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INFLUENCE OF WORK MATERIALS, CUTTING CONDITIONS AND RIGIDITY OF TOOL HOLDERS ON MACHINE TOOL CHATTER

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ABSTRACT

Experimental investigation have been carried out to determine the influence of job materials, cutting speed and stiffness of tool holder on chatter phenomenon which arises during metal cutting operation. Experiments were performed on Engine Lathe of model Celtic-14. Medium Carbon Steel Stainless Steel, Cast Iron and Brass were taken as work materials. Cemented Carbide containing 92% WC and 8% Co was taken as cutting tool material. Three different tool holders having different cross-sectional areas and mechanical clamping arrangement for tool bits, were used. An experimental set-up, consisting of a function generator, amplifiers, vibrator head, pressure transducer, oscilloscope and camera were used for determining the natural frequency of the different elastic elements, including the tool holders. Frequency and amplitude of vibration and chatter were determined by two methods - by using the above mentioned experimental set-up and by measuring the average distance between two vibration marks on job surface or between two chip elements using an instrumental microscope.

It has been established by the experimental investigation that single or multiple number of horizontal segments of the frequency versus cutting speed curve correspond to chatter, which appear within narrow range of cutting speeds during cutting of Brass and Cast-Iron; but within wide ranges of cutting speeds during cutting of Medium Carbon and stainless steel. Frequency of chatter corresponding to different horizontal segments of the frequency characteristic curve are almost integer multiples (1, 2, 3, 4, etc.) of the natural frequency of tool holder. It has been also found that the amplitude of chatter and the range of cutting speed corresponding to the horizontal segments of the frequency characteristic curve decrease and these segments are shifted towards higher cutting speeds with an increase in the stiffness of the tool holder and vice versa. The lengths of the horizontal segments of the frequency characteristic curve decrease but their number increase with an increase in the "stiffness" of the instability of the chip formation process and brittleness of job materials.

INTRODUCTION

Machine tool vibrations are broadly classified into two types - forced vibrations and self induced vibrations or chatter. Causes of forced vibrations of machine tools and their remedies are well established. But the causes of chatter and its remedies are less high lighted, although a lot of research works have been performed on this topic during the last two decades in different parts of the world.

It was established by Talantov and Chereumushnikov[1],[2] that the process of chip formation during machining of Heat Resistant Steel at all cutting speeds and that of Mild Steel (containing 0.4% C) at high cutting speed (above 100m/min) is unstable. The frequency and amplitude of such instability are directly proportional to cutting speed. It was established by the author[3] that when the frequency of this instability is close to the natural frequency of the different elements of the Machine-Tool-Fixture-Work (MTFW) system, such as the spindle-work system, tool holder, etc. resonance is created. During resonance the frequency of vibration remains constant within a given range of cutting speed. This resonant type vibration is known as chatter. At relatively lower cutting speeds resonance is caused due to the loss of stability of the spindle-work system, but at higher cutting speeds resonance is due to the loss of stability of the tool holder[4],[5],[6]. It has been also established by these works that stiffness of the MTFW system, tool geometry, feed and depth of cut, work and tool materials have definite influence on chatter. Their influence should be studied in more details to workout chatter free cutting conditions.

The present work aims at determining the influence of work material, stiffness of tool holder and cutting conditions on chatter.

EXPERIMENTAL SET-UP AND METHODOLOGY

Two different methods were used to determine the natural frequency of the tool bit holders. In the first method the tool holders of different cross-sectional area and overhang were attached to the tool post of the lathe machine and were vibrated with an electromechanical vibrator. Vibration signals from a function generator were amplified by an amplifier and supplied to the vibrator head. Vibration signals from the tool holder were picked up by a pressure transducer, amplified by a charge amplifier and then fed into the oscilloscope. When the imposed frequency of the tool holder coincided with the natural frequency of the tool holder resonance occured, when the vibration signals on the oscilloscoped showed maximum amplitude values. This theoretically facilitated the determination of the natural frequency of the tool holder. But since the set-up was composed of many mechanical parts, resonance occured at different imposed frequencies. So the natural frequencies of the tool holders had to be determined by method of elimination of external natural frequencies.

In the second method the tool holders attached to the tool post were struck by an wooden mallet. this caused vibration of

the tool holder with its natural frequency. These vibration signals were picked up by a pressure trandducer, amplified by a charge amplifier and then fed into the oscilloscope as in the first method. The oscilloscope signals were photographed by a camera and the natural frequencies were calculated from the photographs[7].

The average values of the natural frequencies determined by these two methods are shown in Table-1.

The same experimental set-up was also used for determination of chatter frequencies during turning operation. Chatter frequencies were calculated by two additional methods: wave length of chatter marks on job and wave length of chatter marks on chip according to equations (1) and (2).

$$f = \frac{100V}{L_1} \qquad (1)$$

$$f = \frac{100v}{L_2 K} \qquad (2)$$

where,

V is cutting speed in m/sec, L_1 is wave length on job surface in mm, L_2 is wave length on chip, K is coefficient of chip shrinkage.

Experiments were performed on an engine lathe model Celtic-14. Natural dry turning were performed under the following cutting conditions:

Feed,	S = 0.2 mm/rev.
Depth of cut,	t = 1.5 mm
Cutting speed,	V = From 0.125 to 4.00 m/sec

Tool Geometry:
Side and end rake angles = 0°
Clerance angle = 10°
Principal cutting edge angle = 45°
Auxiliary cutting edge angle = 25°
Tool material:
Cemented Carbide BK-8(92% WC, 8% Co)
Work Materials:
Medium Carbon Steel (0.45% C)
Stainless Steel,
Grey Cast Iron   and
Brass

EXPERIMENTAL RESULTS AND DISCUSSIONS

Frequency of the instability of chip formation and chatter were calculated by the methods discussed in the previous section and curves of frequency versus cutting speed were plotted for different work materials, tool cross-sections and overhang value. Some of these curves are shown in Figures 1, 2, 3 & 4. It may be
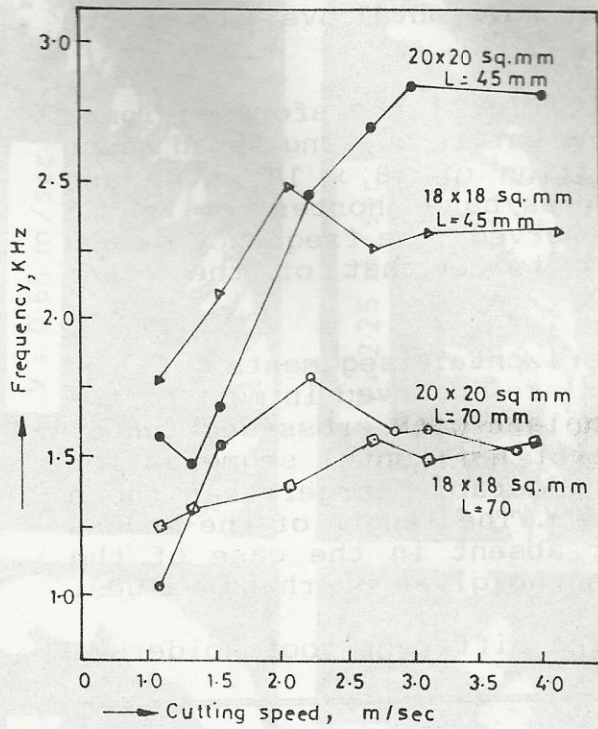
352

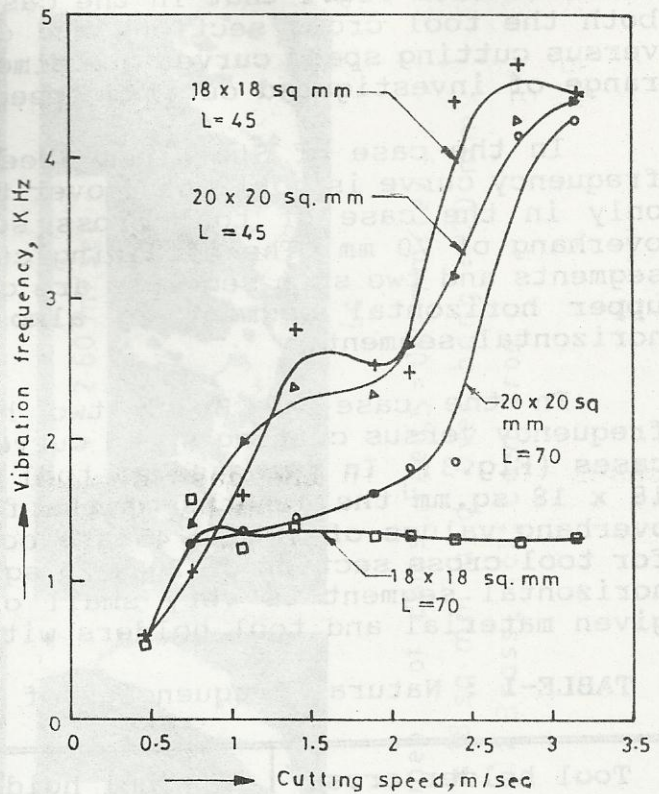Fig.1 Frequency characteristic curves
Metal : Medium Carbon Steel
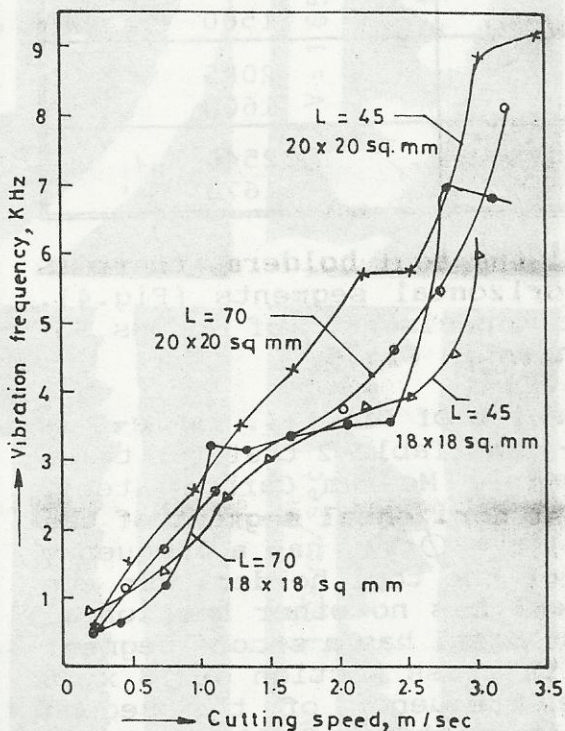

Fig.2 Frequency characteristic curves
Metal : S.S.
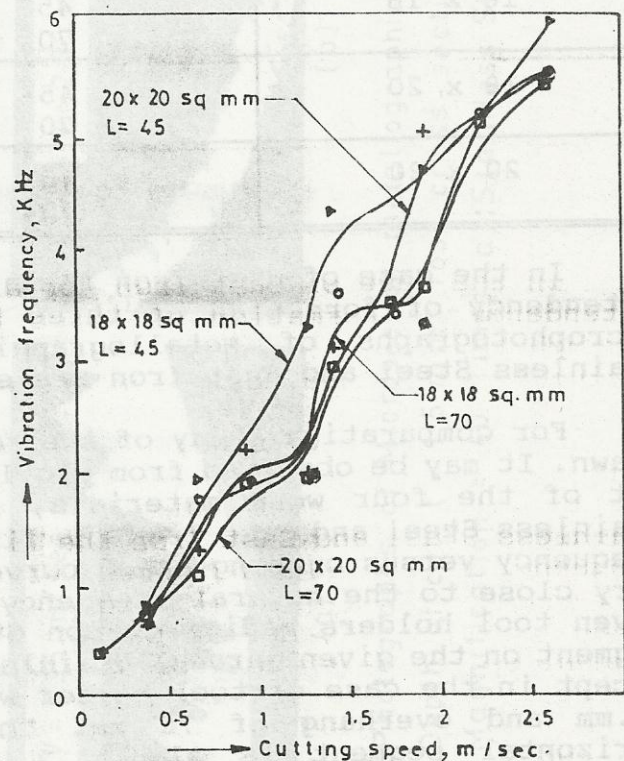

Fig.3 Frequency characteristic curves
Metal : Brass

Fig.4 Frequency characteristic curves
Metal : C.I.

observed from Fig.1 that in the case of Medium Carbon Steel, for both the tool cross sections and overhang values the frequency versus cutting speed curves are almost horizontal over the entire range of investigated cutting speed.

In the case of Stainless Steel (Fig.2) the aforementioned frequency curve is horizontal over the entire cutting speed range only in the case of tool cross section of 18 x 18 sq.mm and overhang of 70 mm. The remaining curves have shorter horizontal segments and two such segments are observed, the frequency of the upper horizontal segment is almost twice that of the lower horizontal segment.

In the case of Brass two horizontal segements of the frequency versus cutting speed curves are observed in most of the cases (Fig.3). In the case of tool holder with cross-section of 18 x 18 sq.mm the lengths of the first horizontal segments for overhang values of 70 and 45 are considerably larger than those for tool cross section of 20 x 20 sq.mm. The length of the second horizontal segment is very small or absent in the case of the given material and tool holders with the given overhang values.

TABLE-1 : Natural frequencies of the different tool holders

Tool holder cross section sq.mm	Tool holder overhang mm	Natural Frequency Hz
18 x 18	45	1925
	70	1500
18 x 20	45	2085
	70	1600
20 x 20	45	2540
	70	1670

In the case of Cast Iron for all the tool holders, there is a tendency of formation of three horizontal segments (Fig.4). Microphotographs of metallographic specimens, of chips of Stainless Steel and Cast Iron are shown in Fig.5.

For comparative study of the results of Fig.1-4. Table-2 is drawn. It may be observed from Fig.1-4 and Table-2 that for three out of the four work materials, namely Medium Carbon Steel, Stainless Steel and Cast Iron the first horizontal segment of the frequency versus cutting speed curve, $f = \phi(V)$, has a frequency very close to the natural frequency of the tool holder. For the given tool holders Medium Carbon Steel has no other horizontal segment on the given curves. Stainless Steel has a second segment except in the case of tool holder with cross section of 18 x 18 sq.mm and overhang of 70 mm. The frequency of the second horizontal segment is almost 2 times that of the natural frequency of the tool holder. In the case of Cast Iron there are three short horizontal segments of the said curve and the chatter frequency of the first, second and the third horizontal segments are close respectively 1, 2 and 3 times that of the natural
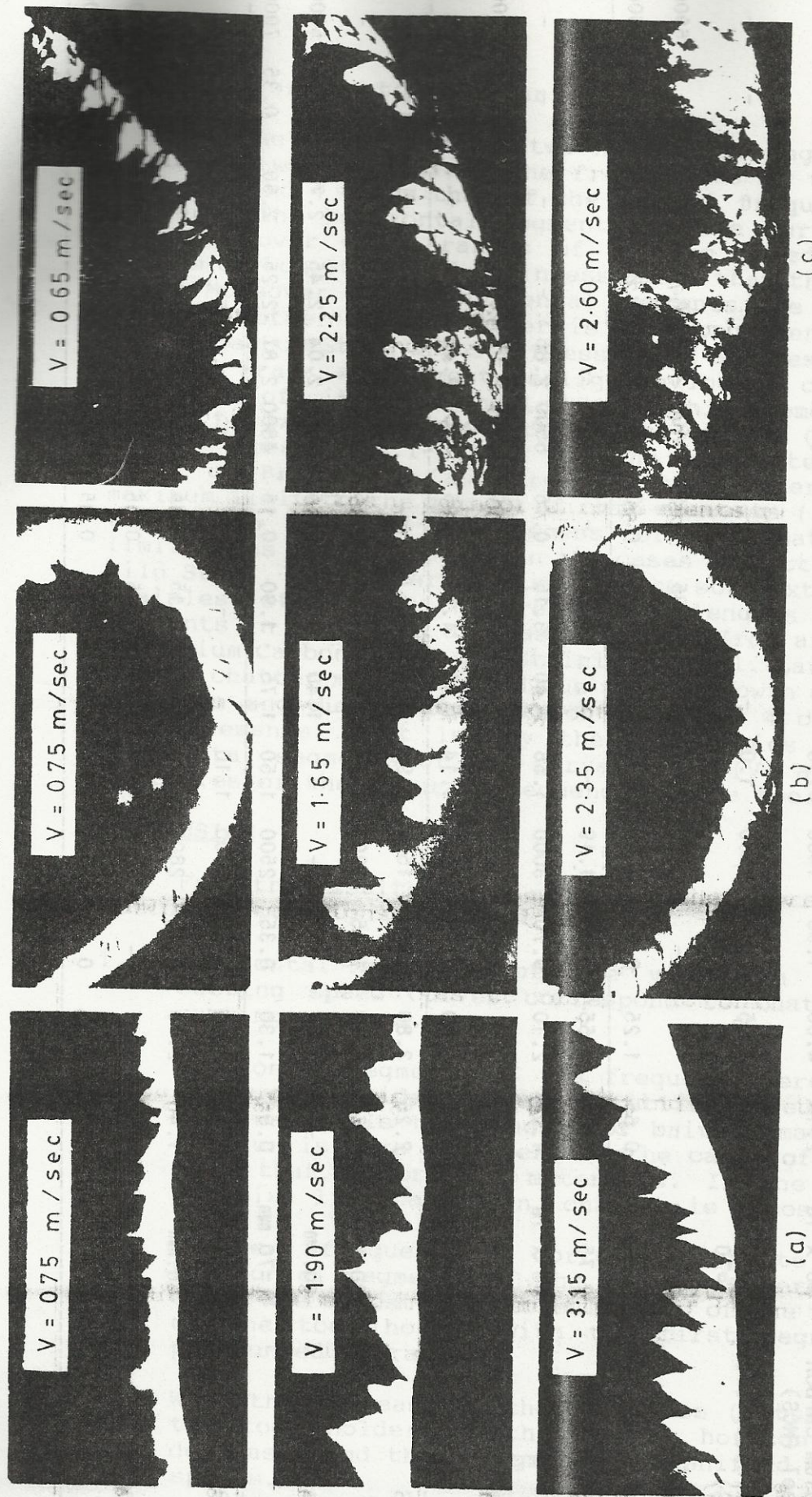
Fig. 4. Photographs of Microsection metallographic specimen of chips, Feed, $S = 0.2$ mm/rev, Depth of cut, $t = 1.5$ mm, Tool cross-section $= 18 \times 18$ sq.mm and Over hang $= 70$ mm, Magnification $= 40$ Times (a):Stainless Steel, (b): Brass, (c): Cast Iron

TABLE-2 : Chatter frequencies and unstable cutting speed ranges for different work materials and tool holders

Work Material	Tool Holder	V_1 m/sec	V_2 m/sec	V_{1-2} m/sec	f_{c1} Hz	$\frac{f_{c1}}{f_n}$	V_3 m/sec	V_4 m/sec	V_{3-4} m/sec	f_{c2} Hz	$\frac{f_{c2}}{f_n}$	V_5 m/sec	V_6 m/sec	V_{5-6} m/sec	f_{c3} Hz	$\frac{f_{c3}}{f_n}$
Medium Carbon Steel (MCS)	18 x 18 sq.mm L=70	2.10	4.00	1.90	1400	0.93	-	-	-	-	-	-	-	-	-	-
Stainless Steel (SS)		0.75	3.15	2.40	1550	1.00	1.10	2.35	1.25	3100	2.03	2.75	-	-	6900	4.45
Brass		-	-	-	-	-	1.40	1.90	0.50	3750	2.42	2.25	2.60	0.35	6000	3.87
Cast Iron (CI)		0.65	1.25	0.60	1900	1.27	-	-	-	-	-	-	-	-	-	-
MCS	2.75 18 x 18 sq.mm L = 45 mm	4.20	1.55	-	2300	1.19	-	-	-	-	-	-	-	-	-	-
SS		1.04	2.10	0.70	3000	1.56	2.40	3.15	0.75	5500	2.86	3.00	-	-	6000	3.12
Brass		-	-	-	-	-	1.50	2.50	1.00	3900	2.03	-	-	-	-	-
CI		0.65	0.90	0.25	2200	1.14	1.40	1.75	0.35	465	2.42	-	-	-	-	-
MCS	20 X 20 sq.mm L=70 mm	2.25	3.80	1.55	1500	0.90	-	-	-	-	-	-	-	-	-	-
SS		0.75	2.40	1.65	2200	1.32	2.80	3.15	0.35	4800	2.87	2.45	2.75	0.30	5500	3.29
Brass		-	-	-	-	-	1.40	2.05	0.65	3400	2.04	-	-	-	-	-
CI		0.95	1.30	0.35	2500	1.50	1.75	1.90	0.15	4800	2.87	2.25	2.60	0.35	7000	4.19
MCS	20 x 20 sq.mm L=45 mm	2.75	4.00	1.25	2800	1.10	-	-	-	-	-	-	-	-	-	-
SS		1.40	2.10	0.70	2800	1.10	2.80	3.15	0.35	5100	2.01	-	-	-	-	-
Brass		-	-	-	-	-	2.20	1.75	0.35	5700	2.26	2.25	2.60	0.35	9200	3.62
CI		0.95	1.30	0.35	2800	1.10	1.40	1.75	0.35	4700	1.85	2.25	2.60	0.35	7200	2.83

frequency of the tool holder.

In the case of Brass two horizontal segments of the $f = \emptyset(V)$ curve were observed. The frequencies of these segments are almost 2 and 4 times that of the natural frequencies of the tool holders. The horizontal segments of the curve $f = \emptyset(V)$ are extended over wider ranges of cutting speed in the cases of Medium Carbon Steel and Stainless Steel than those Brass and Cast Iron. Moreover these horizontal segments are shortest for Cast Iron. In other words chatter is more **prominent** in the cases of Medium Carbon Steel and Stainless Steel and less prominent in the case of Brass and almost negligible in the case of Cast Iron. Amplitude of vibration and length of chip elements corresponding to the horizontal segments of the curve, $f = \emptyset(V)$ increase with cutting speed (Fig.1-5) for all the work-materials, but in the cases of Brass and Cast Iron (brittle materials) there is a maximum limit to the growth of chip elements (less than 1.5 to 2 time) due to the brittleness of the material. But such limitations do not prevail in the cases of ductile materials like Mild Steel, Medium Carbon Steel and to some extent in the case of stainless steel. For this reason the lengths of the horizontal segments in the cases of Brass and Cast Iron are less than those of Medium Carbon Steel and Stainless Steel. Larger chip elements during chatter may be formed due to the growth of individual chip elements and due to coagulation of 2, 3, 4 or more individual chip elements. That is why the frequencies of the different horizontal segments of the curve, $f = \emptyset(V)$ are almost integer multiples of the natural frequency of the tool holder.

CONCLUSION

From the results and discussion of the previous section the following conclusions may be drawn.

1. Horizontal segments of the vibration frequency versus cutting speed curves correspond to chatter during metal cutting process.

2. Horizontal segments of the frequency versus cutting speed curve cover wider ranges of cutting speed in cases ductile work materials than those for brittle materials and hence chatter is more prominent in the cases of ductile material than that of brittle materials. In the case of brittle material like cast iron, chatter is almost absent.

3. Chatter frequencies corresponding to the different horizontal segments of the frequency versus cutting speed curve are almost integer multiples of the natural frequency of the tool holder with the first segment having most pronounced vibrations.

4. With the increase in the stiffness (natural frequency) of the tool holder lengths of the horizontal segments are decreased and these segments are shifted to higher cutting speeds.