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Influence of the Characteristics of Machine-Tool-Fixture-Work (MTFW) System on Chatter

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Abstract :

Experiments have been carried out to determine the influence of different elements of MTFW system on the frequency and amplitude of chatter and on the ranges of cutting speeds where chatter exists. Ithas been established that, at definite ranges of cutting speeds metal cutting process is accompanied with chatter, when either spindle-work system or tool bit holder vibrates with their natural frequencies. Source of such chatter is the unstability of metal cutting process at all cuttiug speeds with frequencies which is directly proportional to cutting speed. Dependence of the frequencies of chatter, when resonunce occurs, on cutting speed is defined by straight lines, either perallel to or abit inclined with the axis of cutting speed. Frequency level and amplitude of such chatter and extent of the ranges of cutting speed, where it exists depend mainly on the rigidity of spindle-work system for low frequency chatter and on the rigidity of tool-bit holder for medium frequency chatter.

Introduction :

During metal cutting process a relative vibration of high amplitude between work and tool is often encountered. Such vibration is technically termed as chatter. Chatter is not desirable because it causes adverse effects to surface finish, machining accuracy, tool life, longibility of machine part and operator's health due to intensive noise created by chatter. Further more chatter is also responsible for reducing output because metal removal rates have to be lowered in order to get rid of chatter in the absence of other remedies.

Unlike other forms of vibration phenomenon occuring under practical conditions such ag free vibrations (induced shocks) and forced vibrations (induced by unbalanced effects, gear and bearing errors, etc.) either arising in the machine itself or transmitted through the foundation from other machines, the physical causes of chatter is more complex.

Large number of Research works all over the world have enlightened this very topic. These works deal with various aspects of chatter. Partial solution of this problem have also been proposed by various groups of investigators. But still then there remains a wide variation in the opinion of the scientists regarding the actual nature, causes and laws governing chatter. This led to the present investigations.

It should be noted that experiments carried out by the author under his Ph. D. programme have helped

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establish the following regarding the laws of chatter formation:

1. Machining of hardenable metals in a wide range of cutting speeds is accompanied with an unstability of the metal cutting process itself.
2. The frequency and amplitude of this unstability rises monotonously with cutting spead.
3. The frequency and amplitude of such unstability is a function of work and tool materials, cutting conditions and to some extent of the characteristics of MTFW System.
4. Considering negative damping effect of chatter it was concluded that, the generative force of chatter is the unstability of metal cutting process.
5. Chatter is a form of resonance vibrations, which arises when the frequency of the unstability of metal cutting process coincides with the frequency of self vibration of any part of the MTFW system.
6. Two definite ranges of cutting speed with intensive chatter were encountered within a range of approximately upto 300 m/min. while machining metals.
7. The characteristics of the process of unstability i. e. Frequency amplitude and so termed "rigidity" of unstability considerably influence the amplitude of chatter and cutting speeds, where chatter appears and disappears in these two ranges.

Aims of the Experiments :

The aims of the present work were:

1. To determine the influences of the characteristics (rigidity) of the MTFW system on the frequency and amplitude of chatter and also on the ranges of cutting speeds where it exists.
2. To detect the weakest element/elements of MTFW system, which is/are responsible for chatter in the 1st and 2nd ranges of cutting speed respectively.
3. To determine ways of minimising or even eliminating chatter by altering the characteristics of MTFW system or with the definite characteristics of MTFW system predetermine cutttng conditions for particular work-tool materials, where chatter will be absent.

Conditions of Experiments :

Investigations were carried out on four different types of lathe machines, having different values of the rigidity of spindle, tailstock and tool holder, which are given in Table-1.

TABLE-1 :

Lathe Machine No.	Value of rigidity of spindle (y — y) N/mm × 10^{+4}	Tool post (y — y) N/mm × 10^{+4}	Tailstock centre (y — y) N/mm × 10^{+4}
1	2.17	1.33	3.33
2	10.00	4.88	4.88
3	6.35	8.16	7.27
4	1.30	4.35	3.50

Values of the rigidity of tool bit holders at various overhang are given in Table-2. Work materials, used in the experiments were (1) medium carbon steel containing 0.45% of carbon and (2) steel with high thermal stability, while tungsten carbide (rectangular type) tips served as tool material. The conditions of cut were as follows: depth of cut = 2 mm. Geometry of the tool was as follows: rake angle, $\gamma = 0°$, side and end clearance angles, α, $\alpha_1 = 10°$, side cutting edge angle, $\rho = 45°$, and cutting edge angle, $\rho_1 = 20°$ and inclination angle, $\lambda = 0°$.

Low Frequency Chatter :

Influence of the rigidity of spindle on low frequency chatter:

Influences of the rigidity of only spindle on frequency of chatter and range of cutting speed, where it exists in machining high strength steel with tungsten carbide, while the rigidity of other elements (work, tool, tailstock centre etc.) remained fixed, are shown in Fig. 1. It can be concluded from the figure that: (1) with the rise in the rigidity of spindle of frequency of chatter rises. Oscillograms of

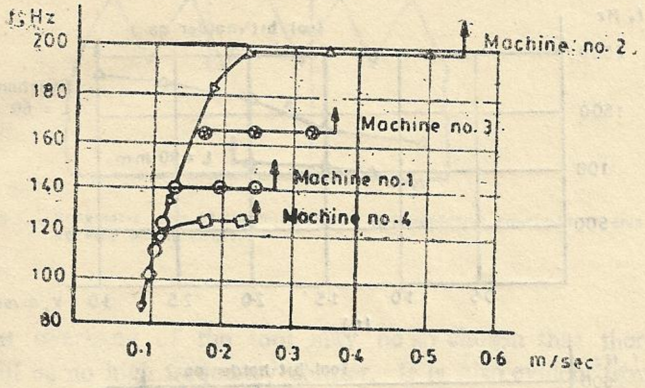

Fig. 1. Influence of the rigidity of spindle on the frequeney of chatter and range of cutting speed with low frequency chatter. Depth of cut = 2mm. Feed = 0.467 mm/rev., work material: Steel with high thermal resistance, Tool material: tungsten carbide.

cutting force show that corresponding to the inclined portion of the curve $f = \rho (v)$, amplitude of chatter is very small but in the ranges of cutting speeds, where the curve is almost horizontal amplitude of chatter continuously rises with cutting speed till a maximum is reached towards the end of the curve. For this reason amplitude of chatter increases with an increases in the rigidity of spindle (Fig. 1). (2) Cutting speed at which this type of chatter starts (beginning of the horizontal portion of the curve $f = \rho$ (v) slightly increases with the increase in rigidity of the spindle (Fig. 2). Cutting speed at which chatter vanishes is considerably higher for higher value of rigidity of the same element. It means that the range of cutting speed with this type of chatter increases with rigidity of spindle.

Influence of the rigidity of work on low frequency chatter:

In order to very the rigidity of the work its length was varied. Rigidity of other elements (spindle, tool holder, tailstock centre etc.) were kept constant. Work and tool materials were respectively: medium carbon steel (containing 0.45% C) and tungsten carbide (92% W + 8%Co.).

Dependence of the frequency of chatter on length of work at a constant cutting speed is given in Fig. 2, which shows that with the increase of length i.e. decrease of rigidity, frequency of chatter decreases. Oscillograms of cutting force and vibration marks on the cutting surface show that amplitude of chatter in this case continues rising.

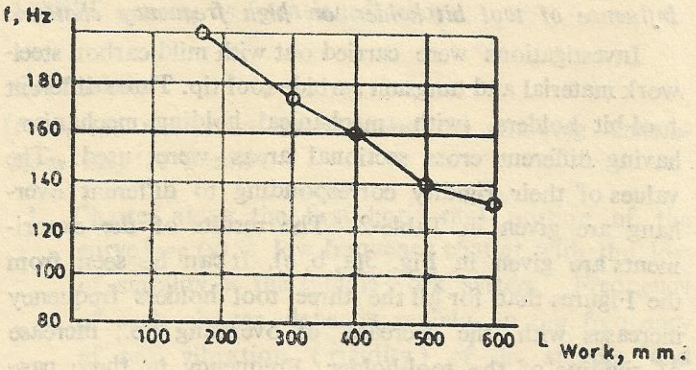

Fig. 2. Influence of the length of work on the frequency of chatter. Cutting speed, V = 0.67 m/sec., depth of cut = 2mm., feed = 0.467 mm/rev. work material: low carbon steel, tool material: tungsten carbide tip.

This type of chatter is termed as low frequency chatter, because the frequency of these types of chatter is comparatively low and remains within a range of 130 to 250 Hz. Investigarions of the influence of rigidity of tool holder, tailstock and other parts on the frequency and amplitude of such chatter show negligible effect.

It should be also noted that such type of chatter appears at cutting speed, where built-up edge just vanishes. Within the range of built-up edge resonance vibrations are hindered by the unstability of the process of metal cutting due to built-up edge. Cutting speed, at which chatter vanishes, depends on the rigidity of spindle work system: decreases with the decrease of the rigidity of spindle, increase with the decrease of the rigidity of work, increase of cutting, force & deviation of the axies of the centre hole from the axis of rotation of the work.

From the above mentioned it can be concluded that, low frequency chatter is due to the loss of stability of the spindle-work system, which enters into resonance and vibrates with a constant frequency at different cutting speeds, with high amplitude of vibration of cutting force, chip thickness and metal removal rate.

High Frequency Chatter :

Influence of tool bit holder on high frequency chatter:

Investigations were carried out with mild carbon steel-work material and tungsten carbide tool tip. Three different tool-bit holders (with mechanical holding mechanism) having different cross sectional areas were used. The values of their rigidity corresponding to different overhang are given in Table-2. The results of the experiments are given in Fig. 3(a, b, c). It can be seen from the Figures that, for all the three tool holders frequency increases with the decrease of overhang i.e., increase of rigidity of the tool-holder. Frequency in these case ʌaries from 600 to 2400 Hz.

Table - 2

Tool bit holder no	Cross Section	Over hang mm	rigidity in the direction Z-Z N/mm x 10^4
1	18 × 28	60	1.8
		73	1.5
		90	1.1
2	20 × 47	65	4.4
		85	3.3
		110	2.4
		170	1.0
3	20 × 28	65	2.0
		75	1.7
		85	1.3

In order to investigate the variation of amplitude of chip thickness along the horizontal portions of the curves f = ρ (v) for different tool holders and their overhang microsection metallographic specimens of chip at different cutting speeds were prepared. On the middle section of the chip the ratio of the ampitude of

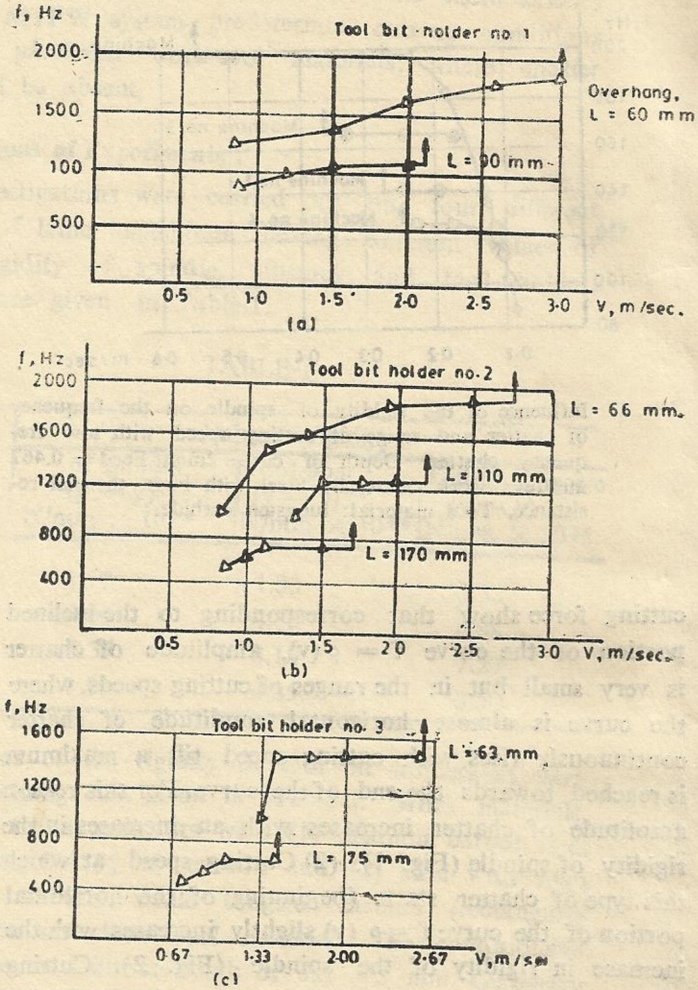

Fig. 3. Influence of the overhang (rigidity of tool holders) on the frequency of chatter and ranges of cutting speed with high frequency chatter, a) for tool holder no.1 b) for tool holder no.2 c) for tool holder no.3 Work material: Medium carbon steel (0.45 %c) tool material: tungsten carbide, depth of cut = 2mm Feed 0.467 mm/rev.

variation of chip thickness he to the maximum thickness of chip ha (fig. 4) were measured. The results of the experiments are given in Fig. 5. for two tool-bit holders. From the figure it is evident that, with the decrease of rigidity of tool bit holder amplitude of vibration increases but the maximum value of the ratio is drifted towards lower valued of cutting speed. And hence khowing the condition o cut and cutting speed

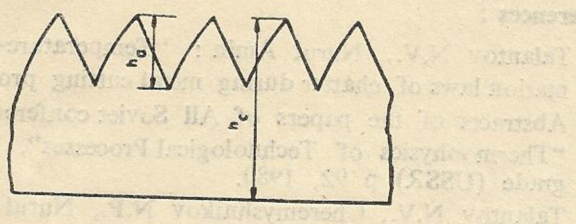

Fig. 4. Schematic view of the microsection metallographic specimen of chip, formed during chatter

the overhang of the tool may be so chosen that there will be no high frequency chatter. It is also evident from Fig. 5, that a more rigid tool bit holder allows lower amplitude of chatter than a less rigid tool holder. So in order to lower the amplitude of such chatter the tool bit holder taken must be rigid enough.

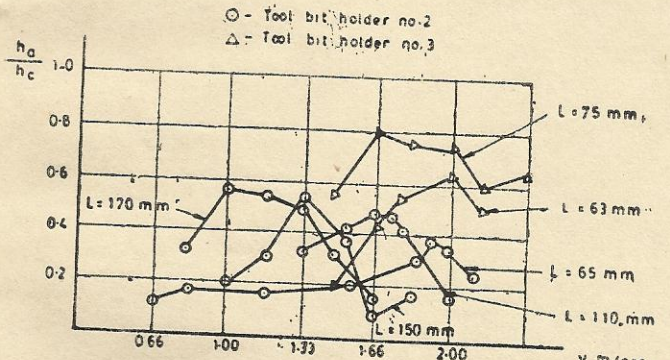

Fig. 5. Influence of the overhang of tool holder on the dependence $\frac{h_a}{h_c} = f(V)$

h_a - amplitude of vibration of chip thickness

h_c - maximum value of chip thickness

Work material: Mediumcarbon steel (0.45 % c)

Tool material: Tungsten carbide, Depth of cut : 2 mm.

Feed : 0·467 mm/rev

Influence of other elements of MTFW system on high frequency chatter :

Investigation of influence of other elements of MTFW system such as spindle, tailstock, work, type of lathe machine etc. shows that, their influence on the frequency and amplitude of chatter is negligible, although they may influence the extent of the range of cutting speed with such chatter. It was also observed during experiments that, this type of chatter is accompanied with a whistle sound created by the tool bit holder.

The above mentioned enabled draw conclusion regarding the weakest point of the MTFW system; which looses its stability and vibrates with reasonance frequency. And therefore the remedy of high frequency chatter also lies in the improvement of this very element of MTFW system, as mentioned above.

Conclusion :

From the results of investigation the following conclusions may be drawn :

1. Chatter along the first horizontal portion of the curve $f = \rho(v)$ is low frequency chatter with the loss of stability of the spindle-work system. Frequency of such chatter depends mainly on the frequency of self vibration (rigidity) of the spindle and work.

2. Chatter along the second horizontal of the curve $f = \rho(v)$ is high frequency chatter with the loss of stability of the tool-bit holder. Frequency of such chatter mainly depends on the frequency of self vibration (rigidity) of the same element (tool-bit holder), for a definite pair of work and tool materials and condition of cut.

3. Beginning of the ranges of cutting speed with low and high frequency chatter are located in the region, where the frequency curve of the unstability of chip formation intersects the straight lines of self frequencies of vibration of the spindle-work system and tool bit holder respectively. For low frequency chatter this point is obviously beyond the range of builtup edge formation.

4. Cutting speed, at which low frequency chatter vanishes (end of the first horizontal line of $f = \rho(v)$), decreases as rigidity of spindle decreases, rigidity of work increases, inaccuracy of the location of centre hole decreases for the given pair of work and tool materials and condition of cut.

5. Cutting speed, at which high frequency chatter vanishes, decreases as overhang of the tool bit holder increases (for rigid tool-bit holders specially), the cross section (rigidity) of the tool-bit holder increases for definite work-tool materials and conditions of cut.

6. The appearance of low and high frequency chatter may be ommitted during metal cutting process by chosing the desired characteristics (rigidity) of the spindle-work system and tool bit holder respectively for definite type of work-tool materials and conditions of cut, and also for a definite type of MTFW system chatter may be avoided by chosing the right conditions of cut (cutting speed).

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