**Contemporary Engineering Sciences, Vol. 11, 2018, no. 57, 2831 - 2838**
**HIKARI Ltd, www.m-hikari.com**
**https://doi.org/10.12988/ces.2018.86285**

# Regenerative Reassembly Phenomenon in the Turning Process Machining the A1020 Steel

**Milton Coba Salcedo[1], Carlos Acevedo Peñaloza[2]**
**and Guillermo Valencia Ochoa[3]**

[1] Materials Engineering and Manufacturing Technology Research Group –
IMTEF, Universidad del Atlántico, Carrera 30 Número 8 – 49
Puerto Colombia – Colombia

[2] Mechanical Engineering Department, Faculty of Engineering
Universidad Francisco de Paula Santander, Cucuta– Colombia

[3] Efficient Energy Management Research Group, Universidad del Atlántico
Carrera 30 Número 8 - 49, Puerto Colombia – Colombia

## Abstract

The chattering in the machine tools is a phenomenon that causes instability in the machining process, surface finish with high roughness, also produces excessive and accelerated wear on the tool in the metal cutting processes, this phenomenon consists of self-excited vibrations which are produced and maintained due to the cutting forces, the purpose of this article is to analyze regenerative chatter and predict the optimal points of operation in the turning process for 1020 carbon steel by developing analytical methods for generating stability lobe diagrams. To achieve this objective, the methods proposed by Altinas and Budak to stabilize the self-excited vibrations in the turning process applied to the orthogonal cut were studied in detail. These methods are widely accepted within the community of researchers and specialists in the field, thanks to the excellent results obtained in practice. Once the models studied were compressed, a computational algorithm was developed with the help of the MATLAB® software that was able to generate stability lobe diagrams for the turning operation in order to find the optimal points of operation so that there was no chatter, thus improving the material removal rate and increasing productivity.

**Keywords**: Chatter, Lobe Diagram, Turning

## 1. Introduction

Chattering is a self-excited vibration that can occur during machining operations and becomes a common limitation to part productivity and quality. For this reason, it has been a topic of industrial and academic interest in the manufacturing sector for many years. Since the late 1950s, a great deal of research has been done to solve the problem of chatter. Researchers have studied how to detect, identify, avoid, prevent, reduce, control or suppress chatter [1].

This phenomenon occurs when the dynamics of the closed-loop cutting system becomes unstable, causing a chip thickness with an increasing amplitude; therefore, high cutting forces and vibrations. Unless avoided, chattering leaves an unacceptable vibration on the finishing surface and may damage the cutting tool and machine tool head [2].

Regenerative chatter is the most damaging to any process, as it is excessive vibration between the tool and the workpiece, resulting in poor surface finish, high pitch noise and accelerated tool wear, which in turn reduces the life of the machine tool, reliability and safety of the machining operation. There are several techniques proposed by several researchers to predict and detect chatter, the objective of which is to prevent the appearance of chatter in the cutting process in order to obtain a better surface finish of the product, higher productivity and longer tool life [3]. Tobias and Fishwick [4], and Tlusty [5] were the first to present a theory of regenerative vibration stability for orthogonal cuts, describing a simple relationship between shear force, dynamic stiffness of the structure, spindle rotational speed and depth of cut.

Turning processes often require high dimensional accuracy despite tool wear, variations in cutting conditions and variations in the dynamic properties of the machine tool system [6]. In a turning process, three different types of mechanical vibrations occur due to the lack of dynamic rigidity of the machine tool system comprising the tool, the tool holder, the part and the machine tool itself, as explained by Tobias [7]. They are free, forced and self-excited vibrations. Free vibrations are induced by shocks and forced vibrations are due to unbalance effects in machine tool assemblies such as gears, bearings, spindles. Free and forced vibrations can be easily identified and eliminated. But self-excited chattering vibrations are not yet fully understood due to their complex nature. They are the most damaging to any machining process, including turning [3].

## 2. Methodology

### 2.1 General purpose of the software

An innovative computer tool designed and developed in MATLAB® software was used to perform analysis and solve real problems related to the turning process, more specifically to solve the problem of regenerative chatter. For the generation of stability lobes for turning operations, it is required to know a series of parameters that are related to some physical properties inherent to the material of the part to be machined and to the nature of the cutting tool, these are the input parameters of the program and are those that govern the behavior of the system. What he delivered as output of the program were the rotation speeds of the lathe spindle, and the critical chip thicknesses for these speeds, and from this the stability lobe diagrams were constructed [8].

### 2.2 Fundamental Equations

To facilitate the study, the structure was assumed to be perfectly rigid, while the structure of the cutting tool was determined with vibration capacity in longitudinal direction, i.e. vibration on the "Y" axis, and because it was not easy to determine a simple mathematical modeling for the dynamics of the oblique cut, the theory of orthogonal cutting mechanics was used to estimate the shear force, as described in the equation (1)

$$F_c = K_c a h, \tag{1}$$

where $K_c$ is the specific cutting force in $[\mathrm{N/m^2}]$, $a$ is the thickness or depth of cut measured in $[\mathrm{mm^2}]$ and $h$ is the thickness of the chip in [m]. Figure 1 shows the diagram of a turning operation.

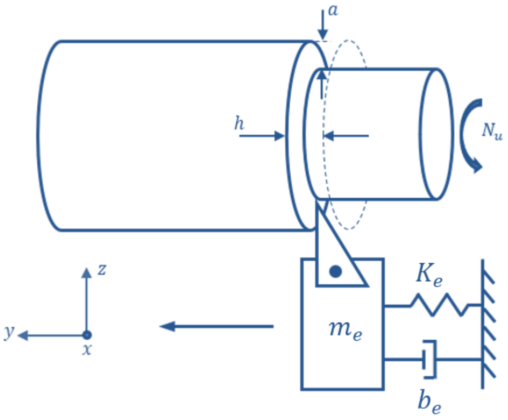

Figure 1. Turning operation diagram.

The turning operation can be modeled as a second order system of one degree of freedom, because it has rigidity, damping, mass and the function of the input that excites the system is the cutting force, so it is said that the structure presents self-excited vibrations, this plant can describe as follows

$$m_e \ddot{y}(t) + b_e \dot{y}(t) + k_e y(t) = F_c(t). \tag{2}$$

The depth of cut is taken as a constant value, however, the feed rate (h) varies over time, and therefore the shear force also varies over time, all due to structural vibrations, so it can be assumed that the shear force is not dependent on the cutting speed, so the equation (2) can be rewritten as follows

$$m_e\ddot{y}(t) + b_e\dot{y}(t) + k_e y(t) = K_c a \cdot h(t). \tag{3}$$

Then the term $h(t)$ is known as the general dynamic chip thickness as shown in

Figure 2, this is described as

$$h(t) = h_o - \Delta h(t), \tag{4}$$

where $h_o$ is the nominal thickness of the tool or static feed rate and $\Delta h(t)$ is known as the dynamic thickness, which is the product of tool vibration.

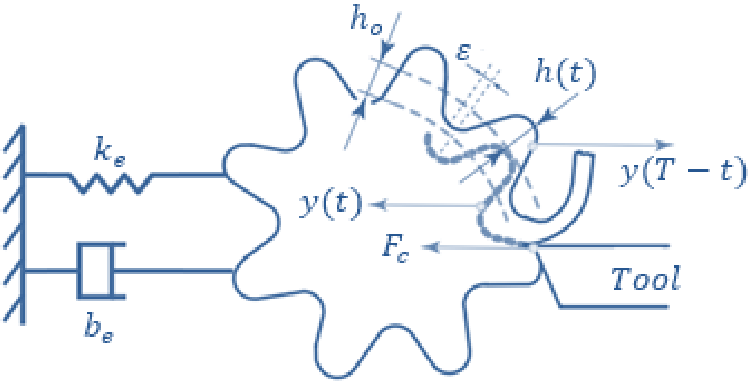

Figure 2. Regenerative chatter in orthogonal cut.

In turn, the dynamic thickness is calculated as

$$\Delta h(t) = y(t - T) - y(t), \tag{5}$$

where $T$ is the period of spindle rotation, then replacing the equation (4) in the equation (5) gives the following

$$h(t) = h_0 + y(t - T) - y(t). \tag{6}$$

*Since $h_o$ is the non-vibration feed rate of $Y_o$ and since the analysis performed was taken from the tool, i.e. $Y$, with respect to this reference axis, an $h_o$ value of 0 is obtained, as shown in*

Figure 3

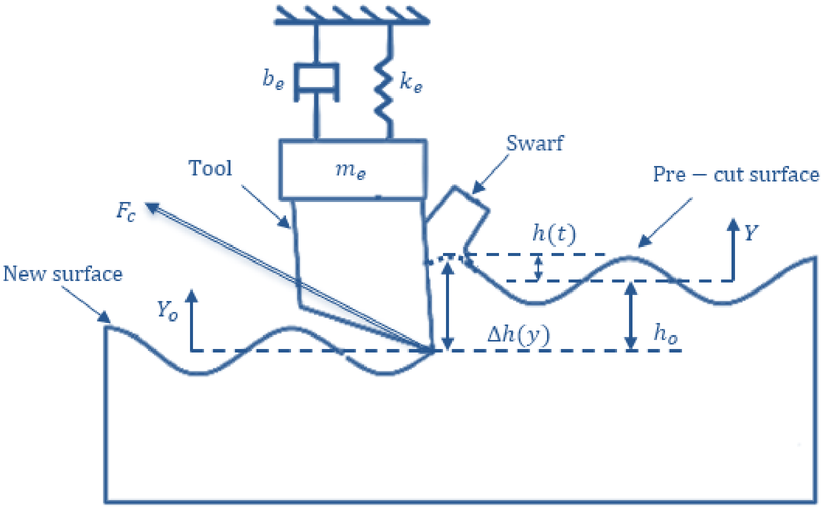

Figure 3. Vibration system with one degree of freedom and dynamic chip thickness.

By retaking the equation (3) and substituting $h(t)$ and considering the above, the result obtained is

$$m_e\ddot{y}(t) + b_e\dot{y}(t) + k_e y(t) = K_c a * [y(t-T) - y(t)\,]. \tag{7}$$

## 3. Results and discussion

The following are the results of three case studies in which some important parameters in the process are varied.

### 3.1 Case Study: Varying the damping constant

Figure 4 shows the penetration of the cutting tool in relation to the spindle rotation speed for machining a 1020 carbon steel, taking into account that machine tool parameters such as the natural frequency and the stiffness constant took fixed values of 500 $hz$ and 10 $kN/mm$ respectively, and the damping constant adopted values from $z = 0.2$ to $z = 0.4$, It is important to highlight the proportional behaviour of the chip thickness with respect to the damping constant, for example, in processes where the machine tool has a $z = 0.4$ the chip thickness can reach higher proportions without any instability compared to a machine tool whose $z = 0.2$ with a similar spindle speed.

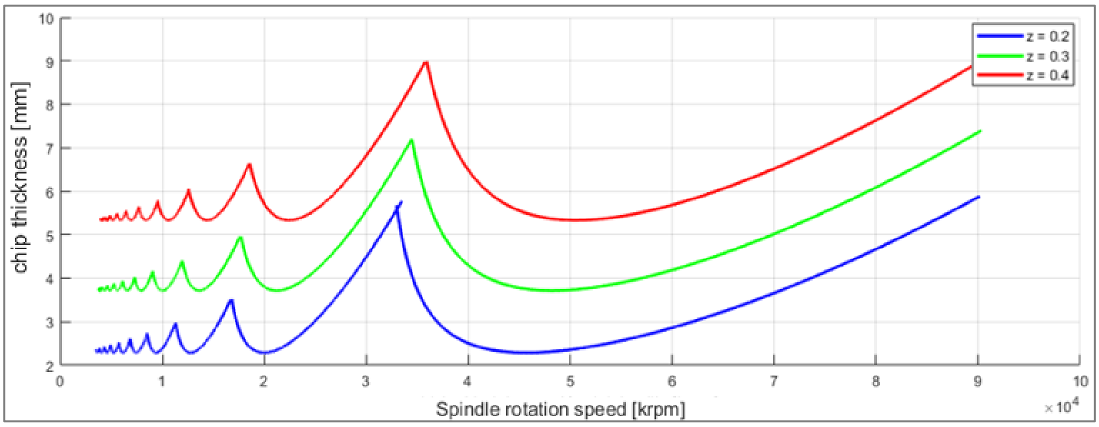

Figure 4. Stability lobes for 1020 steel varying damping.

### 3.2 Case Study: Varying the natural frequency of the system.

The natural frequency of the system is one of the most relevant factors in the analysis of the phenomenon of rewinding in machine tools. One way to observe how much this parameter influences the machining process is to maintain the damping constant and the stiffness constant without variation and to modify the natural frequency of the system. For this case a value of $z = 0.3$ and $k_e = 10$ was set and the natural frequency of the system was assigned values of $400\ hz, 500\ hz\ y\ 600\ hz$, the results obtained are presented in Figure 5. It shows that as $w_n$ increases it is necessary to increase the spindle rotation speed to reach a high chip thickness in certain operating ranges.

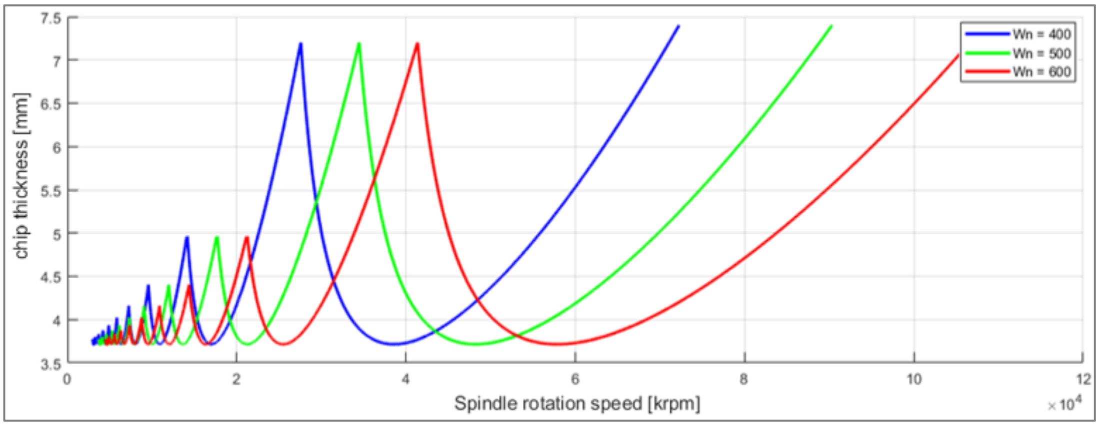

Figure 5. Stability lobes for 1020 steel varying natural frequency.

### 3.3 Case Study: Varying the stiffness constant.

In this case, the aim is to analyze the behavior of the turning process when the stiffness constant varies from $k_e = 8\ kN/mm$ to $k_e = 12\ kN/m$, considering that the other factors are not modified, $w_n = 500\ hz$ and $z = 0.3$. Figure 6 shows a tendency to increase chip thickness as the stiffness constant increases, reaching a high chip thickness between 3000 and 4000 rpm.

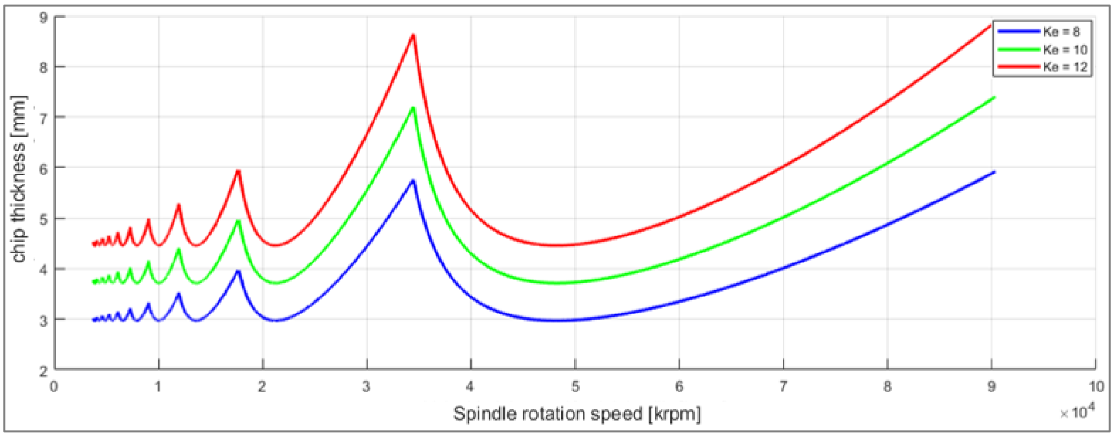

Figure 6. Stability lobes for 1020 steel varying stiffness.

## 4. Conclusions

The stability lobe diagrams provide significant information at the time of working the high-speed machining processes, allow to obtain under dynamically stable cutting conditions the highest possible efficiency of the machine tool, achieving high roughing rates of material, good surface finishes of the machined part and avoiding the accelerated wear of the cutting tool, as well as a significant increase in production times and therefore in their costs.

In the case studies discussed in this paper, it was possible to identify a considerably increasing behavior of the stability limit as the damping constant increased, a similar behavior was obtained when the stiffness value of the machine tool showed an increasing trend. On the other hand, when the natural frequency of the system increased the lobes shifted to the right, however, the magnitude of the lobes' stability zones remained the same.

## References

[1] G. Quintana and J. Ciurana, Chatter in machining processes: A review, *Int. J. Mach. Tools Manuf.*, **51** (2011), no. 5, 363–376. https://doi.org/10.1016/j.ijmachtools.2011.01.001

[2] M. Eynian and Y. Altintas, Chatter Stability of General Turning Operations With Process Damping, *J. Manuf. Sci. Eng.*, **131** (2009), no. 4, 41005–41010. https://doi.org/10.1115/1.3159047

[3] M. Siddhpura and R. Paurobally, A review of chatter vibration research in turning, *Int. J. Mach. Tools Manuf.*, **61** (2012), 27–47. https://doi.org/10.1016/j.ijmachtools.2012.05.007

[4] S. A. Tobias and W. Fishwick, A theory of Regenerative chatter, *The Engineer*, **205** (1958), no. 7, 199-203.

[5] J. Tlusty and F. Koenigsberger, Preface, F. Koenigsberger and J. B. T.-M. T. S. Tlusty, Eds. Pergamon, 1970

[6] H. Moradi, M. R. Movahhedy and G. R. Vossoughi, Robust control strategy for suppression of regenerative chatter in turning, *J. Manuf. Process.*, **11** (2009), no. 2, 55–65. https://doi.org/10.1016/j.jmapro.2009.06.002

[7] S. A. Tobias, Machine tool vibration research, *Int. J. Mach. Tool Des. Res.*, **1** (1961), no. 1, 1–14. https://doi.org/10.1016/0020-7357(61)90040-3

[8] J. Arenas, A. Andión, and M. Coba, *Diseño De Una Aplicación Informática Para El Estudio Y Predicción Del Fenómeno De Retemblado Regenerativo En Los Procesos De Torneado Y Fresado*, Universidad del Atlántico, 2016.

**Received: July 1, 2018; Published: August 1, 2018**