THE MODELING AND SIMULATION OF GRINDING PROCESSES

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ABSTRACT
The vibrations that occur in the elastic structure of the grinding machine determine formation of waves on the finished surfaces. In order to optimize the technological process, a series of quantitative relations between the parameters of the grinding wheel and the surface quality. The presented model uses Snoes' round grinding model. From the block schematic under simplifying assumptions is obtained a Simulink model, by means of which the lobe generation on the workpiece surface is attenuated or eliminated. In this case the technological process is unstable. The model designed can perform simulation of the peripheral workpiece geometry. A series of non-linear effects can be modeled, such as: use of various longitudinal advances, interference between successive tool rotations, and so on.

1. INTRODUCTION

The kinematics of grinding processes represents a series of interconditioning connections that depend on the microstructure of the abrasive tool, on the movement measures and on the geometric parameters.

These are described by geometric and chip forming models, in which the energy is transformed. The forces generated during grinding by the geometry of the cutting edge determine the tool wear. These are described by force and wear models.

Because of the important relations established between the geometry of the grinding wheel, forces and wear, the grinding process is variable depending on time.

Many models ignore this aspect, considering the work processes as being stationary. One unlikely supposition is that the wheel state doesn't change. On the other hand, taking into account the time dependence determines complex research models, giving a large number of parameters, which determine substantial errors as compared to the static models.

Several authors designed corresponding models and simulated them using discrete time values.

Kassen used the geometry and its own chip thickness model and simulated the superposition of the grain traces using a computer. Due to the limited processing capacity of computers at that time, the grinding wheel had to be described under restrictive assumptions.

Based on vectorial measures, Steffens developed a mathematical concept for numerical description of kinematics. Its simulation describes simple grain coupling during grinding operations.

It is assumed an idealized kinematics, i.e. no material wrinkle occurs and each cinematic grain removes completely the available material. The specific material removing speed was kept constant, while the advance speed and processing depth varied conversely.

According to the results obtained, the number of cinematic grains and the chip thickness are maximum at 10 μm processing depth.

Other authors, such as Konig and Steffens [2], [3] presented a closed-loop simulation method. It is assumed that thermo-mechanical balance is established during processing.

Closed-loop simulation is based on iterative computations. The simulation program requires the following input measures: geometry of the abrasive wheel, physical system characteristics, machine tool tuning parameters and time dependent workpiece material such as flowing effort, thermal conductivity and thermal diffusion. The outputs are normal and tangential forces, the workpiece temperature and surface roughness.

The model uses discrete time values. Simulation with a previously sharpened tool shows that initially there are produced large grinding forces. As the grains are removed, the grinding forces decrease with the increase of the grinding time, reaching a minimum value. The subsequent increase in the force is due to the tool sag.

The simulation follows accurately the real process. As far as kinematics is concerned, the simulation of Konig and Steffens is based on measuring the microstructure of the abrasive wheel, and hence its applicability is limited.

2. MODEL DESCRIPTION

Mathematical modeling of surface grinding based on normal distribution of dimensions and positions of the abrasive grains allows predetermination of micro and macro-geometry of resulting surfaces and provides for establishing of surface formation kinematics during grinding.

The vibrations in the elastic structure of the machine determine waves on the grinded surfaces and a significant increase of the load applied to the abrasive grains, yielding an increased wear.

Some quantitative relations can be established between the grinding wheel parameters, process parameters and surface quality, which are meant to allow for grinding process optimization.

The optimization criteria may be: wheel lifetime, processing precision, the dynamic state level which accompanies the grinding process.

Some unknown aspects are given by the quantitative correlation of energy consumption, the modeling of the thermal processes in the work zone and the structural modifications of the workpiece.

There are other means for dynamic modeling of grinding, such as Simulink Matlab, which provides an intuitive and efficient modeling of grinding processes [4].

It is known the fact that many researchers based their models on closed-loop block schematics, which serve as basis for many subsequent research papers.

Inasaki [1] uses the characteristic equation of the grinding process to study the roots within the stability limits.

Srinivenson introduces the concept of regeneration spectrum, his method constituting an approximate but very efficient way to analyze the stability of a regeneration process.

Weck studies the autovibrations during processing, in his opinion these cause the lobes in the piece profile, while Steffens studies the interference between the grinding wheel and the workpiece.

Based on previous work, it is proposed a simulation in the time domain of the grinding vibration, taking also into account the effect of forced vibrations. The study based on this method offers a simple perspective for grinding process modeling.

The block schematics can be viewed and modified directly and the results are interpreted in accordance to the input parameters. The basis for establishing the model is Snoes round grinding model.

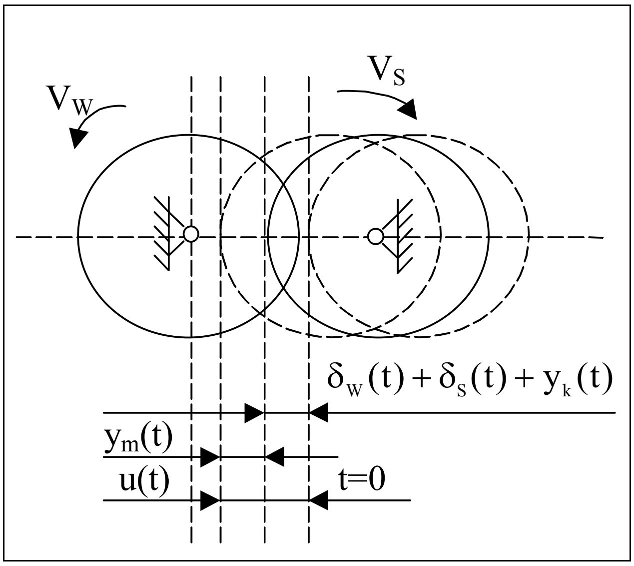

Fig. 1 – Round grinding process schematic

According to Figure 1, the equation of the grinding process is:

$$\delta_W(t)+\delta_S(t)=u(t)-y_k(t)-y_m(t) \tag{1}$$

where:

u(t) – transversal advance
$y_k(t)$ – contact deformation
$y_m(t)$ –structure contact deformation
$\delta_W(t)$ – workpiece wear
$\delta_S(t)$ – abrasive wheel wear

Denoting $\Delta\delta_\omega(t)$ and $\Delta\delta_s(t)$ the instant deformation of piece and wheel:

$$\begin{aligned}\Delta\delta_W &= \delta_W(t)-\delta_W(t-\tau_W)\\ \Delta\delta_S &= \delta_S(t)-\delta_S(t-\tau_S)\end{aligned} \tag{2}$$

where $\delta_\omega(t-\tau_\omega)$ and $\delta_S(t-\tau_S)$ represent the wear of the two elements at a previous rotation.

Assuming a linear dependency between the cutting force and wear:

$$\begin{aligned}F_c &= k_S\cdot\Delta\delta_S = k_S(\delta_S(t)-\delta_S(t-\tau_S))\\ F_c &= k_W\cdot\Delta\delta_W = k_W(\delta_W(t)-\delta_W(t-\tau_W))\end{aligned} \tag{3}$$

To characterize the machine behavior, an experimentally determined transfer function H(s) is used. The theoretical expression is:

$$H(s)=\frac{y_n}{F_c} \tag{4}$$

The relation (5) is a non-linear equation because of the dependency of the contact rigidity on other parameters (such as grinding force).

$$F_c = k\cdot y_k \tag{5}$$

In order to represent the effects in the contact zone, the following assumptions are made:

- the surface of the abrasive wheel is considered to be a system of individual springs, one for each abrasive grain;
- the radial distribution of abrasive grains with respect to the external wheel circumference is linear;
- each spring has the same constant *k*.

Based on the previous equations, the following block schematic was created:

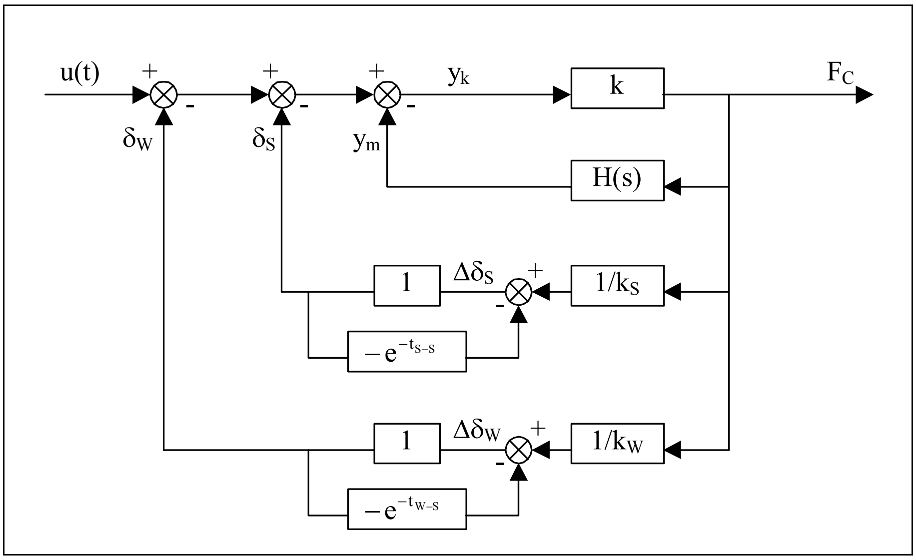

Fig. 2 – Block schematic used for modeling the grinding process

$e^{-tw\cdot s}$, $e^{-ts\cdot s}$ represent the regeneration effect of the workpiece and wheel, respectively. $1/k_S$, $1/k_\omega$ represent the flexibility of the wheel and of the grinding process. H(s) takes into account the machine tool flexibility.

From this schematic can be obtained the Simulink model (Figure 3) in which:

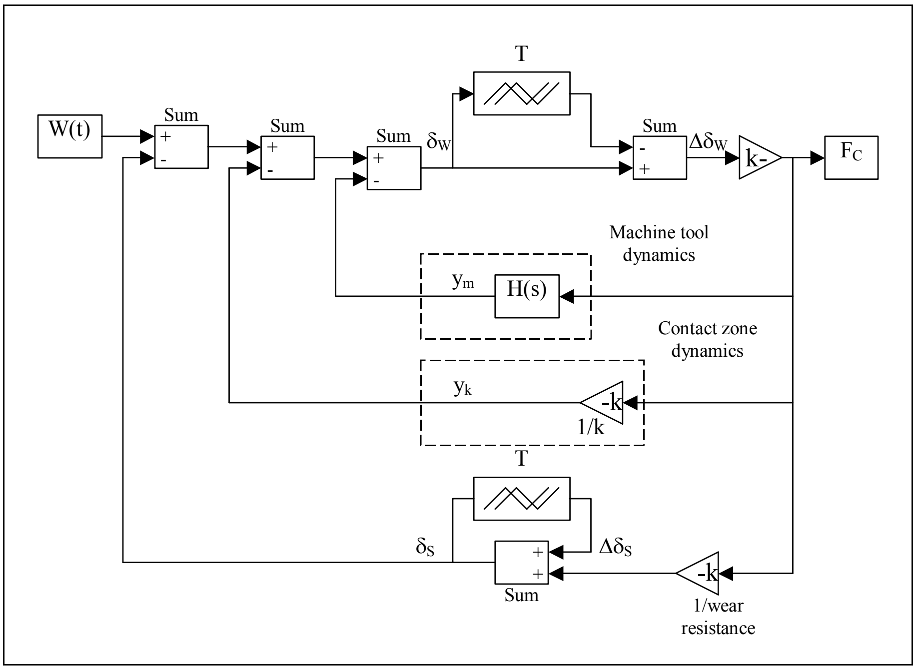

Fig. 3 – Simulink model obtained from the block schematic

- each block corresponds to a series of functions and variables which need to be evaluated prior to simulation;
- the regeneration effects of the workpiece and wheel are modeled by a delay block.

The model input is the transversal advance of the wheel.

The previous model can be completed such that to improve the possibility of lobe generation and destruction when the process becomes unstable. If the process is unstable (Figure 3) the result is an exponential increase of defects.

Actually there is an interference (partial lobe destruction) between successive rotations of the tool and piece. Correspondingly, there are two different phases: lobe generation and interference.

In the first phase, the cutting depth is greater than the defect, consequently defects are generated at each rotation, and they increase until a threshold is reached. This is when the interference occurs. This phase is characterized by certain moments in which there is no contact between tool and piece due to previously created lobes. The interference phase is a non-linear process, which can be simulated in the Simulink model.

The new model takes into account the interference by introducing restrictions to check whether the tool and piece are in contact.

If the following holds:

$$\{d_W/2-[u(t)-y_m(t)]\}-[d_W/2-\delta_W(t-\tau_W)]\geq 0 \tag{6}$$

then

$$\delta_W(t)=\delta_W(t-\tau_W) \tag{7}$$

and

$$\Delta\delta_W(t)=0 \Rightarrow F_c=0 \tag{8}$$

The new structure is (Figure 4):

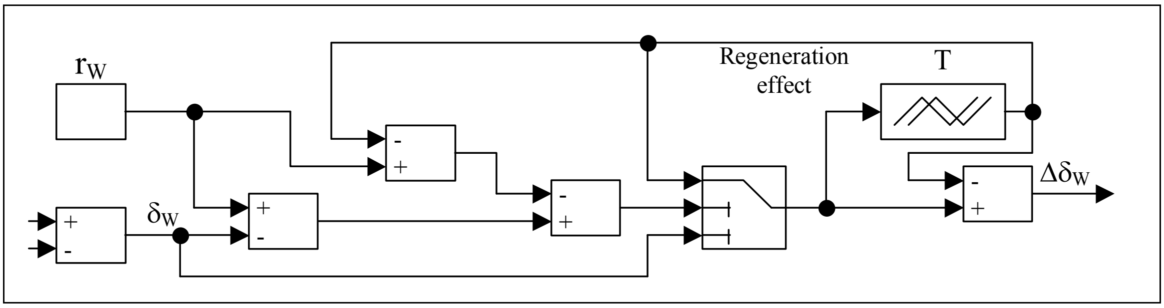

Fig. 4 – Simulink model used for emphasizing the interference phase

The peripheral geometry can be simulated as in Figure 5:

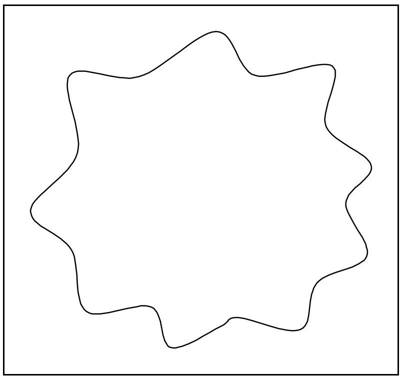

Fig. 5 – Peripheral profile of the workpiece obtained by simulation

The workpiece peripheral can be modeled both under and without interference conditions (Figure 6). The present rotation is plotted with solid line, while the previous rotation is represented with a dotted line. The simulation results are compared with an experimental profile.

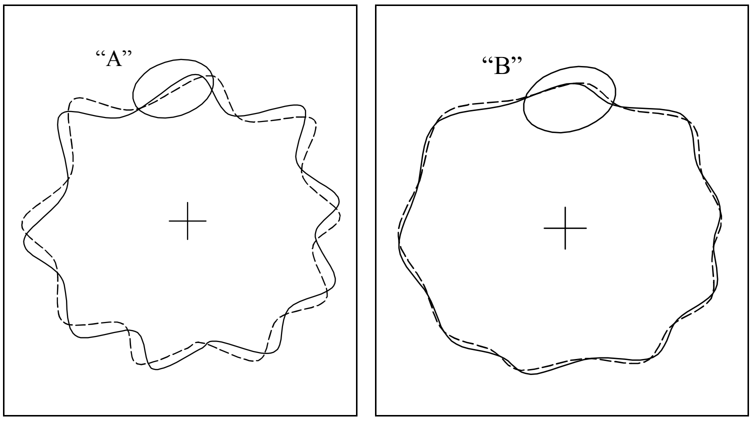

Fig. 6 – Lobe destruction (A, B) due to interference

3. CONCLUSIONS

The model described provides for simulation of certain effects which were considered non-linear, such as introduction of different transversal advances, sparking, interference between successive workpiece rotations, which lead under unstable conditions to acceptable results through the lobe destruction process.

REFERENCES

[1] Inasaki I., Yonetsu S. – Regenerative Chatter in Grinding, Proc. of the 18th MTDR Conference, Pergamon Press, p.267-270, 1985
[2] König W., Steffens K. – A Closed Loop Computer Technique to Simulate Grinding Process, International Grinding Conference, Aug.27-29, Fontana, Wisconsin, 1984
[3] König W., Steffens K. – A Numerical Method to Describe the Kinematics of Grinding - Anals of CIRP 31 (1982) 1, p.201-206
[4] Vinolev J., Bicra J. – The use of an Efficient and Intuitive Tool for Dynamic Modeling of Grinding Processes, Anals of CIRP, vol.46/1/1997