INVESTIGATION OF THE INFLUENCE OF DIFFERENT PARAMETERS ON CHATTER ARISING DURING METAL CUTTING PROCESS

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ABSTRACT

Stiffness of tool bit holder, cutting variables and tool geometry are the most important elements which determine machine tool chatter, the stiffness of tool bit holder playing the major role. chatter, the stiffness of tool bit holder playing the major role. During metal cutting operation high frequency chatter maintains a definite relationship with stiffness of tool bit holder, cutting variables and tool geometry. High frequency chatter can be identified by the poorer surface finish and whisling sound during metal cutting operation. At critical range of cutting speed, metal cutting process is accompanied with chatter, when either the job and spindle or the tool bit holder vibrate with their natural frequenies. Frequency level and amplitude of such chatter, depend mainly on the stiffness of tool bit holder. It has been established in the present work that chatter can be controlled by controlling stiffness of tool bit holder and cutting variables, The results of the present study may facilitate the selec tion of appropriate tool bit holders for specific type of metal cutting operation.

1. INTRODUCTION :

With the modern trend of machine tool development, accuracy and reliablility are gradually becoming more prominent features. To achieve higher accuracy and productivity it is not enough to design the machine tools from static consideration without considering the dynamic stability of the machine tools. If there be any relative vibratory motion present between the cutting tool and the job, it is obvious that the performance of the machine tool will not be satisfactory. Moreover machine tool vibration has detrimental effect on tool life which, in tern lowers the productivity and increases cost of production.

Machine tool chatter is a self-excited vibration, the amplitude of which can build up without the presence of any oscillatory foreign agent. Chatter arises during the process of chip formation and interacts with the Machine-Tool-Fixture-Work (MTFW) system to form a dynamically unstable system. The effect of chatter on the MTFW system can be disastrous, as mentioned earlier, due to the resonance effect of vibration. Resonance occurs due to an interaction of the instability of chip formation and self vibration of the MTFW system. The problem of chatter is prominent in the existing metal cutting industries and also engineering workshops which are engaged in manufacturing of machine tools, cutting tools, spare parts and agricultural and general purpose machines.

To improve upon this undesirable condition it is necessary to study the influence of MTFW system and cutting variables on chatter in order to determine the appropriate stiffness of MTFW system and cutting varibales, This will in turn raise productivity, increase machining accuracy and ensure machining economy.

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2.0 MACHINE TOOL CHATTER

Many scientists considered regenerative force (vibration marks on the job surface) as the basis of their theories for explaining the physical cause of chatter. But the experimental work of Amin(1) and theoretical analysis made by Eliasberg(2) show that the vibration marks on the machining surface cannot be the cause of chatter, since it is found that under changed conditions of cutting the frequency of the vibration marks are not repeated.

Eliasberg considered that the formation of a crack above the tool point causes chatter. He observed this pheno menon with the help of a movie camera. But at the same time it was established by Loladze(3) & Talantov(4) that at higher cutting speeds where built-up-edge vanishes there can not be any space between the chip and the tool, since the chip fully adheres to the tool surface, Crack formation, therefore, can not be accepted as the physical cause of chatter.

It has been established by several researchers workers at the Volgograde Polytechnic Institute(5),(6) while machining high temperature resistant steel and carbon steel (containing 0.4%C) at high cutting speed (above 100 m/min), that the process of plastic deformation at the zone of chip formation is unstable. This type of instability leads to the so called "cyclic" chip formation, which is very much similar to segment chip formation as observed visually. The process is cyclic, because the instability occurs in indefinite cycle, which includes two phases- namely, phase of compression of the approaching volume of fresh metal and the phase of shear in a thin revolving zone of chip formation. The frequency of this instability increases continuously with the increase of cutting speed.

When the frequency of the cyclic chip formation is close to the natural frequency of the different components of the MTFW system chatter is generated. Therefore it was concluded that chatter is nothing but a resonant type of vibration.

Several machine tool investigators have proposed different methods to suppress or eliminate chatter(7),(8). Reduction of cutting speed, a popular method of chatter suppression, suffers from the drawback of resultant reduced production rate. It has been established by experimental investigation of Amin and Talantov(9) that instability of cutting process can be greatly reduced by preliminary heating of the work piece up to a certain optimum temperature which varies with work piece and tool materials as well as with cutting conditions. However this increases cost of operation and not very practicable in normal production situation but can be applied in special situations.

According to Kim and Ha(10) machine tool chatter can be suppressed by an appropriately designed visco-elastic damper attached to the tool post of a lathe. To maximize the capability of the damper the pre strain of the visco-elastic element has to be adjusted at different locations of the carriage, which presents inconvenience in the use of such dampers.

Keeping in view the earlier works on chatter arising during machining, experimental work was undertaken to identify the influence of stiffness of tool bit holder and cutting variables o chatter in order to suppress chatter which may be profitable during production. Thus the objectives of the work were set on this basis and are described in the following section.

3.0 AIMS AND OBJECTIVES:

The aim of the experimental work was to establish the appropriate stiffness of tool holder and cutting variable to minimize the effect of chatter during metal cutting operations.
To achieve this aim the following objectives were set:

1. To determine the effect of stiffness of tool bit holder on the chatter frequency,

2. To identify the influence of cutting variables on chatter,
3. To determine the optimum combination of the stiffness of tool bit holder and cutting variables to suppress chatter during metal cutting operation.

4.0 EXPERIMENTAL SETUP AND PRODURE:

4.1 Determination of natural frequency of tool holders

The following experimental procedure was followed for determination of natural frequencies of different elements of MTFW system and in determining the influence of these frequencies on chatter. Two different methods, were used to determine the natural frequency of the tool bit holder.

4.1.1: Method Using Function Generator:

In this first method tool holders of different cross-sectional area, attached to the tool post, were vibrated with an electro-mechanical vibrator as shown in Fig.1. The vibrator head was actuated with vibrations at different frequencies from a function generator. The frequency of this A. C current supplied by the function generator through the amplifier could be varied from 0.12 Hz to 100 KHz by means of a graduated disc attached to the function generator. By varying the frequency of the current supplied to the vibrator head tool bit holders attached to the vibrator head were excited to various natural frequencies. Determination of natural frequencies of tool holders with different cross-sectional areas and overhang were accomplished by three additional electrical equipment, namely (i) Oscilloscope (ii) Charge amplifier and (iii) Pressure transducer, as shown in Fig. 1.

In this method resonance occurs at different exciting frequencies which are not multiple of each other. This is because of the presence of large number of components involved in the vibrator head, vibrator head stand and transducer holding stand. The natural frequencies of these components interact with various exciting frequencies and resonance occurs at various frequencies.

After careful study of the results it is clear hat above certain exciting frequencies are not considered for the determination of natural frequency of tool holder. After elimination of these frequencies it is observed that certain resonance frequencies are repeated for different cross-section and overhang of tool bit holder. So these could not be the resonance frequency due to the tool holder, and might be due to the other elements present in vibrator head,vibrator head stands, transducer holding stand etc. From the above considerations the frequencies mentioned before were eliminated and the values of resonance frequencies for different overhangs and cross section of tool big holder were determined as shown in Table-1.

Table: 1 Natural frequencies' of different tools for various overhangs, as determined by the first method.

Cross-section area of tool holder, mm^2	Tool holder overhang mm	Resonance frequency, fn Hz
18×18	45	2272
	60	2142
	70	1904
20×18	45	2387
	60	2200
	70	2105
20×20	45	3333
	60	2564
	70	2166

It should be noted here that this method is not very reliable due to super imposition of different natural frequencies. For this reason a second method was adopted for determination of natural frequency of the tool holder.

4.1.2 'Knocking' Method

In the second method, tool holders of different cross sectional areas and overhang attached to the tool post were knocked by on wooden mallet as shown in Fig. 2. This action displaced the tool holder from its equilibrium position and it began to vibrate with its natural frequency. The signal from the transducer which is attached to the tool holder by means of a magnetic stand was fed into the charge amplifier and then displayed into the oscilloscope screen. These vibration signals were recorded by means of a camera. From the photographs the natural frequencies were calculated. The values of the natural frequencies are shown in Table-2.

Table-2: Natural frequency of tool holder for different cross section andoverhang, as determined by the second method.

Cross section of Tool mm^2	Tool Over hang mm	Oscilloscope Sweep time m sec/cm	Oscilloscope vertical sensitivity volt/cm	Natural frequency fn Hz	Chatter Frequency fc Hz
	45	1	1	1520	2300
18×18	60	1	1	1430	1650
	70	1	1	1130	1450
	45	1	1	1785	2400
20×18	60	1	1	1570	1850
	70	1	1	1250	1525
	45	1	1	1750	2800
20×20	60	1	1	1715	1950
	70	1	1	11175	1550

Main drawback of this method was that it was very difficult to take photograph of the vibration signals from the oscilloscope screen because the vibration signals disappeared almost instantly from the screen. Yet using ultra fast film more reliable data of natural frequencies were obtained by this method.

4.2 Determination of the effect of stiffness of tool holder and cutting variables on chatter

The experiment was performed on an engine lathe model celtic-14 with stepped spindle speed, manufactured by Bangladesh Machine Tool Factory Ltd. Machining was carried out using single carbide tool of grade BK8 (USSR make) having 92% WC and 8% Co. The carbide tips were held mechanically on tool holders. The following were the cutting conditions:

Feed,	S	=	0.11, 0.16 and 0.2 mm. rev
Depth of cut.	t	=	0.5, 1.0 and 1.5 mm
cutting speed,	V	=	1.4, 1.6, 1.9, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.4, 4.6 mm/sec.

Tool geometry : Rake angle,	γ	$= 0°$
Side and end clearance angles	α, α_1	$= 10°$
Side cutting edge angle	φ	$= 45°$
End cutting edge angle	φ_1	$= 25°$

Work piece material: carbon steel (0.4%C)

A computer program (Fig.3) was developed on a main frame computer IBM-4331 to select the spindle RPM and diameter of the work piece material with a view to maintaining the desired cutting speed.

Cutting tests were carried out at room temperature by employing natural dry turning with various combinations of cutting variables as mentioned earlier. The occurrence of instability of metal cutting process was determined by an experimental setup similar to Fig. 2. Work piece was used in place of mallet.

The vibration signal was picked up by the transducer attached to the tool holder and was fed into the charge amplifier and then displayed on to the oscilloscope screen. The appearance of the instability is indicated by the sudden increase of the vibration amplitude. Frequencies of the instability of the metal cutting process were determined by the chatter mark on the work piece. The frequency f_c was calculated from the chatter mark considering (wave length L1 mm and the known cutting speed V m/sec.) as follows:

$$f_c = \frac{V \times 1000}{L_1} \text{ cycles/sec.} \quad \ldots \ldots \ldots \ldots \ldots (1)$$

Frequency f_c can also be determined from the reading of oscilloscope screen.

5.0 EXPERIMENTAL RESULTS:

5.1 Effect of stiffness of Tool Holder on Chatter

Stiffness of tool bit holder is one of the most important factors upon which chatter depends. Experiment was carried out to determine the effect of stiffness of tool bit holder with feed of 0.2 mm/rev and depth of cut of 1.5 mm. The experimental set up similar to the one shwon fig. 2 was used for this purpose.The frequency of vibration before appearance of chatter was calculated from photographs of the oscilloscope screen. From these records the frequency of vibration was calculated by inverting the product of time base and the average peak to peak distance of vibration signal. For example if the sweep time selection switch be at t_1 sec/cm and length of wave be m cm, then the frequency may be calculated as follows:

$$f = \frac{1}{t_1 \times (m/n)} = \frac{n}{t_1 m} \text{ cycles/sec} \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

The chatter frequency was calculated from the wave length L_1 of chatter mark and known cutting speed using equation (1). These results are shown in Fig. 4 (a, b, c) as $f = \varphi(V)$. It is evident from the figures that for tool holder with cross section 18×18 mm^2 and overhang values 45, 50 and 70 mm chatter appeared at cutting speed 2.75, 2.15 and 2.12 m/sec. respectively. The chatter frequencies are represented by horizontal portions of the cures and values of these frequencies are 2300, 1650 and 1450 Hz respectively (Fig. 4a). For tool holder with cross section 20×18 mm^2 having the same set of overhang values chatter started at cutting speed 2.29, 2.21 and 2.20 m/sec. respectively with chatter frequency 2400, 1850 and 1525 Hz respectively (Fig 4b). Similarly for tool holder with Cross section 20×20 mm^2 and overhang valves 45, 60 and 70 mm chatter started at cutting speed 2.76, 2.75 and 2.25 m/sec respectively. The chatter frequencies corresponding to the above mentioned overhang are 2800, 1950 and 1550 Hz respectively (Fig 4c). As such the chatte frequencies followed the trend of natural frequencies of the different tool holders shown Table-2.

5.2 Effect of Depth of Cut, Feed & Cutting Speed on Chatter

To find the effect of depth of cut and feed on chatter experiments were conduced using the tool holders withcross section 20 × 20, 20 × 18, and 18 × 18 mm^2 and overhang values 45, 60 and 70 mm. For every tool bit holder and overhang experiments were conducted with various combinations of feed and depth of cut as mentioned earlier. It was found that for depth of cut 0.5 mm and feed of 0.11, 0.16 and 0.2 mm/rev chatter did not appear at all. For particular tool bit holder, overhang, feed and depth of cut, four readings were taken. These were the cutting speed at which instability started, cutting speed just before that speed, cutting speed where instability disappeared and cutting speed just before this speed. Whistling sound was used to detect the instability of metal cutting process. Stability chart can be used for determining unstable variables. The hatched part on of the chart is the unstable region for depth of 1.5 mm, feed 0.2 mm/rev and different tool holders. For instance, tool holder with chatter frequency of 2100 Hz is ustablein the range of cutting speed, determined by drawing a horizontal line through 2100 Hz. The values of the cutting speed where chatter appears and disappears are found from inter section of this line with the corresponding curves. These values are 2.22 and 3.26 m/sec respectively for the above mentioned cutting conditions. To study the effect of depth of cut Fig. 6 was plotted with depth of cut 1.5 mm and 1.0 mm keeping feed constant at 0.2 mm/rev.

In order to obtain an overall picture showing the effect of stiffness of tool bit holder and cutting conditions under which chatter would appear, the statility diagram as shown in Fig. 7 was developed. The vibration amplitude was used to the field $f = \varphi(v)$ curve to separate out the stable and unstable regions. For each tool and overhang with various combinations of feed and depth of cut the range of unstable speed was determined. With the help of the given stability chart stable and unstable rages of cutting speed may be determined during cutting carbon steel with single carbide tool meterial for a given tool holder (knowing its natural frequency) and given values of feed and depth of cut.

6.0 DISCUSSION AND CONCLUSION:

After careful study of the experimental results, it was found that stiffness of tool bit holder and cutting variables have a considerable effect on chatter formation.

It is seen from Fig. 4(a, b, c) that for all the three tool holders frequency increases with the decrease of ovrhang i. e. increase of rigidity of the tool bit holder. Frequencies in these cases vary from 1450 to 2800 Hz. It is observed that with the decrease of stiffness of tool bit holder, vibration started at a lower value of cutting speed.

From the experimental result it was found that for depth of cut of 0.5 mm and feed 0.11, 0.16 and 0.2 mm/rev, instability of chip formation did not appear at all but on the same set up for depth of cut of 1.0, 1.0 mm and feed 0.11, 0.16, and 0.2 mm/rev instability did appear.

From the stability chart of Fig. 7 it is seen that the unstable region covers a large area ranging from about 1.8 m/sec. to 4 m/sec. It was also observed that tool holder with cross section of 20 × 20 mm^2 and 18 × 18 mm^2 and overhang of 60 mm gave better results than tool holders having the same cross-section but other overhang values. For these tool bit holders the unstable regions cover smaller areas.

From Fig. 5 it is clear that changes in the feed result in a horizontal shift of the unstable range. It was observed that an increase in feed shifts the unstable range towards lower cutting speeds. It was also observed that for a larger depth of cut the unstable region is shifted to the right for more stiff tools and to the left for less stiff tools (Fig. 6). From the results of investigation and discussion the following conclusions may be drawn.

1. Stiffness of tool holder has considerable influence on chatter formation, and the frequency of chatter mainly depends on its natural frequency.
2. For any particular tool holder, starting point of chatter is shifted towards lower values of cutting speed as natural frequency of tool holder decreases.
3. Cutting speed at which chatter appears increases with the decrease of feed irrespective of the stiffness of tool holders.
4. With decrease in the depth of cut, the cutting speed at which chatter starts decreases for tool holders having natural frequencies above a given value and decreases when the natural frequencies is below that given value.
5. The appearance of chatter may be controlled during metal cutting operations by choosing the apropriate characteristics. (stiffness) of the tool holder for a given pair of work-tool materials and condition of cutting (cutting speed, feed and depth of cut).

REFERENCES:

1. Amin A. K. M. N., "Investigation of the Mechanism of Chatter Formation and its Influence on Tool Wear", Ph.D. thesis (in Russian), Department Technology of Machine Building, Georgian Polytechnic Institutek, USSR, 1982.
2. Eliasberg M. E., "Basis of Theroy of Chatter Arising During Metal Cutting Process", (in Russian), Journal of Machine and tools, No. 10 Moscow, 1962 pp-3-8.
3. Loladze T. N., "Chip Formation During Metal Cutting Process" (in Russian), Publication of Machine Building, Moscow, 1980.
4. Talantov N. V., "Temperature-Deformation Nature of Instability of Metal Cutting process"(in Russian), paper of 4th National conference onHeat Physics of Technological process" Toliatti (USSR), 1976.
5. Talantov N. V., Chereumushnikov N. P., "Instability of the Deformation Process at the Zone of Chip Formation", J. Obrabotka Metalov Rezaniem, Moscow, 1977, pp 81-85.
6. Tanantov N. V. and Chereumushnikov N. P., "Investigation and Classification oftheTypes of Istability of Metal Cutting Process" J Technologia Machinostroenie e Abtomatizatchia Proidbodstvennikh Protchesov", Volgograd, 1987, pp 49-62.
7. Steinberg I. s., "Removal of Vibrations Arising during Metal Cutting Process on Lathe Machines" Mashgiz, Moscow, 1947.
8. Sata T, "Development of Method to Predict and Prevent Chattering in Metal Cutting". Analysis of the CIRP (USSR), V. 24 Moscow, 1975, pp. 309-314.
9. Amin A. K. M. N., "Influence of Instability of Chip Formation and Preheating of work on Tool Life in Machining High Temperature Resistant Steel and Titanium Alloys", Mech. Engg. Res. Bull., Vol. 9, Dhaka pp. 52-62.
10. Kim J. J., Ha J. Y.; Inamura T. "Suppression of Machine Tool Chatter using a Visco-elastic Dynamic Damer", Journal of Engineering Industry, Transaction of the ASME, Vol. 09, Feb. 1987, pp. 58-65.

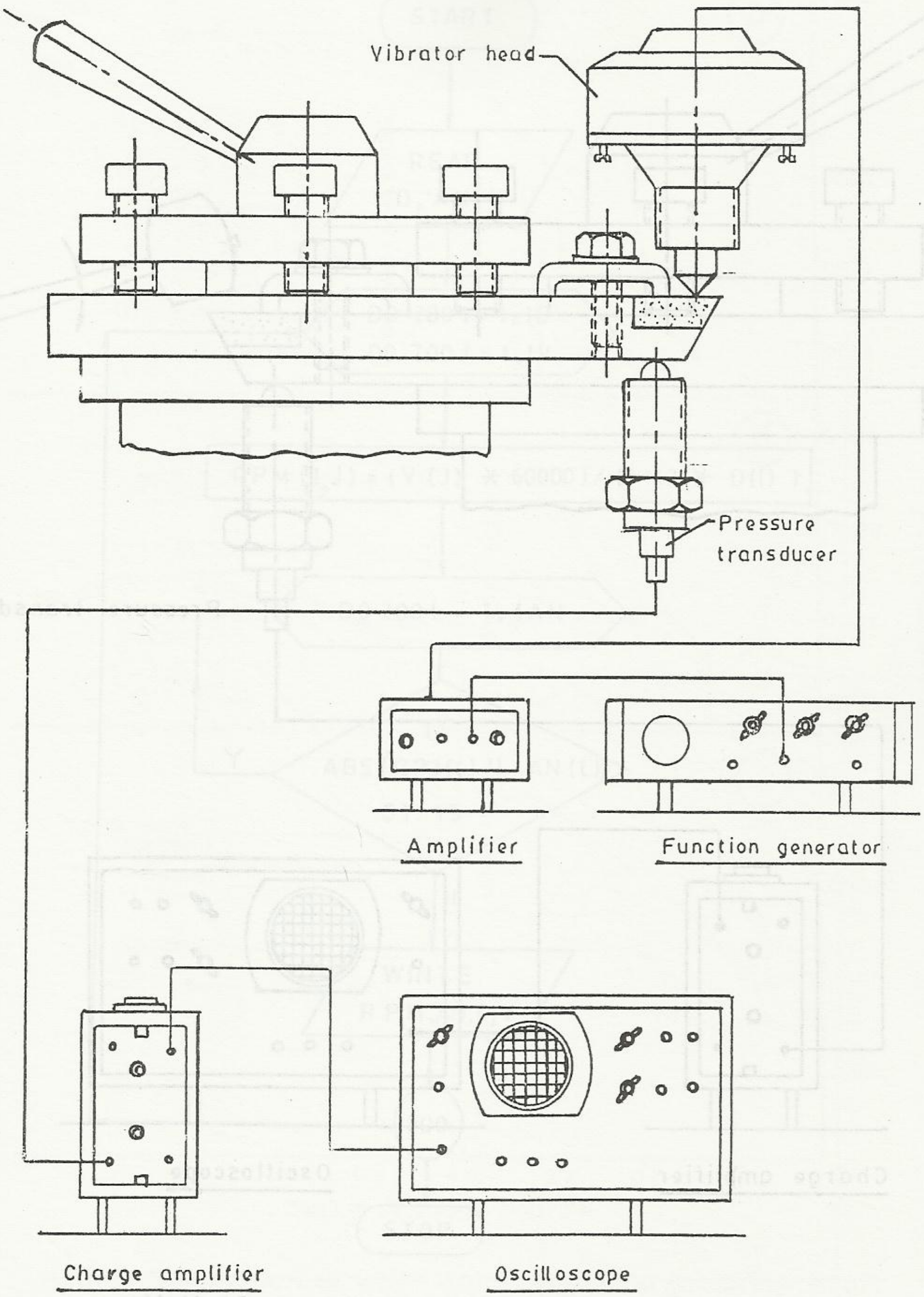

Fig. 1 : Experimental setup for determining natural frequency of tool holder (Using function generator)

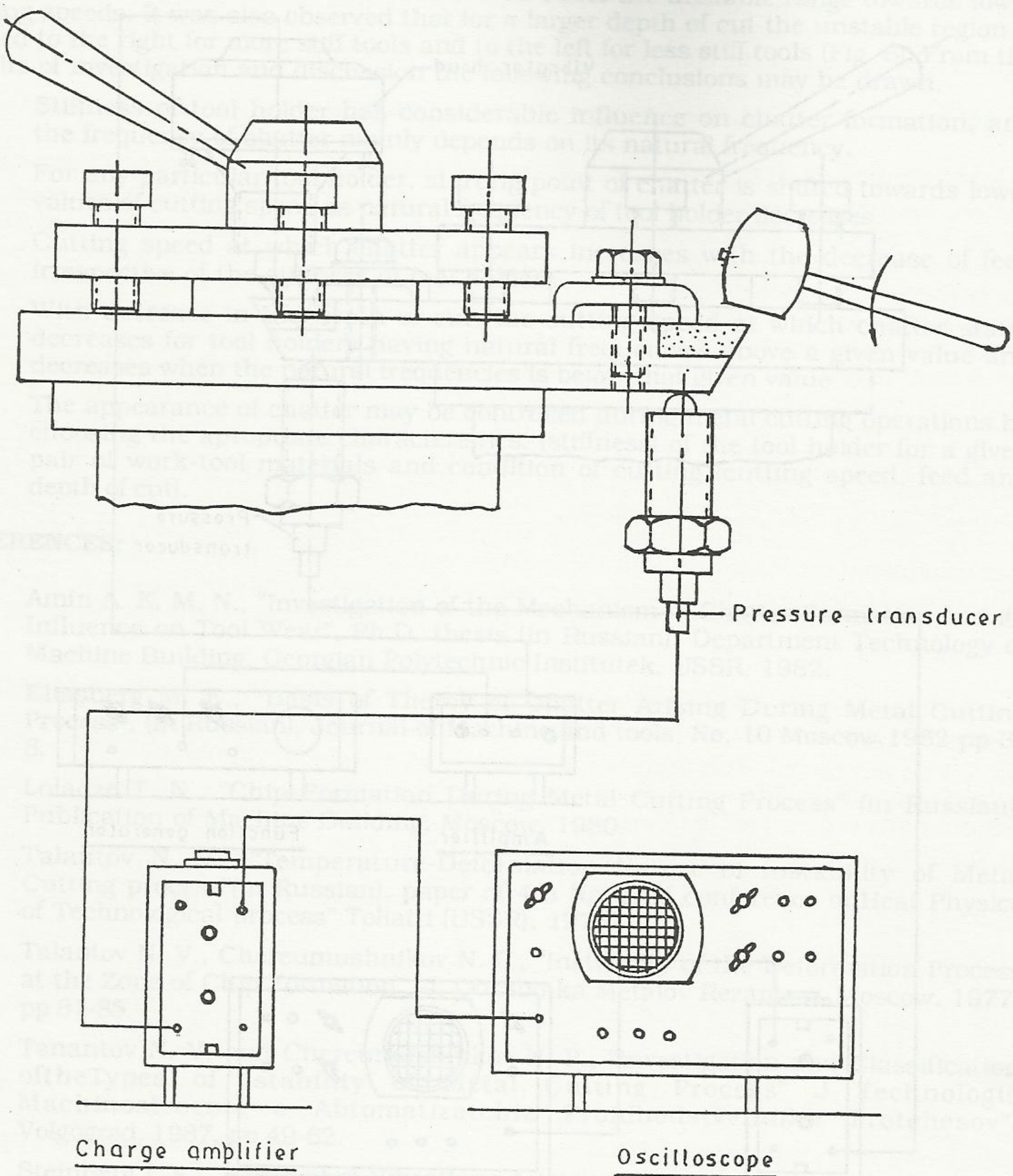

Fig. 2 : Experimental setup for determining natural frequency of tool holder
(Without function generator)

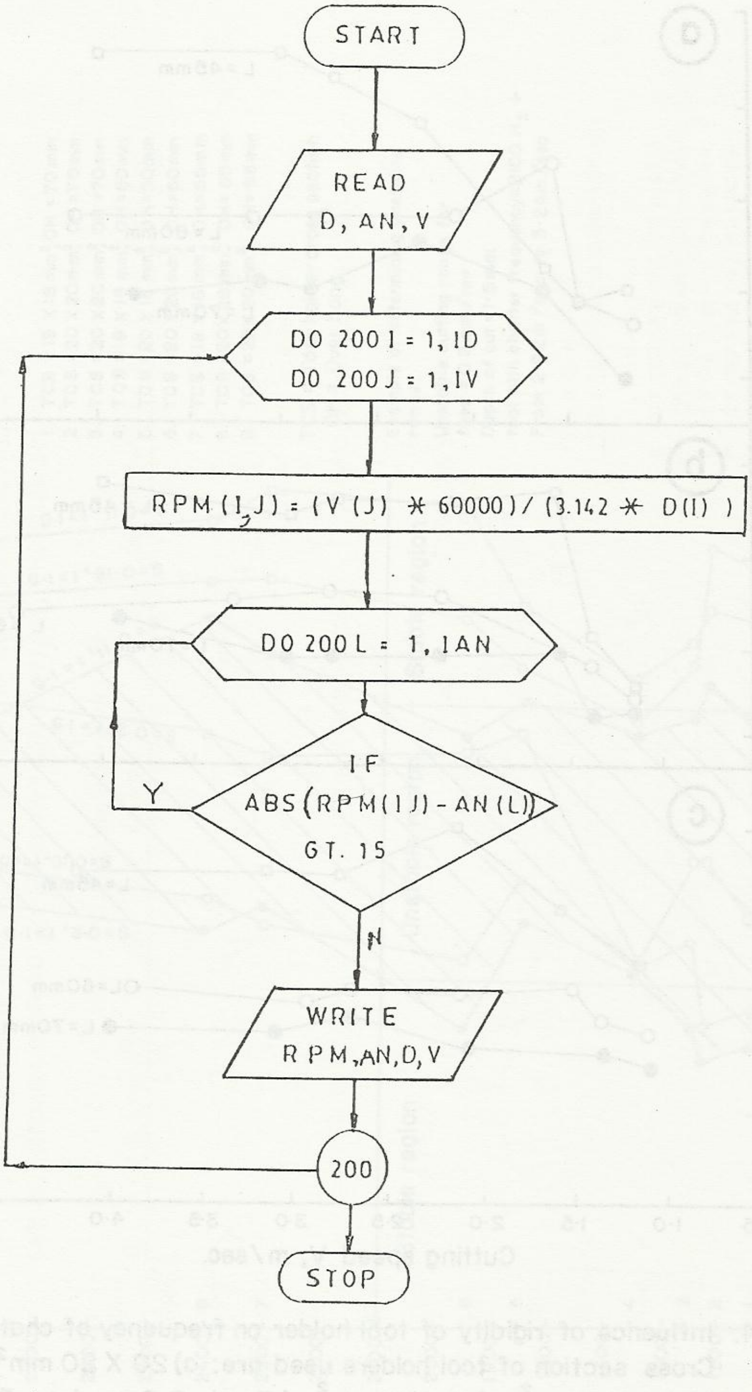

Fig. 3 : Chart of the computer program for selecting machine R.P.M and job diameter corresponding to desired cutting speed values. .

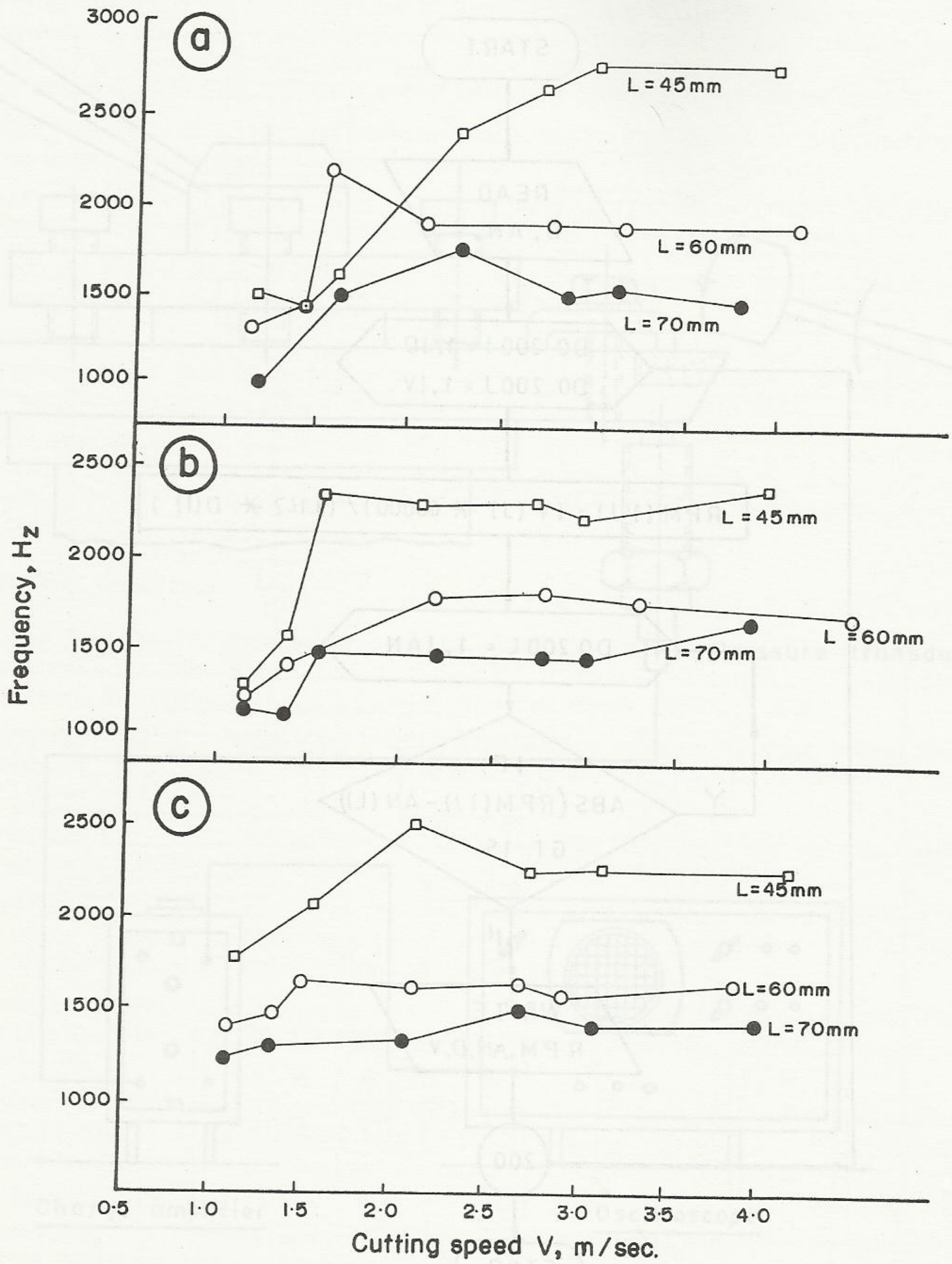

Fig. 4. Influence of rigidity of tool holder on frequency of chatter. Cross section of tool holders used are: a) 20 X 20 mm^2 b) 20 X 18 mm^2 c) 18 X 18 mm^2 (Feed- 0·2 mm/rev. Depth of cut = 1·5 mm).

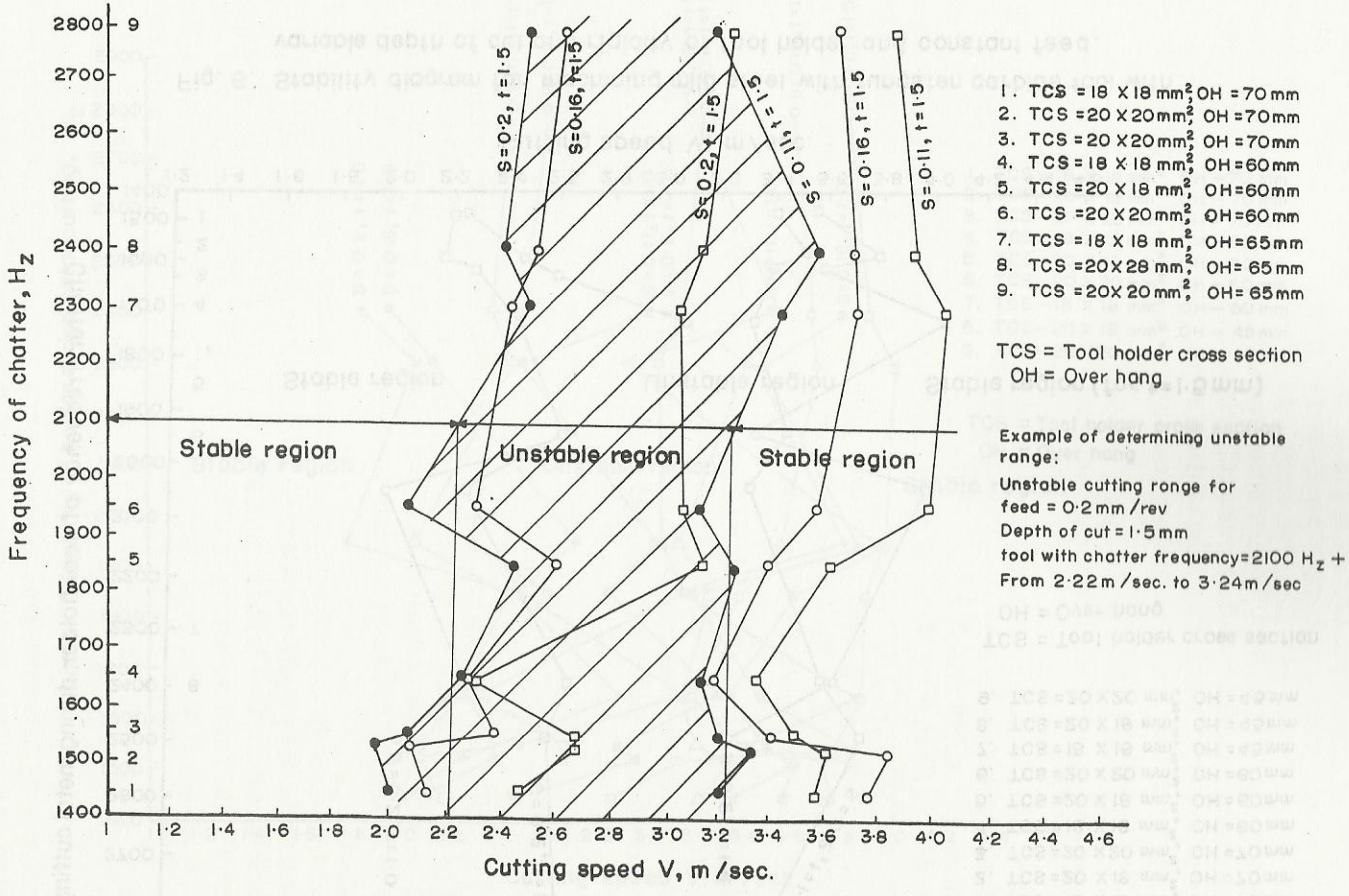

Fig. 5. Diagram for machining mild steel with tungsten carbide tool with variable feed values and rigidity of tool holder and constand depth of cut.

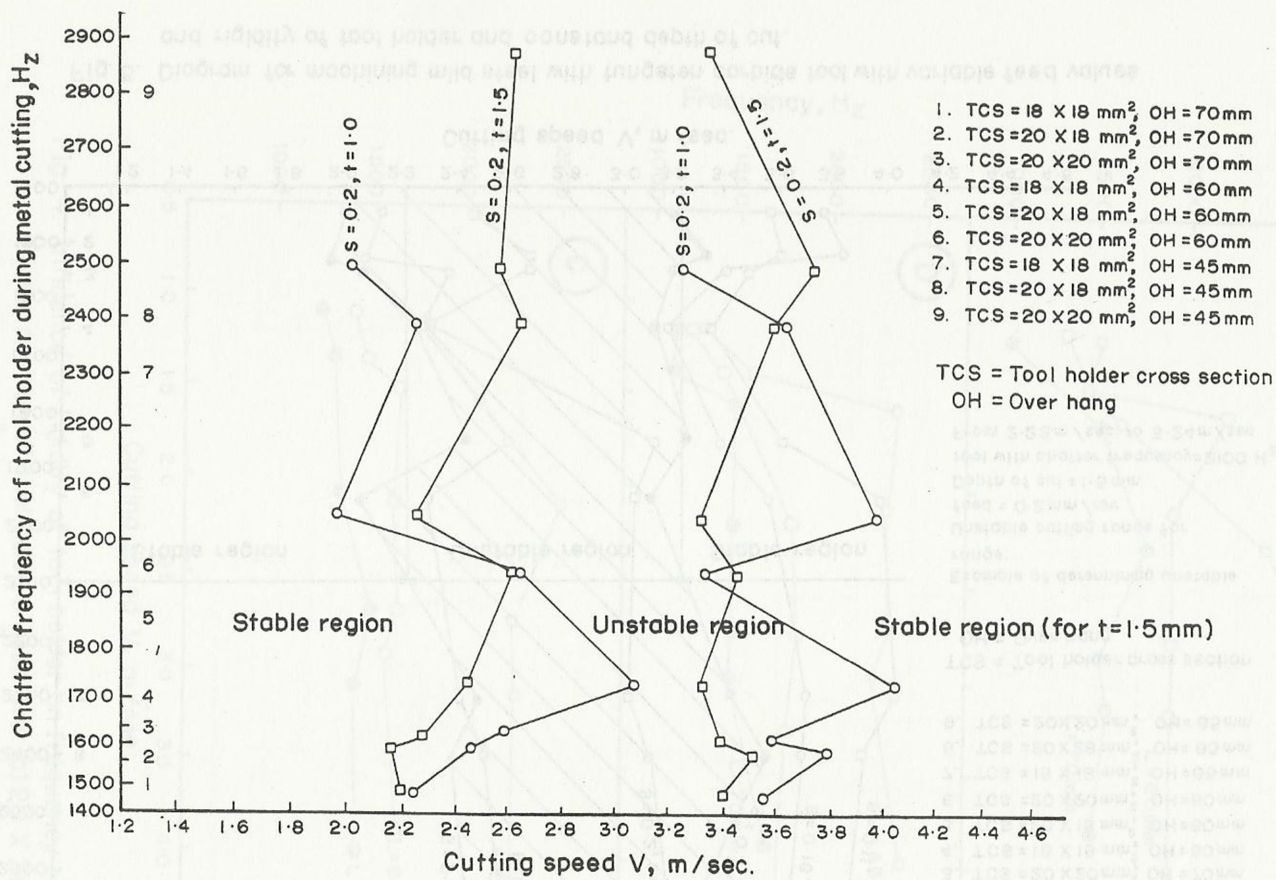

Fig. 6. Stability diagram for machining mild steel with tungsten carbide tool with variable depth of cut and rigidity of tool holder and constant feed.

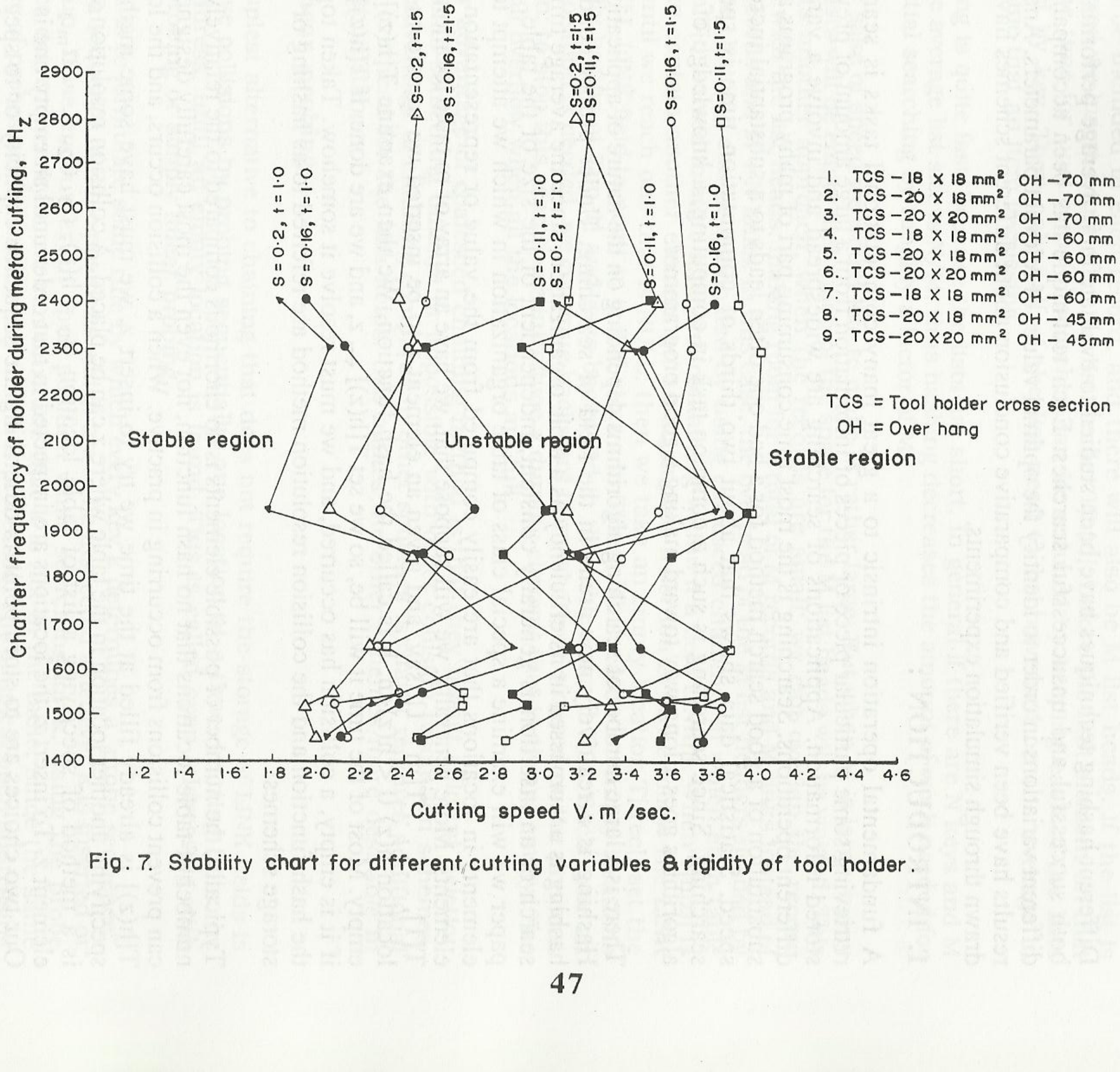

Fig. 7. Stability chart for different cutting variables & rigidity of tool holder.