Investigation of Frequency Characteristics of Machine-Tools-Fixture-Work (MTFW) System and their Influence on Chatter

A Project Thesis

by

A.H.M. Quamrul Hasan

Department of Industrial & Production Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

September, 1991

Investigation of Frequency Characteristics of Machine-Tools-Fixture-Work (MTFW) System and their Influence on Chatter

By

A.H.M. Quamrul Hasan

Submitted to the department of Industrial & Production Engineering, Bangladesh University of Engineering and Technology, Dhaka in partial fulfilment of the requirements for the degree of MASTER OF ENGINEERING in Industrial and Production.

Department of Industrial and Production Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

September, 1991

Investigation of Frequency Characteristics of Machine-Tools-Fixture-Work (MTFW) System and their Influence on Chatter

By

A.H.M. Quamrul Hasan

1. Dr. A.K.M. Nurul Amin — Chairman
Associate Professor
IPE Department, BUET

2. Dr. Md. Mizanur Rahman — Member
Professor
IPE Department, BUET

3. Dr. Ahsan Ali Khan — Member
Associate Professor
IPE Department, BUET

Department of Industrial and Production Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

CERTIFICATE

This is to certify that this work has been done by me and it was not submitted elsewhere for the award of any degree or diploma or for any publication

Supervisor

Author

ACKNOWLEDGEMENT

The author expresses his indebtness and sincere gratitude to Dr. A.K.M. Nurul Amin, Associate Professor of Industrial and Production Engineering (IPE) Department for his constant guidance, constructive suggestions and encouragement to prepare this project thesis.

The author expresses his heartfelt gratitude to Dr. Md. Mizanur Rahman, Professor and Head, Department of Industrial and Production Engineering, BUET for providing all facilities in the department at various stages of the work.

The author is grateful to all the staff of Machine Shop and Machine Tools Lab. of the IPE Department of BUET for their sincere help in the work.

Finally, the author offers his sincere thanks to all those who either directly or indirectly helped him in various ways to complete this project thesis.

September, 1991 Author

ABSTRACT

Rigidity of tool bit holder, values of cutting variables and tool geometry are the most important factors which control the machine tool chatter. During metal cutting process the occurance of chatter always maintains a definite relationship with the rigidity of tool bit holder, values of cutting variables and tool geometry. Chatter frequency can be identified by the poorer surface finish and whistling sound during metal cutting process. To conduct the experiment an experimental set-up was developed for determining the natural frequency of the tool holder, which plays a vital role in chatter formation. Turning operations were conducted with stainless steel work material and cemented carbide tool with different feed, depth of cut and cutting speed values. The experimental setup was used to register the vibrations of the tool holder. From these records and by observation of the teeth spacing on the chip and the job surface the frequency and amplitude of chatter were determined. It has been established by these experiments that frequency and amplitude of chatter mainly depend on the cross-sectional area and overhang (rigidity) of the tool holder. Higher the rigidity of the tool lower is the possibility of the appearance of chatter. It has also

been established that frequencies of vibration of the tool at different cutting speed ranges are integer multiples of the natural frequency of the tool holders. Furthermore, the possibility of chatter formation increases with the increase of feed and depth of cut values, with feed palying more prominent role than depth of cut on chatter formation. So it was concluded that chatter can be controlled by proper selection of tool holder and cutting variables.

CONTENTS

Chapter — 1

INTRODUCTION

1.1 INTRODUCTION:

The accuracy and reliability of machine tools are gradually becoming more prominent features. It is necessary to design the machine tools considering the dynamic as well as static stability to get higher accuracy and productivity of the machine tools. Furthermore, it becomes clear that the performance of the machine tool will not be satisfactory if there is any relative vibratory motion of high amplitude between the cutting tool and the job. This machine vibration is called chatter. It is responsible for higher noise level, lower life of machine tool elements, lower machining accuracy and surface finish and higher rate of tool wear etc., these in turn lower down the productivity and increase the cost of production.

With the improvement of machine tools and cutting tools, the power and rpm availability are raised. Introduction of new metals and alloys with high strength and mechanical properties also lead to tougher conditions of machining. Metal cutting at elevated cutting speeds are accompanied with more serious types of chatter. Machining of stainless steel and other heat and corrosion resistant steels, titanium and its alloys are accompanied with an instability of chip formation process, which is primarily responsible for the generation of chatter[Ref]. This presents difficulties in machining of these work materials. So it is necessary to study the nature of chatter, arising during machining such materials and also to find out the influence of different factors such as the rigidity of the Machine-Tool-Fixture-Work (MTFW) system, cutting conditions etc. on chatter phenomena. This will help in finding out solutions to the problems of chatter during machining of such low machinable materials and raise productivity, improve product quality and lower down the cost of production.

1.2 LITERATURE SURVEY:

During the past few decades, scientists have faced an increasing number of vibration problems in the development of machine tools. Designers and engineers, working on machine tools, are fully conscious that chatter leads to shorter tool life, poorer surface finish and lower output. That is why researchers stress more and more on finding the physical causes of chatter and also on finding solutions to chatter problems. Various aspects of chatter have been considered and a large number of solutions have also been proposed. But there still remains a wide variation in the opinion of the researchers regarding the actual cause, laws governing chatter and the methods proposed to suppress or eliminate chatter.

A loss of stability of the system is often observed in the operation of machine tools. The instability of the system may be manifested in the form of nonuniform, stick-slip travel of the machine tool units, commonly observed at low sliding speeds. Such a travel accompanying the cutting process is especially harmful for machine tools used in finishing operations.

One of the main problems of present day machine tool engineering is the development of machine tools with high vibration-proof properties. The conditions for the loss of stability of a system are determined by the values of the parameters of all the elements of the closed dynamic system of the machine tool, as well as linkages (primarily, the construction of the machine tool and its operating conditions). Defects in the manufacture and assembly may affect the values of the parameters of the elastic system, introduce new linkages into the system, leads to various kinds of disturbances, etc. and thus lower the established stability level of the system. Consequently, the stability of the dynamic system of a machine tool may serve as a reliable criterion of efficient design and the quality of manufacture and assembly of a machine tool.[1]

As regards the cause of chatter formation there are many theories proposed. In the opinion of one of the leading groups of scientists[2], chatter is caused due to natural interaction of different vibrations with natural frequencies of the various elements of the Machine-Tool-Fixture-Work (MTFW) system. Another group[3] is of the opinion that chatter is the result of resonance caused when the natural frequency of any elements of machine coincides with or is close to the frequency of instability of chip formation. It has been established by the latter group that there are mainly two ranges of cutting speed where chatter may appear. The first range refer to a relatively lower cutting speed, where the spindle work system losses stability and enters into resonance. The second range is offset with respect to the first towards higher cutting speed. In this range the tool bit holder enters into resonance. Amplitude of vibration in these two ranges is high and is a function of the rigidity and damping characteristics of the closed dynamic MTFW system and cutting parameters. Depending on them amplitude may be either so high that metal cutting process is bound to be interrupted or it may be so low that there is no sufficient influences of it on metal cutting process. Frequency of chatter in each of the above mention range remains practically constant during resonance.

Tailor F.B. considered that, element and segment chip formation is responsible for chatter[4]. But according to other researchers, since element and segment chip formation occur at very low cutting speeds, where chatter is absent, this cannot be considered to be the right cause of chatter. Steinberg[5], Kudinov [6], Eliasberg M.E. considered that, the instability of the built up edge is responsible for chatter formation during metal cutting process. But it is well established that most intensive chatter exists at relatively high cutting speeds, where built up edge is absent.

According to Doi and Kato metal cutting process is always accompanied by a lacking back of cutting force in phase with respect to chip thickness[7]. The experimental results of Tashlitsky, Shou and Holken helped to establish that the above mentioned phenomena may be the cause of chatter[7]. But Smith, Tobias, Albert, Iollec and Andrew proved through experiments that change of cutting force may stay back and as well as exceed in phase with the change of chip thickness depending on the conditions of chip formation[8].

Many scientists considered regenerative force on the basis of their theories for explaining the physical causes of chatter. But experimental results of Amin[7] and theoretical analysis of Eliasberg proved that the vibrational marks on the machined surface can not be the cause of chatter with similar frequencies if the cutting conditions are changed.

Eliasberg[6] considered that the cause of chatter is the formation of a crack above the tool point, which he observed with the help of a movie camera. But at the same time it has been established by Loladze Talantov, Trent et al.[9] that at higher cutting speeds where built-up edge vanishes there can not be any space between the chip and tool since the chip fully adheres to the tool surface. As such, the exceeding crack formation can not be accepted as the physical cause of chatter.

But the research work of the Volgograd Polytechnic Institute under the guidance of Talantov[10] it has been earlier established that while machining high temperature strength steel and mild carbon steel (containing 0.45%C) at extremely high cutting speed the process of plastic deformation at the zone of chip formation is unstable. This type of instability leads to the so termed "cyclic chip" formation, which is very much similar to segment chip formation on external view. Cyclic, because the process of instability is performed in definite cycles which include two phases, namely phase of compression of the approaching volume of fresh metal and phase of shear in a thin revolving zone of chip formation. The frequency of the instability is determined by the temperature-deformation conditions at the zone of chip formation. With the increase of cutting speed frequency of this instability increases continuously. But Amin, traced out the presence of this instability at all cutting speeds including the cutting speeds, where chatter exists and hence proved that this is the cause of chatter formation.

It has been established by experimental investigation of Amin and Talantov that instability of cutting process can be greatly reduced by preliminary heating of the work upto a certain optimum temperature which varies with work, tool material and conditions of cut.[11]

According to Kim and Ha machine tool chatter suppressed by an optimum desired visco-elastic damper attached on the tool post of the lathe. To minimize the capability of the damper the prestrain of the visco-elastic element have to be readjusted at different location of the carriage, which presents an inconvenience in the use of such dampers.[12]

1.3 AIMS AND OBJECTIVES:

The aim of the present work was to identify the appropriate rigidity of different elements of MTFW system and cutting variables to minimize the effect of chatter during metal cutting operations.

To achieve this aim the following objectives were set on the present work.

1. *Design and fabrication of experimental setup.*
2. *Determination of the natural frequency of tool bit holder.*
3. *Investigation of the influence of rigidity, natural frequency of tool bit holders, on the frequency of vibration and chatter during machining stainless steel material with cemented carbide tool.*

Chapter — II

2.1 DEVELOPMENT OF EXPERIMENTAL SET UP:

The experimental set up shown in Fig. 2.1. was developed to determine the frequency and amplitude of a vibratory body. The idea of such a set up was taken from the set up used to measure the frequency of human bone at the Bangladesh Diabetic Centre. In the present work, some changes were made in the original set up. The idea of using pressure transducer as vibration pick-up device was completely new. And the magnetic stand, which was used to keep the pressure transducer in proper place, also a new idea. The following components were required for the experimental set up.

a. Pressure transducer
b. Charge amplifier
c. Oscilloscope
d. Function generator
e. Amplifier
f. Vibrator head (vibration impaser)
g. Magnetic stand, etc.

a) **Pressure Transducer**:

A Kistler Quartz pressure transducer was used to develope the experimental set up. The function of this transducer is to convert a mechanical input signal into an electrical output signal. These transducers are stable, versatile and dynamic instruments which can precisely convert applied pressure into electrical signal. For this experiment, model-601 was used, which is a heavy diaphram fast responsive, miniature quartz transducer, capable of converting pressure upto 15,000 psi. Pressure applied to the diaphram of the transducer is converted to a force acting on the transducer crystals, which generates an electrical output proportional to the pressure input. To pick up the vibrational signal suitably from a solid body the above transducer is modified by fixing a steel ball (After grinding the half circle of the ball) on the diaphram of the transducer as shown in figure -

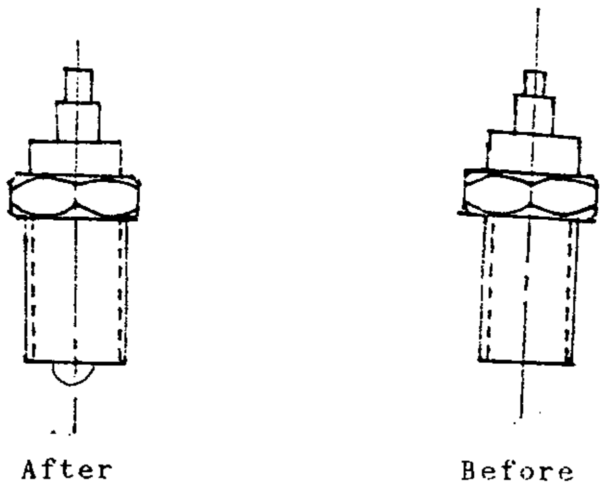


Fig.2.2 : Pressure transducer before and after modification.

b) **Charge Amplifier**:

A solid state charge amplifier of model 504 A was used to convert the high impedance charge signal from the transducer to an low-impedance voltage or current signal for display on the oscilloscope.

c) **Oscilloscope**:

A Hewlett packard model 132 A dual beam oscilloscope was used as an integral part of the experimental set up. The function of oscilloscope is to display signal from the charge amplifier on its screen. The continuous display on the oscilloscope is limited to frequencies from 1/5 Hz to 1 M Hz range. The simplest method of measuring frequency with this oscilloscope is to determine the distance between two identical points in a wave form and multiply this by the time base setting to obtain the period and hence the frequency. A photographic still camera was used to take snap as permanent record of oscilloscope trace for further analysis.

d) **Function Generator**:

A Hewlett Packard model 3300 A solid state function generator was used for imposing forced vibration signals on machine elements through the vibrator head. Three output waveforms are available from front panel connector sine, square and triangle. Frequency can be controlled by either the front panel frequency dial or an external voltage applied to a rear terminal connector. Frequency can be varied from 0.01 Hz to 100 Hz in seven decade range.

e) **Amplifier**:

A Koyo 30W transistor amplifier was used to amplify the signal from the function generator for feeding the signal into the vibrator head.

f) **Vibrator Head**:

Driver unit of a public address system p-30F with input power 30W and VC1MP-16 was converted into a vibrator head by the addition of an Alluminium cylinder having a spherical shape face. This Alluminium cylinder is glued to the diaphragm of the driver unit as shown in Fig.2.3 & 2.4. So that is can vibrate with the same frequency and amplitude as the diaphragm.

g) **Magnetic Stand**:

A C-clamp was used in conjunction with a magnetic stand to hold the transducer in position as shown in Fig.2.5. But proper contact cannot be maintained with this arrangement since it is very difficult to keep the transducer in a fixed position. For this reason, C-clamp was replaced by a nut and

M.S. rod as shown in Fig.2.6. The nut is welded on the end of the rod and by turning the transducer through the nut, it is possible to keep the transducer in a fixed position.

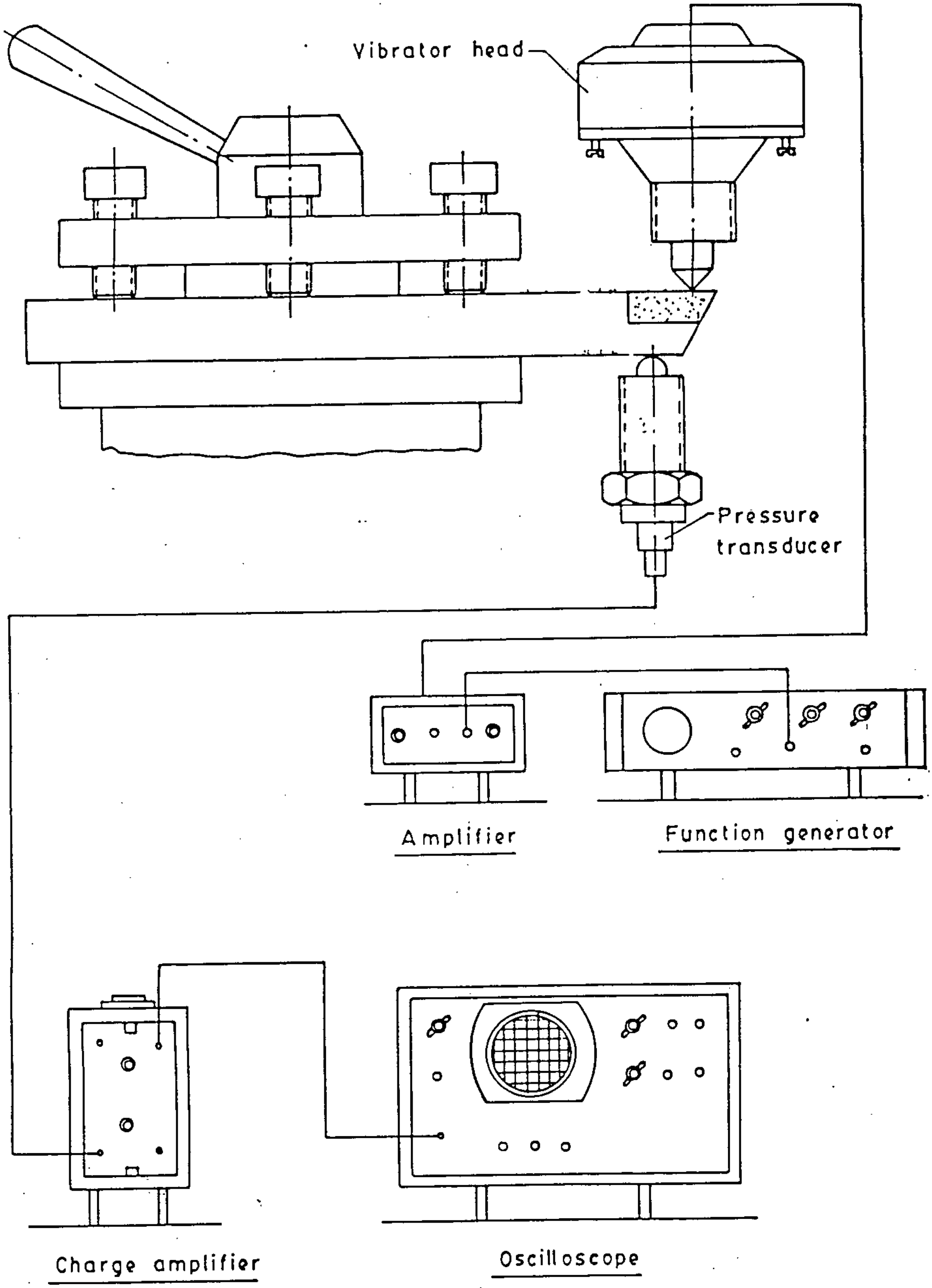


Fig. 2.1.: Experimental setup for natural frequency determination of tool bit holder using vibrator head

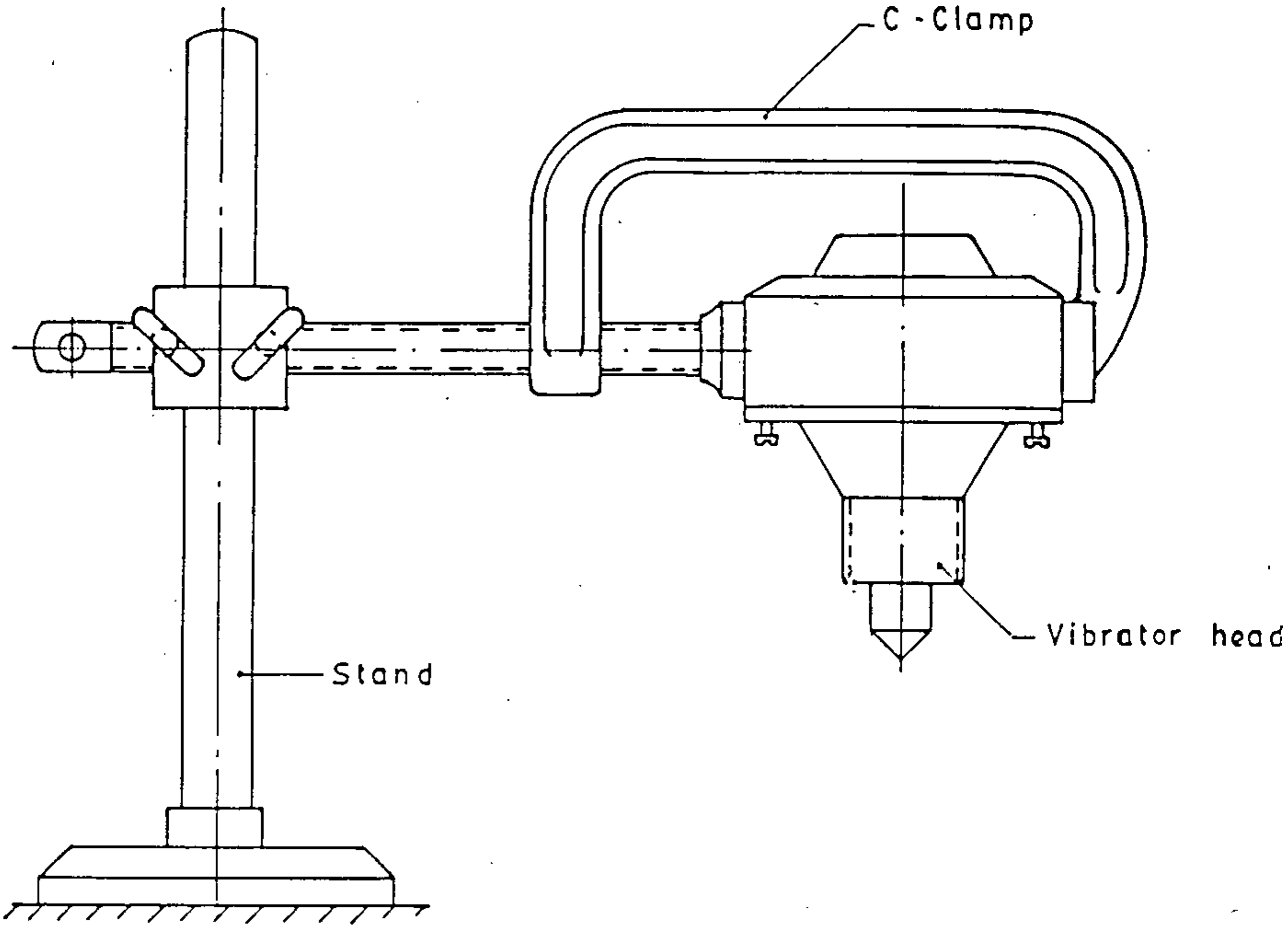


Fig.2.3: Vibrator head with holding stand

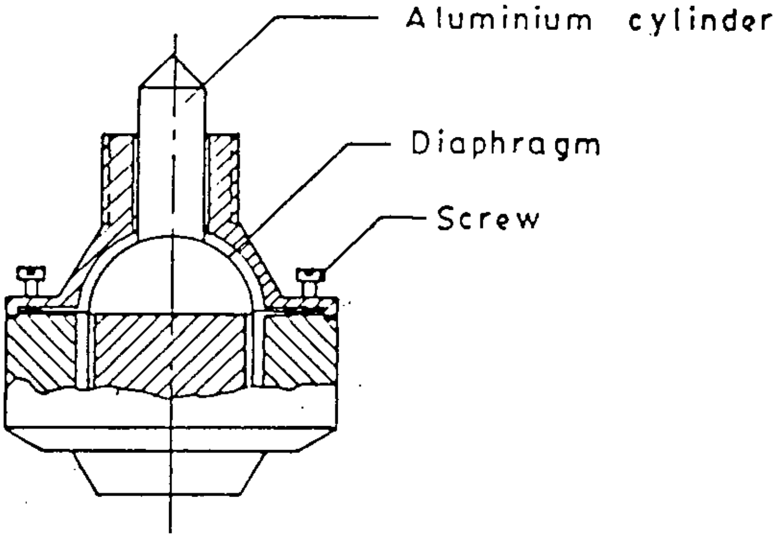


Fig.2.4: Cross sectional view of vibrator head

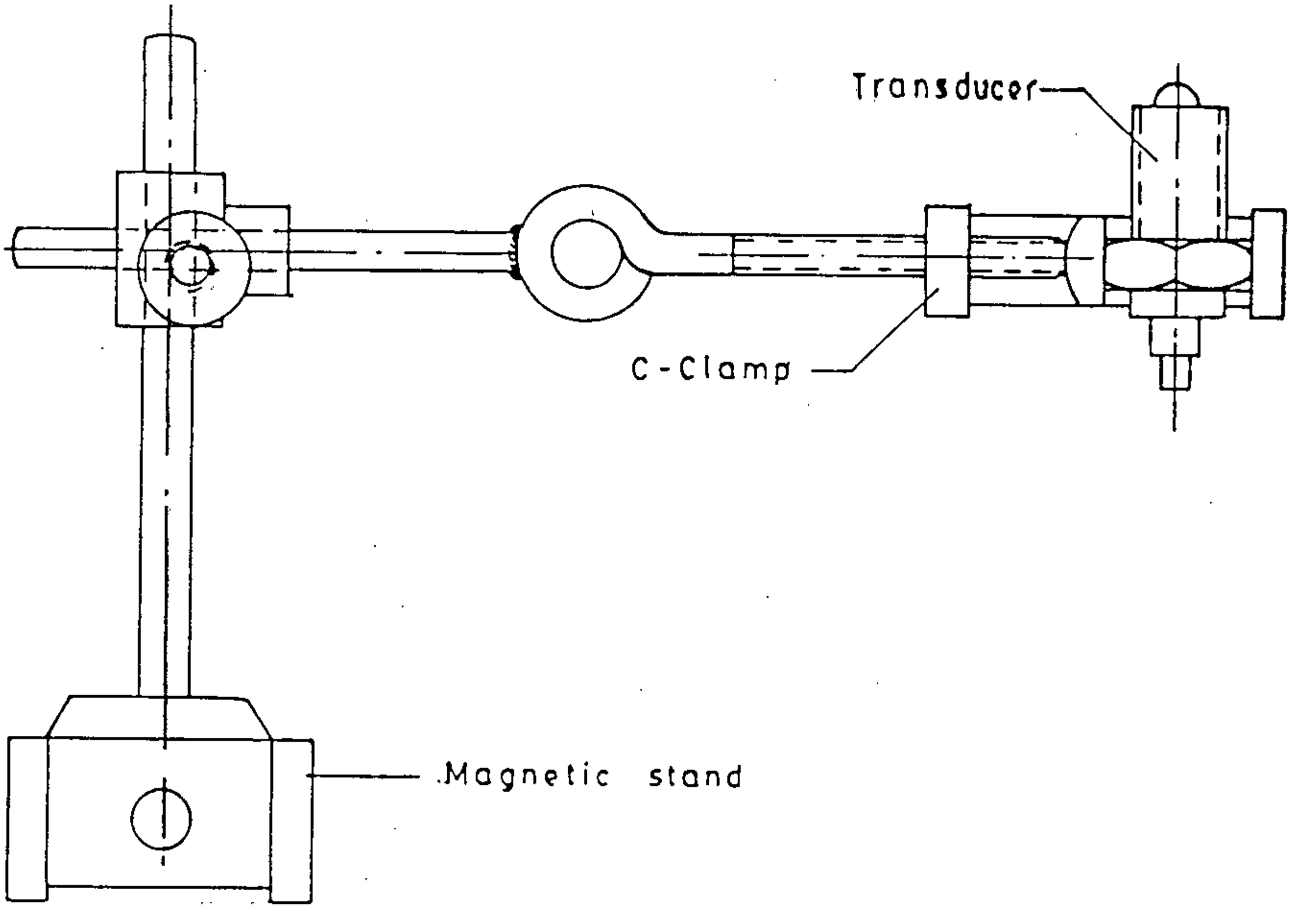


Fig.2.5Old arrangement for holding transducer

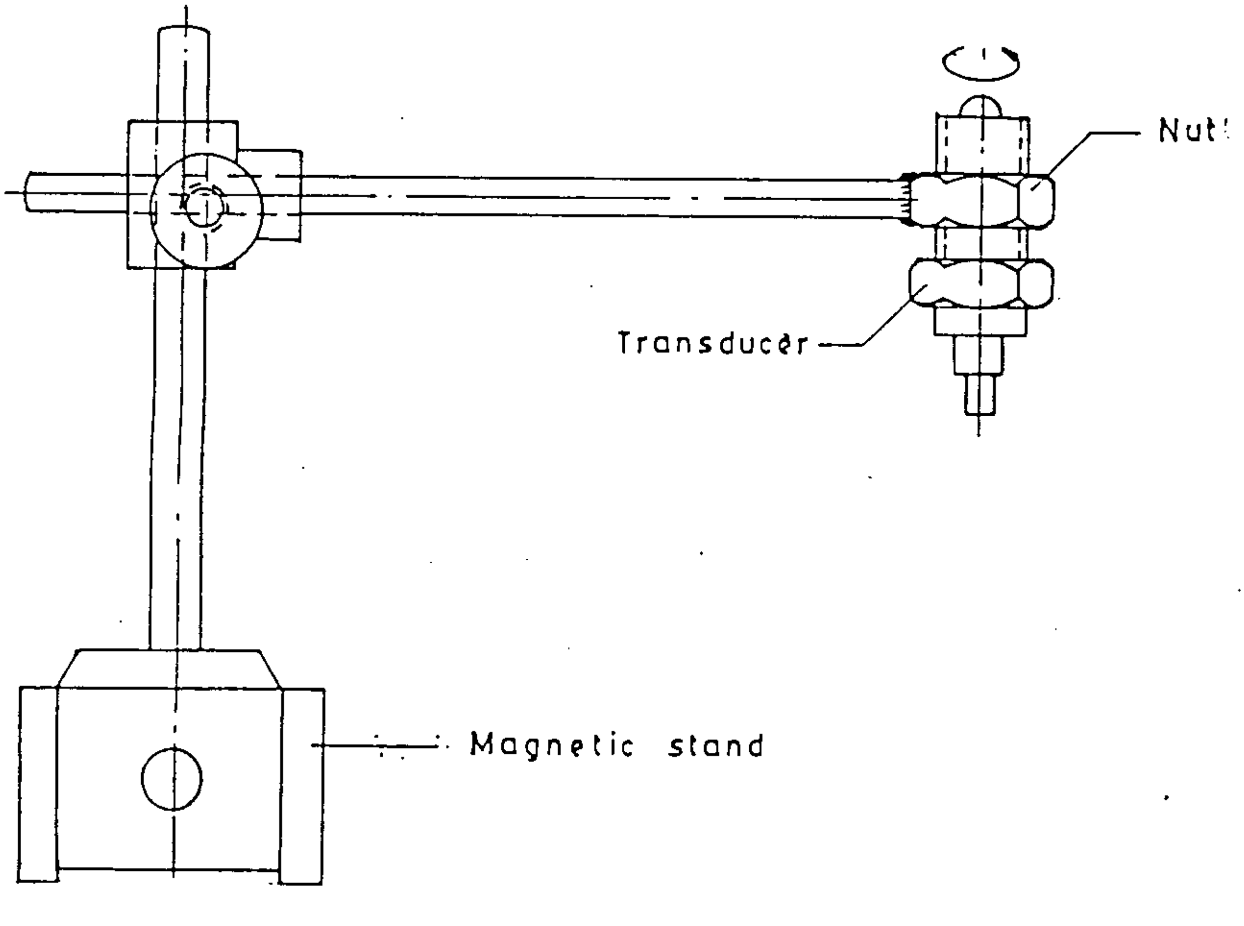


Fig.2.6:Modified arrangement for holding transducer

2.2 FABRICATION OF TOOL BIT HOLDER:

Design and fabrication of tool bit holder mainly depends on the type, size of the machine on which it is to be used and size of tool bit to be used for the experiment. In this experiment the tool bit holder was designed for a 4' bed lathe,having a square turret of tool fixing space (x = 95mm, y = 18mm, z = 34mm) and the distance from the base of the turret to the centre line of the lathe (S = 20 mm) is shown in Fig.2.7. On the basis of the above criteria, the dimensions of tool bit holder were determined. Three different tool holders were fabricated and carbide tips were brazed on them. These three tools were used through out the experiment.

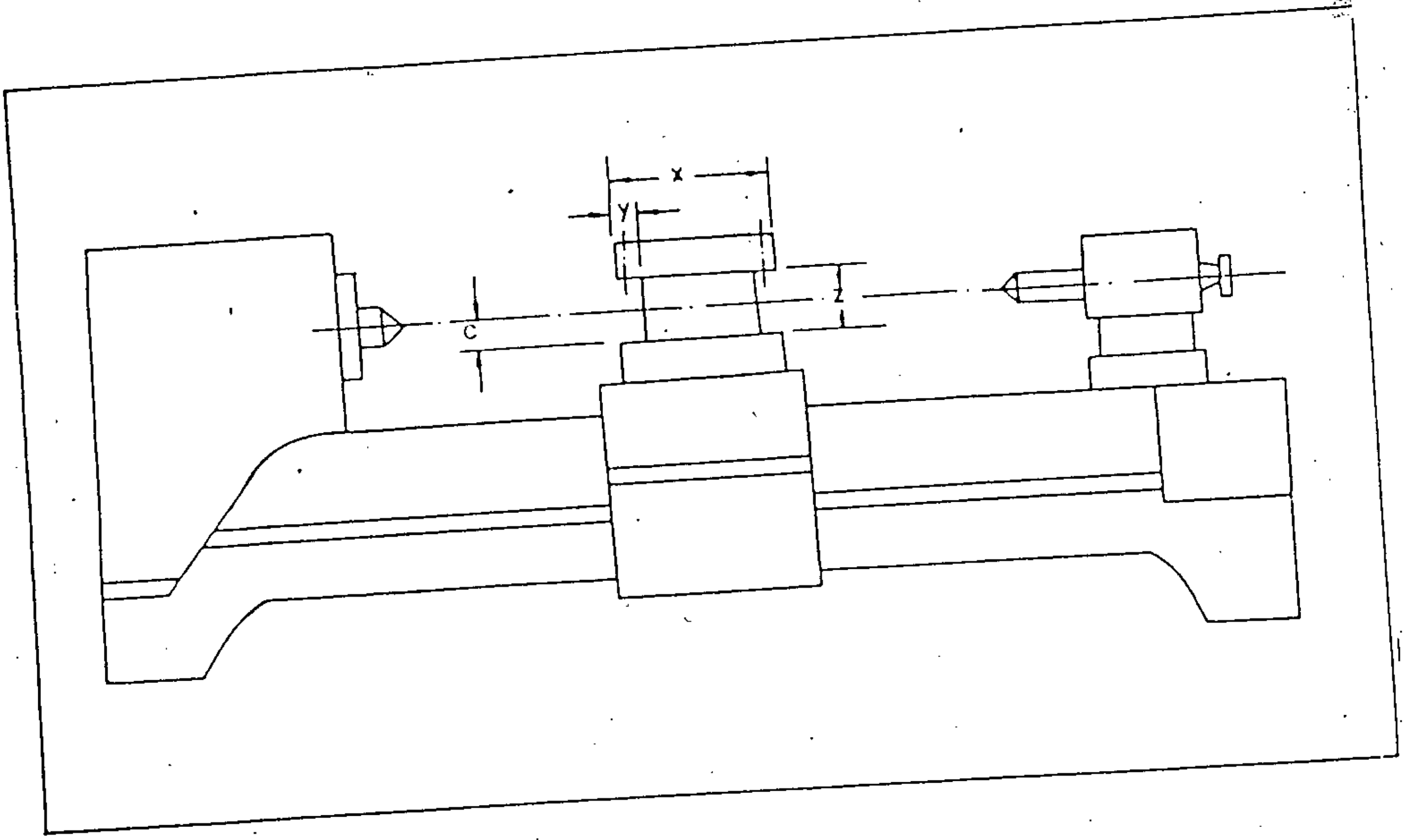


Fig.-2.7 Sketch of lathe

Chapter — III

EXPERIMENTAL WORK

3.1 DETERMINATION OF NATURAL FREQUENCY OF THE DIFFERENT ELEMENTS OF MTFW SYSTEM:

To obtain the natural frequency of the different elements of MTFW system under actual condition it is necessary to take the test data. The following method was actually used to determine the natural frequency. Different elements were vibrated with an electro-mechanical vibrator. The vibrator head is supplied with vibrations at different frequencies from a function generator in the form of alternating current. The result is that a alternating polarity is set-up in the vibrator head which produces a to-and-fro motion of the diaphragm. The frequency of vibration of the diaphragm is the same as that of the A.C. current supplied by the function generator through the amplifier which can be varied from 0.01 Hz to 100 K Hz by means of a graduated disk attached to the function generator. By varying the frequency of the current supplied to the vibrator head, elements attached to the vibrator head were excited to various natural frequencies.

Determination of natural frequency were accomplished by three additional electrical equipment -

(i) Oscilloscope,

(ii) Charge amplifier and

(iii) Pressure transducer.

When any elements of MTFW system vibrates, it causes a change in the pressure acting on the diaphragm of the transducer. The transducer picks up this change in pressure and sends it to the oscilloscope through charge amplifier, where it is reproduced in the oscilloscope screen in the form of vibration signals. The natural frequencies of different elements were determined by exciting these elements into various forced frequencies and the natural frequencies were indicated by the sudden increase in the amplitude of vibration signal on the oscilloscope screen. This occurred when the frequency of forced vibration coincides with the natural frequency of any element. But the experimental data show that the resonance occurs at different exciting frequencies which are not always multiple of each other.

Table - 1 : Tool specification R25Q8NFE66/336

	TOOL HOLDER OVERHANG 30 mm					TOOL HOLDER OVERHANG 50 mm					TOOL HOLDER OVERHANG 65 mm				
No. of Obs.	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt
1	50	58	3333	0.20	0.24	50	66	2500	0.20	0.24	50	67	2500	0.20	0.20
2	100	111	3333	0.72	0.40	100	111	2857	0.88	0.20	100	111	2500	0.80	0.40
3	300	312	2857	1.44	0.80	300	312	2500	1.60	0.40	300	294	2647	1.84	1.04
4	500	526	3000	1.68	0.80	390	400	2750	2.48	0.96	420	416	2500	2.60	2.00
5	660	714	2856	2.40	1.00	530	555	2777	2.56	1.60	500	500	2500	2.40	1.80
6	910	1000	3000	2.24	1.20	840	882	2500	2.96	2.6	780	869	2608	3.70	3.40
7	1000	1111	3333	1.92	1.00	1000	1111	2222	2.48	1.52	1000	1111	2222	2.40	1.80
8	2000	1666	3333	1.44	1.04	2000	1666	3333	1.44	0.88	2000	1818	3636	1.40	1.00

Table - 2 : Tool specification R25Q8NFE66 331

	TOOL HOLDER OVERHANG 30 mm					TOOL HOLDER OVERHANG 50 mm					TOOL HOLDER OVERHANG 65 mm				
No. of Obs.	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt
1	50	66	2428	0.40	0.30	50	66	2500	0.16	0.20	50	57	1428	0.40	0.20
2	100	111	2500	0.96	0.40	100	113	1500	1.44	0.60	100	113	2000	0.96	0.40
3	300	294	3330	2.00	1.20	300	294	1250	3.50	2.00	300	294	1666	1.70	1.00
4	500	526	3000	3.50	1.40	500	500	3000	3.50	1.60	450	500	1428	2.50	1.40
5	650	714	1666	3.00	2.00	650	666	1333	4.0	2.75	500	526	2857	1.8	1.00
6	750	833	2500	1.20	1.20	750	833	2500	2.6	1.40	655	714	1428	3.4	2.20
7	930	1000	2000	3.10	2.00	1000	1111	3333	3.20	2.00	750	833	2500	1.75	1.00
8	1000	1111	2222	2.4	2.0	2000	1818	3636	5.0	3.0	1000	1111	2222	1.80	0.75

Table - 3 : Tool specification R20Q8NFE66331

	TOOL HOLDER OVERHANG 30 mm					TOOL HOLDER OVERHANG 50 mm					TOOL HOLDER OVERHANG 65 mm				
No. of Obs.	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt	Imposed freq. Hz	Real imposed freq. Hz.	Natural freq. Hz.	Ampl.of imposed freq. Volt	Ampl.of natural freq. Volt
1	50	67	2500	0.16	0.12	50	67	2500	0.12	0.10	50	67	2500	0.20	0.16
2	100	117	2000	0.44	0.22	100	111	1250	0.52	0.28	100	117	2857	0.56	0.40
3	300	277	2500	0.68	0.40	300	294	1428	1.00	0.50	300	294	2500	1.40	0.50
4	350	333	2500	0.96	0.60	450	454	1428	1.50	1.00	500	540	2500	1.50	1.00
5	500	500	3333	0.80	0.40	500	500	3000	0.90	0.50	750	833	2500	1.10	0.55
6	750	1250	2500	0.52	0.40	645	714	1428	2.00	1.60	785	869	2608	1.90	1.00
7	900	1000	3000	2.4	1.40	750	769	2307	0.75	0.50	1000	1111	2222	1.00	0.50
8	1000	1111	2222	1.1	0.7	1000	1111	2222	0.75	0.50	2000	1818	3636	1.10	0.50
9	2000	1818	3636	1.25	1.10	2000	1818	3636	0.80	0.40	-	-	-	-	-

Table - 4 : NATURAL FREQUENCY OF TOOL BIT HOLDER AT DIFFERENT OVERHANGS

TOOL	OVERHANG	NATURAL FREQ.
	30 mm	2856 Hzs.
R25Q8NFE66/336	50 mm	2777 Hzs.
	65 mm	2647 Hzs.
	30 mm	3333 Hzs.
R25Q8NFE66331	50 mm	3000 Hzs.
	65 mm	2856 Hzs.
	30 mm	3333 Hzs.
R20Q8NFE66331	50 mm	2856 Hzs.
	65 mm	2608 Hzs.

3.2 EXPERIMENTAL PROCEDURE:

The experiment was performed on a Celtic Lathe with stepped spindle speed, manufactured by Bangladesh Machine Tools Factory having a 4' bed. Machining was done by using single carbide tool of grade BK8 (USSR) having 92% Wc and 8% Co. The carbide tips were brazed on tool bit holders. The following were the cutting conditions:

Feed : 0.13; 0.2 mm/rotation

Depth of cut : 1.0; 1.5 mm

Tool holder overhang : 65 mm; 50 mm; 30 mm

Work piece material : Stainless steel.

Cutting of materials were carried out at normal atmospheric condition. Turning of workpiece was done with various combination of cutting variables and tools. The occurrence of the instability of metal cutting process was determined by the experimental set up. The vibrational signal was picked up by the transducer and fed into the charge amplifier for displaying on to the oscilloscope screen. From these signals, frequencies were determined. The occurrence of the instability was indicated by the sudden increase of the vibration amplitude.

Frequencies of the instability of the metal cutting were determined by the chatter marks on the workpiece. Chips of every turning operations were collected and frequencies were calculated from the vibrational marks on these chips. The distance between two adjacent marks on chip was determined with the help of a microscope. Multiplying this distance by the coefficient of chip shrinkage, the distance between two adjacent marks on job was determined. Frequency F , was calculated using the following formula,

$$F = \frac{V \times 1000}{l} \text{ cps.}$$

where, V = cutting speed, m/sec.

l = distance between two adjacent vibrational marks on job.

Sample calculations:

$$\text{Frequency, } F = \frac{V \times 1000}{l} \text{ cps}$$

Where, v = cutting speed, m/sec.

l = distance between two adjacent vibrational marks on job. mm

Now, l = ks'

where, k = coefficient of chip shrinkage

and s' = distance between two adjacent vibration marks on chip, mm.

$$\text{Again, } k = \frac{3.1428 \times D}{l'}$$

where, D = job diameter, mm.

l' = chip length, mm.

If, D = 80 mm. ; l' = 129.6 mm ;

v = 29.65 m/min. = 0.494 m/sec. and

s' = 0.196 mm ;

then, k = 1.9392 and l = 0.380 mm

So, F = 1300 cps.

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
1	80	0.13	1.0	118	29.65	129.6	1.9392	0.196	1300.11	
2	80	0.13	1.0	130	32.67	129.2	1.9452	0.180	1555.06	
3	80	0.13	1.0	185	46.49	124.1	2.0252	0.182	2102.17	
4	80	0.13	1.0	260	65.34	124.0	2.0268	0.224	2398.62	
5	80	0.13	1.0	375	94.24	112.5	2.2340	0.164	4286.99	

Table - 3.5 : Determination of the influence of rigidity of tool bit holder with cross-sectional area of 25mm x 25mm on chatter during metal cutting process.

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
7	84	0.13	1.5	118	31.13	130.0	2.0299	0.238	1073.9	
8	84	0.13	1.5	130	34.30	138.8	1.9012	0.224	1342.57	
9	84	0.13	1.5	185	48.82	131.3	2.0098	0.220	1840.17	
10	84	0.13	1.5	260	68.61	126.0	2.0943	0.224	2437.41	
11	84	0.13	1.5	375	98.96	140.0	1.8849	0.182	4807.68	
12	84	0.13	1.5	455	120.07	133.2	1.9811	0.140	7214.89	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
13	80	0.2	1.0	118	29.65	130.8	1.9214	0.196	1312.59	
14	80	0.2	1.0	130	32.67	127.0	1.9789	0.242	1135.25	
15	80	0.2	1.0	185	46.49	128.8	1.9512	0.288	1378.76	
16	80	0.2	1.0	260	65.34	128.0	1.9634	0.240	2311.04	
17	80	0.2	1.0	375	94.24	136.8	1.8371	0.268	3190.03	
18	80	0.2	1.0	455	114.35	144.3	1.7417	0.162	6754.54	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
19	84	0.2	1.5	118	31.13	137.8	1.9150	0.288	940.70	
20	84	0.2	1.5	130	34.30	135.0	1.9547	0.250	1169.82	
21	84	0.2	1.5	185	48.82	137.2	1.9234	0.252	1678.69	
22	84	0.2	1.5	260	68.61	143.6	1.8377	0.294	2116.47	
23	84	0.2	1.5	375	98.96	131.5	2.0067	0.290	2834.18	
24	84	0.2	1.5	455	120.07	148.5	1.7770	0.280	4021.96	
24(a)	84	0.2	1.5	590	155.69	151.5	1.7418	0.204	7302.65	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
25	80	0.13	1.0	118	29.65	130.0	1.9332	0.180	1420.11	
26	80	0.13	1.0	130	32.67	130.9	1.9199	0.182	1558.28	
27	80	0.13	1.0	185	46.49	124.7	2.0154	0.162	2373.12	
28	80	0.13	1.0	260	65.34	123.4	2.0366	0.180	2970.50	
29	80	0.13	1.0	375	94.24	122.5	2.0516	0.160	4784.76	
30	80	0.13	1.0	455	114.35	141.3	1.7786	0.140	7653.48	
30(a)	80	0.13	1.0	590	148.28	118.4	2.1226	0.174	6691.04	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
31	84	0.13	1.5	118	31.13	129.3	2.0409	0.200	1271.08	
32	84	0.13	1.5	130	34.30	132.2	1.9961	0.220	1301.73	
33	84	0.13	1.5	185	48.82	133.2	1.9811	0.198	2074.22	
34	84	0.13	1.5	260	68.61	138.8	1.9012	0.222	2709.28	
35	84	0.13	1.5	375	98.96	140.0	1.8849	0.148	5912.15	
36	84	0.13	1.5	455	120.07	149.0	1.7710	0.134	8432.09	
36(a)	84	0.13	1.5	590	155.69	146.5	1.8013	0.224	6430.87	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
37	80	0.2	1.0	118	29.65	136.5	1.8412	0.188	1427.81	
38	80	0.2	1.0	130	32.67	132.7	1.8939	0.192	1497.40	
39	80	0.2	1.0	185	46.49	125.5	2.0026	0.208	1860.16	
40	80	0.2	1.0	260	65.34	137.5	1.8278	0.242	2461.92	
41	80	0.2	1.0	375	94.24	141.5	1.7761	0.226	3886.82	
42	80	0.2	1.0	455	114.35	140.0	1.7951	0.244	4350.94	
42(a)	80	0.2	1.0	590	148.24	134.0	1.8755	0.204	6459.01	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
43	84	0.2	1.5	118	31.13	139.0	1.8985	0.204	1339.62	
44	84	0.2	1.5	130	34.30	140.0	1.8849	0.178	1703.81	
45	84	0.2	1.5	185	48.82	130.9	2.0159	0.204	1978.45	
46	84	0.2	1.5	260	68.61	148.7	1.7746	0.228	2826.07	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
49	80	0.13	1.0	118	29.65	130.6	1.9244	0.212	1211.26	
50	80	0.13	1.0	130	32.67	129.4	1.9422	0.172	1629.91	
51	80	0.13	1.0	185	46.49	127.8	1.9665	0.140	2814.30	
52	80	0.13	1.0	260	65.34	127.2	1.9758	0.168	3280.76	
53	80	0.13	1.0	375	94.24	133.0	1.8896	0.168	4947.50	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
55	84	0.13	1.5	118	31.13	124.3	2.1230	0.258	947.21	
56	84	0.13	1.5	130	34.30	129.2	2.0425	0.172	1627.22	
57	84	0.13	1.5	185	48.82	131.5	1.9767	0.184	2237.11	
58	84	0.13	1.5	260	68.61	128.7	2.0504	0.160	3485.50	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
61	80	0.2	1.0	118	29.65	138.4	1.8159	0.224	1215.06	
62	80	0.2	1.0	130	32.67	133.8	1.8783	0.210	1380.57	
63	80	0.2	1.0	185	46.49	135.3	1.8575	0.230	1813.64	
64	80	0.2	1.0	260	65.34	141.2	1.7799	0.182	3361.64	
65	80	0.2	1.0	375	94.24	141.6	1.7749	0.218	4059.32	
66	80	0.2	1.0	455	114.35	148.0	1.6981	0.242	4637.57	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66/336

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
67	84	0.2	1.5	118	31.13	128.2	2.0584	0.172	1465.40	
68	84	0.2	1.5	130	34.30	133.1	1.9826	0.182	1584.29	
69	84	0.2	1.5	185	48.82	134.7	1.9591	0.252	1648.10	
70	84	0.2	1.5	260	68.61	132.3	1.9946	0.224	2559.28	
71	84	0.2	1.5	375	98.96	117.2	2.2516	0.238	3077.72	
72	84	0.2	1.5	455	120.07	115.2	2.2907	0.266	3284.16	
72(a)	84	0.2	1.5	590	155.69	113.6	2.323	0.188	5941.56	

Table - 3.5 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
73	86	0.13	1.0	95	25.66	139.5	1.936	0.218	1013.40	
74	86	0.13	1.0	130	35.12	133.5	2.023	0.192	1508.59	
75	86	0.13	1.0	185	49.98	129.7	2.083	0.194	2061.88	
76	86	0.13	1.0	230	62.14	127.0	2.127	0.170	2864.12	
77	86	0.13	1.0	260	70.24	132.5	2.039	0.220	2606.68	
78	86	0.13	1.0	375	101.31	133.0	2.031	0.176	4723.07	

Table - 3.6 : Determination of the influence of rigidity of another tool bit holder with same cross-sectional area of 25mm x 25mm on chatter during metal cutting process.

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
79	84	0.13	1.5	95	25.06	133.2	1.981	0.180	1173.22	
80	84	0.13	1.5	130	34.30	128.2	2.058	0.120	2324.25	
81	84	0.13	1.5	185	48.82	128.1	2.060	0.176	2244.59	
82	84	0.13	1.5	230	60.69	125.0	2.111	0.202	2371.82	
83	84	0.13	1.5	260	68.61	129.8	2.033	0.176	3196.01	
84	84	0.13	1.5	375	98.96	126.5	2.086	0.182	4344.92	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
85	86	0.2	1.0	95	25.66	140.5	1.9229	0.258	862.25	
86	86	0.2	1.0	130	35.12	140.0	1.9298	0.246	1233.06	
87	86	0.2	1.0	185	49.98	138.7	1.9479	0.186	2299.11	
88	86	0.2	1.0	230	62.14	136.0	1.9860	0.172	3030.97	
89	86	0.2	1.0	260	70.24	135.5	1.9930	0.206	2850.32	
90	86	0.2	1.0	375	101.31	147.5	1.8317	0.212	4348.21	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
91	84	0.2	1.5	95	25.06	138.0	1.9122	0.262	833.97	
92	84	0.2	1.5	130	34.30	154.0	1.7130	0.212	1573.89	
93	84	0.2	1.5	185	48.82	126.0	2.0943	0.222	1750.19	
94	84	0.2	1.5	230	60.69	133.0	1.9841	0.226	2255.89	
95	84	0.2	1.5	260	68.61	124.5	2.1196	0.228	2366.14	
96	84	0.2	1.5	375	98.96	139.5	1.8917	0.198	4403.40	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
97	86	0.13	1.0	95	25.66	144.2	1.8736	0.220	1037.77	
98	86	0.13	1.0	130	35.12	128.2	2.1070	0.174	1596.35	
99	86	0.13	1.0	185	49.98	135.0	2.0010	0.206	2020.60	
100	86	0.13	1.0	230	62.14	129.7	2.0830	0.194	2562.92	
101	86	0.13	1.0	260	70.24	135.1	1.9998	0.214	2735.66	
102	86	0.13	1.0	375	101.31	135.6	1.9924	0.148	5726.00	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
103	84	0.13	1.5	95	25.06	133.7	1.9737	0.180	1175.59	
104	84	0.13	1.5	130	34.30	125.3	2.1060	0.190	1428.85	
105	84	0.13	1.5	185	48.82	129.1	2.0441	0.166	2397.92	
106	84	0.13	1.5	230	60.69	122.0	2.1630	0.146	3203.27	
107	84	0.13	1.5	260	68.61	129.0	2.0456	0.170	3288.00	
108	84	0.13	1.5	375	98.96	127.0	2.0779	0.194	4091.48	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
109	86	0.2	1.0	95	25.66	144.0	1.8762	0.204	1117.61	
110	86	0.2	1.0	130	35.12	151.5	1.7833	0.198	1657.82	
111	86	0.2	1.0	185	49.98	135.7	1.9909	0.194	2156.62	
112	86	0.2	1.0	230	62.14	130.1	2.0766	0.206	2420.92	
113	86	0.2	1.0	260	70.24	135.6	1.9924	0.218	2690.56	
114	86	0.2	1.0	375	101.31	137.0	1.9720	0.212	4038.85	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
115	84	0.2	1.5	95	25.06	141.0	1.8715	0.174	1282.53	
116	84	0.2	1.5	130	34.30	131.0	2.0144	0.254	1117.40	
117	84	0.2	1.5	185	48.82	125.6	2.1010	0.216	1792.88	
118	84	0.2	1.5	230	60.69	123.8	2.1316	0.176	2696.15	
119	84	0.2	1.5	260	68.61	129.2	2.0425	0.174	3217.51	
120	84	0.2	1.5	375	98.96	133.7	1.9737	0.184	4541.43	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
121	86	0.13	1.0	95	25.66	138.0	1.9578	0.150	1456.62	
122	86	0.13	1.0	130	35.12	129.6	2.0846	0.184	1526.08	
123	86	0.13	1.0	185	49.98	125.5	2.1528	0.176	2198.50	
124	86	0.13	1.0	230	62.14	127.0	2.1273	0.174	2797.86	
125	86	0.13	1.0	260	70.24	126.8	2.1307	0.162	3392.25	
126	86	0.13	1.0	375	101.31	136.1	1.9851	0.178	4778.49	
126(a)	86	0.13	1.0	455	122.93	141.2	1.9134	0.202	5307.24	

Table - 3.6 (Contd.

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
127	84	0.13	1.5	95	25.06	132.6	1.9900	0.186	1128.31	
128	84	0.13	1.5	130	34.30	124.2	2.1247	0.188	1431.12	
129	84	0.13	1.5	185	48.82	119.3	2.2120	0.202	1820.98	
130	84	0.13	1.5	230	60.69	118.6	2.2250	0.182	2497.75	
131	84	0.13	1.5	260	68.61	120.0	2.1991	0.194	2680.31	
132	84	0.13	1.5	375	98.96	124.6	2.1179	0.152	5123.34	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
133	86	0.2	1.0	95	25.66	142.0	1.9026	0.238	944.64	
134	86	0.2	1.0	130	35.12	137.2	1.9692	0.178	1670.03	
135	86	0.2	1.0	185	49.98	142.3	1.9026	0.180	2435.67	
136	86	0.2	1.0	230	62.14	127.2	2.1240	0.194	2513.37	
137	86	0.2	1.0	260	70.24	128.0	2.1100	0.184	3014.23	
138	86	0.2	1.0	375	101.31	127.4	2.1206	0.142	5607.04	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R25Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
139	84	0.2	1.5	95	25.06	136.0	1.9403	0.196	1098.20	
140	84	0.2	1.5	130	34.30	129.6	2.0362	0.192	1462.23	
141	84	0.2	1.5	185	48.82	121.1	2.1791	0.168	2222.55	
142	84	0.2	1.5	230	60.69	116.7	2.2613	0.198	2259.13	
143	84	0.2	1.5	260	68.61	126.0	2.0943	0.162	3370.25	
144	84	0.2	1.5	375	98.96	128.7	2.0504	0.178	4518.95	

Table - 3.6 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
157	86	0.13	1.0	95	25.66	125.0	2.1562	0.152	1305.19	
158	86	0.13	1.0	130	35.12	135.0	2.0013	0.146	2003.25	
159	86	0.13	1.0	185	49.98	124.0	2.1788	0.166	2303.08	
160	86	0.13	1.0	260	70.24	123.6	2.1858	0.140	3825.38	
161	86	0.13	1.0	375	101.31	130.0	2.0782	0.156	5208.00	
162	86	0.13	1.0	455	122.93	138.0	1.9578	0.150	6978.31	

Table - 3.7 : Determination of the influence of rigidity of tool bit holderw with cross-sectional area of 25mm x 20mm on chatter during metal cutting process.

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
163	84	0.13	1.5	95	25.06	128.8	2.0488	0.158	1290.28	
164	84	0.13	1.5	130	34.30	116.0	2.2749	0.154	1631.93	
165	84	0.13	1.5	185	48.82	115.0	2.2947	0.180	1969.89	
166	84	0.13	1.5	260	68.61	113.2	2.3312	0.184	2665.84	
167	84	0.13	1.5	375	98.96	117.4	2.2478	0.140	5241.06	
168	84	0.13	1.5	455	120.07	121.6	2.1701	0.116	7949.31	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
145	86	0.2	1.0	95	25.66	130.0	2.0780	0.216	953.03	
146	86	0.2	1.0	130	35.12	134.0	2.0162	0.148	1961.58	
147	86	0.2	1.0	185	49.98	130.2	2.0750	0.168	2389.45	
148	86	0.2	1.0	230	62.14	133.8	2.0192	0.200	2564.47	
149	86	0.2	1.0	260	70.24	125.8	2.1476	0.210	2595.65	
150	86	0.2	1.0	375	101.31	132.2	2.0436	0.160	5163.73	
150(a)	86	0.2	1.0	455	122.93	141.0	1.9160	0.174	6145.08	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 65 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
151	84	0.2	1.5	95	25.06	141.0	1.8715	0.204	1093.93	
152	84	0.2	1.5	130	34.30	129.0	2.0456	0.236	1184.31	
153	84	0.2	1.5	185	48.82	128.8	2.0488	0.216	1838.56	
154	84	0.2	1.5	216	68.61	133.0	1.9841	0.280	2058.26	
155	84	0.2	1.5	375	98.98	128.0	2.0616	0.194	4123.70	
156	84	0.2	1.5	455	120.07	131.0	2.0144	0.166	5984.35	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
169	86	0.13	1.0	95	25.66	124.9	2.1631	0.186	1062.95	
170	86	0.13	1.0	130	35.12	128.4	2.1041	0.170	1636.33	
171	86	0.13	1.0	185	49.98	123.6	2.1858	0.144	2646.38	
172	86	0.13	1.0	230	62.14	116.0	2.3290	0.102	4927.91	
173	86	0.13	1.0	260	70.24	117.2	2.3052	0.104	7043.02	
174	86	0.13	1.0	375	101.31	131.2	2.0592	0.140	7106.6	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
175	84	0.13	1.5	95	25.06	128.4	2.0552	0.184	1104.45	
176	84	0.13	1.5	130	34.30	119.0	2.2175	0.200	1288.98	
177	84	0.13	1.5	185	48.82	114.0	2.3148	0.144	2440.94	
178	84	0.13	1.5	260	68.61	112.8	2.3394	0.174	2809.09	
179	84	0.13	1.5	375	98.96	123.0	2.1450	0.138	5570.64	
180	84	0.13	1.5	455	120.07	120.0	2.1991	0.118	7711.75	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
181	86	0.2	1.0	95	25.66	139.0	1.9437	0.246	894.61	
182	86	0.2	1.0	130	35.12	132.5	2.0390	0.216	1328.97	
183	86	0.2	1.0	185	49.98	136.4	1.9807	0.278	1512.79	
184	86	0.2	1.0	260	70.24	133.2	2.0283	0.194	2975.00	
185	86	0.2	1.0	375	101.31	128.0	2.1107	0.170	4705.58	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 50 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
187	84	0.2	1.5	95	25.06	137.8	1.9150	0.244	893.84	
188	84	0.2	1.5	130	34.30	132.5	1.9916	0.270	1063.17	
189	84	0.2	1.5	185	48.82	135.3	1.9504	0.172	2425.95	
190	84	0.2	1.5	260	68.61	133.2	1.9811	0.190	3037.91	
191	84	0.2	1.5	375	98.96	139.0	1.8985	0.238	3650.20	
192	84	0.2	1.5	455	120.07	144.4	1.8275	0.132	8295.59	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
193	86	0.13	1.0	95	25.66	142.3	1.8986	0.192	1173.29	
194	86	0.13	1.0	130	35.12	120.0	2.2514	0.194	1340.09	
195	86	0.13	1.0	185	49.98	127.7	2.1157	0.176	2237.04	
196	86	0.13	1.0	260	70.24	129.0	2.0943	0.158	3538.89	
197	86	0.13	1.0	375	101.31	134.4	2.0102	0.114	7369.95	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
199	84	0.13	1.5	95	25.06	111.0	2.3774	0.128	1372.5	
200	84	0.13	1.5	130	34.30	129.4	2.0393	0.200	1401.58	
201	84	0.13	1.5	185	48.82	126.7	2.0828	0.214	1825.51	
202	84	0.13	1.5	260	68.61	124.6	2.1179	0.228	2368.04	
203	84	0.13	1.5	375	98.98	137.6	1.9178	0.118	7288.12	
204	84	0.13	1.5	455	120.07	142.0	1.8584	0.142	7583.22	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
205	86	0.2	1.0	95	25.66	122.5	2.2055	0.238	814.73	
206	86	0.2	1.0	130	35.12	129.0	2.0940	0.176	1587.93	

Table - 3.7 (Contd.)

TOOL SPECIFICATION : R20Q8NFE66331

OVER HANG : 30 mm

No. of Obs.	Job dia (D) mm/rev.	Feed (S) mm/rev	Depth of cut (d) mm	R.P.M. (N)	Cutting speed (v) m/min	Chip length (l') mm	Coefficient of shrinkage $k = \frac{D}{l'}$	Distance between to adjacent vibration marks on Chip(S')mm	Frequency (F_1) (From Chip) Hz.	Frequency (F_2) (From photograph) Hz.
211	84	0.2	1.5	95	25.06	138.5	1.9053	0.172	1274.44	
212	84	0.2	1.5	130	34.30	138.4	1.9067	0.224	1338.48	
213	84	0.2	1.5	185	48.82	133.0	1.9841	0.212	1934.40	
214	84	0.2	1.5	260	68.61	157.0	1.6808	0.176	3865.39	
215	84	0.2	1.5	375	98.96	154.8	1.7047	0.190	5092.09	
216	84	0.2	1.5	455	120.07	148.6	1.7758	0.210	5366.03	

Table - 3.7 (Contd.)

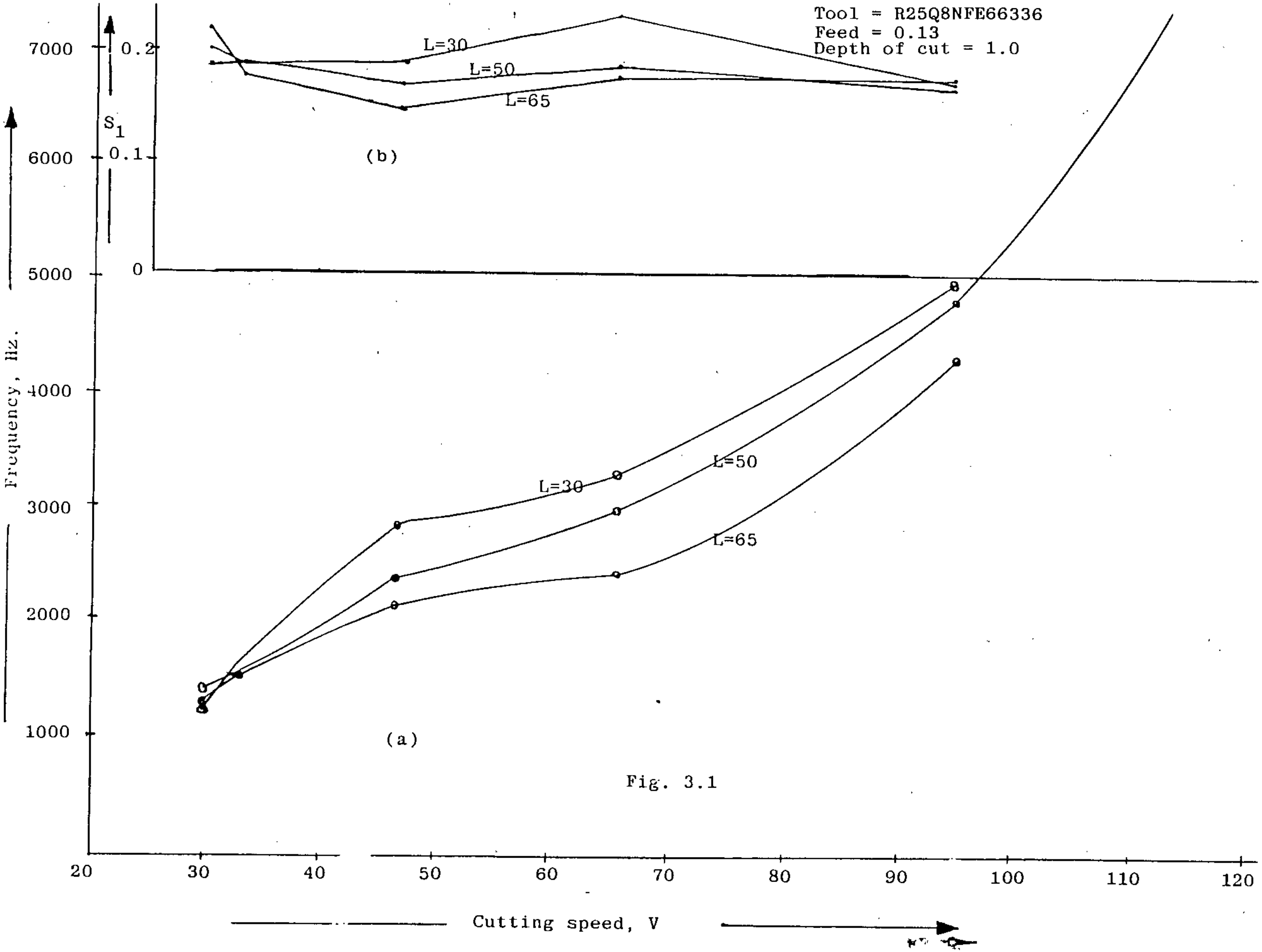

Tool = R25Q8NFE66336
Feed = 0.13
Depth of cut = 1.0
L=30
L=50
L=65
(b)
(a)
S_1
0.2
0.1
0
7000
6000
5000
4000
3000
2000
1000
Frequency, Hz.
20
30
40
50
60
70
80
90
100
110
120
Cutting speed, V

Fig. 3.1

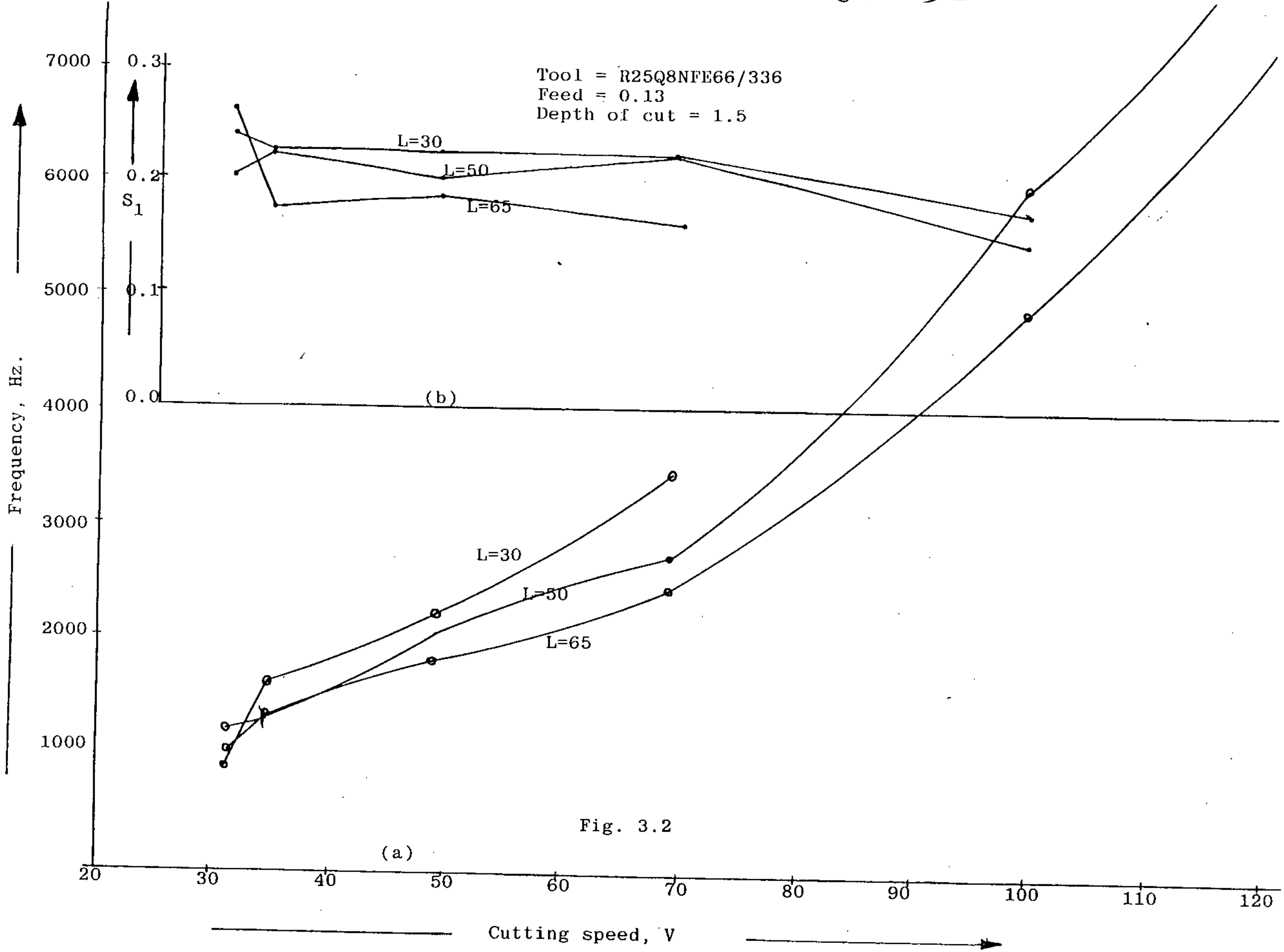

Tool = R25Q8NFE66/336
Feed = 0.13
Depth of cut = 1.5
7000
6000
5000
4000
3000
2000
1000
0.3
0.2
0.1
0.0
S_1
L=30
L=50
L=65
(b)
L=30
L=50
L=65
Frequency, Hz.
(a)
20
30
40
50
60
70
80
90
100
110
120
Cutting speed, V

Fig. 3.2

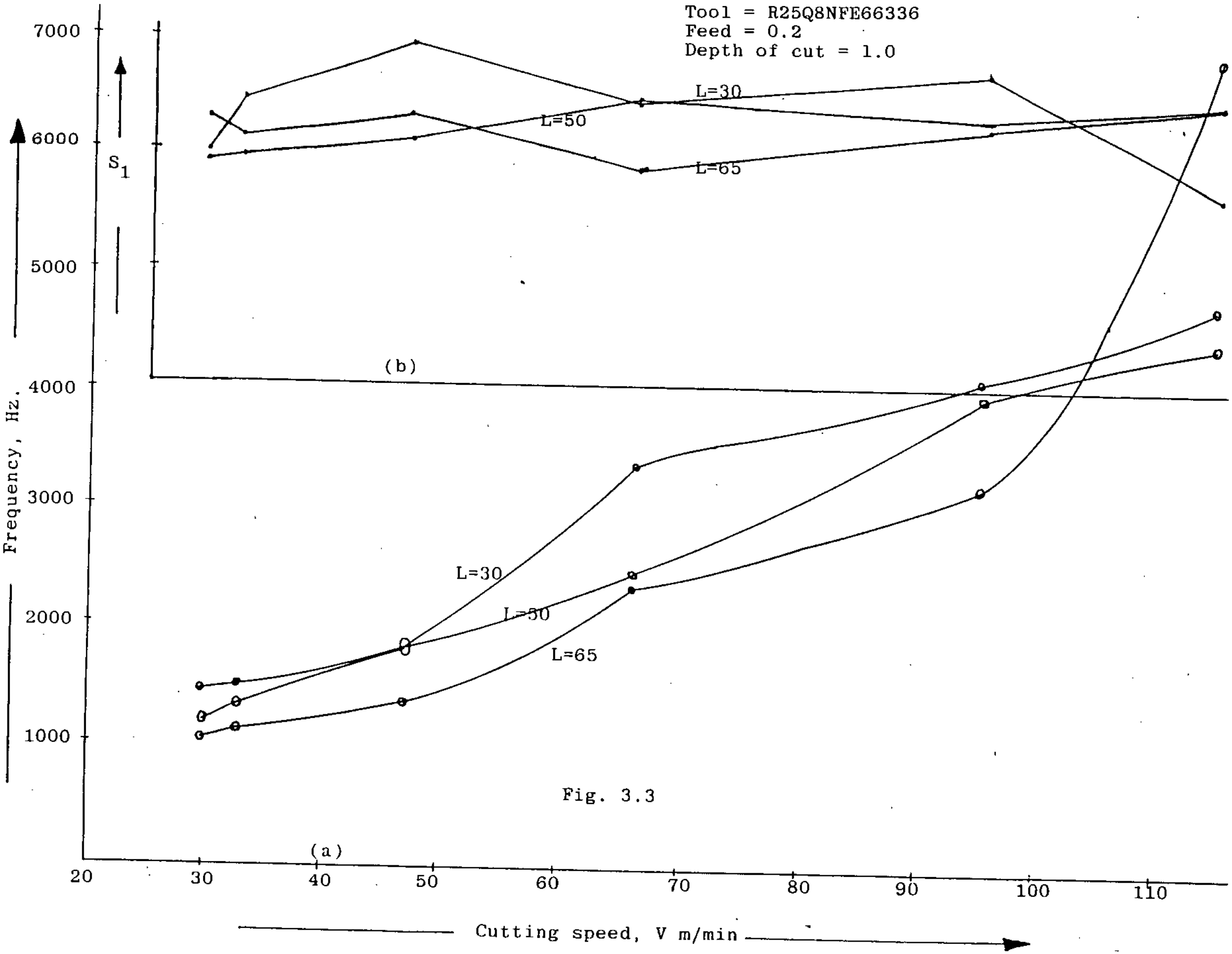

Tool = R25Q8NFE66336
Feed = 0.2
Depth of cut = 1.0
7000
6000
5000
4000
3000
2000
1000
Frequency, Hz.
S1
L=30
L=50
L=65
(b)
L=30
L=50
L=65
(a)
20
30
40
50
60
70
80
90
100
110
Cutting speed, V m/min

Fig. 3.3

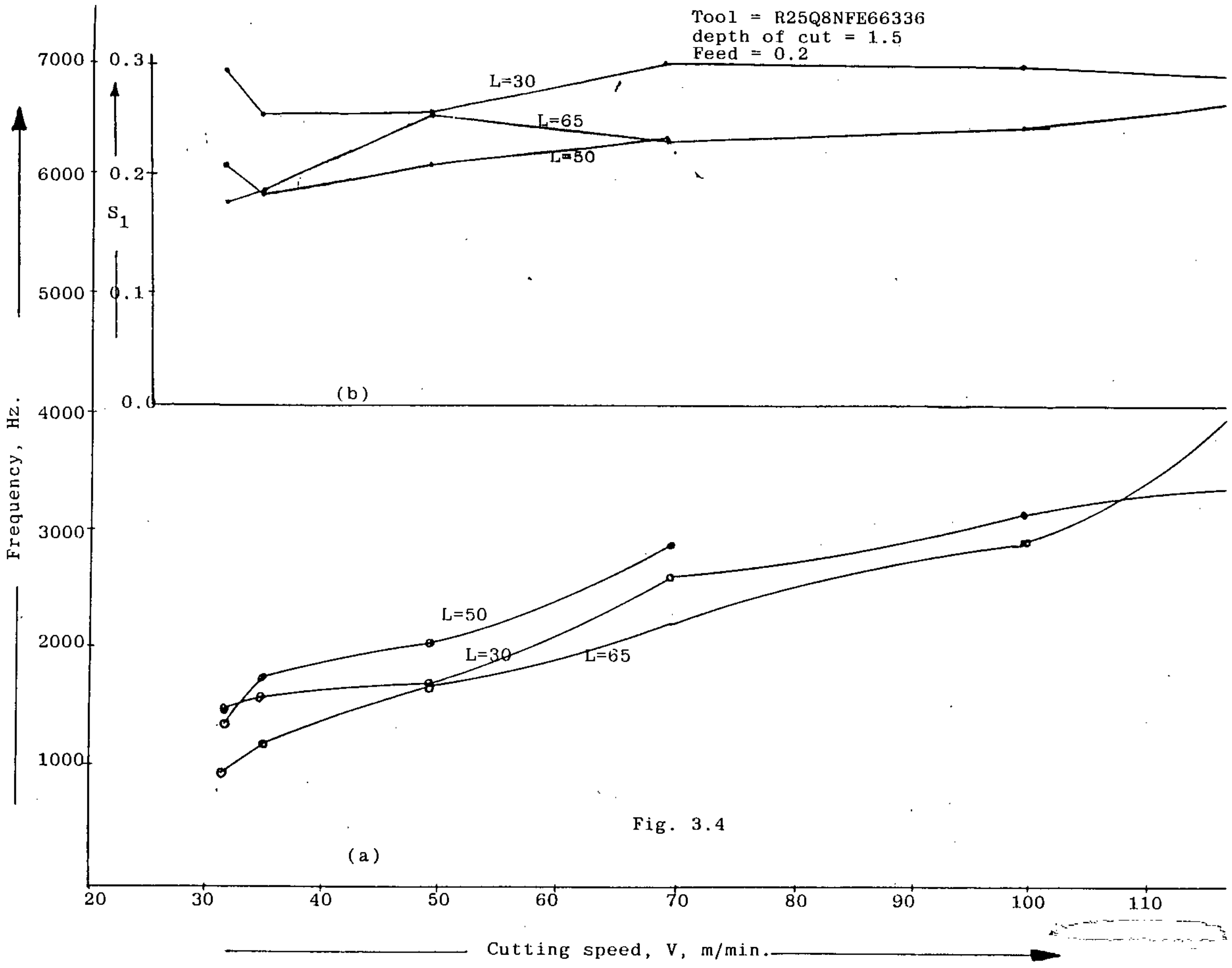
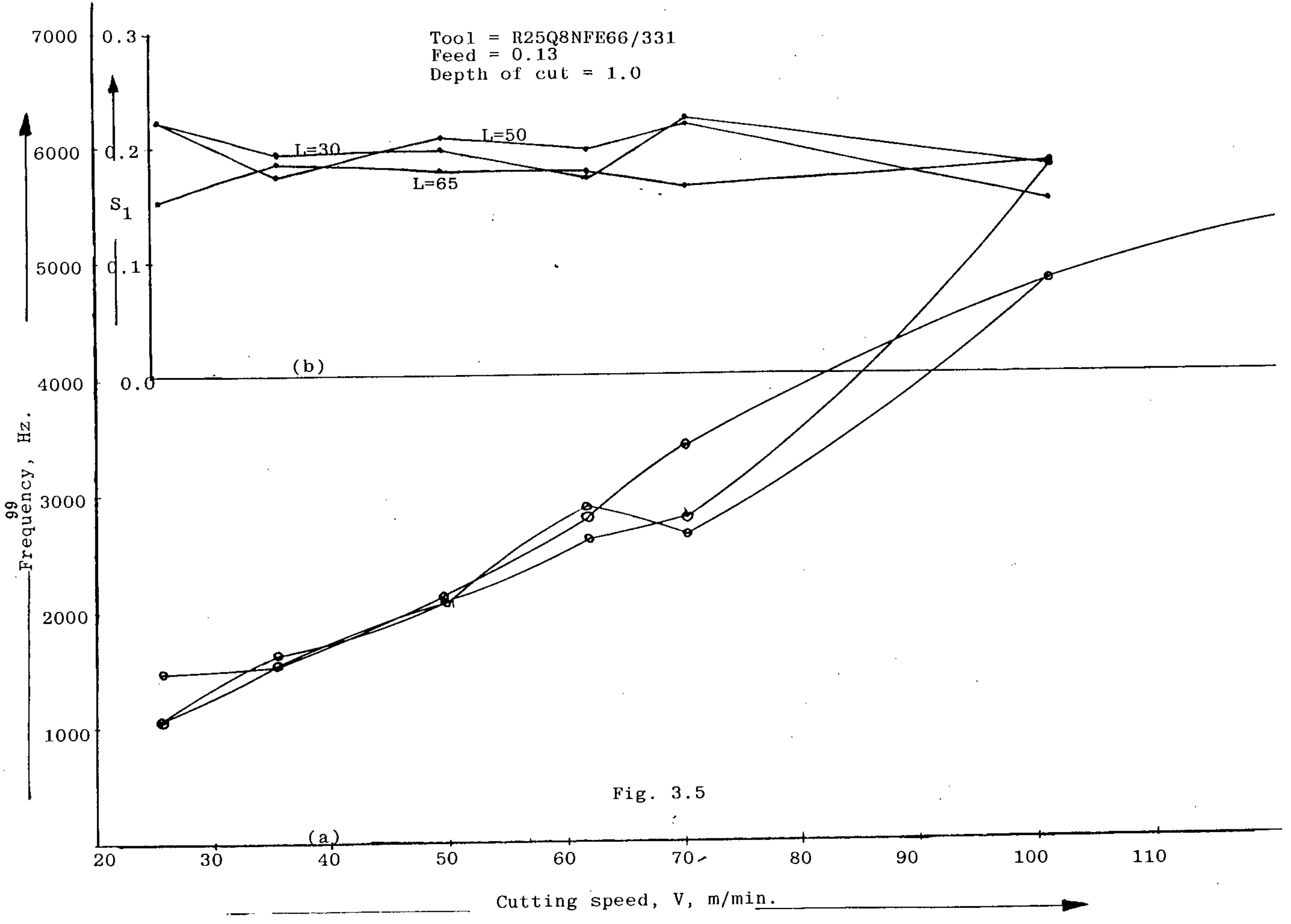

Tool = R25Q8NFE66336
depth of cut = 1.5
Feed = 0.2
7000
6000
5000
4000
3000
2000
1000
0.3
0.2
0.1
0.0
S_1
L=30
L=65
L=50
(b)
Frequency, Hz.
L=50
L=30
L=65
(a)
20
30
40
50
60
70
80
90
100
110
Cutting speed, V, m/min.

Fig. 3.4



Tool = R25Q8NFE66/331
Feed = 0.13
Depth of cut = 1.0
L=30
L=50
L=65
S1
(b)
(a)
7000
6000
5000
4000
3000
2000
1000
0.3
0.2
0.1
0.0
Frequency, Hz.
20
30
40
50
60
70
80
90
100
110
Cutting speed, V, m/min.

Fig. 3.5

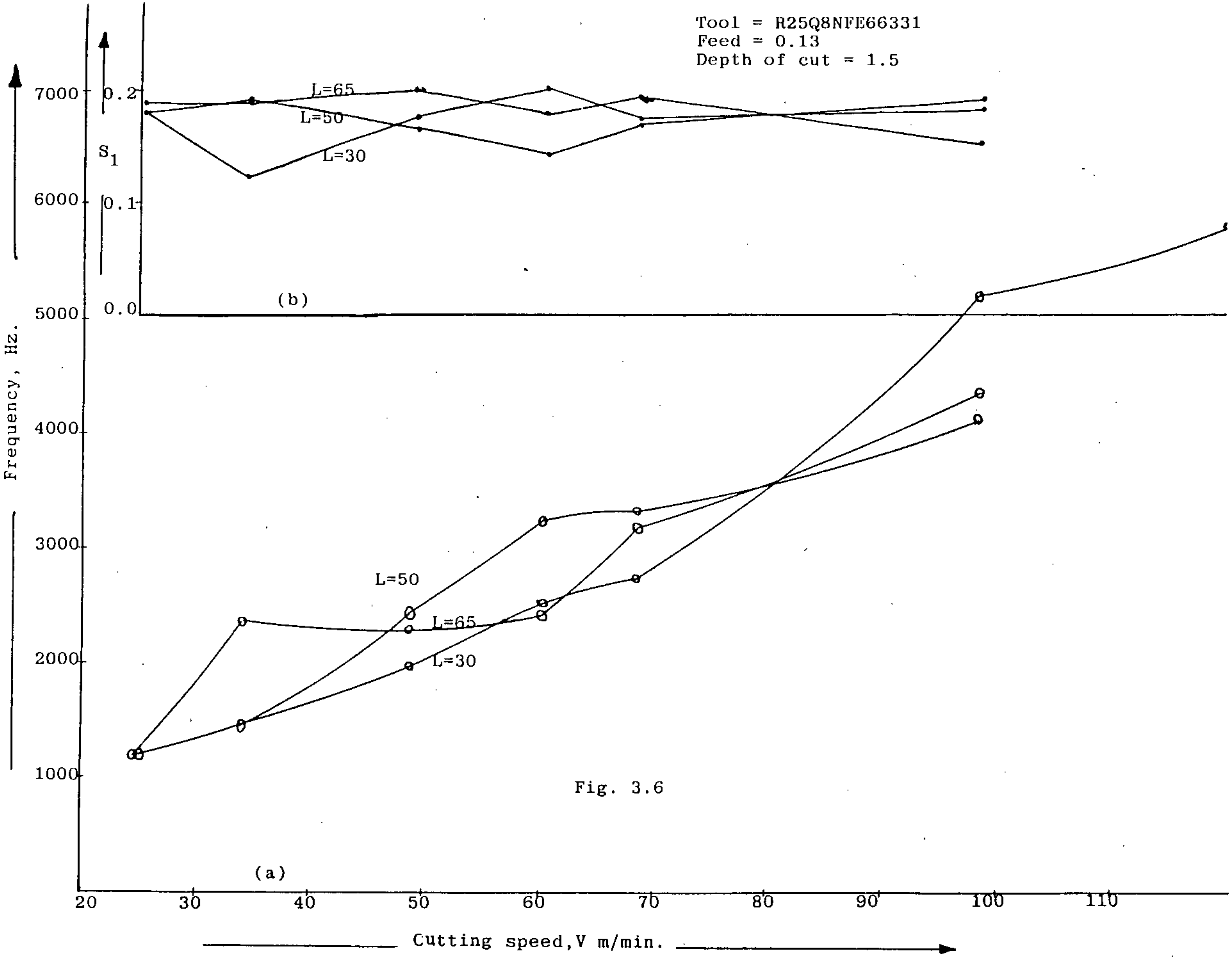
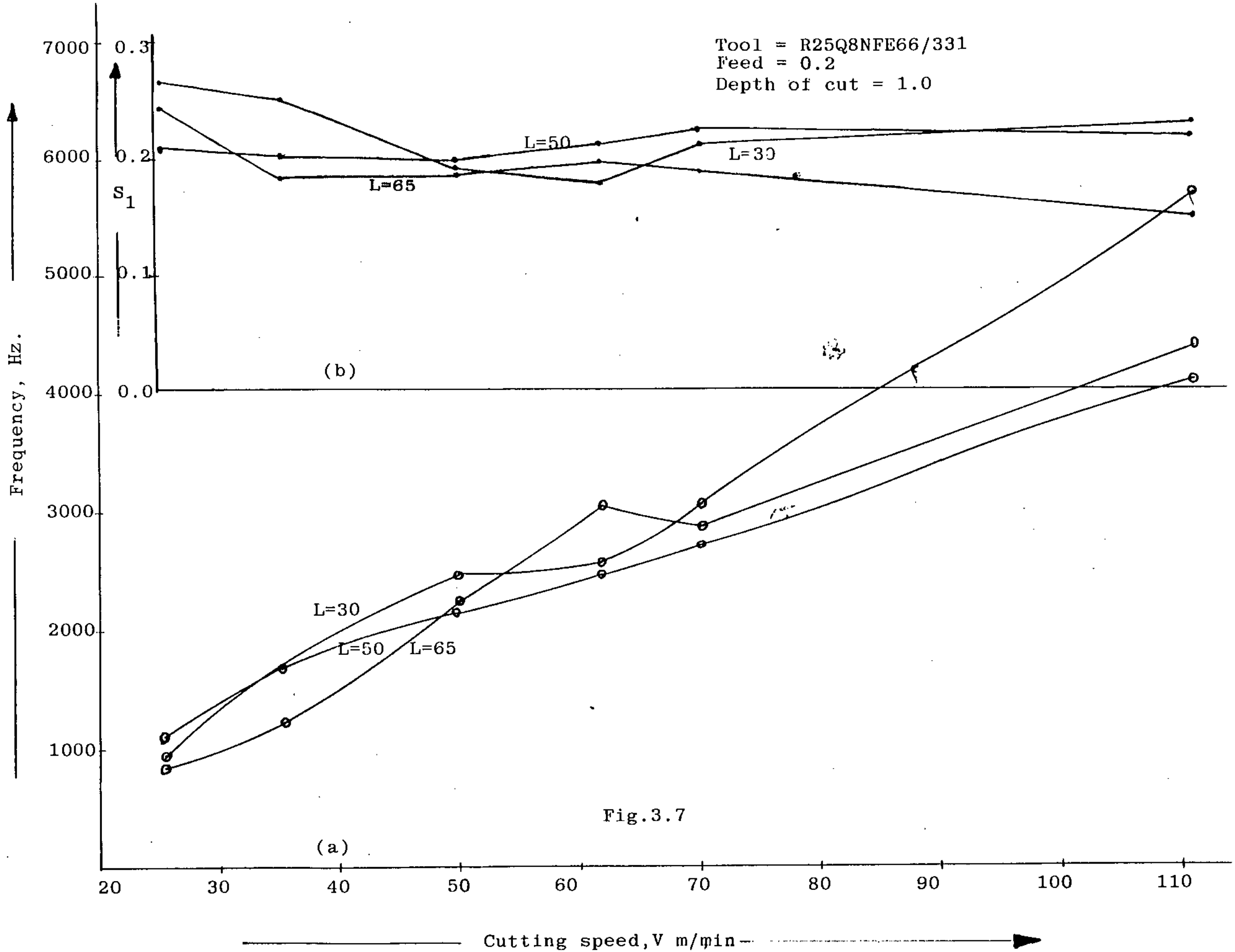

Tool = R25Q8NFE66331
Feed = 0.13
Depth of cut = 1.5
L=65
L=50
L=30
S_1
0.2
0.1
0.0
(b)
7000
6000
5000
4000
3000
2000
1000
Frequency, Hz.
L=50
L=65
L=30
(a)
20
30
40
50
60
70
80
90
100
110
Cutting speed,V m/min.

Fig. 3.6



Tool = R25Q8NFE66/331
Feed = 0.2
Depth of cut = 1.0
7000
6000
5000
4000
3000
2000
1000
0.3
0.2
0.1
0.0
S_1
L=50
L=30
L=65
(b)
Frequency, Hz.
L=30
L=50
L=65
(a)
20
30
40
50
60
70
80
90
100
110
Cutting speed,V m/min

Fig.3.7

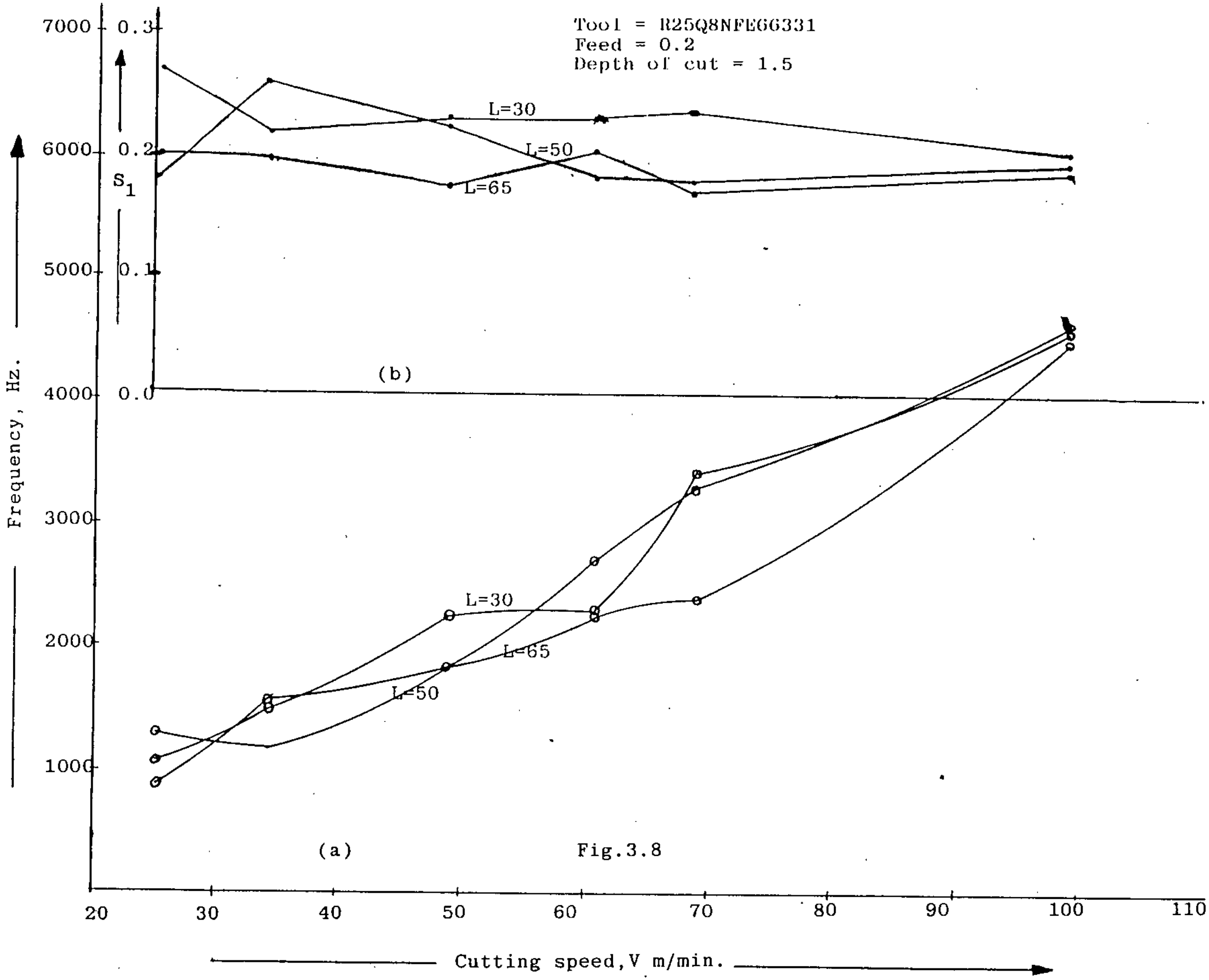

Tool = R25Q8NFE66331
Feed = 0.2
Depth of cut = 1.5
7000
6000
5000
4000
3000
2000
1000
0.3
0.2
0.1
0.0
S_1
L=30
L=50
L=65
(b)
L=30
L=65
L=50
(a)
20
30
40
50
60
70
80
90
100
110
Frequency, Hz.
Cutting speed, V m/min.

Fig.3.8

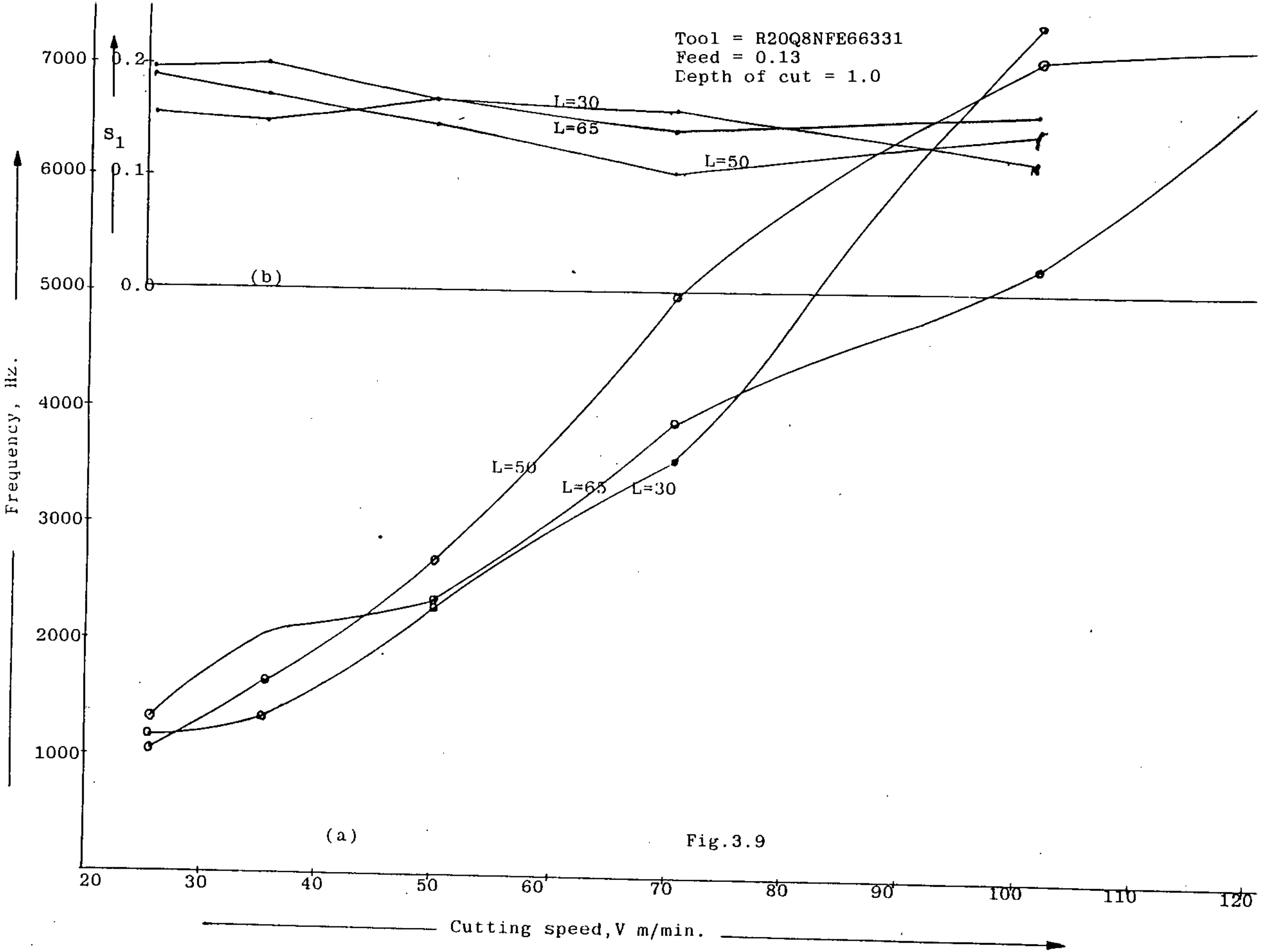

Tool = R20Q8NFE66331
Feed = 0.13
Depth of cut = 1.0
S_1
0.2
0.1
0.0
L=30
L=65
L=50
(b)
Frequency, Hz.
7000
6000
5000
4000
3000
2000
1000
L=50
L=65
L=30
(a)
20
30
40
50
60
70
80
90
100
110
120
Cutting speed, V m/min.

Fig.3.9

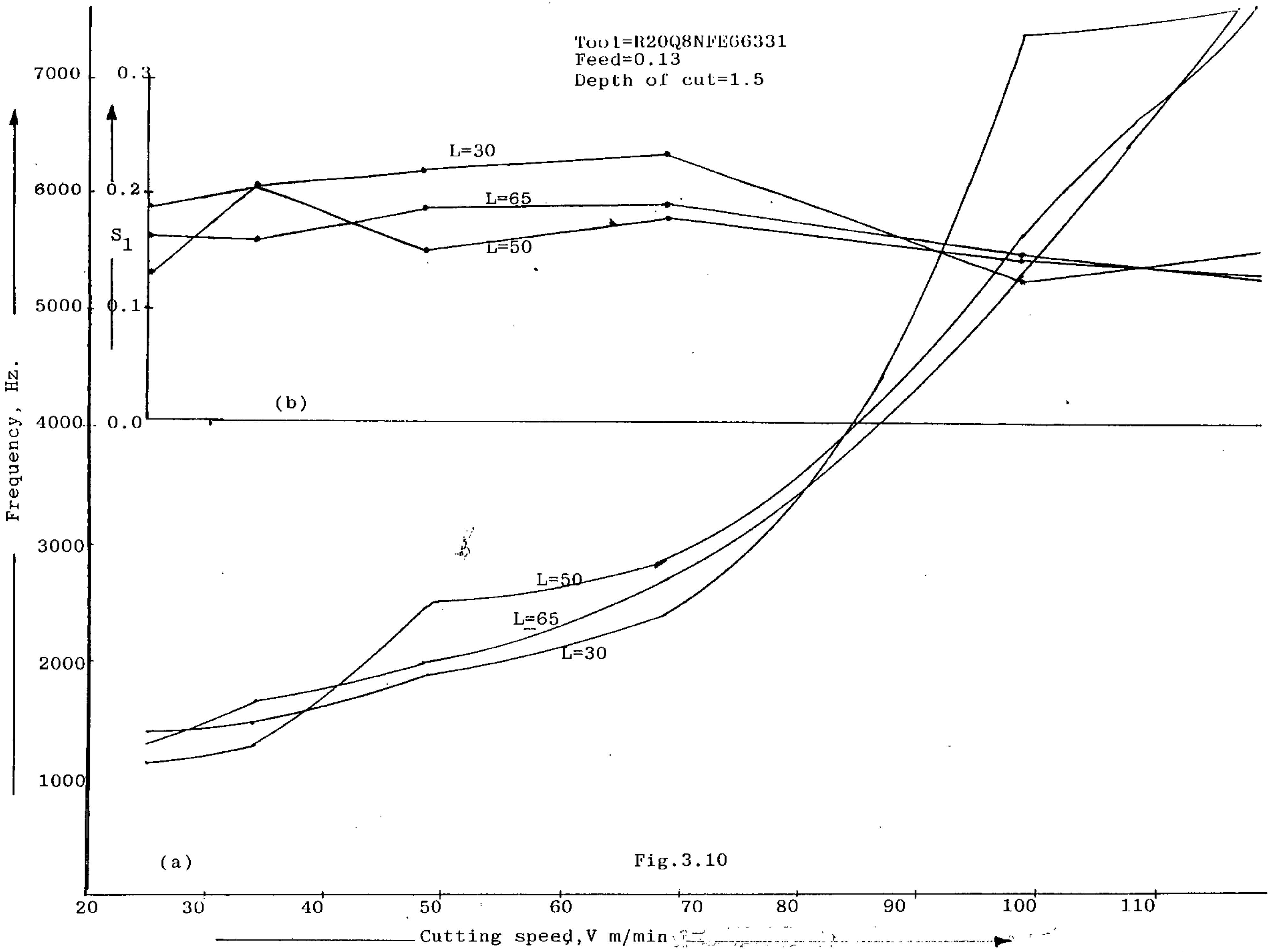

Tool=R20Q8NFEG6331
Feed=0.13
Depth of cut=1.5
Frequency, Hz.
S_1
L=30
L=65
L=50
(b)
(a)
7000
6000
5000
4000
3000
2000
1000
0.3
0.2
0.1
0.0
20
30
40
50
60
70
80
90
100
110
Cutting speed, V m/min

Fig.3.10

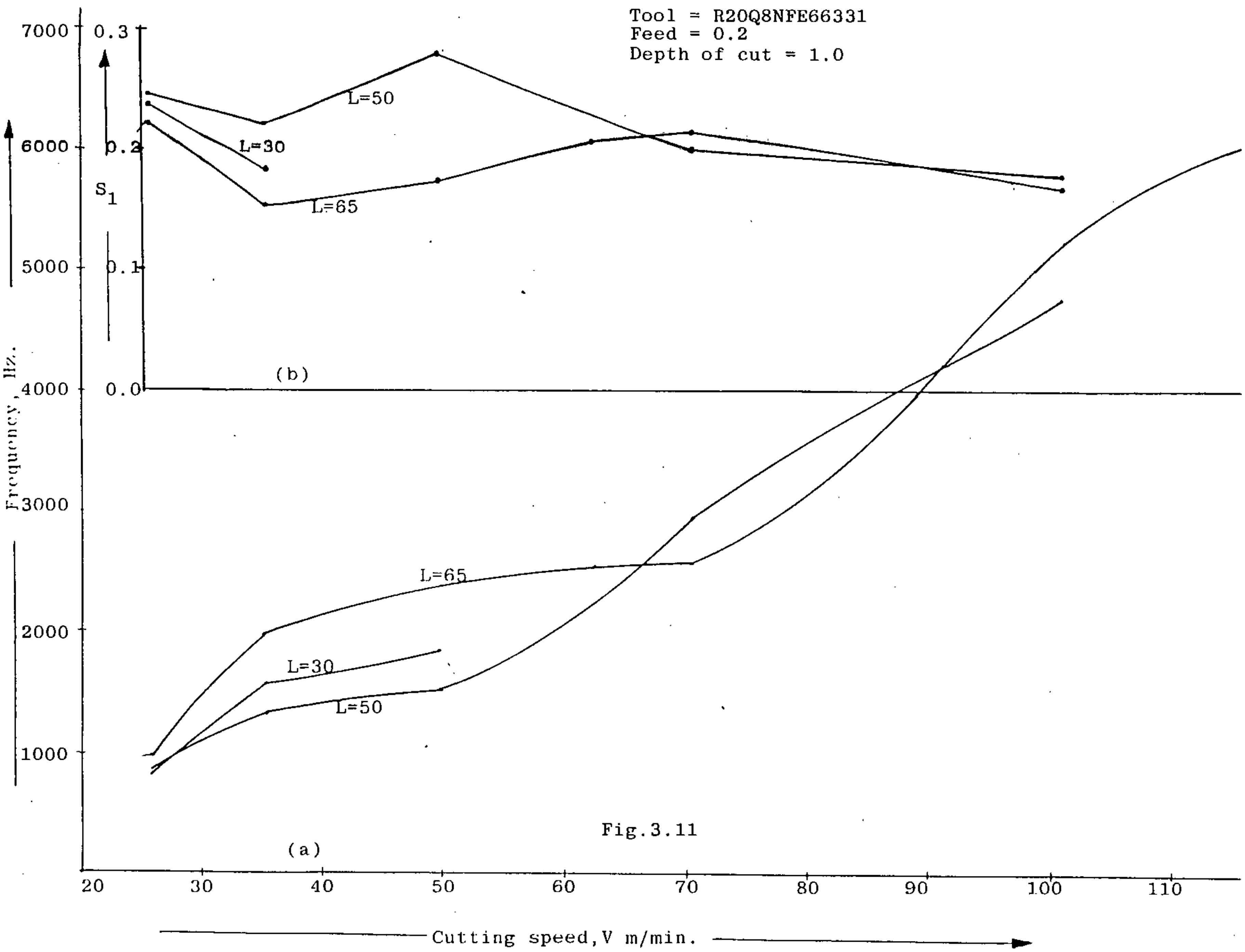

Tool = R20Q8NFE66331
Feed = 0.2
Depth of cut = 1.0
L=50
L=30
L=65
S_1
(b)
L=65
L=30
L=50
(a)
Frequency, Hz.
Cutting speed, V m/min.
7000
6000
5000
4000
3000
2000
1000
0.3
0.2
0.1
0.0
20
30
40
50
60
70
80
90
100
110

Fig.3.11

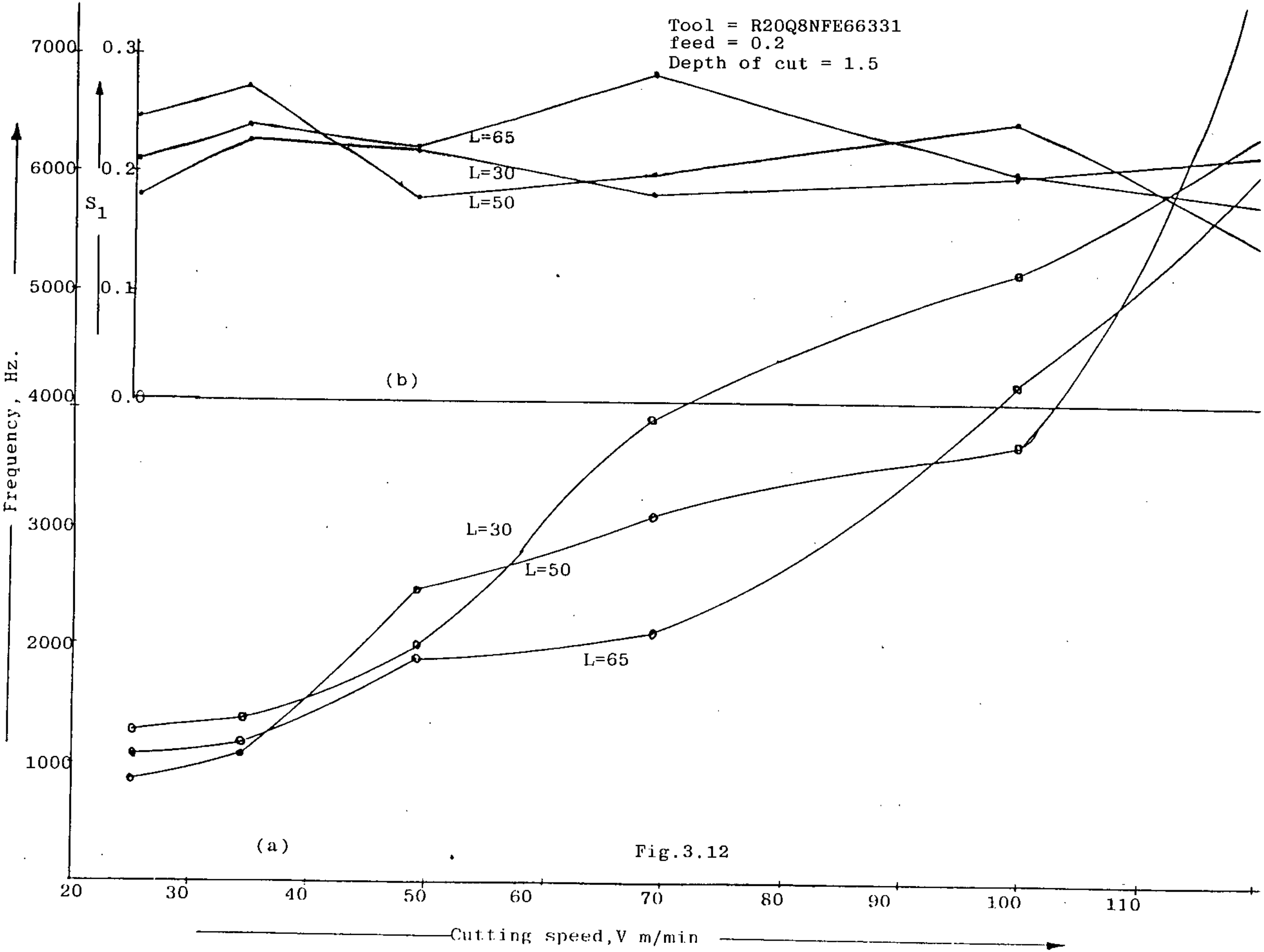
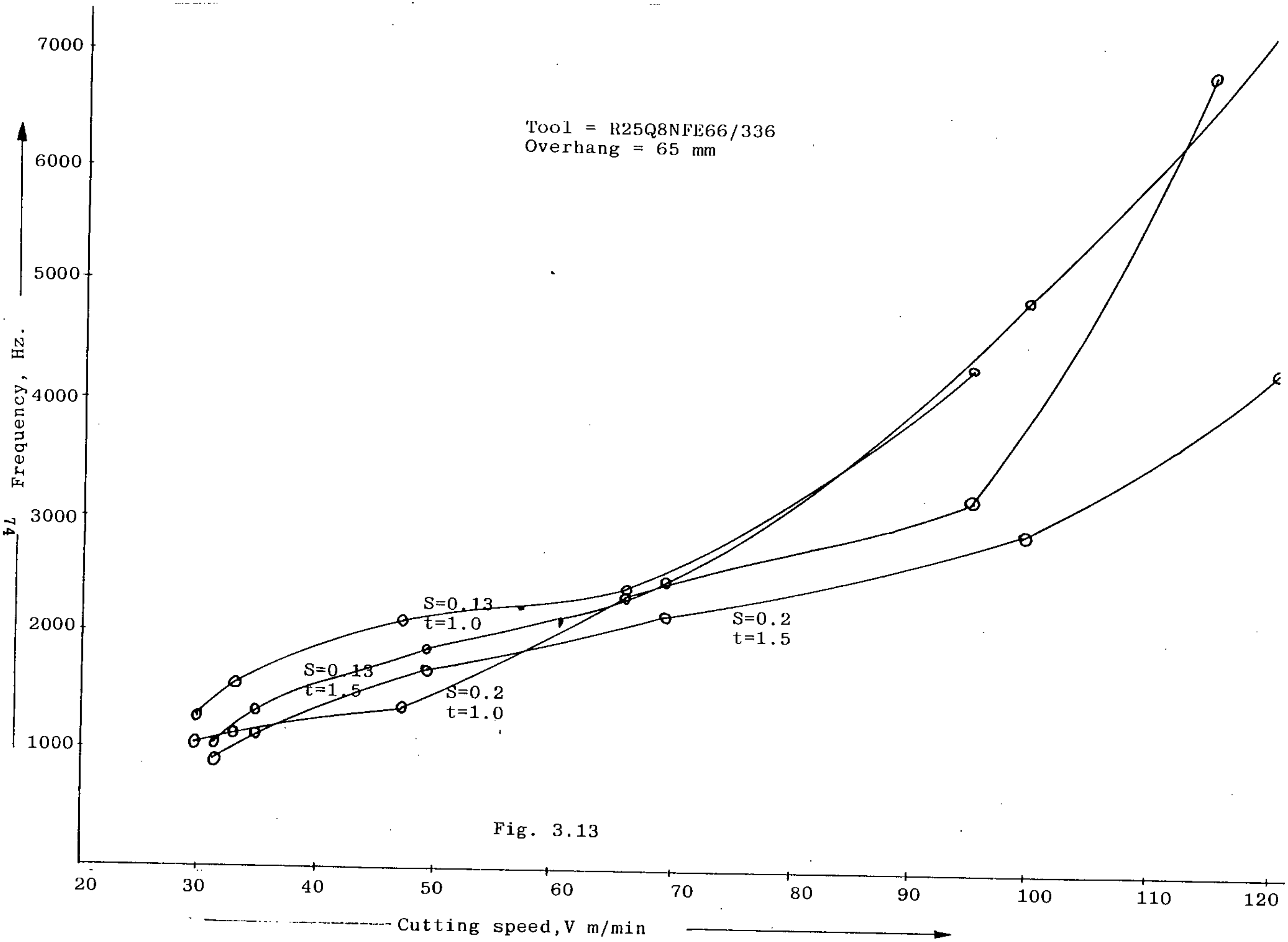

Tool = R20Q8NFE66331
feed = 0.2
Depth of cut = 1.5
L=65
L=30
L=50
(b)
S_1
0.3
0.2
0.1
0.0
7000
6000
5000
4000
3000
2000
1000
Frequency, Hz.
L=30
L=50
L=65
(a)
20
30
40
50
60
70
80
90
100
110
Cutting speed,V m/min

Fig.3.12



Tool = R25Q8NFE66/336
Overhang = 65 mm
Frequency, Hz.
7000
6000
5000
4000
3000
2000
1000
S=0.13
t=1.0
S=0.13
t=1.5
S=0.2
t=1.0
S=0.2
t=1.5
20
30
40
50
60
70
80
90
100
110
120
Cutting speed,V m/min

Fig. 3.13

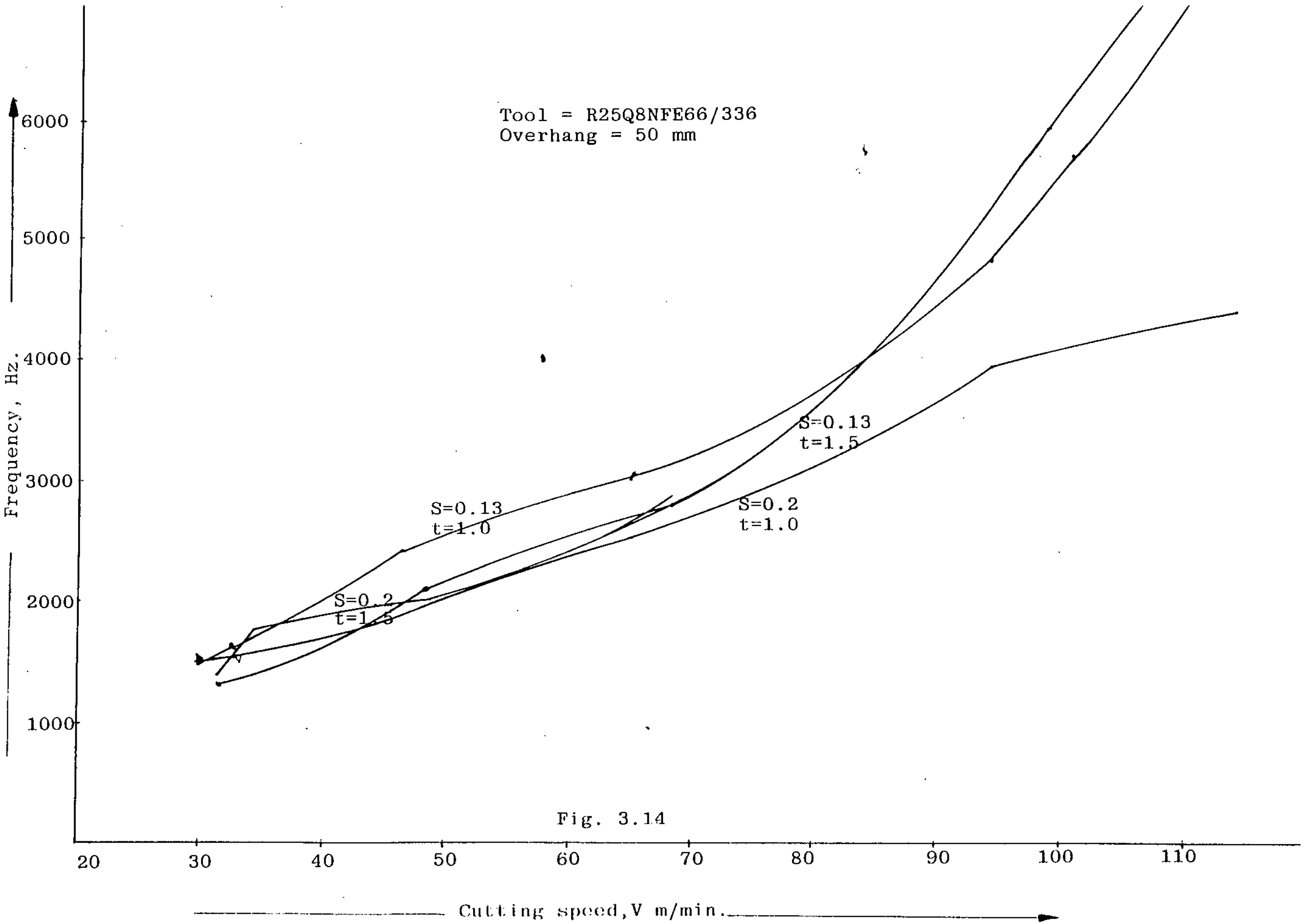

Tool = R25Q8NFE66/336
Overhang = 50 mm
Frequency, Hz.
6000
5000
4000
3000
2000
1000
S=0.13
t=1.0
S=0.2
t=1.5
S=0.13
t=1.5
S=0.2
t=1.0
20
30
40
50
60
70
80
90
100
110
Cutting speed,V m/min.

Fig. 3.14

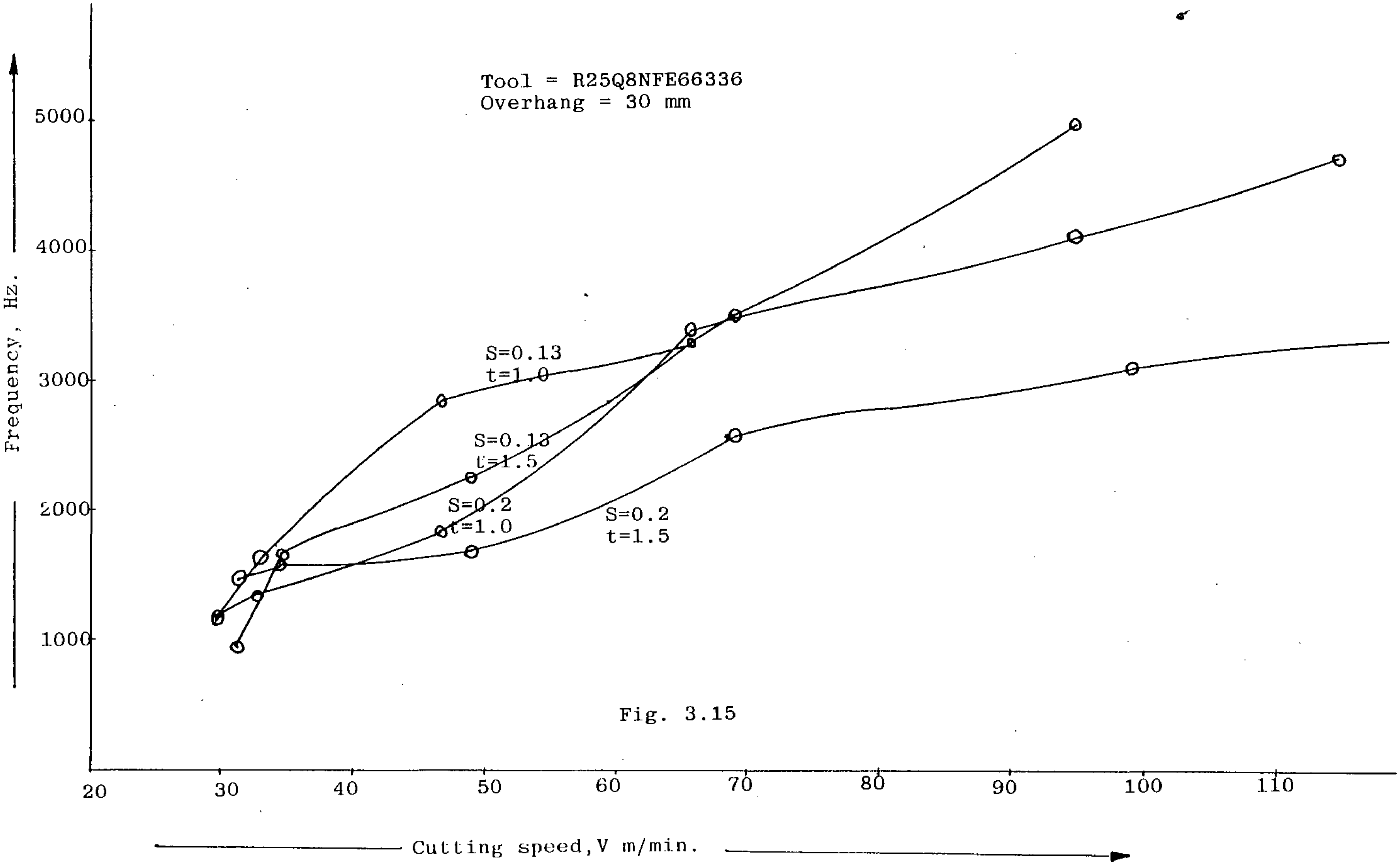

Tool = R25Q8NFE66336
Overhang = 30 mm
Frequency, Hz.
5000
4000
3000
2000
1000
S=0.13
t=1.0
S=0.13
t=1.5
S=0.2
t=1.0
S=0.2
t=1.5
20
30
40
50
60
70
80
90
100
110
Cutting speed, V m/min.

Fig. 3.15

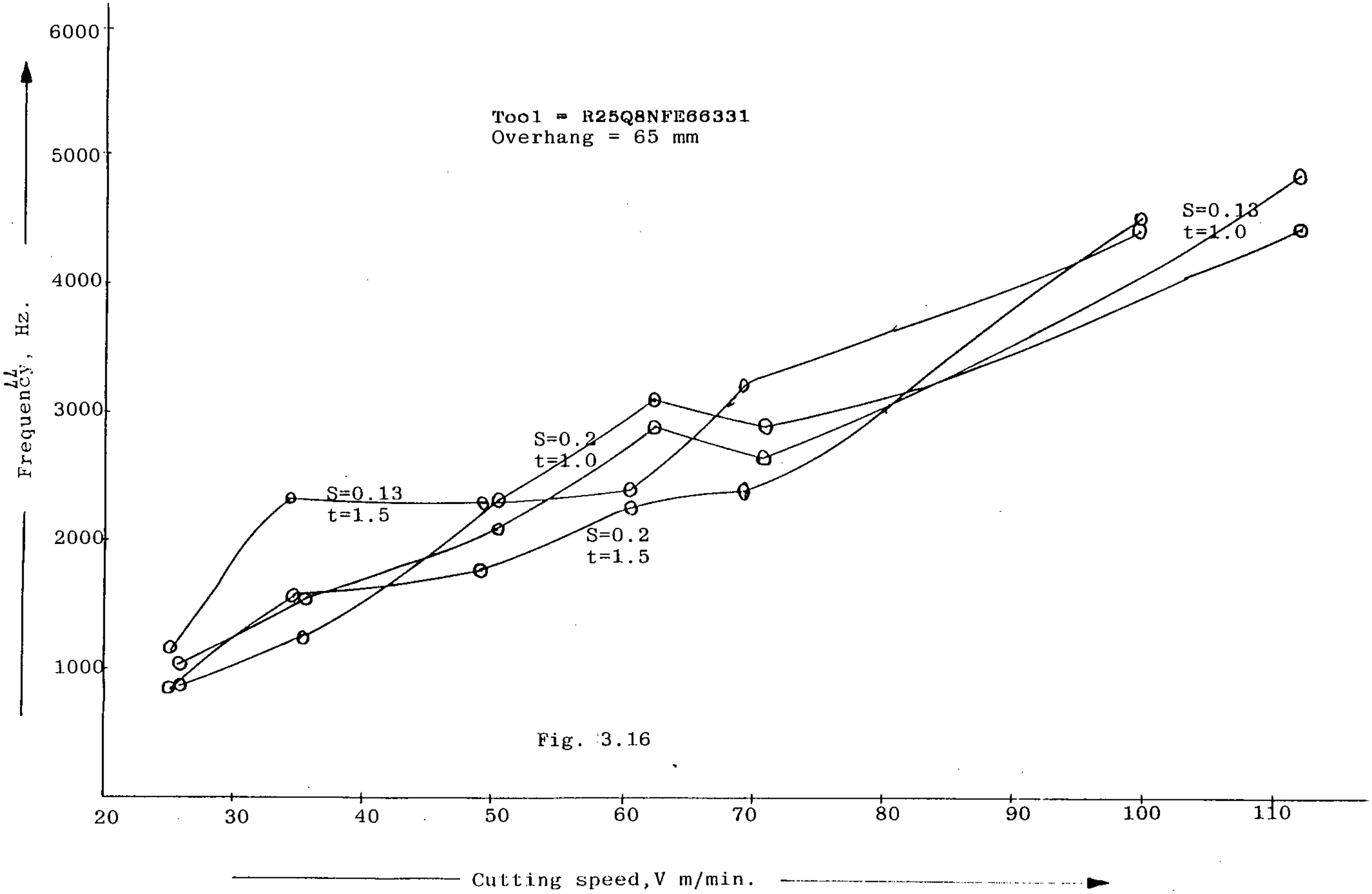

Tool = R25Q8NFE66331
Overhang = 65 mm
Frequency, Hz.
6000
5000
4000
3000
2000
1000
S=0.13
t=1.5
S=0.2
t=1.0
S=0.2
t=1.5
S=0.13
t=1.0
20
30
40
50
60
70
80
90
100
110
Cutting speed,V m/min.

Fig. 3.16

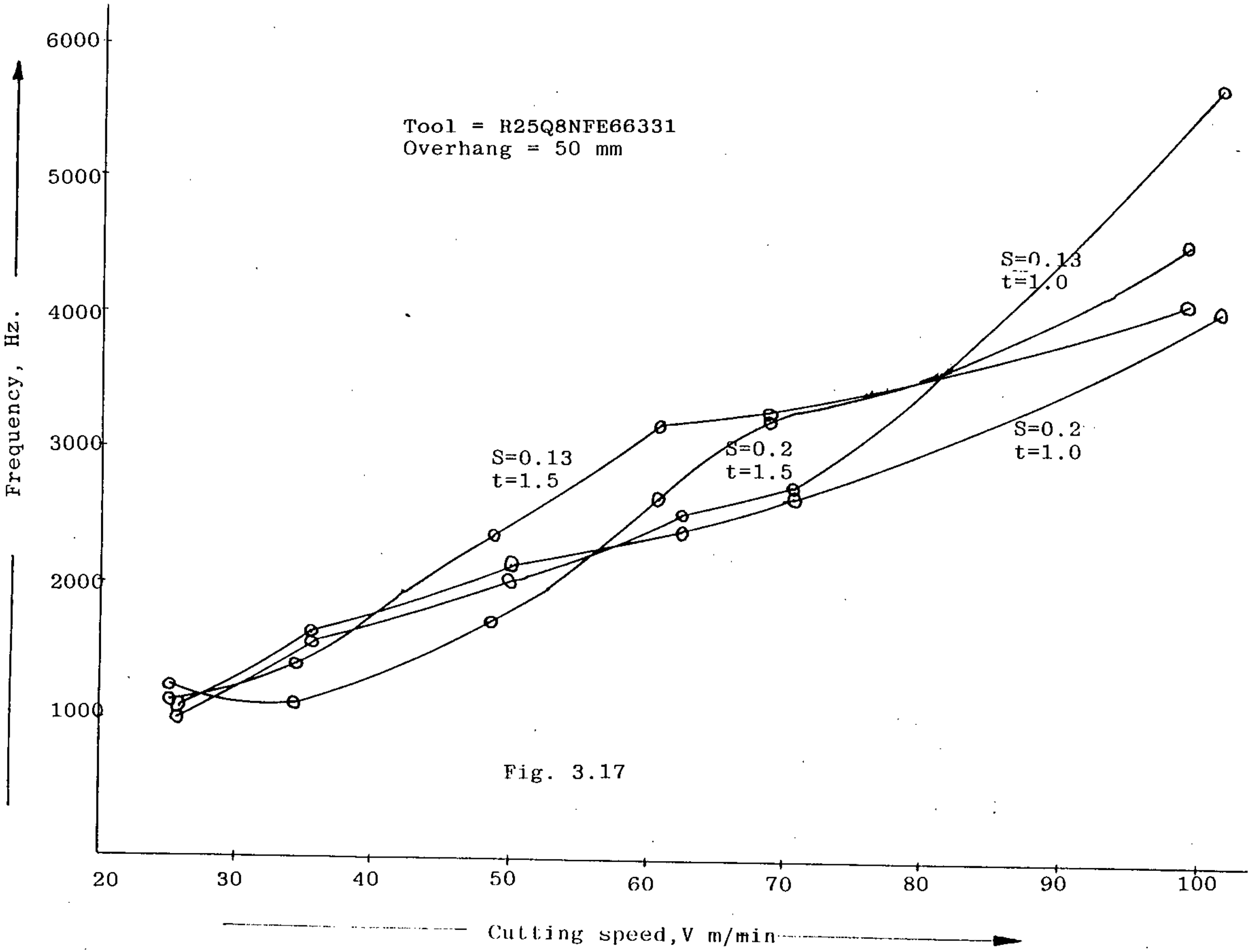
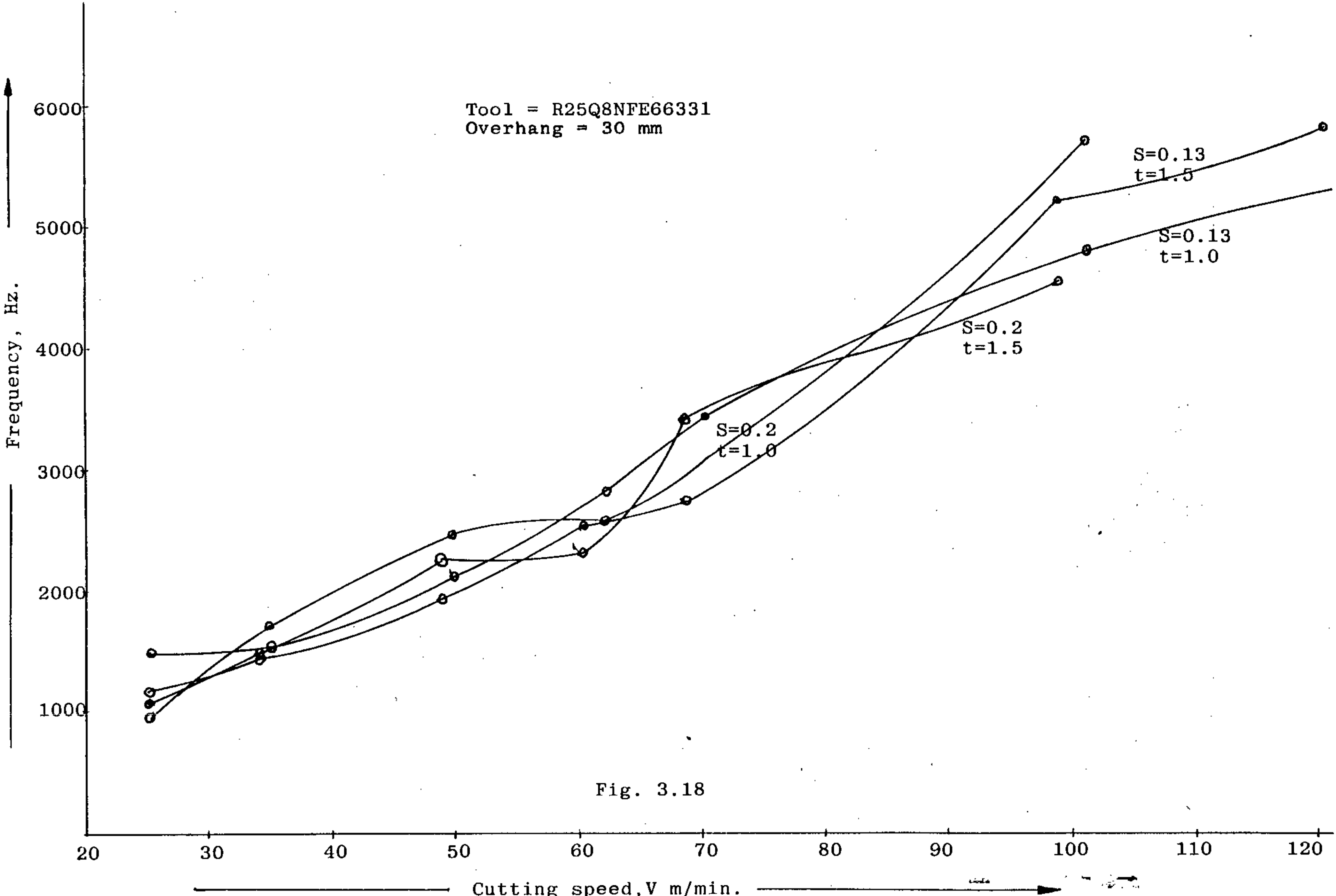
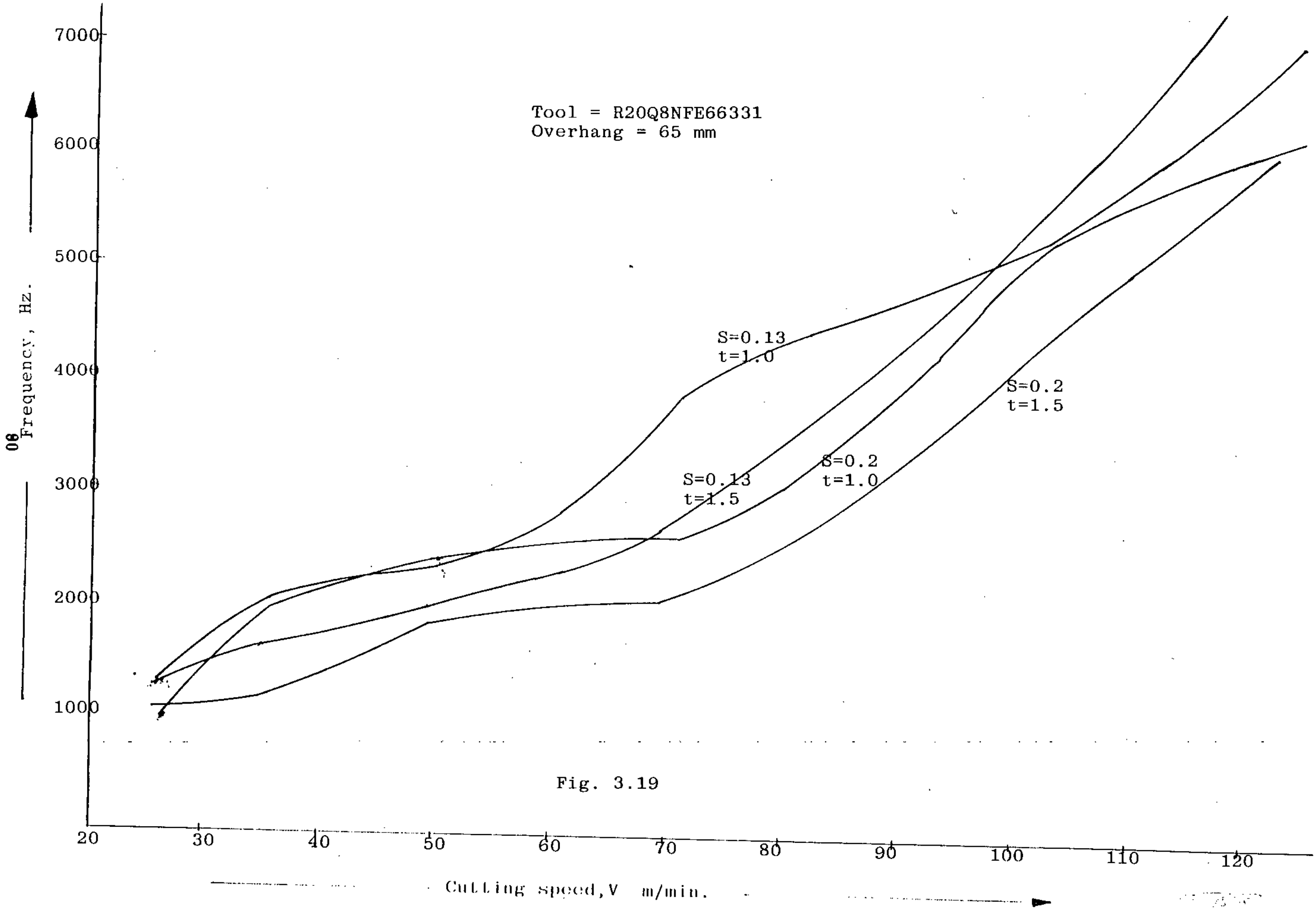

Tool = R25Q8NFE66331
Overhang = 50 mm
Frequency, Hz.
6000
5000
4000
3000
2000
1000
S=0.13
t=1.0
S=0.13
t=1.5
S=0.2
t=1.5
S=0.2
t=1.0
20
30
40
50
60
70
80
90
100
Cutting speed,V m/min

Fig. 3.17



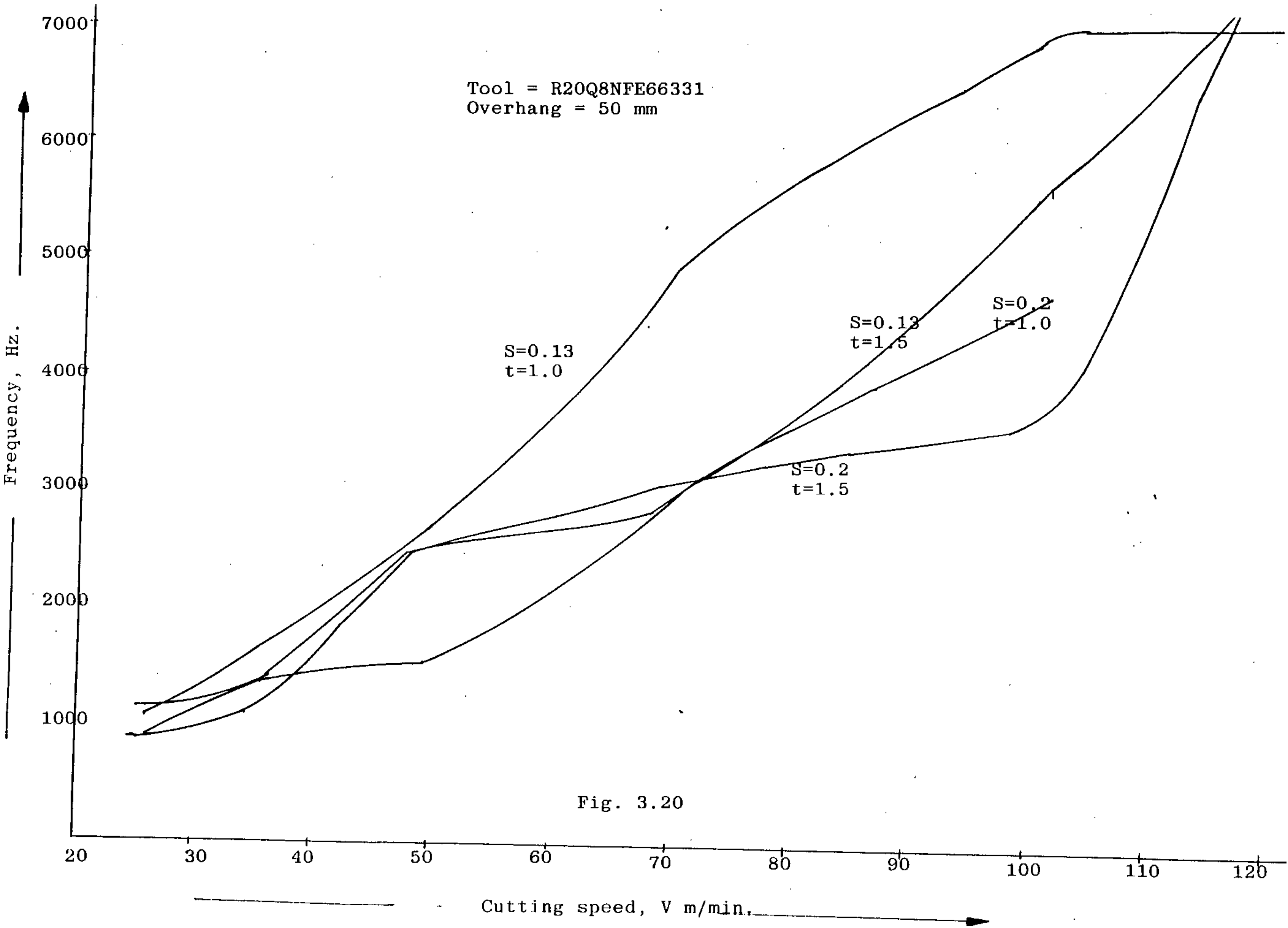
Tool = R25Q8NFE66331
Overhang = 30 mm
S=0.13
t=1.5
S=0.13
t=1.0
S=0.2
t=1.5
S=0.2
t=1.0
Frequency, Hz.
6000
5000
4000
3000
2000
1000
20
30
40
50
60
70
80
90
100
110
120
Cutting speed,V m/min.

Fig. 3.18



Tool = R20Q8NFE66331
Overhang = 65 mm
S=0.13
t=1.0
S=0.13
t=1.5
S=0.2
t=1.0
S=0.2
t=1.5
Frequency, Hz.
7000
6000
5000
4000
3000
2000
1000
20
30
40
50
60
70
80
90
100
110
120
Cutting speed,V m/min.

Fig. 3.19



Tool = R20Q8NFE66331
Overhang = 50 mm
7000
6000
5000
4000
3000
2000
1000
Frequency, Hz.
S=0.13
t=1.0
S=0.13
t=1.5
S=0.2
t=1.0
S=0.2
t=1.5
20
30
40
50
60
70
80
90
100
110
120
Cutting speed, V m/min.

Fig. 3.20

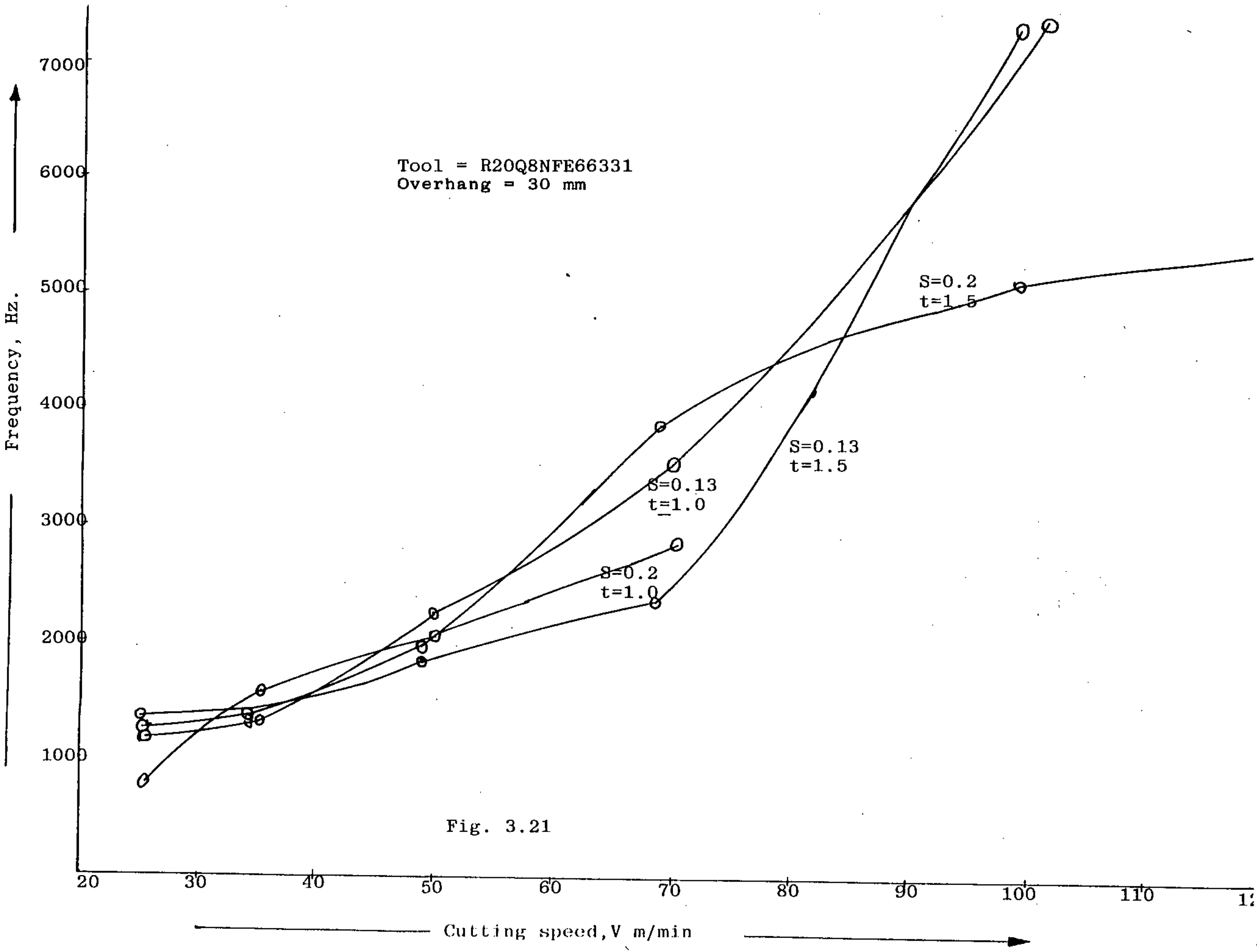
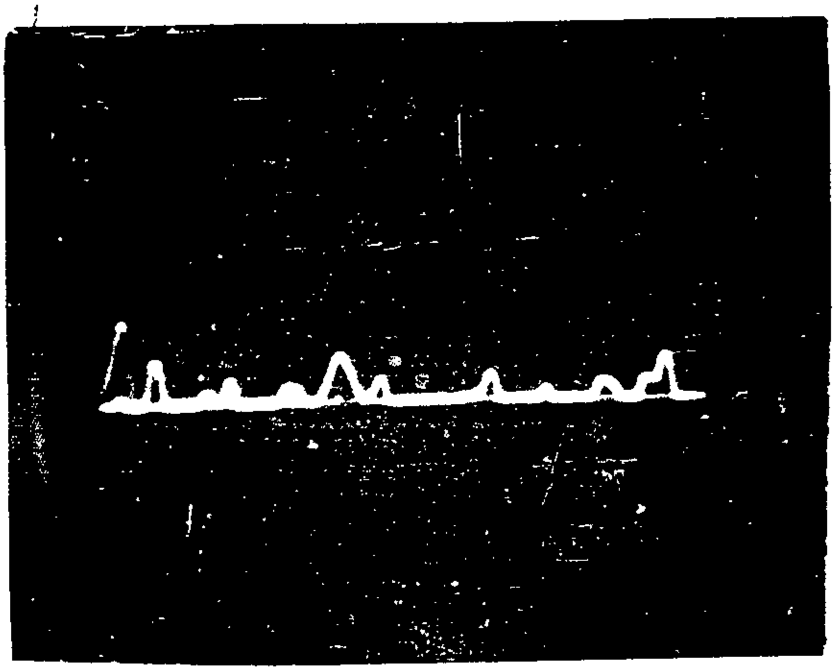
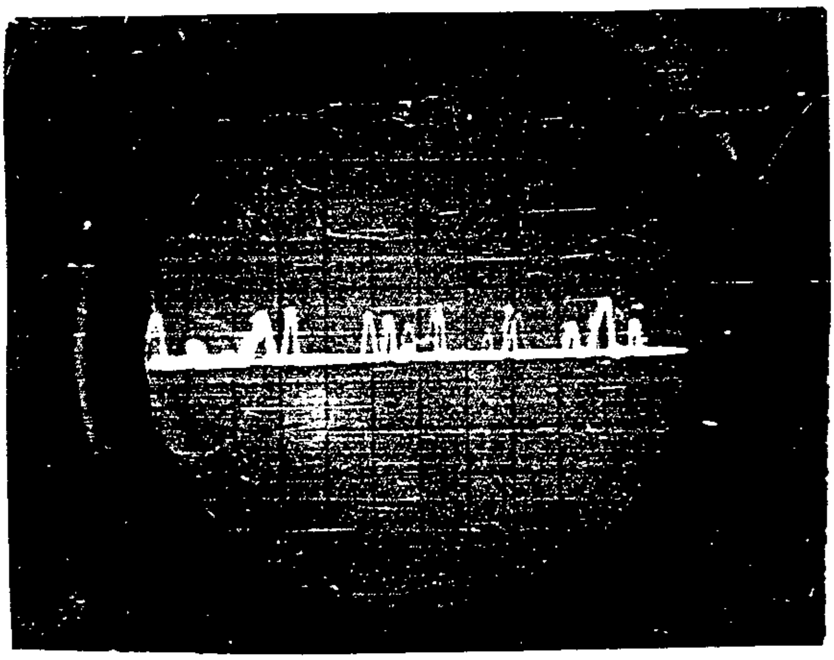

Tool = R20Q8NFE66331
Overhang = 30 mm
Frequency, Hz.
7000
6000
5000
4000
3000
2000
1000
S=0.2
t=1.5
S=0.13
t=1.5
S=0.13
t=1.0
S=0.2
t=1.0
20
30
40
50
60
70
80
90
100
110
Cutting speed,V m/min

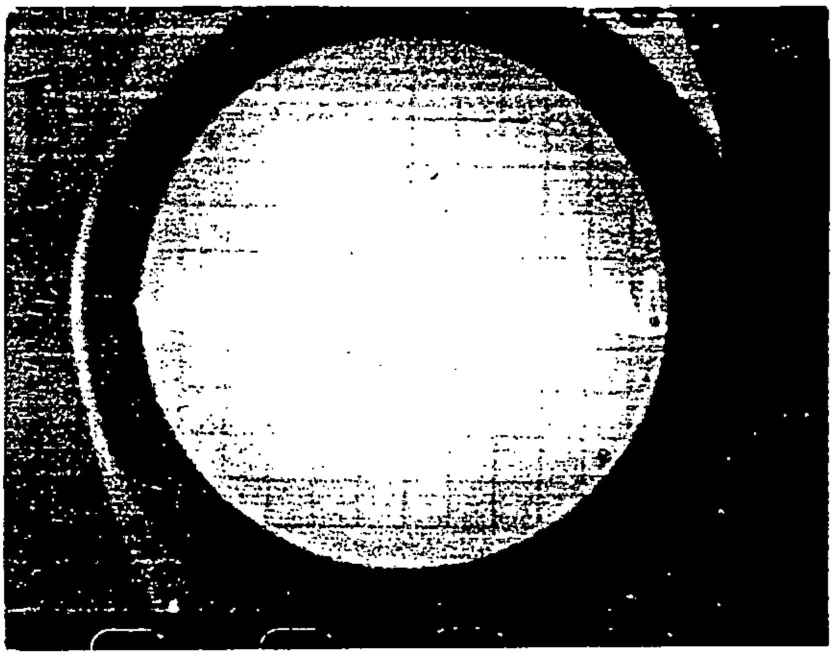
Fig. 3.21



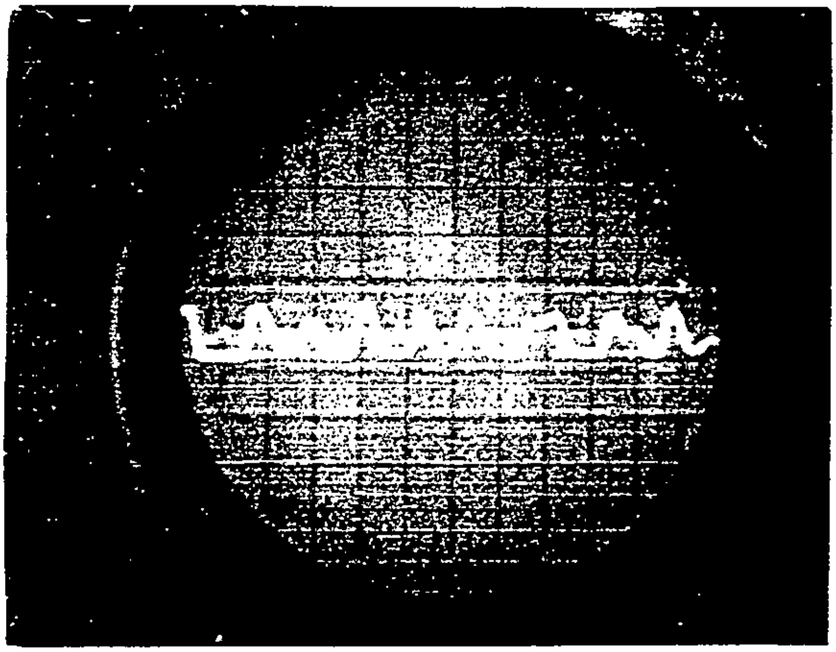
Tool = R25Q8NFE66336, Feed = 0.2, Depth of cut = 1.5
Cutting speed = 68.61 m/min, Overhang = 30 mm



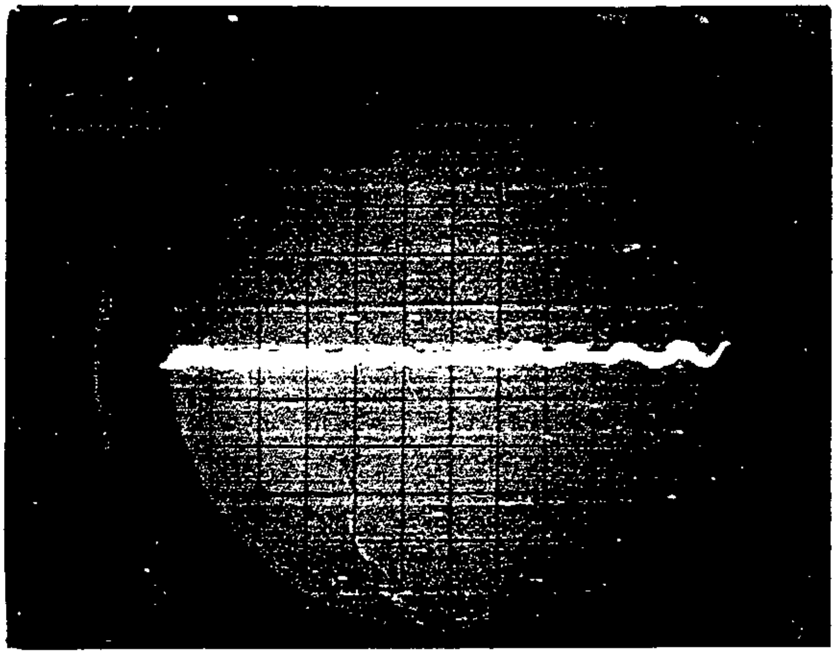
Tool = R25Q8NFE66336, Feed = 0.2, Depth of cut = 1.5
Cutting speed = 120.07 m/min., Overhang = 30 mm



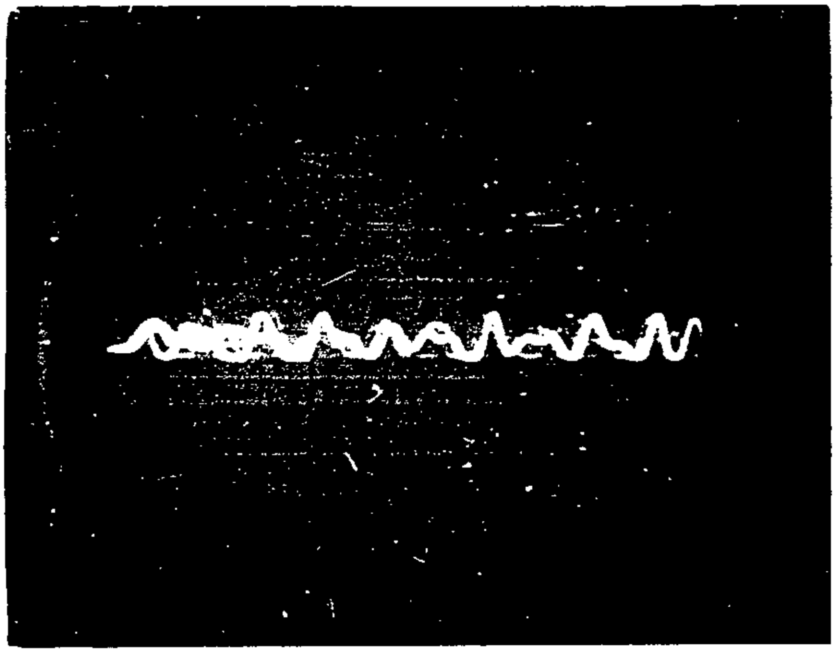
Tool = R25Q8NFE66336, Feed = 0.2, Depth of cut = 1.5
Cutting speed = 34.30 m/min, Overhang = 50 mm



Tool = R25Q8NFE66336, Feed = 0.2, Depth of cut = 1.5
Cutting speed = 48.80 m/min, Overhang = 50 mm

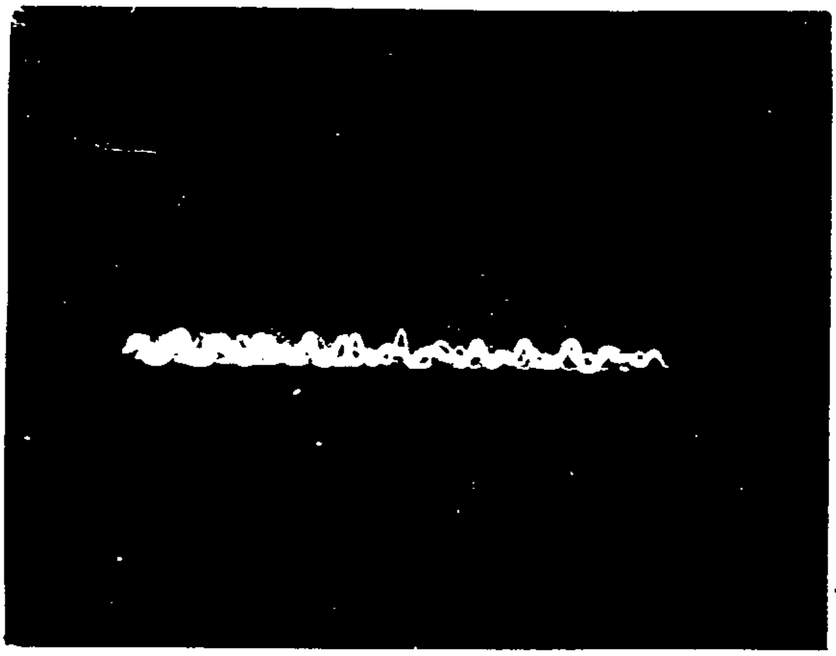


Tool = R25Q8NFE66336, Feed = 0.2, Depth of cut = 1.0
Cutting speed = 32.67 m/min, Overhang = 50 mm

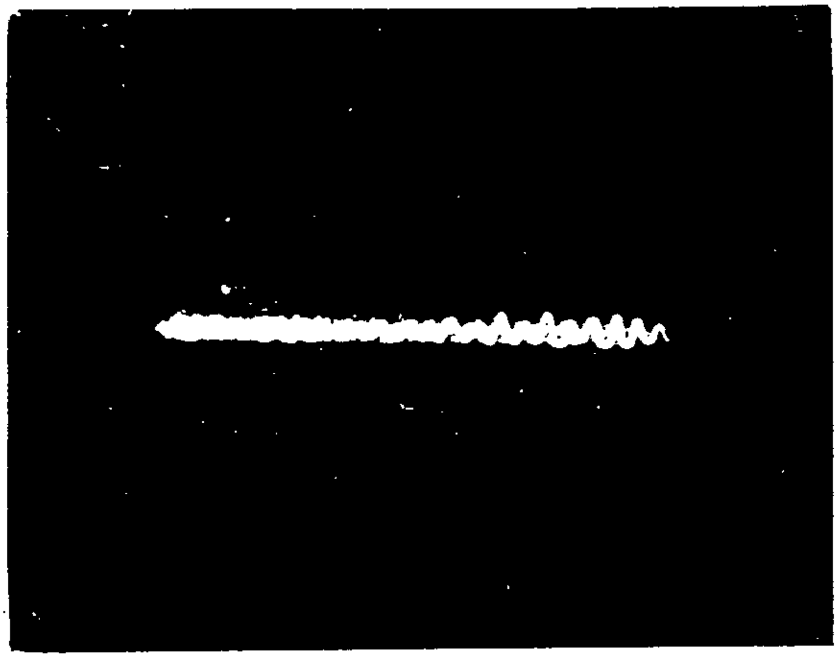


Tool = R25Q8NFE66336, Feed = 0.2, Depth of cut = 1.0
Cutting speed = 46.49 m/min, Overhang = 50 mm

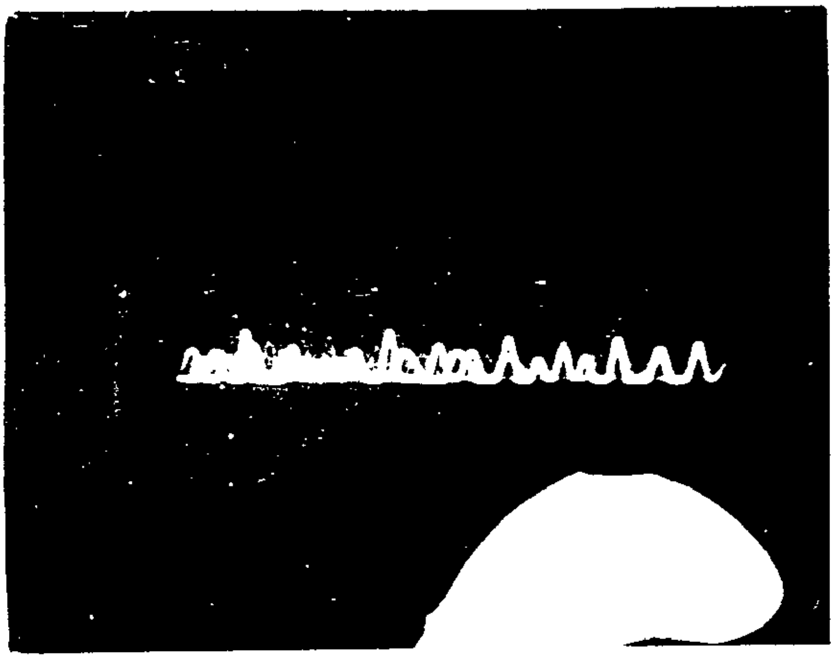
Tool = R25Q8NFE66336, Feed = 0.13, Depth of cut = 1.0
Cutting speed = 46.49 m/min, Overhang = 50 mm



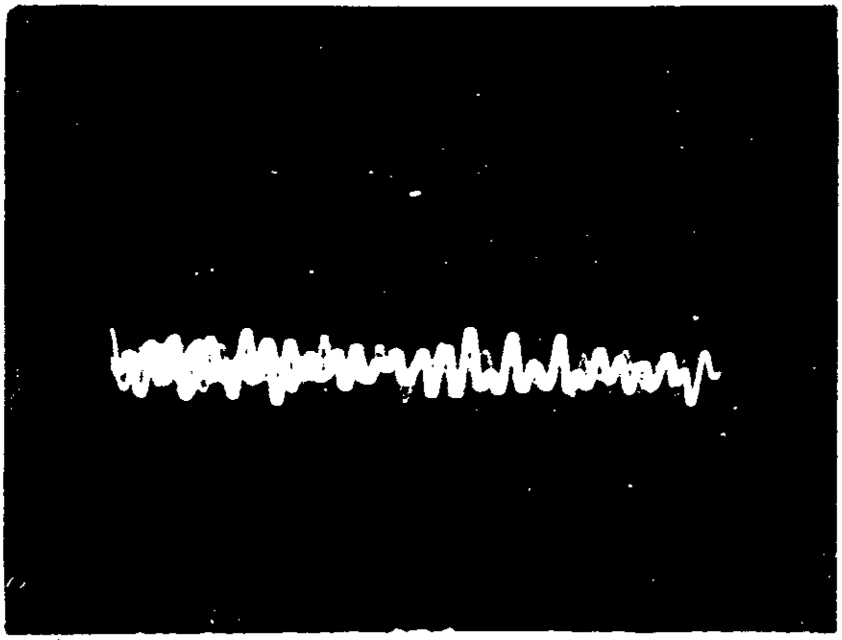
Tool = R25Q8NFE66336, Feed = 0.13, Depth of cut = 1.0
Cutting sped = 65.34 m/min., Overhang = 50 mm



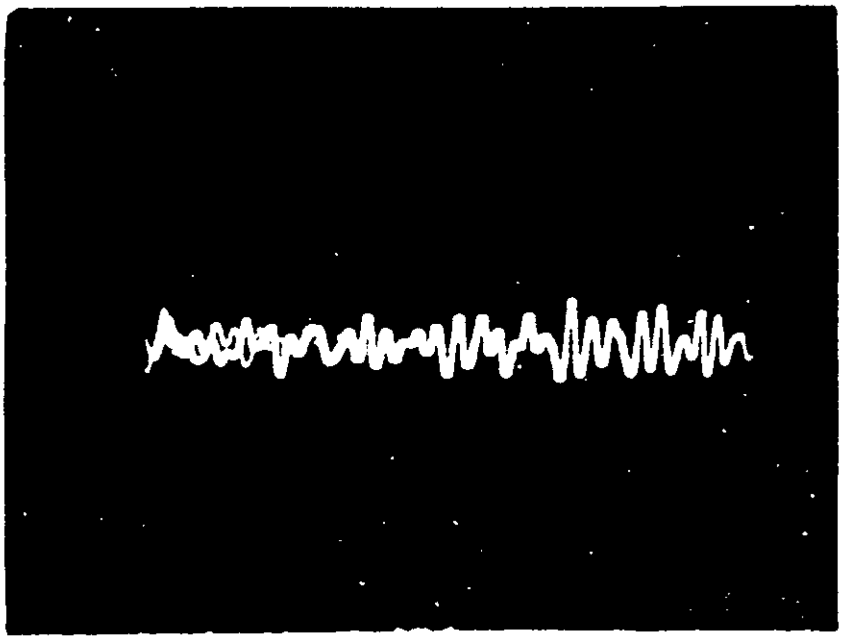
Tool = R25Q8NFE66336, Feed = 0.13, Depth of cut = 1.0
Cutting speed = 114.35 m/min, Overhang = 50 mm



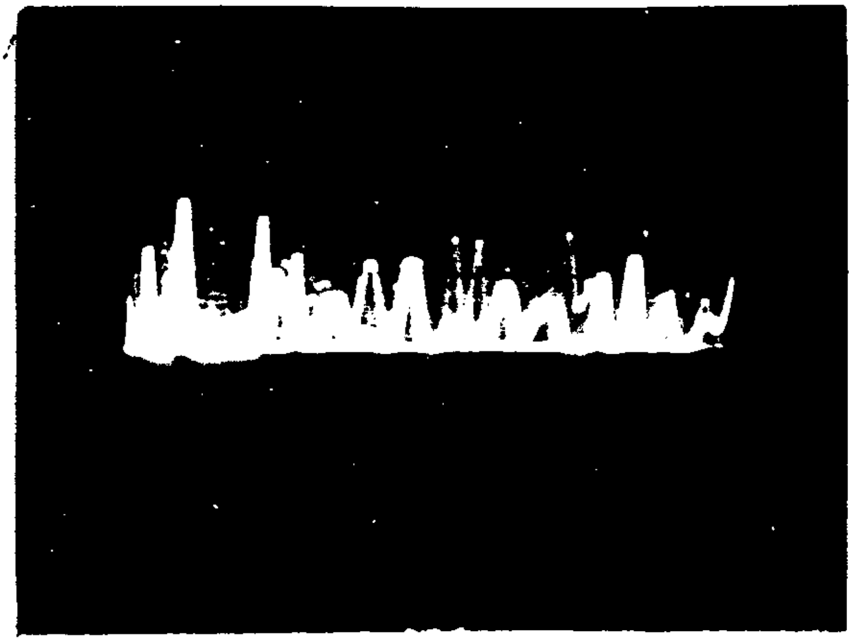
Tool = R25Q8NFE66336, Feed = 0.13, Depth of cut = 1.5
Cutting speed = 68.61 m/min, Overhang = 50



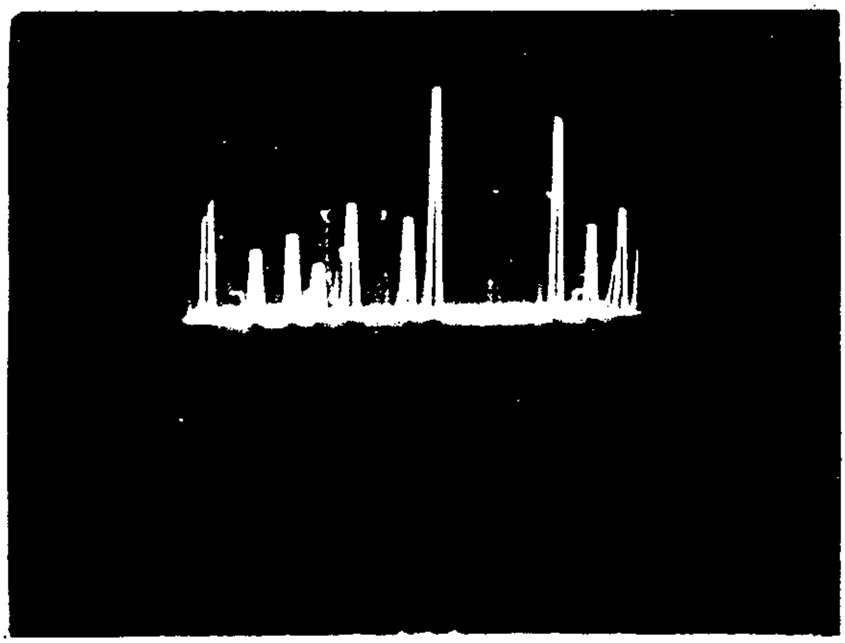
Tool = R25Q8NFE66331, Feed =.13, Depth of cut = 1.5
Cutting speed = 98.96 m/min., Overhang = 30 mm



Tool = R25Q8NFE66331,Feed = 0.13, Depth of cut = 1.5
Cutting speed = 120.07 m/min., Overhang = 30 mm



Tool = R20Q8NFE66331, Feed = 0.2, Depth of cut = 1.0
Cutting speed = 35.12 m/min., Overhang = 65 mm



Tool = R20Q8NFE66331, Feed = 0.2, Depth of cut = 1.0
Cutting speed = 49.98 m/min., Overhang = 65 mm

Tool = R20Q8NFE66331, Feed = 0.13, Depth of cut = 1.5
Cutting speed = 34.30 m/min., Overhang = 50 mm

Chapter — IV

EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 INFLUENCE OF NATURAL FREQUENCY ON VIBRATION OF CHIP FORMATION

To find the influence of natural frequency on vibration of chip formation, curves of distance between two adjacent vibration marks on chip denoted by S_1 vs. cutting speed are to be plotted. These curves are plotted on the same page where frequency vs. cutting speed curves for different overhangs at fixed feed and depth of cut are previously plotted. It makes the comparison between these two types of curves easier.

While studying the curve for overhang 30 mm of Fig. 3(a) it was observed that from cutting speed 46.49 m/min to 65.34 m/min the curve remains nearly horizontal i.e. frequency at these range of cutting speed, increases from 2814 Hzs to 3280 Hzs. So, the first level of natural frequency may exist between the above frequency range. This frequency may also be called as natural frequency. The frequency at cutting speed 65.34 m/min is so low because there was some influence of natural frequency on it. Then the frequency at cutting speed 94.24 m/min rises sharply. The value of frequency at this cutting speed is 4947 Hzs, which is nearly twice the first level value of chatter frequency. These phenomena can also be seen from Fig. 3.1(b) while increasing the values of cutting speed from 46.49 m/min the distance between two adjacent vibration marks on chip becomes larger so when frequency remains atmost contant values of S_1 gradually increases. And as frequency increases sharply, values of S_1 decrease suddenly. So, from the above results it can be decided that the natural frequency of tool R25Q8NFE 66/336 at overhang 30 mm should be 2800 Hzs to 3200 Hzs, from table it was found that these value is 2856 Hzs. Hence, the determination of natural frequency with tool R25Q8NFE 66/336 at overhang value 30 mm may be correct. For overhang 50 mm, frequency increases slowly as the value of cutting speed increases from 46.49 m/min to 65.34 m/min.

So, the first level of chatter frequency should be between 2074 Hzs to 2709 Hzs. From table that value was found 2777, which is very close to the above range of frequency. After that as cutting speed increases from 65.34 m/min to 94.24 m/min., frequency value increases from 2709 Hzs to 4784 Hz which is almost two times the value of first level of natural frequency. As cutting speed increases further to 114.35 m/min, frequency again increases very sharply to a value of 7653 Hzs which value is nearly three times the value of natural frequency. So, it can be decided that as many times the value of S_1 decreases, every times frequency increases very sharply and at that point the value of frequency is nearly some integer value of the first level of chatter frequency.

For overhang 65 mm, frequency increases from 2102 Hzs to 2398 Hzs as cutting speed increases from 46.49 m/min to 65.34 m/min. So, the first level of chatter frequency should lie between 2102 Hzs and 2398 Hzs.

From table 3.4 natural frequency at overhang 65 mm is 2647 Hzs. Then at cutting speed 94.24 m/min frequency rises to 4286 Hzs which is about two times the value of first level of chatter frequency.

The rest of the curves for tool R2528NFE66/336 also follow the above nature thus can explain in the same manner.

For tool R25Q8NFE 66331 and overhang 30 mm, frequency increases gradually as the cutting speed increases. So, the probable natural frequency cannot be found from the Fig.3.5. For overhang 50 mm it can be found while cutting speed increases from 25.66 m/min to 35.12 m/min value of S_1 drops from 0.220 to 0.174 then it increases to 0.206 as cutting speed increases to 49.98 m/min. So, the first level of chatter frequency may be in between 1596 Hzs to 2020 Hzs. Again, the value of S_1 drop down to 0.194 as cutting speed increases to 62.14 m/min then again the value of S_1 increases to 0.214 at cutting speed of 70.24 m/min. So, the first level of chatter frequency may also exist between 2562 Hzs to 2735 Hzs. Then again the value of S_1 drop suddenly to 0.148 as cutting speed increases to 101.31 m/min at a frequency of 5726 Hzs. So, these value of frequency may be termed as the second level of chatter frequency if the first level of chatter frequency be in between 2562 Hzs to 2735 Hzs. These values of natural frequency do not coincide with the determined value of natural frequency.

In case of overhang 65 mm the value of S_1 follows the same pattern as in case of overhang 50 mm. Hence, here the first level of chatter frequency may be considered to lie between 2505 Hzs. and 2865 Hzs. Then, when the value of S_1 suddently drop down to 0.176 mm in the cutting speed range from 70.24 m/min to 101.31 m/min, frequency increases sharply to a value of 4725 Hzs. This value of frequency is very close to the twice the value of first level chatter frequency. So, this frequency level may called the second level of chatter frequency. The nature of other curves for tool R25Q8NFE66331 can explain as the above.

In case of tool R20Q8NFE66331 with overhang 65 mm, it was found from Fig. 3.9 that the value of S_1 increases from 0.146 mm to 0.166 mm as the cutting speed increases from 35.12 m/min to 49.98 m/min with frequencies 2005 Hzs and 2305 Hzs respectively. So, the first level of natural frequency may consider to exist between 2003 Hzs and 2303 Hzs, then at cutting speed 70.24 m/min the value of S_1 drop down to 0.140 mm and frequency increases to 3825 Hzs which is very near to the twice the value of natural frequency. Then the value of s_1 again drop at cutting speed 122.93 m/min where the value of frequency is 6978 Hzs. This value is slithly higher than the thrice the value of natural frequency. Thus this value can be called the third level of chatter frequency.

For overhang 50 mm, the experimental results show that the value of S_1 gradually decreases to 0.102 mm as the cutting speed increases upto 62.12 m/min. So, it is very difficult to find out the frequency range at which the natural frequency may exist.

For overhang 30 mm, the experimental results show that the value of S_1 increases from 0.192 mm to 0.194 mm as the cutting speed increases from 25.66 m/min to 35.12 m/min with the frequency of 1173 Hzs and 1340 Hzs respectively. So, it can be considered that the natural frequency exists between these two values, since the value of S_1 then drops to 0.176 at cutting speed 49.98 m/min. It can be found from table that at 49.98 m/min cutting speed, frequency is 2237 Hzs.

This frequency may be considered as the second level of "Chatter" frequency as its value is very close to the twice the value of natural frequency. Tehn the value of S_1 again drops at cutting speed 70.24 m/min with frequency equal to 3538 Hzs. These frequency may consider as the third level of chatter frequency. Then the value of S_1 further drop down to 0.114 mm at cutting speed 101.31 m/min. At this cutting speed, the value of frequency found from table is 7369 Hzs which is almost twice than that of third level chatter frequency. So, this frequency may be called as the sixth level of chatter frequency. The nature of rest of the curves may be explained in the same way as the above.

From the discussions on the results of the experimental investigation, it can be concluded that the value of natural frequency may be determined from the above procedure. It can also be found that chatter occured at frequencies which are integer multiple of natural frequency and this chatter occured in a short ranges of cutting speed with different levels of chatter frequencies, i.e. first level chatter frequency; second level chatter frequency etc.

And amplitude of vibration in this type of chatter is very low and does not lead to the loss of stability of the MTFW system and as such they are quite different from the chatter as described earlier.

4.2 EFFECT OF RIGIDITY OF TOOL BIT HOLDER ON CHATTER

Rigidity of tool bit holder is one of the most important factors to be considered as cause of chatter during metal cutting process. Experiment was carried out with overhang values of 30 mm, 50 mm and 65 mm respectively to find the effect of rigidity of tool bit holder on chatter. From Fig.3.1 to Fig.3.12, there are two different types of curves on every page. One is frequency vs. cutting speed curve for different overhangs. The other type is plotted for distance between two adjacent vibration marks on chip (S_1) vs. cutting speed (V). These two type curves are plotted on same page for the convenience to compare.

The first four figures are for tool R25Q8NFE66/336 with 25 mm x 25mm cross-sectional area. From Fig. 3.1(a) & Fig.3.1(b), it can be seen that there was no clear chatter frequency for overhang 30 mm. But for overhang values of 50 mm & 65 mm chatter frequency range can be found from Fig. 3.1(b) though the amplitude of such chatter is not very high.

Fig.3.2 is for feed = 0.13 mm/rev. and depth of cut = 1.5 mm. Fig.3.2(a) shows no chatter frequency at all for all three overhangs, whereas Fig. 3.2(b) shows a little clear chatter frequency range for overhang 65 mm.

Fig.3.3 shows the curves for feed = 0.2 mm/rev and depth of cut = 1.00 mm. It can be found from Fig.3.3(a) & Fig.3.3(b), no significant chatter occured for all the three overhangs.

Fig. 3.4(a) shows no chatter whereas from Fig. 3.4(b) it can be seen that chatter occured for every values of overhang of tool bit holder.

So, from the above results it can be concluded that with tool bit holder of cross-section 25 mm x 25 mm, there was no significant chatter evolved during cutting of stainless steel materials. But with increasing overhang, tool bit holder has got a growing tendency to vibrate with chatter frequency. At the same time it was found that feed and depth of cut has got some influence on chatter.

Fig.3.5 to Fig. 3.8 shows the experimental results of tool R25q8NFE66331 in the form of curves. From Fig.3.5 & Fig.3.6 no chatter frequency can be found but Fig. 3.7(b) shows almost a clear chatter for each overhang. There was found a clear chatter frequency for overhang 65 mm after studying Fig.3.8(b) whereas curves of Fig. 3.8(a) shows almost no chatter. Thus the experimental results of the second tool confirm the results of the first tool.

Fig.3.9 to Fig. 3.12 are curves for tool R20Q8NFE66331 with cross-sectional area 20 mm x 20 mm. From Fig. 3.9(a) no clear chatter was found but curve of overhang 50 mm shows almost clear chatter on Fig. 3.9(b). From Fig. 3.10(b), chatter frequency range was found for overhang 30 mm and 65 mm. Fig.3.11 shows a clear chatter for overhang 65 mm only.

It can be found from Fig.3.12 that there exist chatter frequency for overhang 65 mm and overhang 50 mm whereas for overhang 30 mm chatter existed but not clearly.

Hence, it was found from above results that for tool with cross section 20 mm x 20 mm chatter occured more frequently than for tool of cross-sectional area 25 mm x 25 mm. So, with reduced cross-sectional area chances of tool bit holder to vibrate with chatter frequency increases. Thus chatter can be avoided or almost eliminated with increased cross-sectional area of tool bit bolder while machining of stainless steel material on a lathe machine.

4.3 EFFECT OF FEED AND DEPTH OF CUT ON CHATTER

To find the effect of depth of cut and feed on chatter, experiment was carried out by using three tool holders and three different overhang values of 30 mm, 50 mm and 65 mm for each tool respectively. For every tool bit holder and overhang, two values of feed i.e. 0.13 mm/rev. & 0.2 mm/rev and two values of depth of cut i.e. 1.0 mm & 1.5 mm were taken to carry out the experiment. Atleast five readings were taken for various combination of tool holder, feed and depth of cut. During metal cutting process, sometimes chip formation was discontinuous. So, in that case frequency cannot be determined on the basis of chip contraction method. High vibrational amplitude and whistling sound was used to detect the chatter frequency range during metal cutting process. It was observed from Fig. 3.13 to Fig. 3.15 that there was almost no clear chatter frequency range was found except in case of feed = 0.2 mm/rev. and depth of cut = 1.5 mm. In that case, a horizontal portion of the curve was found.

So, with tool R25Q8NFE66/336, chatter occured only when feed and depth of cut values were maximum. After studying the curves of Fig. 3.16 to Fig. 3.18 it was found that chatter occured during metal cutting while overhang, feed and depth of cut values were 65 mm, 0.2 mm/rev and 1.5 mm respectively. But when tool R20Q8NFE66331 was used, it was observed from Fig.3.19 to Fig.3.21 that chatter appears more frequently. It can be seen from Fig. 3.19 that with feed = 0.2 mm/rev & depth of cut = 1.0 and feed = 0.2 mm/rev & depth of cut = 1.5 mm, chatter was occured. But with the same values of feed and depth of cut and different values of overhang, horizontal portion of the curves gradually tend to become vertical i.e. chatter frequency range becomes smaller.

So, with the increase of both feed and depth of cut values, probability of chatter increases. But the influence of depth of cut on chatter is more prominent than that of feed.

Photographs confirm the above results.

Chapter — V

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH WORK

5.1 CONCLUSIONS

From the result of investigation and discussion the following conclusion may be drawn.

1. Natural frequency of a tool holder with prefixed value of overhang, may be determined by using the given experimental setup.

2. Machining of stainless steel with cemented carbide tool at different feed, depth of cut and cutting speed was accompanied with chatter with frequencies which are integer mutiple of the determined natural frequency value of the tool holder.

3. Amplitude of vibration of the observed chatter is very low and does not lead to the loss of stability of the MTFW system and as such they are quite different from 'chatter', by which an intensive type of vibration of the MTFW system is generally meant.

4. Chatter occurs more frequently with tool holder of less cross-sectional area than with tool holder of larger cross-sectional area. So, chatter can be avoided almost completely with increased cross-sectional area of tool bit holder while machining stainless steel with cemented carbide tools (brazed on tool holder) on a lathe machine.

5. The probability for the appearance of chatter increases with the increase of overhang i.e. with the decrease of rigidity of tool bit holder.

6. The probability for appearance of chatter increases with the increase of both feed and depth of cut, but the influence of depth of cut on chatter is more prominent than that of feed.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH WORK

The experiment was carried out for a few cutting speed values at large intervals. So, the exact value of first level chatter frequency i.e. natural frequency and other chatter frequencies could not be determined very accurately by the present experiments. Hence for determination of the exact values of such frequencies experiments may be conducted with a large number of cutting speeds at very close intervals.

Morever these experiment may be repeated with other work materials, for which the chip formation process is very unstable to investigate the influence of the natural frequency of tool holder on frequencies and amplitude values of the chatter. It may be assumed that the same results will be repeated with such materials also.

REFERENCES

1. Acherkan, N : "Machine Tool Design" Vol. 4, Mit Publishers, 1973, p-415.

2. Kudinov V.A., : "Dynamics of Machine-Tool" Publication of Machine Building, Moscow, 1965.

3. Amin, A.K.M. N and Talantov, N.V. : "Investigation of the Influence of chatter on Tool Wear" Mech. Engg. Res. Bull. Vol.10 (1987), pp.11-18.

4. Tailor F.B. : "The art of metal cutting". Publication of foreign science and technology", Berlin, 1922.

5. Steinberg I.C. : "Removal of chatter, appearing during metal cutting process on lathe machines", Publication of Machine Building, Moscow, 1976.

6. Eliasberg M.E. : "Fundamentals of the theory of chatter during metal cutting processes"

7. Amin A.K.M.N. : "Investigation of the Mechanism of chatter formation during Metal Cutting Process".

8. Tobias S.A. : "Machine tool vibrations" John Wiley & Sons Inc. New York, 1965, p.14-33.

9. Loladze : Chip formation during Metal Cutting Process", Publication of Machine Building, Moscow, 1980, 462 p.

10. Talantov T.V. : "Temperature-deformation nature of the unstability of metal cutting process". Ppaers of the National conference on "Heat Physics of Technological processes", Toliatti (USSR), 1976, p.67-68.

11. Amin A.K.M.N and Talantov, N.V. : Influence of the Instability of chip Formation and Preheating of Work on Tool life in Machining High Temperature Resistant Steel and Titanium Alloys".

12. Kim, K. J and Ha, 5.Y : Mech. Engg. Res. Bull., Vol.9, (1986) pp.52-62.