ANALYSIS OF WAVINESS TO GRINDING

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1. THEORETICAL CONSIDERATIONS

The formation of waviness on the grinding wheel and workpiece circumferencas is usually associated which may appear during grinding. These vibrations can be divided into the following three groups:

♦ Forced vibration of the machine tool structure or its various parts caused by the action of excitation forces. The magnitude of the periodic force and its change with time may not be known, the presence of force can be identified by the frequency wich normally coincides with the speed of some rotating or reciprocating parts in the system. The most common source of forced vibration in grinding process is usually connected with the grinding wheel unbalance [1], [4], and the number of waves formed on the workpiece periphery is proportional to the rotational speed of the wheel spindle.

♦ *"Passive"* vibrations transmitted throught foundations from other machines or resulting from changes in the workpiece material, non-uniform wear, etc. Vibrations of this type can also be classified as forced.

♦ Self-excited vibration generated by the internal forces formed by the cutting action, without the presence of any external periodic forces.

Under conditions of chatter certain high frequency waves may be observed on the wheel circumference, and as a result of their formation the state of chatter will continue to develop. Although the analysis of self-excited vibrations has been carried out in a number of investigations [5], [12], only a minority of the papers published on this subject have considered the generation of surface waves formed on the grinding wheel periphery.

In Fig.1, the relationship between wheel waviness, workpiece roughness and workpiece vibrations are shown as functions of grinding time.

For different times of machining, the amplitude of wheel waviness and workpiece roughness are not proportional to the amplitude of workpiece vibrations.

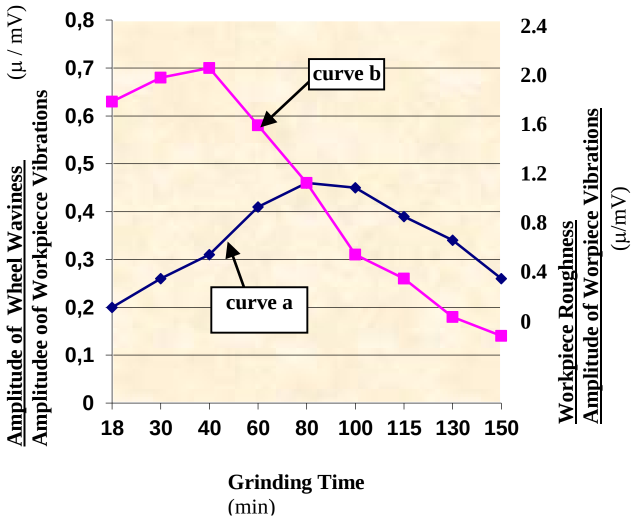

Figure 1. Relationship between workpiece vibrations and surface irregularities as a function of grinding time

The basic equations of motion are derived on the assumption that the amplitude of vibration in radial grinding forces. The validity of this

assumption, will depend largely on the characteristics of the G-W-M (Grinding Wheel-Workpiece-Grinding Machine) system and certain dynamic factors associated with the cutting action itself. Amongst those dynamic factors, the wheel contact stiffness [12],[13] and the coefficient of grinding wheel wear [12] play a very significant part.

The wheel contact stiffness can be defined as a measure of elastic rigidity of the contact zone formed by the wheel and the workpiece. That by considering the wheel contact stiffness, the frequency of chatter vibrations can be shown to be equal to the natural frequencyof the G-W-M system.

From the same investigations it will also appear that the wheel contact stiffness varies with a variation in the radial force (F), and the relationship between the two can be represented by a typical curve. In analysing the basic equations of motion, some of the authors assumed that the amplitude of chatter vibration during grinding remains relatively small.

For such conditions the variations in cutting forces will also be small, and hence the coefficients K3, will remain practically constant without affecting significantly the linearity of the system

On the basis of the above assumption the equation derived for chatter vibration [12] would be of the form,

$$\mathbf{A\ (t) = p\ (q)^t} \quad (1)$$

Where **t** = grinding time,

A (t) = amplitude of vibration at time t,

p = f (k3), and

q = f (k3, k_v)

Equation (1) suggest an infinite rise in the amplitude of chatter vibration; in reality, such infinite rise cannot be confirmed experimentally and instead a finite amplitude is usually observed. The presence of a finite amplitude can be explained by the condition of equilibrium between the internal sources of energy of self-excitation and the damping of the system. The degree of the final build-up in the amplitude of chatter depends upon the nature of non-linearity of the system under investigation [14].

To the changes in the amplitude of chatter vibrations, it has also been established [4], [9], [11], [13], [15] that with increase in grinding time, the frequency of chatter vibrations decreases as their amplitude increases.

As was shown earlier [16] if x and α represent the amplitude of vibrations and C the damping coefficient of the system then the energy of excitation W_e can be expressed as follows,

$$W_e = \frac{C}{2}\alpha^2 x^2 \quad (2)$$

It from equation (2) that at any given level of excitation energy, an increase in the amplitude should decrease the frequency and vive versa.

As explain de earlier an increase in the amplitude causes a decrease in the chatter frequency due to the reduction in the natural frequency of the system. This decease in frequency will, in turn, tend to increase the amplitude of vibrations.

The change in the amplitude and frequency of chatter vibrations are mutually interconnected, influencing each other.

Thus even for a constant level of excitation energy in the system, the amplitude will tend to increase while the frequency will decrease, because of the non-linearity in $\mathbf{k_3}$.

2. EXPERIMENTAL RESULTS

To analyses the process of generating surface waves on the wheel periphery, a number of standard grinding wheels were selected. In all cases the wheels were balanced before dressing, and to study the effect of centrifugal force, certain amounts of unbalance were added afterwards.

Figure 2 (a) shows the amplitude of wheel waviness (**x**) plotted as a function of a function of grinding time, for three wheels with different unbalance.

As can be seen from the figure, a build-up of waviness starts earlier on wheels with greater unbalance

Fig. 2(b), the frequency of self-excited vibrations is plotted for wheels with different amounts of unbalance. In case of higher unbalance, the frequency of chatter vibrations is smaller because of the lower magnitude of $\mathbf{k_3}$. The influence of wheel unbalance can be further studied by comparing the excitation energy provided by wheel with various magnitudes of unbalance.

The energy of self-excited vibrations is consumed mainly by the process of forming the waves on the wheel periphery. Therefore, when the amplitude and the frequency of the waviness for various magnitudes of wheel unbalance are known (as shown in fig. 2, the energy of vibrations can be calculated by applying equation (2). The coefficient of damping c which appears in this equation may be considered constant since the dynamic characteristics for the G-W-M system remain unchanged. The amplitude of resonance vibrations in the equation is assumed to be equal to the amplitude of wheel waviness.

The factor representing the energy of self-excited vibrations is plotted as a function of grinding time, fig. 2(c),. It will be seen that a wheel with higher unbalance will accumulate a greater amount of excitation energy.

Finally, special wheels were manufactures to study the effect of variation in the wheel hardness. Ideally, these wheels should have two different hardness sectors located opposite to each other. Since such wheels would possess very large unbalance, wheels with four different sectors were used instead. These wheels had different hardness in the adjacent sectors but with the same hardness in diametrally opposite sectors.

It should be mentioned that in the case of wheels with non-uniform hardness, no vibrations were observed on the wheelhead.

Hence, that wheel unbalance, as well as a “hard spot” on the grinding wheel, may promote chatter vibrations.

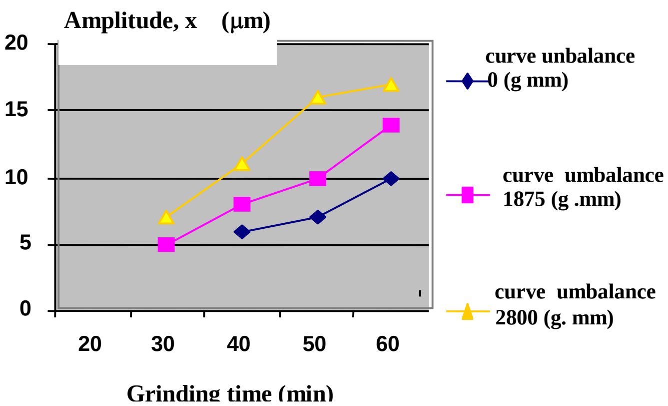

Figure 2(a) Amplitude of wheel waviness as a function of grinding time

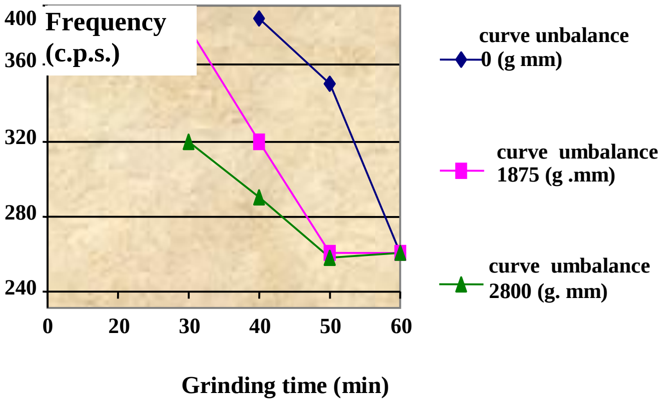

Figure 2(b) Frecuency of wheel waviness as a function of grinding time

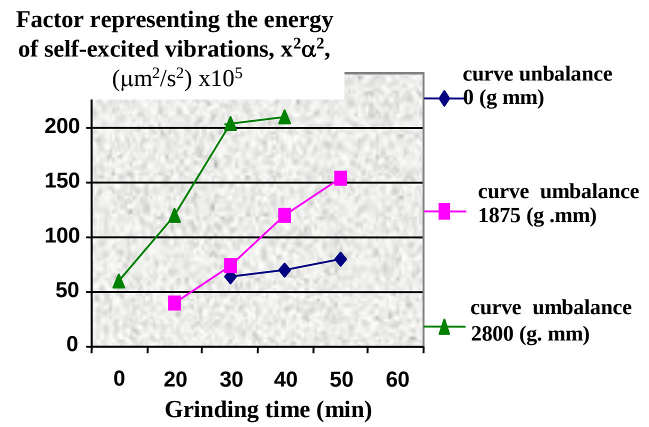

Figure 2(c). Factor representing the energy of self-excited vibrations as a function of grinding time

These vibrations, however, generate waviness on the grinding wheel only. The frequency of waviness formed on the workpiece correspond to the frequency of forced vibrations which are caused by wheel unbalance or non-uniform hardness.

3. CONCLUSION

- A complete analysis of generations of waviness during grinding requires not only the measurement of vibrations but also the measurement of surface profiles of the workpiece and grinding wheel peripheries.
- To study chatter vibrations it is essential to consider the coefficient of wheel contact stiffness and the coefficient of grinding wheel wear.
  Both these coefficients, being non-linear in character, will influence the linearity of the basic equation describing the motions in the cases when chatter vibrations are being developed.
- Any relative vibrations in the radial directions results in a greater waviness on the wheel as compared with that on the workpiece. With increase in frequency this effect becomes more pronounced.

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