, based on a Magnetorheological Fluid.

4. Experimental analysis

4.1. Initial test

The objective pursued with these initial tests was to define what the workpiece thickness that marked the frontier for chatter apparition was. For this, starting from an initial thickness of 9 mm, 5 mm and 2 mm, some parts were machined with axial depth of cut of 8 mm for the first two cases and 1.25 mm for the last case. The cutting parameters were selected so as to be the maximum ones permitted by the machining center and are summarized in Table 1. The machining strategy was circular interpolation.

Table 1. Cutting parameters selected for the initial tests.

Type of cut	Spindle speed	Feed per teeth	Radial depth of cut
Down milling	24,000 rpm	0.05 mm/teeth	62.5%

After all the tests, it could be observed that only in case of an initial thickness of 2 mm chatter appeared. That instability could be seen both on the FFT accelerometer signal and on the marks on the workpiece surface (see Fig. 5).

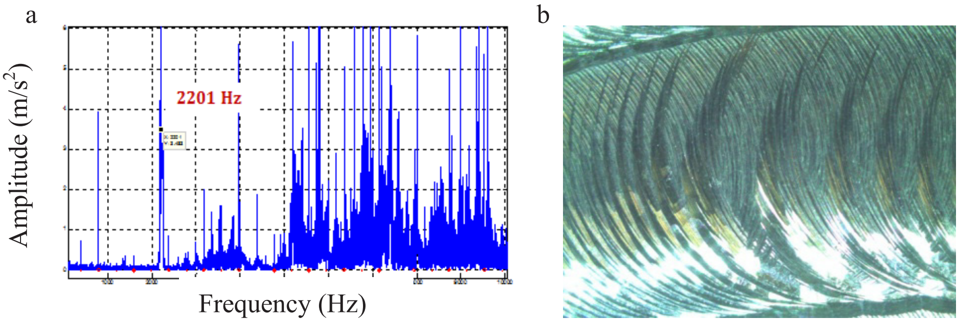

Fig. 5. (a) Signal of the accelerometer under chatter conditions; (b) Chatter marks on the workpiece surface.

In view of the results of these first tests, it was decided that the workpiece would have an initial thickness of 2 mm and it would be machined with an axial depth of cut of 1.25 mm from now on, in order to work under chatter conditions.

4.2. Variation of modal parameters

When a thin floor part is machined, its dynamic characteristics change over the time due to several reasons. During the process, the material is being removed, which reduced mass and rigidity of workpiece and modal parameters varied along the cutting area. These topics were studied by Budak (1994) and Altintas and Budak (1995) respectively.

In this study, the variation of the modal parameters was obtained by discretization of the tool path, dividing it into 32 steps. The measurements were made by placing the accelerometer at the top of the piece and striking in one side with the impact hammer. Over 10 strikes were done, ensuring reliability in shock and trying to maintain consistency above 60%.

Fig. 6 shows the variation of damping, rigidity and frequency versus tool path trajectory for the case of study.

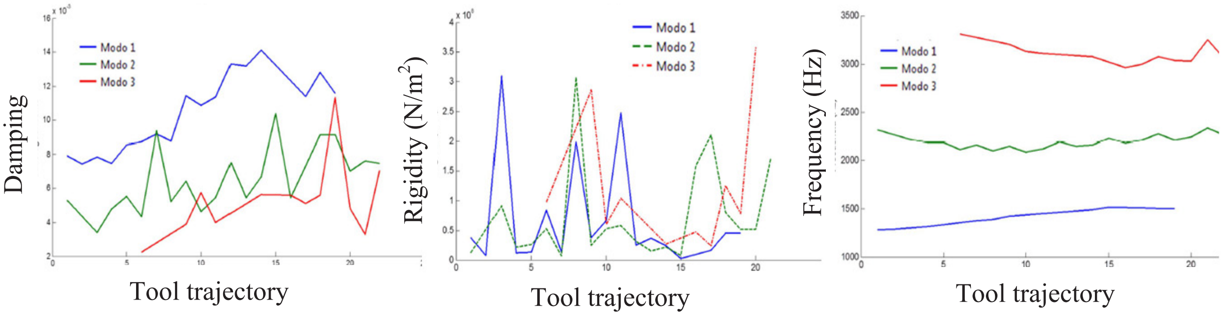

Fig. 6. Variation of modal parameters with tool trajectory.

4.3. Obtaining 3D stability lobes diagram

Knowing the variation of modal parameters (Fig. 6) the next step was to obtain 3D stability lobes diagram. For that purpose, some simplifications were made: the cutting forces were related directly to chip thickness, run-out and process damping effects were not taken into account and only main cutting edges were supposed to cut.

Furthermore, in the case of study the only variable was the spindle speed, since the axial depth was defined like the other cutting parameters. 3D stability lobes diagram could be then simplified to a 2D one, as it can be seen in Fig. 7.

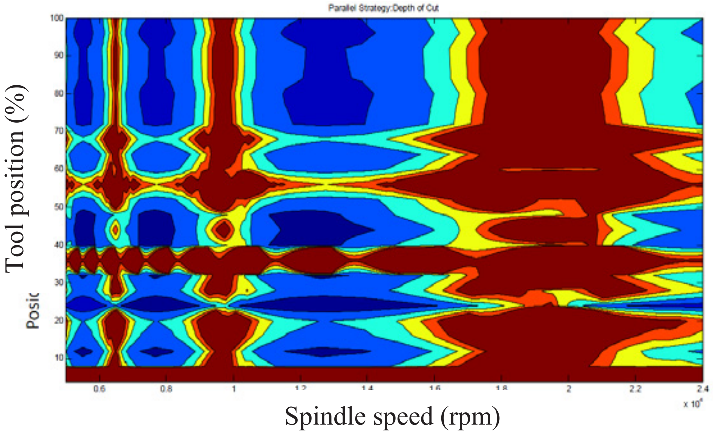

Fig. 7. Stability diagram under the cutting conditions studied using the algorithm of Campa (2009).

4.4. Results

In the 2D stability diagram obtained, it was concluded that if it is wanted to avoid unstable areas during machining, the cutting speed should be varied. Or failing that, the cutting parameters should be decreased, thereby decreasing productivity away from the optimization.

So if it is wanted to avoid instability problems during machining of thin floor parts as here, without neglecting the idea of optimizing the process, it is necessary to look for an alternative solution.

5. Shock absorber based on Magnetorheological Fluid

In order to avoid chatter during the machining of thin floor parts and with the idea of maintaining optimal cutting conditions, it was decided to design a shock absorber bed, based on Magnetorheological Fluid.

Smart Materials are commonly used in machining processes. Electrorehological (ER) and Magnetorheological (MR) fluids are two of them. The rheological properties of these fluids can be controlled externally with an electric or magnetic field respectively. If a field is applied to this kind of fluids, it generates a change in the viscosity and hence, a change in the yield stress of the fluids. The MR fluids usually consist of an oil (generally, mineral or silicone) and ferrous particles which have a diameter between 0.05-0.1 microns.

The advantages of use this kind of fluids in machining process are related to their properties: they can work at a wide range of frequencies, they have reduced response time, they can be interchangeable easily and they can return to their natural liquid state (reversible).

For the assembly of the shock absorber, the following elements were required: MR fluid, a rubber pad, an electrical variator (Polylux EA3000) and an electromagnetic disk (NAFSA VEM200), this one adapted to the dimensions of the holding device used in the tests (see Fig. 4). The assembly was performed as follows: first, the fluid was introduced into the rubber pad, thus to prevent direct contact with the workpiece. The rubber pad was placed over the disk and both were introduced between the piece test and the machining table, as it can be seen in Fig. 8. The electromagnetic disk was then connected to the variator so as to activate the magnetic field.

Some previous tests have to be made, as is important to determine: MR appropriate amount of fluid in the pad, necessary distance between the shock and the workpiece, applied voltage and the size of the pad containing the fluid. If these parameters are not controlled, the magnetic field could saturate the fluid or even the fluid could do a pushing force on the workpiece flexing it or also breaking it.

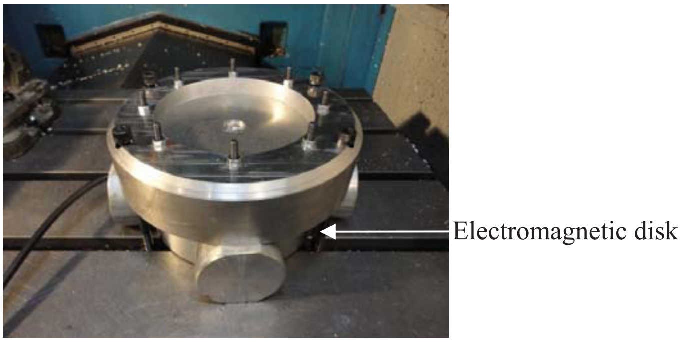

Fig. 8. Placing the electromagnetic disk and the pad on the machining center.

After some tests, it was concluded that the MR fluid changed its viscosity without pushing the workpiece with a voltage of 25 VAC (10% of the capacity of the electrical variator). Knowing this, a new test was made with the parameters listed in Table 1 but now under MR shock absorber presence. As named before, the initial thickness was 2 mm and the final one 0.75 mm, resulting in a 1.25 mm axial depth of cut.

No chatter appeared during the cutting process. The workpiece surface did not present chatter marks and the accelerometer signal, Fig. 9, indicates stability during machining.

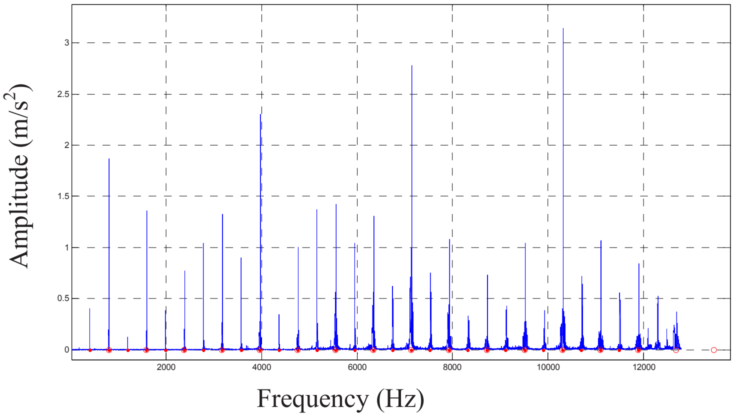

Fig. 9. Signal of the accelerometer under stability conditions.

6. Conclusions

Through this study, it has been concluded that under optimum cutting conditions thin floor parts machining is conditioned by instabilities apparition. To prevent this effect, the spindle speed should be reduced or either work with variable cutting conditions, even though it results in a decrease of productivity and an increase of cost.

As a solution to this problem, it has been proposed the use of a shock absorber based on Magnetorheological Fluid. Is a fluid which has the ability to change from liquid to a semi-solid state due to the action of a magnetic field. It has been determined the way to assembly the elements that compound the shock absorber and also some important things to consider. Such as, the amount of fluid, the distance between disk and workpiece and finally how much voltage has to be applied. These issues are of vital importance, since if they are not taken into account the shock absorber would not be used correctly. Then chatter would not be avoided, or even worst, the shock absorber would bend the workpiece.

Placing the shock absorber bed under the test piece, it was possible to reach optimum machining speeds (24,000 rpm) in the absence of instabilities during the machining of a thin floor part. As well, a good quality of the final piece was obtained.

Other advantage of the shock absorber presented on this paper is the ability to be interchangeable and adaptable. This involves that it could be used in any machining center and with any workpiece geometry, even if they are complex geometries. Has to be taken into account that clamping devices are usually specific to each application and must be designed and manufactured each time. So this would lead to save in clamping devices and reduce cost.

In summary, the present study is the base to reach to a relationship between the damping provided by the Magnetorheological Fluid shocker and tension of the magnetic field, in order to extend its application to any part geometry, material or process.

Acknowledgements

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