A NEW THEORY CONCERNING CUTTING STABILITY, BASED ON PROCESS CHAOTIC DYNAMICS AND ITS APPLICATION TO STABILITY INTELLIGENT CONTROL

- State of the art -

When referring to manufacturing field, investments larger part consists in buying the great number of required technological systems; to get back these money sums is, generally speaking, difficult, because technological systems resources of productivity aren't entirely used. In majority of the situations the main obstacle is processes instability. The aim of this project is to enounce and to validate a new theory concerning cutting processes instability and also to conceive an intelligent system used to do on-line stability control.

a) ***Chaos Theory***, under its largest acceptation [13], [14], is referring to the behaviour of some systems with nonlinear dynamics, highly sensitive to initial conditions. Although at a first look this behaviour may seem stochastic, in fact it is deterministic (their future dynamics is entirely defined through initial conditions, without random elements being involved). The sensitivity to initial conditions means that a small, arbitrary perturbation applied to system current trajectory, may lead to total changed future evolution.

Mathematicians researches furnished tools that can be used to study the systems with chaotic dynamics: attractors fractal dimension, Lyapunov exponent, Poincare Map, bifurcation map a.o.

b) ***Current cutting stability theory*** [1], [4], [12], starts from the regeneration phenomenon, during current cutting cycle, of perturbations appeared during previous cycle and its base is the physical model shown in Fig.1. Elastic deformation from previous cycle, y(t-T), induces cutting force F variation, which further determines y(t) deformation of mechanical construction during current cycle. As consequence, chip real thickness is given by

$$BD = a(t) = a_0(t) - y(t) + y(t - T),$$

where a_0 means chip programmed thickness.

The block-scheme describing perturbations regeneration phenomenon is shown in Fig.2 and enables to find system transfer function,

$$Y = \frac{a(s)}{a_0(s)} = \frac{1}{1 + Y_1(s)Y_2(s)\left(1 - e^{-sT}\right)}.$$

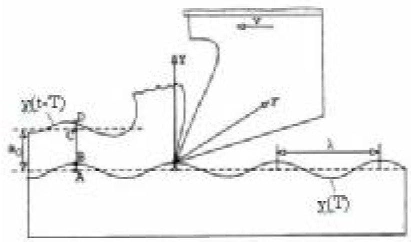

Fig.1 – *Cutting Process Physical Model*

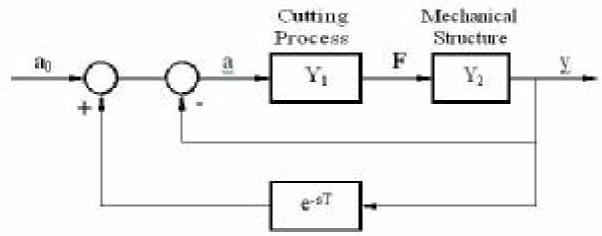

Fig.2 – *Manufacturing Systems Block-Scheme, Modelling the Connection between Process and Machine-Tool: a_0/a – programmed / real chip thickness; y – system elastic deformation; T – cutting cycle duration; F – cutting force.*

Stability is approached based on stability general criterion, according to who if one of characteristic equation has a positive real part, then the system is unstable. Referring to cutting process, characteristic equation is

$$1+Y_1(s)Y_2(s)\left(1-e^{-sT}\right)=0 .$$

To find the limit separating stable from unstable domain, we must impose to characteristic equation to have pure imaginary solutions, resulting the following equation of stability limit:

$$1+Y_1(j\omega)Y_2(j\omega)\left(1-e^{-j\omega T}\right)=0 .$$

In current cutting stability theory, transfer function $Y_1(j\omega)$ is considered to be a real constant, by entirely neglecting cutting process dynamics. On the other hand, system mechanical structure is considered linear, which allows to look $Y_2(j\omega)$ as frequency characteristic of the mechanical structure (that can be experimentally found). Under these conditions, stability limit results from relation

$$A(j\omega)=B(j\omega), \text{ where } A(j\omega)=Y_1(j\omega)Y_2(j\omega) \text{ and } B(j\omega)=\frac{1}{e^{-j\omega T}-1} .$$

To solve this equation, a graphic-analytical method is used, Fig.3, where, by increasing $A(j\omega)$ constant, the expanding of frequency characteristic $Y_2(j\omega)$ is obtained, until touching $B(j\omega)$ line, when instability phenomenon appears.

c) ***Recent evolutions in cutting stability theory*** are concretizing through a significant number of papers, which can be grouped, depending on the aspects approached, in more research directions. The first direction is to theoretical investigate new methods and models to study manufacturing processes dynamics, [1], [2], [3], [7], [9], [11]. A second direction is based on analysing and interpreting the phenomenology regarding the instability of cutting processes, taking place on more types of machine-tools, [4], [5], [6], [8]. The third research direction is oriented towards finding concrete solutions to eliminate cutting processes instability [10], [12]. It can be observed in most of the approaches the tendency of going away from cutting classic model and finding new approaches.

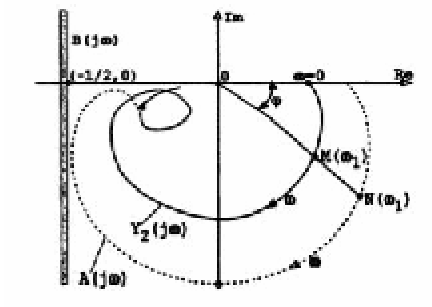

Fig.3 – *Graphic-Analytical Method to Find Stability Limit*

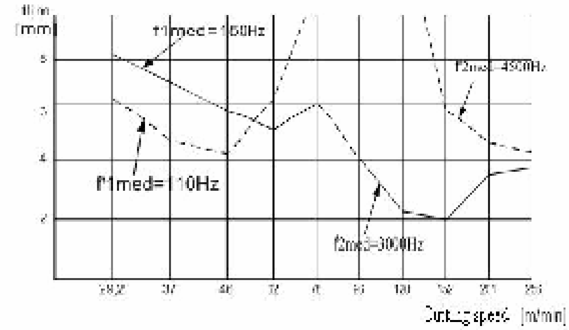

Fig.4 – *Dependence between Stability Limit and Cutting Speed*

d) *Limits of current stability theory:* even by considering recent scientific contributions to cutting process stability theory, a critic analysis reveals the following limits and unexplained things:

1. Cutting process dynamics is not considered, although in cutting instability phenomenon it plays an essential role. Thus, it cannot be explained the dependence between cut material - chip shape – process stability (e.g. comparative stability between steel and bronze).
2. There is no explanation for dependence between cutting speed and feed on one hand and stability limit, on the other hand, as this dependence can be experimentally observed (Fig.4) and nor to the relation between self-excited vibrations frequency and cutting speed, as we can also practically see in all cases.
3. Instability phenomena appearing during a single cutting cycle cannot be justified, in this case regeneration phenomenon which stays at the base of current approach being inexistent.
4. Current approach cannot explain why, as we can always see in practice, instability only appears when wave length of traces let by self-excited vibration on piece's surface has values between 0,5 and 12 mm and nor why at the middle of the interval the stability has a minimum level.
5. Current theory cannot enable to find functioning point position referred to stability limit. More precisely, we cannot appreciate the reserve of stability existing at a given moment.
6. To find stability limit, in the context of actual stability theory means to know system frequency characteristic. To obtain it supposes to follow a complex experimental plan. On the other hand, right in the moment when tool moves along worked piece generating line, frequency characteristic permanently changes. Thus, current theory doesn't offer the possibility of monitoring, in real time, technological system reserve of stability. This is the reason to intervene on the system only after it reached the unstable functioning domain. Briefly, any kind of stability prognosis is impossible, especially on-line, and that's why actual technological systems doesn't have a system to control stability.

The importance and the relevance of scientific content of this project are resulting, according to the things upper exposed, from the possibility to open the way for going over the enounced limits, through the new theory concerning cutting process stability, based on chaotic models. Grounded on the new theory, an intelligent system to control cutting stability will be realized, leading to a complete exploitation of technological system resources of productivity, by working with cutting regimes more intense, to the limit of stability domain. Thus, it will result both a maximisation of manufacturing processes efficiency and a superior quality of manufactured surfaces, by eliminating the risk of instability appearance.

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