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STABILITY CONCEPT OF THE MILLING PROCESS

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Abstract: *In the present paper there are presented some theoretical aspects about the concept of stability in the milling process. It is presented a short overview of some topics presented in different articles. There mentioned some definition about the stability in machining process [29 and a short simulation based on the program presented in [11].*
Keywords: *milling process, vibrations, stability*

1. INTRODUCTION

The instability of the cutting process is an undesirable phenomenon, as it negatively affects the machining process, pieces, tools, devices and machine tool. In case of instability, vibrations with very high amplitudes are associated with the relative motion between the tool and the piece.
As is known the milling operation can be defined as a cutting process which uses a rotating cutter with one or more teeth. As a result of the manufacturing process there are developed chatter vibrations between the cutter and work piece. The prediction of the level of these vibrations is very important for an optimal cutting regime more precise in the proper depth of cut and spindle rotation selection. The main objective in the cutting regime definition is to be obtained a maximum chip that is removed without undesirable vibrations development.
Generally, as is mentioned in many papers as [1, 2, 3, 4, 5, 6, 7,8], each cutting edge determines cuts that are less than half of the cutter revolution. As a result, there are produced chips with variable thickness and on the workpiece, there are generate impacts. In turn, these impacts have to create vibrations.

2. STABILITY AND INSTABILITY IN CASE OF DYNAMIC MANUFACTURING PROCESS

The problem of the systems instability is one of the most undesirable phenomena having a direct negatively action on the manufactured pieces, tools, devices and machine tools. The study of the stability is based on some terms and definitions that are focused on Liapunov’s theory. În [9] there are defined the definitions of Liapunov’s theory applied for the manufacturing process:
Definition 1: The stability of the dynamic processing system means the property of keeping the disturbed movements in the vicinity of the undisturbed movements.
Definition 2: If the disruptive movement tends to move away from the basic motion, the dynamic processing system is said to be unstable.
Definition 3: The banal (trivial) response of the dynamic processing system is locally stable if for any $\varepsilon > 0$ there is a quantity $\delta_x(t_0, \varepsilon_x) > 0$ when $|x(t_0)| \le \delta_x(t_0, \varepsilon_x)$ to be satisfied the inequality $|x(t, t_0, x(t_0))| \le \varepsilon_x$ for $t \ge t_0$.
Definition 4: The banal (trivial) response of the dynamic processing system is an local uniform stable if $\delta_x = \delta_x(\varepsilon_x)$, i.e. in Definition 3 there is the addiction of δ_x on the initial moment t_0.
Definition 5: the banal (trivial) response of the dynamic processing system is local asymptotic stable if it is stable within the meaning of definition 3 and in addition:

$$\lim_{t \to \infty} x(t; t_0, x(t_0)) \to 0 \text{ for } |x(t_0)| \le \delta_x(t_0). \quad (1)$$

Definition 6: The banal response of the dynamic processing system is uniformly asymptotic local stable if it is local in the uniformly stable local sense within the meaning of definition 4 and if δ_x, which limits the initial condition $x(t_0)$, is independent of t_0, and the first relation from (1) is satisfied in a uniform way for $x(t_0)$ and t_0.
Definition 7: The banal response of the dynamic processing system is global asymptotic stable if any disturbed movement tends to cancel by the passage of time

The definitions 3-7 refer only to the only to the cases when the dynamic processing system have the input equal with zero. In the case of long-term disturbances, the concept of total stability [10].

Definition 8: The banal response of the dynamic processing system is in relation to long-term (permanent) or totally stable disturbances, if for any $\varepsilon_x > 0$ there are two values δ_{1x} and δ_{2x} so $\left| x(t;t_0, x(t_0)) \right| \le \varepsilon_x$ when $\left| x(t_0) \right| < \delta_{1x}(\varepsilon_x)$ and the disturbances do not exceed the quantity δ_{2x}.

The definition 8 expresses the fact that the correction of the total stability of the dynamic processing system implies the specification of the analytical expressions of long-term (permanent) disturbances.

Definition9: The dynamic processing system that has non-linearities of a given class, it is absolutely stable if its banal response is asymptotic stable for any non-linearity in a given class.

Definition 10: The range of parameters of the dynamic processing system with zero input to which only a transient response appears that is depreciated, whatever the initial conditions of the movement, and the concrete parameters of the non-linearities do not intervene in stability conditions, is called the absolute stability domain it is called the area of absolute stability.

Definition 11: The domain of the parameters of the dynamic processing system to which, for $F_0(t) = 0$, appears a transient response that increases whatever the initial conditions of the movement and whatever the non-linearities of the given class, is called the area of absolute instability.

Definition 12: The domain of parameters of the dynamic processing system with null input to which appears a transient response that is depreciated, whatever the initial conditions of the movement, and the conditions of stability depend on the concrete parameters of the non-linearities, is called complementary area of stability.

Definition 13: The domain of parameters of the dynamic processing system at which the amplitude of the self-vibrations does not exceed an imposed value, and their pulsation is maintained within a given interval, is called the practical field of stability.

Depending on the physical-mechanical properties of the working material, the geometry of the tool cutting, the parameters of the cutting regime, etc. when generating surfaces, on machine tools, there are generate continuous or discontinuous chips.

In the case of continuous chips the own instability of the cutting process occurs when the conditions of formation and periodic detachment of the deposit cutting are fulfilled, and in the case of discontinuous chips the instability of the cutting process can be caused by the periodic variation of the cutting force (following the periodic detachment of the cuttings).

3. MILLING DYNAMIC PROCESS MODELING

The milling process is a very complex one and the model is done considering the following three assumptions [9]:

a) the dynamic variation ΔF_i of the cutting force of the i - tooth, which is in the process of cutting (with $i = 1, 2, 3, ..., z$ and z represents the total number of teeth), depends only on the modulation Δa_i of the cutting thickness corresponding to that tooth;
b) the direction in which Δa_i is measured is perpendicular to the direction of the cutting speed;
c) the angle θ_0 between the directions where are measured ΔF_i and Δa_i is the same for all z_0 teeth that are simultaneous in cutting process.

Based on these assumptions one can say that if the advance speed is smaller than the main cutting speed, than the direction of Δa_i measurement is radial reported to the milling tool.

Considering an orthogonal milling process with a cylindrical milltool (Figure 1) with straight teeth it can be written the equation following equation:

$$\Delta F_i = K_{a,i} \Delta a_i = -K_{a,i} \left(1 - \mu e^{-sT}\right) \left[\cos\theta_i, \sin\theta_i\right] \mathbf{x}, \tag{2}$$

where:

$$\mathbf{x} = \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix}, \tag{3}$$

and $\mu = 1$, θ_i is the angle that defines the position of the i -tooth according with the normal to the processed surface, $K_{a,i}$ is the static stiffness of a tooth, and T is given by the relation:

$$T \cong \frac{1}{nz} - \frac{a_0}{v_0} ctg\phi , \tag{4}$$

with n - angular velocity, a_0 - is the prescribed cutting depth, v_0 - represents tool advance speed, and ϕ is the shear angle of the chip.

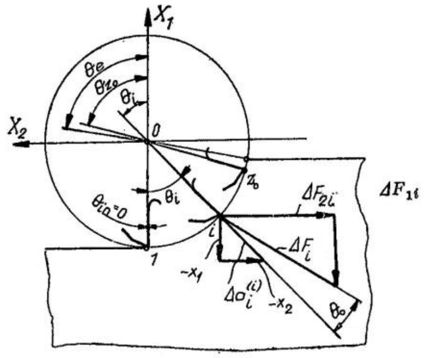
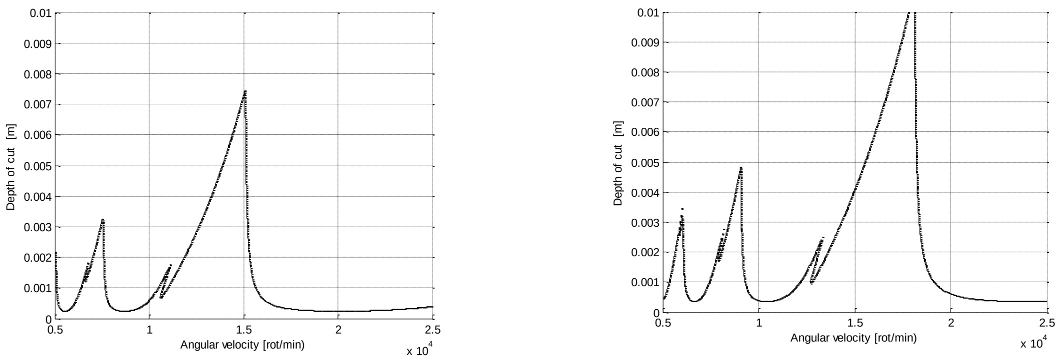


Figure 1: The scheme of dynamic milling force calculation [9]

During a complete rotation of the milltool, the i -tooth has contact with the manufactured piece in space defined by two values of the θ_i : entrance (input) angle θ_{in} and exit angle θ_e .
As a result, the stiffness matrix $\mathbf{K}_{a,i}$ from (2) has to be considered as a function of angle θ_i and can be written as [9]:

$$\mathbf{H}_{a,i} = \left(1 - \mu e^{-sT}\right) \begin{bmatrix} \sum_{i=1}^{z} K_{a,i}(\theta)\cos(\theta_i + \theta_0)\cos\theta_i & \sum_{i=1}^{z} K_{a,i}(\theta)\cos(\theta_i + \theta_0)\sin\theta_i \\ \sum_{i=1}^{z} K_{a,i}(\theta)\sin(\theta_i + \theta_0)\cos\theta_i & \sum_{i=1}^{z} K_{a,i}(\theta)\sin(\theta_i + \theta_0)\sin\theta_i \end{bmatrix}. \tag{5}$$

As a conclusion it can be seen that the level of the dynamic cutting forces depend on the number of teeth that are involved, in the same time, in the cutting process.
In [11] it is presented a MATLAB program of establishing the stability of the milling process. Based on it, in the present paper, there were done some simulations for different angular velocities (Figure 2). The program uses the theory of a full-discretization method based on the direct integration scheme for prediction of milling stability. In simulation was considered a mill tool with 4 teeth and two angular velocities: $n = 1000\, rot/\min$ (Figure 2,a) and $n = 1200\, rot/\min$ (Figure 2,b).



a) b)

Figure 2 Stability diagrams for two angular velocities: a) $n = 1000\, rot/\min$; b) $n = 1200\, rot/\min$

As it can be seen the stability of the process change with the increasing of the angular velocity.

4. CONCLUSIONS

The present work was focused on a theoretical presentation of the concept of stability with application in milling process. It was discussed the model of the stability developed in [9] and was used a program described in [11] for obtaining graphical representation of the stability in case of milling.

In the future works considering the state of the art in the field there will be developed a model of the milling process and a program/programs to describe the stability of the milling process.

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