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STABILITY DIAGRAMS PREDICTION IN TURNING PROCESS

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ABSTRACT
In machining processes, the use of models allows to determine the best cutting conditions in order to obtain a good surface finish, without chatter. The determination of these cutting conditions is carried out by so-called stability diagrams. This paper develops stability curves for defining stable and unstable regions for different cutting conditions. These curves are obtained using a model for the simulation of the surface topography developed by the authors in a previous work. The theoretical model predicts the surface roughness of slender parts machined on a lathe. The stability diagrams are obtained through a new approach that enables to define stability in terms of Rt, the maximum peak-to-peak valley height. These diagrams allow identifying the conditions under which the process is stable, i.e., the feed per revolution, depth of cut, and cutting speed.
Keywords: Surface roughness, chatter vibration, stability diagrams

1. INTRODUCTION
Chatter is a phenomenon that adversely affects the machining operations involving material removal. This phenomenon is very important in the manufacture of metal and aircraft parts, where the trend is to reduce weight, producing lighter parts, thin-walled, which leads to a vibration problem, compromising accuracy and surface finish. Although machining dynamics and chatter in machine tools have been widely studied, problems remained in the manufacturing industry. In the fifties, Tobias Tlusty and Merrit studied the vibrations of tools in the case of operations of orthogonal cutting processes, and developed the theory of the linearized stability lobes [1]. In the mid nineties, Altintas [2] presented an analytical form of the theory of stability lobes for milling, using a function of transference. Unlike the work developed by Altintas, the present work deals with the problem of stability starting from a differential equation in the temporal domain, considering all the system non-linearities.
This paper is organized as follows: A development of a model for the generation of the surface roughness is presented, followed by the development of stability diagrams in function of the *Rt* parameter (maximum peak-to-valley distance); then the application of these diagrams to the case of a steel piece is presented, to finish with the conclusions.

2. MODEL FOR GENERATING SURFACE ROUGHNESS
In [3], the authors presented the development of a theoretical one-degree of freedom model of the vibrations generated in an orthogonal cutting process, in cylindrical pieces manufactured on a lathe.

The model, based on the theory of plasticity, is Van der Pol equation type, and incorporates the following as physical causes of the chatter generation: the dynamic modification of the rake angle, the tendency of the cutting force to vary with cutting speed and chip thickness variation. The force function of the system is based on the machining parameters and material properties. Starting from the model developed in [3], a computational algorithm was developed which enables simulation of the surface topography of a workpiece machined on a lathe [4]. The profile is simulated by initially considering the effect of the tool geometry, which derives from the repetition of the cutting tool tip moving along the workpiece at a desired feed rate during the turning process. The profile is affected by the displacements $x_i(t)$, which are generated by vibration of the piece and calculated using the model developed in [4], see figure 1. From the profiled obtained, the values of the average roughness, *Ra*, and the maximum peak-to-valley distance, *Rt*, are calculated. The resulting model was experimentally evaluated by comparing theoretical values obtained for the surfaces of thin cylinders with real values obtained for the surfaces of machined thin cylinders under the same cutting conditions, which include chatter [4].

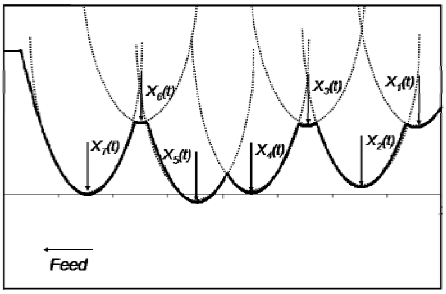


Figure 1. Generation of the surface topography

3. DEVELOPMENT OF STABILITY DIAGRAMS IN FUNCTION OF *Rt*

After verifying that the model for the generation of the surface topography works correctly, it is used for the generation of some diagrams which allow the identification of stability zones in function of the surface roughness parameter *Rt*, defining as a limit the percentage in which the peak-to-valley distance without chatter (Rt_g) is increased. Rt_g is the maximum peak-to-valley distance that results from considering the geometric intersection between the tools and the material to machine, without chatter. The Rt_g for a tool with a radio at the tip is defined as: (being r_h the tooltip radius):

$$Rt_g = \frac{f^2}{8r_h} \qquad (1)$$

The Rt_g magnitude is the roughness which would exist when there is no chatter, and starting from this measure the appearance of chatter is defined as a percentage of the increase of Rt with respect to the corresponding Rt_g.

3.1. Diagrams of stability for a steel workpiece case

In figure 2, the graphics of stability obtained are observed, defining as a limit the fact that the increase of *Rt* with respect to Rt_g is smaller than a 5%, 10% or 20%. The intervals of the study used are $100\ \text{m/min} \le v_c \le 150\ \text{m/min}$; $0{,}05\ \text{mm/rev} \le f \le 0{,}15\ \text{mm/rev}$; $0{,}1\ \text{mm} \le h_0 \le 0{,}6\ \text{mm}$. Some values for depth of cut and feed per revolution for different cutting speed values can be selected in these graphs. For example, for figure 2 a), when a point is selected in the diagram, and this is located under the stability line, this means that, for the corresponding cutting conditions, we can obtain a surface roughness smaller than $1{,}05Rt_g$.

We can observe in figure 2 that the curves for a *Rt* limit of 5%, 10% and 20% increment present a similar behavior. The widest stability zone, for a determined cutting speed, is found for the smaller feed, and it decreases as this increases. As the cutting speed increases, the stability region increases too. The main differences between the graphs is in the appearance of zones that are stable for an *Rt* with an increase of 10% and 20%, but which are not for an *Rt* with an increase of 5%, due to the fact that this value is much more restrictive. The point shown in Fig. 2, with coordinates a = 0,135 mm/rev and h_0 = 0,12 mm is within the region of stability for a limit increase of 10% and 20%, but not for a limit increment of 5%. The figures show that the system is more stable for the values of a and h_0 closer to f = 0,05 mm/rev and h_0 = 0,1 mm.

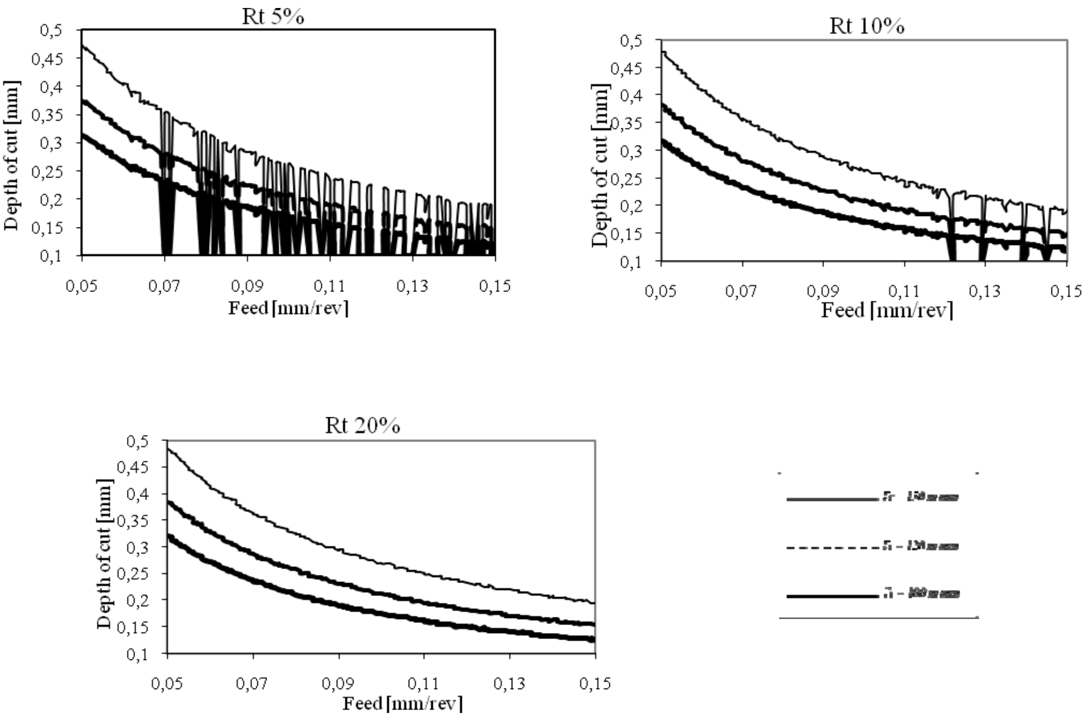


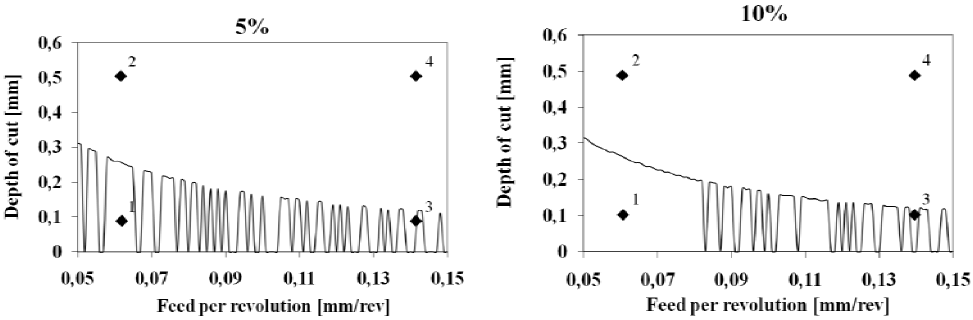
Figure 2. Stability diagrams feed-depth of cut. Workpiece length: 20 mm, Diameter: 9,5mm a) $Rt < 1{,}05Rt_g$, b) $Rt < 1{,}10Rt_g$, c) $Rt < 1{,}20Rt_g$.

3.2. Experimental verification of the stability diagrams

With the purpose of verifying the stability diagrams, four machining processes are carried out, under different cutting conditions. For this purpose, the four experimental points which correspond to stable and unstable zones are drawn on a feed-depth of cut diagram, and then four-piece machining processes are carried out with the selected conditions, to determine what occurs experimentally in each of these cases. The *Rt* values are measured on the four pieces. The selected points are shown in Fig. 3, and are numbered from 1 to 4.

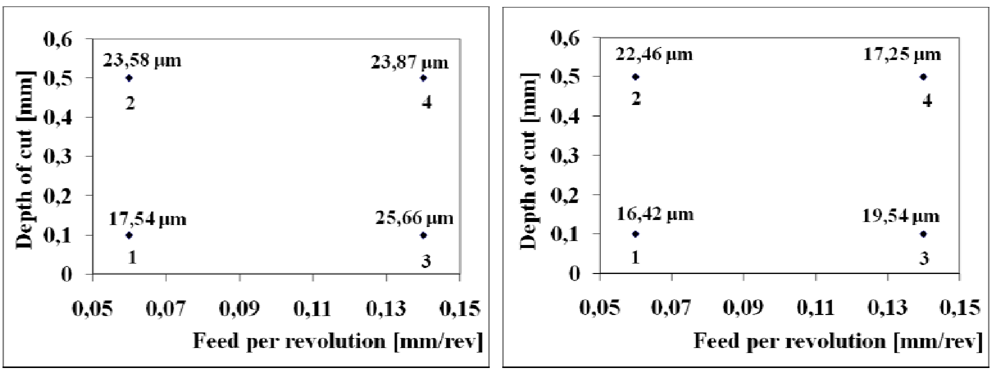
Once the machining processes are carried out with the selected pieces and the corresponding conditions, the values shown in Fig 4 are obtained. For point 1, an *Rt* value of 17,54 µm is obtained. According to the obtained roughness profile, the amplitude values are between -7 µm and 10 µm, and little presence of chatter is noticed on this piece. Point 2, which is, according to the diagrams, in an instability zone, presents an Rt = 25,66 µm, which has a greater value than the previous ones, and the surface roughness gets worse with respect to point 1. Finally, point 4, which is in an instability zone, has an experimental value of Rt = 23,87 µm.

In order to compare the roughness values obtained experimentally, the values of *Rt* on the corresponding points f *vs.* h_0 are presented in figure 4 b). It should be noticed that the effect of Rt_g due to the shape of the tool is found within these values, and that Rt_g depends on the feed value. Due to the influence of the feed, just the roughness obtained for points 1 and 2 can be compared since they have the same feed, and in the same way, the roughness obtained for points 3 and 4, Fig. 4. If we compare the *Rt* of point 1 with that of point 2, we can observe an increase of *Rt*, an expected behavior due to the fact that point 2 is out from the stability zone. When comparing the roughness of point 3 with that of point 4, this one shows that its value has decreased. To make the *Rt* values independent from the feed, the component of geometric roughness Rt_g is subtracted, in order to make them comparable. The resulting values are shown in figure 4 (b). When comparing these values, we notice that, between points 1 and 3, the roughness resulting only from the effect of chatter has worsened, but the opposite occurs between 2 and 4: the roughness improves with the increase in the feed per revolution.



(a) *(b)*

Figure 3. Diagram f vs. h_0, Material: brass, Workpiece diameter: 8 mm; Length: 32 mm α = 6°; Cutting speed: 60 m/min; E= 120 GPa; true fracture strength of the work material= 200 MPa.



(a) *(b)*

Figure 4. (a) Values of Rt obtained experimentally for the four brass pieces (b) Values of Rt increase obtained after subtracting the corresponding value of Rtg

4. CONCLUSIONS

According to the results obtained, it may be concluded that the diagrams developed allow to predict stability and instability zones, based on roughness values: being lower the values of *Rt* in the zones of the diagram considered to be stable, and increasing *Rt* in the unstable zones.

5. REFERENCES

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