VIBRATION IN MACHINE TOOLS

by 580

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Nomenclature

s - chip thickness

s_0 - feed mm/rev

v_0 - cutting speed mm/sec.

R - Radius of the work

N - Rotational speed in r.p.s.

Ω - Angular velo. of the tool

T - Time for one rev.

r_0 - feed rate mm/sec. $r_0 = \frac{s_0 \Omega}{2\Pi}$

P_0 - cutting force

dP - Increment in the force P_0

ds - Chip thickness variation (variation of the rate of penetration)

dr - feed rate variation

k_s - cutting force co-efficient - $\left(\frac{\partial P_0}{\partial s_0}\right)_{dv=0}$

k_Ω - $\left(\frac{\partial P_0}{\partial \Omega_0}\right)_{ds=0} = RK_v$

k_1 - $\left(\frac{\partial P}{\partial r}\right)_{dr=d\Omega=0}$ chip thickness coefficient

k_2 - $\left(\frac{\partial P}{\partial r}\right)_{ds=d\Omega=0}$

k_3 - $\left(\frac{\partial P}{\partial \Omega}\right)_{ds=dr=0}$

$K = k_s - k_1$ = Penetration co-efficient

$k_\Omega - \frac{(k_s - k_1)s_0}{\Omega}$ = cutting speed co-efficient

m - Equivalent mass

λ - Equivalent spring

ρ - Equivalent damper

ν - displacement coefficient

x - amplitudes

$P_z = F_H$ = Tangential force

τ_s - shear stress

F_s - shear force

F_V - vertical force

A_0 - s.d

s_1 - feed in in/rev

d - depth of cut

ϕ - shear angle

β - Friction angle

α - rake angle

γ_e - true rake angle

c - side cutting edge angle

ϕ_n - normal shear angle

ζ_n - normal chip reduction coefficient

CHAPTER I

Introduction

Much emphasis has been placed upon vibrations in machine tools during recent years because many people have recognized that accuracy, surface finish and, last but not least, production costs are considerably influenced by them. Today an arsenal of sophisticated instruments is available for the investigation of machine tool vibration. However, in the final analysis, the finished surface itself will reflect the dynamic behavior of the machine tool.

Machine tools have always vibrated and will continue to do so. We strive to control these vibrations and keep them at or below a tolerable level. This was easier to do in the past than it is today. The older machine tools had fewer auxiliary mechanisms, lower speed and feed ranges, and wide sliding ways which provided plenty of friction and also acted as vibration dampers. Newer machine tools often have sliding ways which have been designed for reduced friction in order to keep servo-mechanisms small in size. Some friction dampening effects of metal to metal sliders have been eliminated because of the introduction of many anti-friction bearing design features. While higher cutting speeds generally contribute to an improvement of the surface finish obtained, they often excite components of the machine tool at their natural frequency. Such resonance conditions can usually be avoided by changing the spindle speed. If the cutting tool and the machine tool were infinitely stiff, it would be possible to predict surface finishes and accuracy of rigid workpieces.

Only the shape of the tool and the feed per revolution or per tooth would have to be taken into consideration. Tests carried out by Okushims have shown that if machining can take place under conditions of great rigidity, no effect of cutting speed upon the surface finish is noticeable. However, to build such machines for production is highly unlikely.

A single-point cutting tool in a lathe will generate a helix or thread whose pitch is determined by the feed per revolution. (vide fig. 1) The influence of the size of the nose radius of the lathe tool upon the surface finish obtained was investigated by Fees in 1939 and recently reported by Wetzel. The following relationship was established:

$$H = \frac{S^2}{8R}$$

in which H is the height of feed mark, S the feed per revolution and R the nose radius.

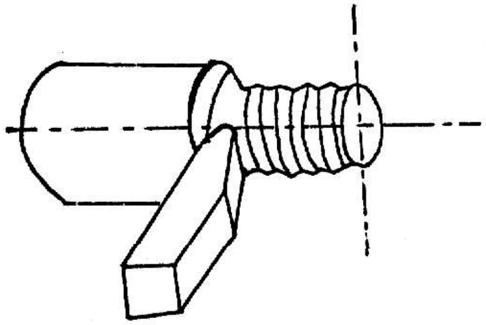

Fig. 1. Single-point tool cutting in a lathe.

The above formula will give a value of surface roughness which can be obtained under good machining conditions when using feeds larger than 0.010 in. per revolution. This relationship also holds true approximately for slab milling if R is considered to be the radius of the cutter.

It can be seen that a theoretically flat surface can be obtained with a tool which has a straight nose. This is often used in planing a finishing cut and sometimes in face milling. In a face mill, a flat region is ground on the tool face, which is in contact with the freshly produced workpiece surface.

Although under certain conditions the surface finish is predictable from a knowledge of the feed and nose radius, the depth of cut and cutting speed have the most decisive influence. The deeper cut and heavier feed may cause deflections in the tool and the workpiece giving rise to a wavy pattern and chatter marks. Cutting speeds which coincide with a natural frequency of the machine tool will create excessive motion between the machine tool elements and naturally will be reflected in a poorer surface finish. Even if all the mechanical conditions are properly taken care of, the metal cutting process itself will contribute a number of unbalancing factors.

Mechanical work is transformed into heat when metal is cut and the temperature in the shear zone and chip-tool interface will be non-uniform. This can be associated with fluctuations in the cutting force and thus be another source of chatter vibrations. Many of the newly developed alloys with high temperature resistant properties will accentuate this effect through their pronounced work-hardening tendencies and contribute further to those perturbations. Pitz and Kob have shown instances in