NON-CIRCULAR BORING ON THE LATHE USING CHAIN DRIVE FOR POWER TRANSMISSION

BY

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A Thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria, in partial fulfillment of the requirements for the award of the degree of Master of Science (M.Sc.) in Production Engineering.

NOVEMBER, 1990

DECLARATION

I hereby declare that this Thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for higher degree. All quotations are distinguished by quotation marks and the sources of information are acknowledged by means of references.

T. N. GUMA

20th NOVEMBER, 1990.

CERTIFICATION

This thesis entitled "Non-circular Boring on the Lathe Using Chain Drive for Power Transmission", by Thomas Ndyar GUMA, meets the regulations governing the award of the degree of Master of Science (Production Engineering) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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Finally I thank the Almighty God for enabling me to cross the difficult stages of this work.

- T. Guma

ABSTRACT_

A non-circular boring attachment has been developed. It consists of a hydraulic power system in the form known as TKBIO Copying Unit various individual templates, and a chain drive power transmission system. Power is tapped from the lathe spindle using a-friction clutch , to drive the template to actuate the hydraulic power system and consequently the boring tool. The attachment has been tested and different shapes of non-circular bores of uniform cross section have been produced.

Surface finish of the produced bores, tool vibrations and cutting forces while machining with the attachment have been measured, presented and analysed. The surface finish of the produced bores compare favourably to the general practical values obtained from boring operations. Tool vibrations while machining with the attachment are generally higher at the start of non-circular boring than at full-shape profile rnachining. In all instances vertical vibrations of the tool increase with increase in spindle speed or depth of cut or feed rate. The cutting forces and the computed machining power are generally similar to what is obtained during conventional cylindrical boring on the lathe.

The experiments have proved that the attachment can be used to effectively produce good quality non-circular bores on the lathe at spindle speeds up to 180 rev/min.

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NOTATIONS

A	=	Piston head area.
A_c	=	Cross-sectional area of cut.
b_1	=	Width between inner plates of roller chain.
C	=	Height of sprocket tooth above root diameter.
C_a	=	Side cutting edge angle of a single point cutting tool.
C_e	=	End cutting edge angle of a single point cutting tool.
C_1, C_2	=	Constants.
D	=	Diameter of the hole being bored.
D_a	=	Tip diameter of the sprocket.
D_b	=	Bore diameter of the sprocket.
D_f	=	Root diameter of the sprocket.
D_h	=	Overall hub diameter of the sprocket.
D_p	=	Pitch diameter of the sprocket.
d_b	=	Diameter of the bigger portion of the shaft.
d_p	=	Diameter of the spindle clutch pin hole.
d_s	=	Diameter of the smaller portion of the shaft.
d_t	=	Diameter of the overhang section of the boring tool.
d_1	=	Chain roller diameter.
E	=	Young's Modulus
F_a	=	Axial component of the resultant cutting force.
F_c	=	Vertical component of the resultant cutting force.
F_r	=	Radial component of the resultant cutting force.
f	=	Feed rate of the boring tool
g	=	Acceleration due to gravity.
H	=	Hub thickness
Hz	=	Hertz
I	=	Second moment of area of a cross section.
L_b	=	length of the bigger diameter portion of the shaft.

L_h = Length of the sprocket hub.

L_s = Length of the smaller diameter portion of the shaft.

K = Fraction of the hole circumference being bored, actually machined per revolution of the workpiece by the boring tool.

L = Overhang length of the boring tool.

M = Force moment.

M_x = Bending force moment at an arbitrary position from a given end of a part or component.

M_J = Bending moment at the position of the pin.

M_{max} = Maximum bending moment.

M_p = Mass of the sprocket.

M_{tor} = Torque on the spindle due to vertical component of the resultant cutting force.

m = Mass of the boring tool

N = Newton.

n = Workpiece rotational speed

p = Pitch of the chain or chordal pitch of the sprocket.

P_e = Exhaust pressure.

P_{eff} = Effective machining power.

P_s = Specific cutting energy.

P_{sp} = Supply pressure

Q = Rate of metal removal.

Rpm = Revolutions per minute

R_1, R_2 = Reactional forces on the shaft at the bearing points.

r_a = Radius of curvature.

r_s = Chain roller sitting radius

s_r = Tooth side relief

T = Number of teeth on the sprocket

T_{min} = Minimum number of teeth on the sprocket.

T_p = Time period

t = Time

t_1 = Minimum sprocket tooth thickness

V_c = Cutting speed

W_p = Weight of the sprocket

W_s = Weight of the shaft

x = Arbitrary length.

y = Deflection of a part or component.

y_{max} = Maximum deflection.

$\bar{y}$ = Distance from the stress free axis (Neutral axis) of a part.

ω = Frequency of vibration of a part or component.

ω_n = Natural frequency of vibration.

α = Chain roller sitting angle.

δ = Wear on the tool flank.

α_s = Side rake angle.

ϕ = Approach angle.

σ_b = Bending stress

$(\sigma_b)_{max}$ = Maximum bending stress

σ_p = Bending stress at the pin point of the spindle clutch.

σ_m = Maximum bending stress due to the maximum bending moment.

ρ_s = Density of steel.

η = Nose radius of a single point cutting tool.

μm = Micro metre.

CHAPTER ONE

INTRODUCTION AND OBJECTIVES

1.1 Introduction:

Machining is one of the fast, economical and efficient processes of manufacturing. Its prime function is to change shape, produce good surface finish and obtain dimensional accuracy. This cannot be achieved without the use of power operated machine tools equipped to hold the workpiece and cutting tool in proper relationship during cutting operations. Different classes of machine tools include: lathes, milling, reaming, boring, drilling, threading, screw and polishing machines; each of which is subdivided into many types. Machine tools form the basis of industrialization and have contributed immensely to economic development world wide [1, 2].

Certain machining processes/operations cannot be easily performed on the ordinary machine tools in small production workshops. Some of these machining processes/operations fall under the heading of non-cylindrical machining. Non-cylindrical machining is a machining process in which there is variation in two axes of the cutting action within the same tool feed per revolution of the workpiece as there is mutual movement of the cutting tool and workpiece around and on one another. The end products of which are non-circular in contour or section [3,4]. Examples of non-cylindrical shapes

and forms that can be produced with difficulty or in a limited number of ways on the ordinary machine tools are components or forms of: elliptical, hexagonal, oval, radii-formed, and square cross-sections.

Because, components or forms of non-circular cross-sections are desirable engineering features, skilled manual machining and other processes of manufacturing such as: casting, forging, stamping, extrusion, rolling, powder metallurgy, die forming, and other similar manufacturing processes are exploited to produce them. In some instances such as in small production workshops, either the manufacturing process is slow or the cost of production is high or both compared to machining. However, machining, which is essentially a shaping operation, could produce better surface finish, and give closer dimensional tolerances that most of these manufacturing processes [1,5] .

Numerical control machine tools have been developed and can be used to produce complex shapes or forms much faster and more economically [6, 7]. However such machine tools are not affordable by most industries and workshops in developing countries mainly because of the following reasons:

(i) the capital cost for buying a numerical control machine tool is high; and

(ii) there is a loss in machine flexibility, if a tape or the control malfunctions,

(iii) maintenance cost is increased owing to the sophistication of the control system.

On the other hand the copy systems of machining which find applications on practically every type of machine tool, depending on the number of axes being controlled have been built into specially designed machines and can be developed on others for particular machining processes [4].

Of all the machine tools the lathe is the oldest and commonest [2, 8]. There are various types of lathes with most diversified uses. All lathes have a similar principle of machining workpieces but differ in terms of strength, operational speeds, size, construction, degree of automation, processing capacity, control, rigidity, supports, accuracy and mechanism of tool control. The probability of finding a lathe in any workshop is higher than that of any other type of machine tool. Apart from its unique function as a turning machine for the production of cylindrical and some symmetrical components; the lathe can be used to perform machining operations that can be done on most of its sister machine tools. Some of the operations performed on the lathe include: drilling, boring, milling, threading, gear cutting, reaming, polishing, grinding, and even non machining operations such as spinning.

A bored hole is one of the common engineering features of important applications in everyday engineering use. conventional cylindrical boring can be accomplished on various boring machines and lathes. One of the difficult machining processes in most small production workshops is the production of non-circular bores of desired sizes, shapes, and surface finish on common lathes and boring machines. In such workshops, production of non-circular bores can be time consuming and expensive, requiring skilled manual machining to be used in conjunction with some conventional machining processes.

Non-circular bores can find applications as: Special Cavities to be used in some manufacturing processes like moulding for casting, powder metallurgy, extrusion, and forging. Non-circular bores can also be used to provide fittings for engineering components of non-circular cross section and some

other applications.

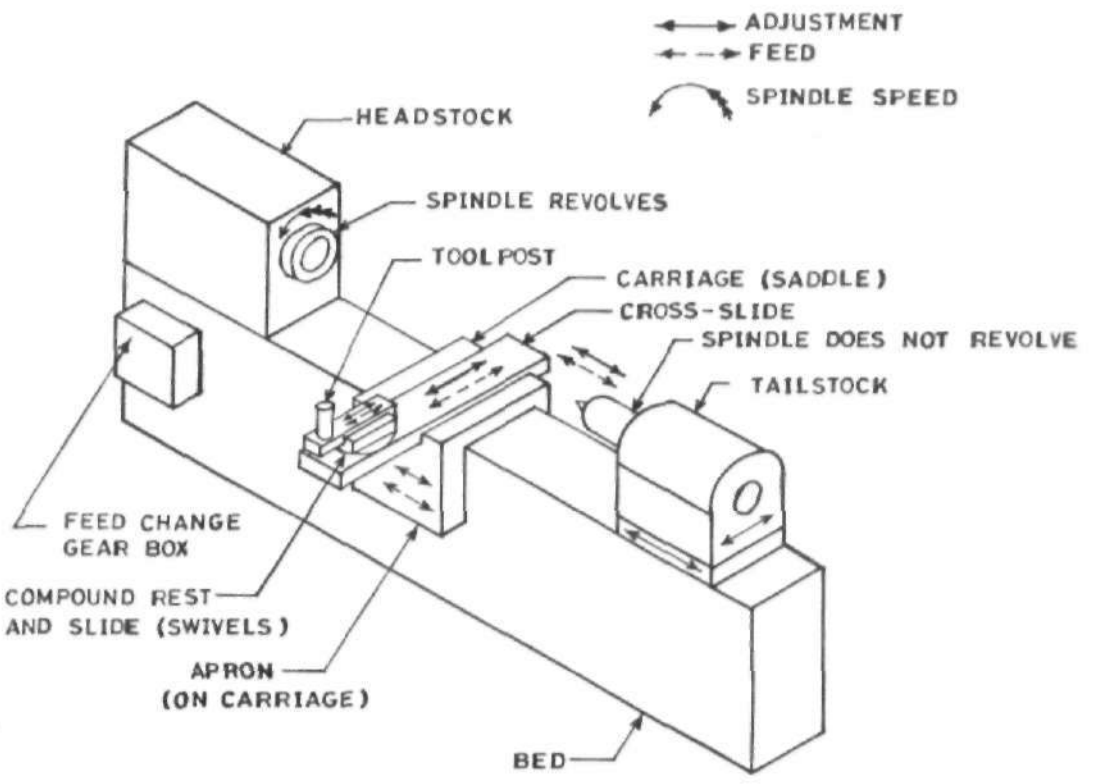


Fig. 1.1: A diagram of the principal parts and movements of a lathe.

In cylindrical boring on the lathe the workpiece is held and rotated in the chuck while the boring tool is held without rotation on the tool post and provides longitudinal infeeds. Figure 1.1 above shows the principal parts and movements of the lathe.

The manner in which non-cylindrical machining differs from the conventional cylindrical machining can be explained in terms of the nature of relative control between the cutting tool and the workpiece. To produce bores of non-circular shape on the lathe, technology demands that the boring tool be actuated in a programmed and co-ordinated fashion relative to the workpiece which is held

and rotated conventionally in the chuck [3, 7, 9]. This necessitates a review of the mechanisms for the necessary automatic control between the boring tool and the workpiece. One versatile and economical method of achieving the desired and necessary boring tool actuation is through the copy system of machining [3, 10].

Copy machining has been effectively used on the lathe for work which has complex profile consisting of many changes in form or non-circular curves such as multi-diameter cylinders and cams by turning operation [7]. Under the copy system of machining the required work shapes are produced as a result of movements of the tool and/or work which are dependent on the passage of a stylus or tracer over the contour of a pattern or template which is the same shape as the work and which has to be rotated at an appropriate speed.

The characteristic features of the lathe such as: through-going hollow spindle, cross and longitudinal motion of its slides can be applied to develop a non-circular boring attachment to produce non-circular bores faster and economically on the ordinary lathes.

A study of any machining process, method and operation would be incomplete without consideration of such factors as: surface finish, cutting forces and machining power, and vibrations. This work has noted the necessity of analysis and measurement of these factors due to the following reasons [1, 11, 12, 13]:

(i) in metal cutting operations, economy demands that just enough power and cutting forces, be produced to cut metals. Excess power and cutting forces for particular machining operations increase the cost of machining due to the extra cost of the unutilized power and forces. Effective power and forces required to cut metals vary for

different machining operations on the same machine tool.

(ii) Vibrations in metal cutting operations are harmful to tool life, cause general machine deterioration, and affect the quality of a machined surface. All these bad effects of metal cutting vibrations increase the cost of machining; polishing, lapping, burnishing may be used

(iii) a machined part with surface finish rougher than is needed to satisfy functional requirement increases the cost of production because additional operations which include: grinding, polishing, lapping, burnishing may be used required to produce the desired surface finish, hence the cost of production increases.

There are practically obtained surface finish ranges from different machining processes and different applications demand particular surface finishes from produced parts.

1.2 OBJECTIVES:

The prime objectives of this work are as follows:

(i) to develop a non-circular boring attachment to be used on the centre lathe in small and medium workshops;

(ii) to test its performance by studying experimentally the effect of depth of cut, feed rate and spindle speed on the cutting forces and consequently the machining power and specific cutting energy while using the developed attachment; and

(iii) finally to study experimentally and analytically the vertical vibrations of the boring tool as they affect the surface finish of the produced bores at various cutting conditions while using the attachment.

CHAPTER TWO

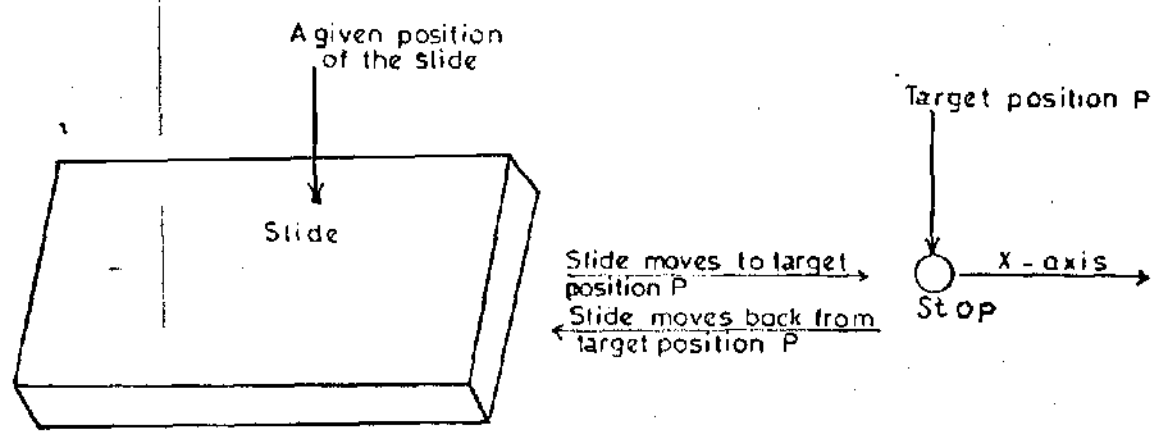
INTRODUCTION TO SERVO-CONTROL OF MACHINE TOOL COPYING SLIDES

2.1 INTRODUCTION:

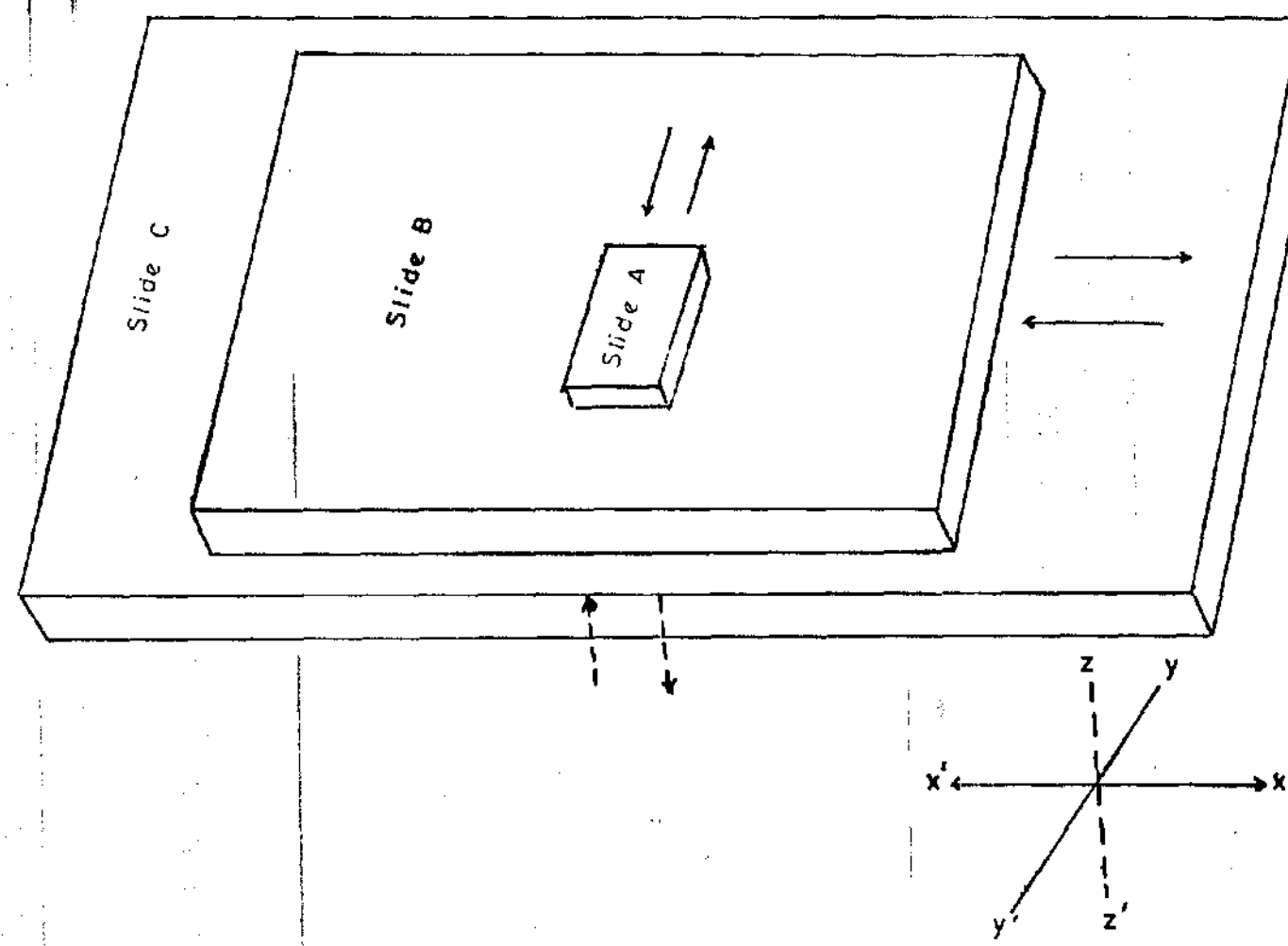
The geometric form of workpieces is dependent on the relative movements of the work and/or tool during machining. The control of movements in machine tools range from fully manual to fully automatic [7].

To produce non-circular bores on the lathe it is therefore necessary to know the principles, techniques and mechanisms that can be employed for the automatic control of the desired relative movements between the boring tool and the workpiece.

The essential object of the automatic control of machine tools is slide positioning in accordance with a predetermined schedule of command instructions based upon the dimensional information obtained from the workpiece drawing. The positioning may be static as when the workpiece - slide combination is moved to the correct position preparatory to drilling or dynamic in which the form produced is the resultant of the continuous and combined motions of the slides along the co-ordinate axes as shown in Figures 2.1 and 2.2. In the static slide positioning shown in Figure 2.1, the slide moves from time to time from a given position to target position P, stopping there for an interval of time before moving back again. In the continuous slide positioning shown in Figure 2.2, each slide is at any instant either moving backward or forward along a given axis. In the static positioning of a slide, machining does not take place while the slide is in motion, whereas in the continuous slide positioning, machining occurs while the slides are in motion.



Fig·2·1: Static positioning of a slide at a single point along the X - axis.



Fig·2·2: Continuous and combined motion of three slides along the co ordinate axes.

The command instructions are embodied or permanently stored, either as a template the profile of which is a replica of the desired form and which deflects the actuating stylus of the slide mechanisms, or as a numerically encoded programme of holes along a tape. To ensure that the slide mechanisms obey the called-for-positioning signal emitted by the command control, the movements of the slides must be monitored continuously so that output position signals can be fed back to control for comparison with the input signal. Such a closed loop, self-monitoring and error-correcting behaviour is the characteristic of servo mechanisms [7, 26].

All machine tool automatic control systems such as templates, tracers and numerical control include a servo mechanism as part of the system. A servo is composed of a number of elements - the input medium that represents the desired position or series of positions forming a continuous path., a comparator sensing the difference between the output and the input; power elements, hydraulic or electrical, for driving the slide transmission and a position feed back unit [3].

Copying units for fitting to or incoporating in machine tools are an important aspect for electrical, hydraulic and electrohydraulic servo mechanisms. Various types of servo mechanisms are available for fitting to most machine tools, and they enable irregularly shaped parts to be produced economically using either a template or a part which has been machined by conventional methods to guide the tool [9].

The simplest copiers are those fitted to lathes, especially those producing multi-diameter shafts. More elaborate copiers are fitted to die sinking machines. In all cases the stylus follows the contour to be copied and operates the servo valves.

2.2 HYDRAULIC COPYING SYSTEMS:

Hydraulic positioning servo systems can be used in machine tools for tracer controlled mechanisms to enable reproduction of profiled parts. These are valve controlled drive systems with a tracer attached to the valve for sensing the template or master. Linear type spool valves with single, 2-edge and 4-edge metering can be used. The flow pressure and characteristics of copying valves and the drive sizes are based on load and load speed requirements with due consideration to response and stability of the servo-system.

The valves are built so that a small shift in the spool position can produce high forces and flow rates resulting in increased copying accuracies. Valves are generally mounted close to the drive with rigid flow paths to minimize the compressibility effects on the system response [4].

The principle of operation of systems with one type of these valves is shown in Figure 2.3. Figure 2.3 demonstrates an asymmetrical system with a differential area piston head ends E_1 and E_2 as shown in the Figure. The oil flow to the head of the cylinder chamber is connected directly to the oil tank through a spool valve. The two ends of the cylinder chamber are interconnected through an orifice type restrictor.

The area of the piston end E_2 is twice that of piston end E_1. The pressure on the head of the cylinder chamber is dependent on the flow across the orifice and the opening of the valve to the cylinder.

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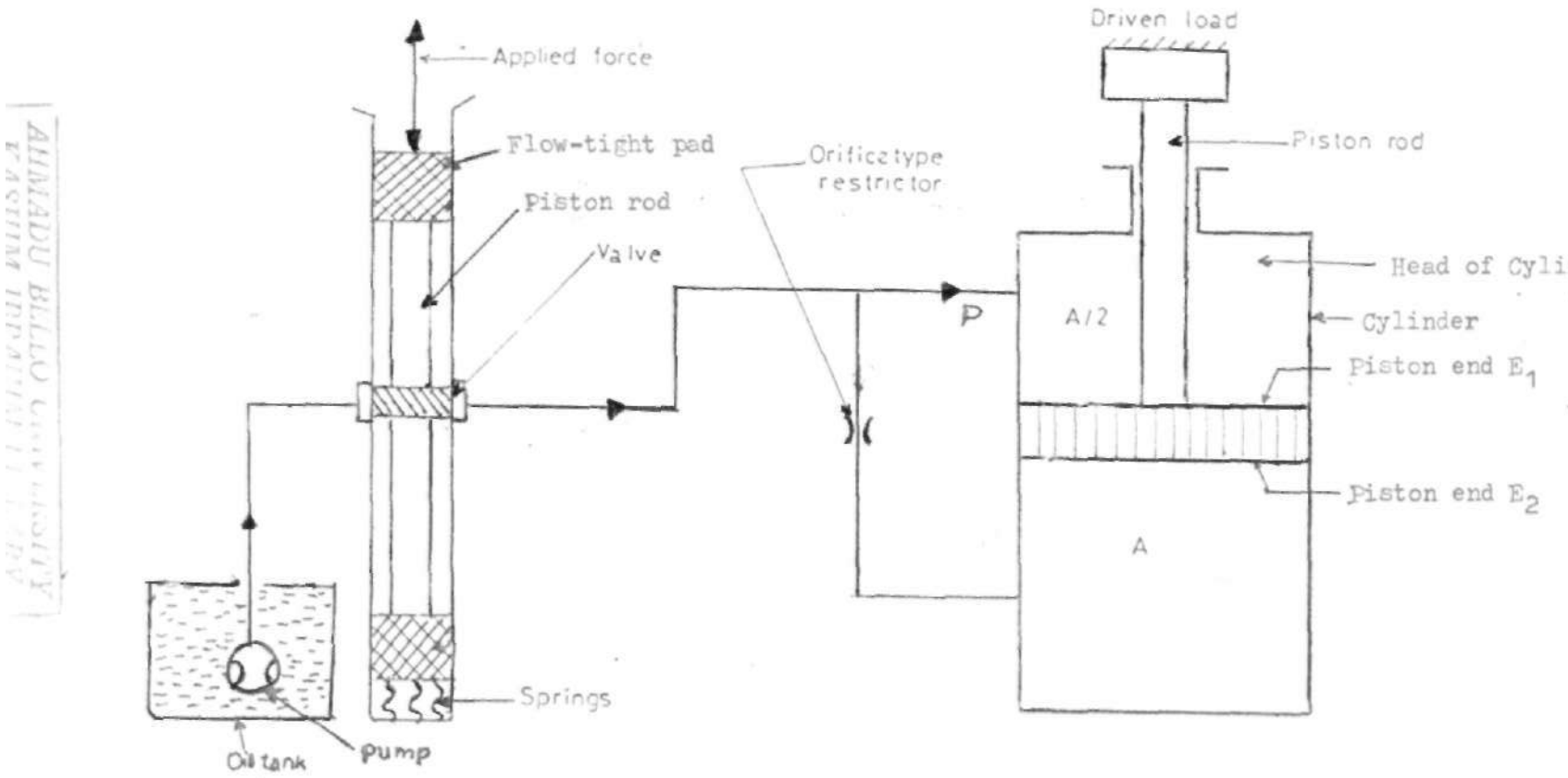


Fig. 2.3: Principle of operation of a system with single edge valve.

At no effect, flow through the valve is such that it creates a pressure on the head side to balance the loads on either side of the piston. A shift in the position of the spool controlling the valve opening increases or decreases the head chamber pressure either to advance or retract a slide load.

2.3 ELECTRICAL COPYING SYSTEMS:

There are various types of electrical copying systems. One type consists of a drive to the copying slide which comprises of a feed motor, bevel reverse gears, and a pair of magnetic clutches. The normal feed gear box is used for the longitudinal feed in this instance. On being deflected by either the template or spring, the stylus energizes the corresponding electromagnetic clutches through a relay and contactors. The direction and magnitude of energization of the clutches depend on the magnitude and directional deflection of the stylus caused by the contour of a co-ordinating template. The continuous and repeated action of this kind is then used to control a copying slide [3].

2.4 ELECTRO-HYDRAULIC COPYING SYSTEMS:

An electro-hydraulic copying system combines both electronic and hydraulic elements; the aim being to utilize the best features of each. Thus there are two main systems:

(i) electronic system for control and

(ii) hydraulic system for slide movements.

The electronic system comprises of two circuits, a basic circuit shown in Figure 2.4 using a high vacuum valve to achieve as many switchings as possible in a given time, with a minimum of control energy and the control circuit containing the amplifiers

and the rectifiers for converting the alternating current (a.c.) to direct current (d.c.).

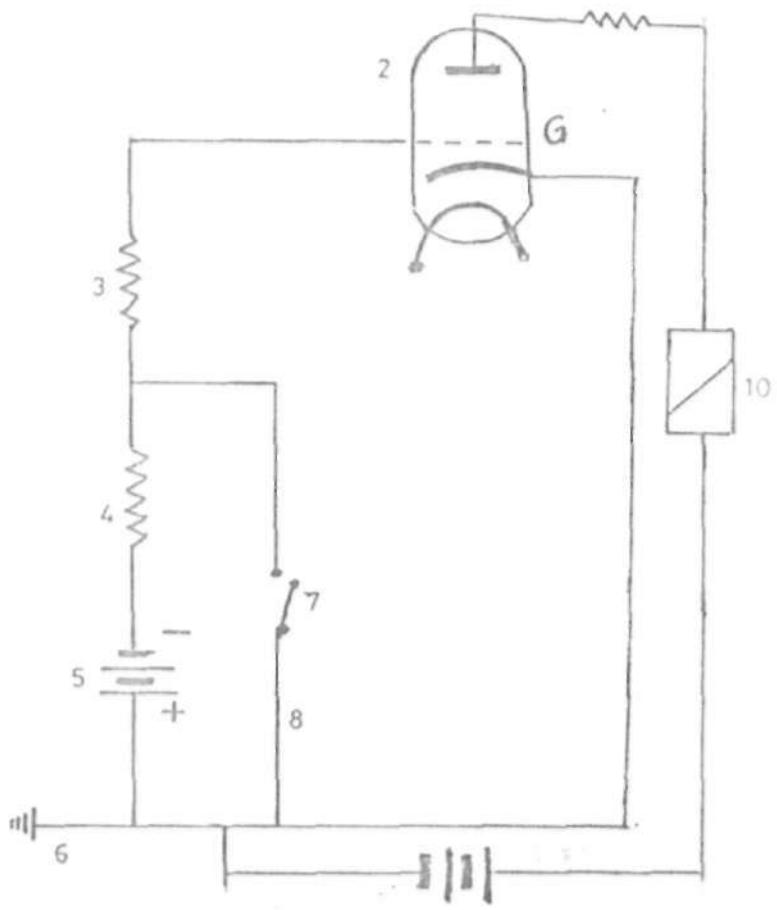


Fig. 2.4 : Basic electronic circuit.

Figure 2.4 above shows the principle that, a sensitive tracer transmits minute electrical impulses to contact 7 which is connected on one side between protective resistance 3 and high resistance 4, and on the other through conductor 8 to earth 6. When contact 7 is open, grid G is connected to the negative steady bias potential of the voltage source 5, hence valve 2 is cut off from the flow of electrons. Consequently no electrons flow through 10, which comprises of a small system of electromagnets that actuate hydraulic valves. If contact 7 is closed by the movement of the stylus, grid G is connected to earth through the protective resistance 3 and the grid bias potential is bypassed.

The valve then conducts anode current which flows to the magnets 10 to actuate the hydraulic valves which in turn release the flow of oil to move the tool slide in a definite direction. The magnitude and direction of the movement of the tool slide depends on the electrical impulses transmitted to contact 7 as determined by the contour of a coordinating template [3].

2.5 NUMERICAL CONTROL:

In numerical control, the continuous, simultaneous and interrelated motions of the slides are controlled by the numerical information input to the control unit of a numerical control machine tool [7]. Irregularly shaped parts and forms can therefore be produced on work-pieces without a template. Strictly speaking this is not copy machining in the sense used.

2.6 TYPES OF CONTROL:

Machine tools servo-control mechanisms or systems can exhibit one dimensional, two dimensional or three dimensional control or positioning of the slides depending on the design [3, 4]. Of these, only two dimensional and three dimensional ones are applicable in producing irregularly shaped parts and forms on workpieces.

2.6.1 TWO DIMENSIONAL CONTROL:

A basic copying system incoporates two controlled motions at right angles. The sensing head also has two orthogonal axes, one of which (the copying axis) is kept substantially normal to the template surface at the point of contact. The second is the feed axis. Feed motion is necessary to derive copying action, but at the same time a feed-axis pick-up detects any departure from a normal position, driving the sensing head in the presence of an error signal to maintain feed and copying axes at right angles [3,9]. A two

dimensional control is as shown in figure 2.5.

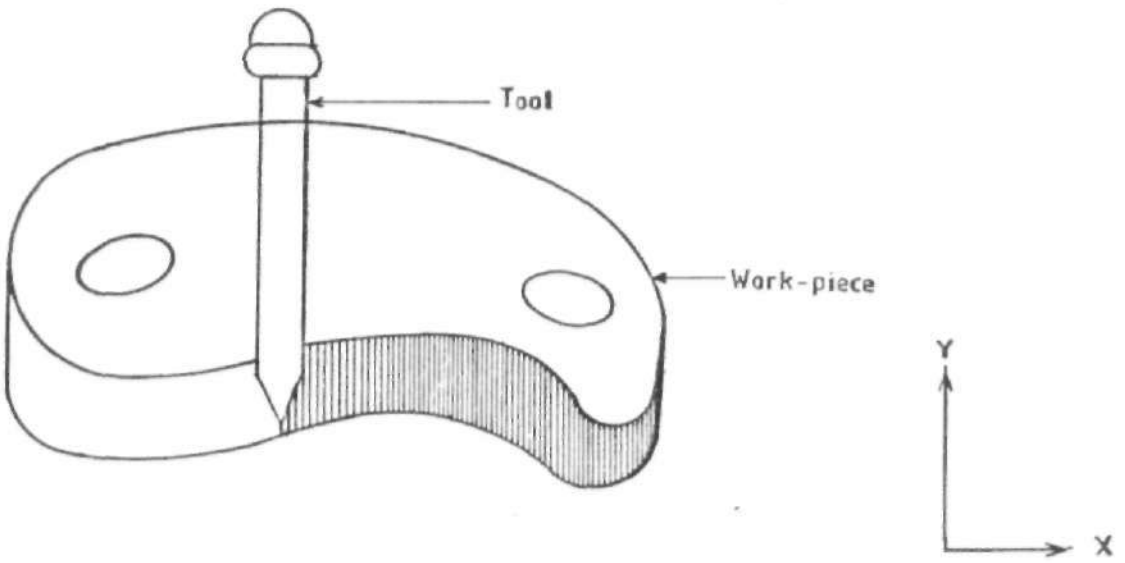


Fig. 2.5 A two dimensional control

2.6.2. THREE DIMENSIONAL CONTROL

In a three dimensional control system all the three co-ordinate axes X, Y and Z, are under copy control to enable contouring as shown in Figure 2.6.

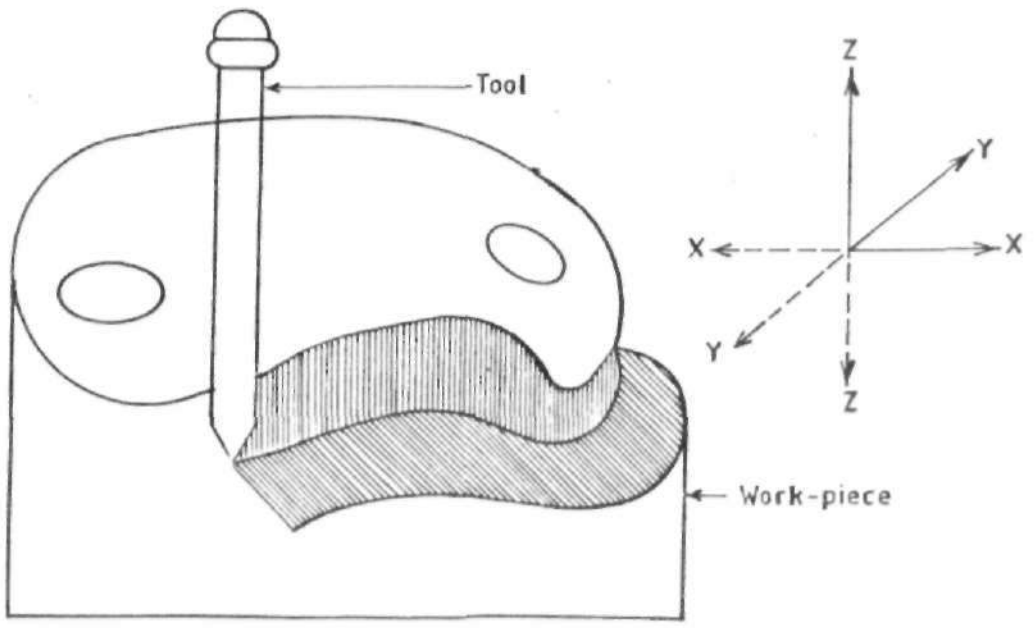


Fig. 2.6 A three dimensional control

For a 3-Dimensional control hydraulic servo-system, the valves for the longitudinal and traverse axes are placed horizontally at 90° to each other, while the valve for the vertical axis is mounted vertically. A stylus deflection in the horizontal plane actuates the X and Y valves and the vertical movement of the stylus actuates the Z-axis valve [4].

CHAPTER THREE

DESIGN OF POWER TRANSMISSION FOR THE NON-CIRCULAR BORING ATTACHMENT

3.1 INTRODUCTION:

Power transmission in machinery is the establishment of a co-ordinated dynamic linkage between two or more acting components of a machine from a source of mechanical power to enable it perform its functions as desired [16, 17]. This is of fundamental consideration in the design of any machine.

Various methods of accomplishing mechanical power transmission in a machine include: gear; belt; chain; pulley; rope and flexible shaft drives. Each method has its own limited areas of application. The choice of any of the methods for a particular situation at hand is a design decision. Such a decision takes into consideration the necessities of economy, reliability, compactness, efficiency, and maintainability of transmission [16, 18].

In copy machining, the template is the embodiment and director of command instructions to the actuation of the cutting tool and/or workpiece via some operative mechanisms [3, 4]. These instructions are only possible through the rotational kinematic linkage of the outline contour of the template with a tracing follower. This means that a drive system is necessary to maintain a steady rotation of the template at a desired speed during the process of machining.

For normal operations on the lathe, it is well known that a small fraction of the lathe motor capacity is used to drive the workpiece [8,15,19]. The source of power to drive the template for non-circular boring on the lathe could be separate from that of

the machine or it could be tapped from the machine's excess power. The latter is much more economical and is adopted. Two possible points of tapping the lathe's excess power are identified:

(i) from the lead screw of the machine and

(ii) from the lathe spindle.

Various standard methods of mechanical power transmission are therefore reviewed in this chapter to decide from amongst the various alternatives the most applicable and optimum method of tapping and transmitting the excess power of the lathe to drive the template.

3.2 POWER TRANSMISSION BY GEARING:

Gears are used to transmit power between two or more shafts that are too close for flexible power transmission methods like rope; chain; belt; and flexible shaft drives to be used [12]. Among the advantages offered by the gear method of power transmission compared with chains or belts are [18]:

(i) accurately cut and installed gears ensure smooth shockless transmission of power regardless of speeds, thus providing a low noise level, and freedom from destructive shock stresses;

(ii) gears are practically unaffected by centrifugal forces;

(iii) gears are compact means of obtaining speed reduction regardless of the amount of power involved;

(iv) properly installed and selected enclosed gear units can be safely said to last longer with less attention than almost any other form of mechanical power transmission;

(v) Spur, and helical gearing are the most efficient means of speed change regardless of the amount of power involved, or the magnitude of the speed ratio;

(vi) Worm reducers provide the most speed reduction and horse power capacity in a given space, but at the sacrifice of efficiency; and

(vii) gear combinations offer a wide variety of physical arrangements to permit changing the direction of the flow of power through almost any angle.

Power transmission by gearing on the other hand suffers the disadvantages of the gears, being less able to absorb shock and vibration compared to flexible power transmission methods. Except for high speed ratio applications, gear units are more expensive than belt or chain drives.

The possible point of tapping power from the lathe by gearing is at the lead screw of the machine. The arrangement consists of [20]:

(i) gearing a worm and wheel to the lead screw;

(ii) transmitting the power from the worm and wheel to the template; and

(iii) adjusting the speed of the lead screw to meet the particular demand at the template.

This method of power transmission has the following shortcomings:

(i) the speed of the lead screw is normally very low which necessitates a high gear ratio;

(ii) apart from the fact that worm gear transmission is inefficient, stepping down the speed before stepping it up again worsens the situation; and

(iii) the design would not be versatile in the sense that it cannot be used on different lathes since the size and pitch of the lead screw may be different for different lathes.

3.3 POWER TRANSMISSION BY CHAIN DRIVE:

The chain drive method of power transmission is especially applicable where the distance between the driving and driven shafts is too close for belting and too long for gearing [17]. The chain drive offers the following advantages:

(i) high efficiency (around 98 - 99%) of power transmission;

(ii) uniform driven speed regardless of load because there is no loss of speed through slippage or creep.

(iii) the chain drive is positive, compact, and without the initial tension required for a belt drive;

(iv) because no slack-side tension is required, the loads on bearings of the driver and driven shafts are the lowest possible, which permits smaller sprocket diameters on motor, allowing a higher speed ratio in a given space than can be obtained from belt drives;

(v) chain drives transmit the most power per centimentre of width for a given diameter and speed;

(vi) because they can be made, endless in any length and are easily installed, chains are easily stocked for replacement purposes;

(vii) the industrial standardization of chains and sprockets makes it easy to obtain replacements without having to worry about any particular manufacturer's specifications;

(viii) the chain is one of the easiest means for driving several shafts in series from one source of power; and

(ix) the chain system of power transmission is more durable than belting and can be substituted for it.

The disadvantages of the chain method of power transmission include the followings:

(i) they are inclined to noisy operation; and

(ii) they are not enclosed for effective lubrication like gears. Chain drives can be used to tap and transmit the lathes excess power from the spindle.

3.4 POWER TRANSMISSION BY BELTING:

The two popular forms of power transmission by belting are flat and V-belts. Flat belts and V-belts are used in conjunction with pulleys and sheaves respectively like chains with sprockets. They are used to transmit power when the centre distance between the driving and driven shafts is too long for gear and chain methods of power transmission. They possess the advantages of being quiet drives, having the ability to absorb shock and operating at low bearing pressure. The slippage associated with belt drives makes them inferior to chain drives for many applications [18].

Like chains belting can be used to tap and transmit the lathes excess power from the spindle.

3.5 POWER TRANSMISSION BY FLEXIBLE SHAFT:

One cheap method of tapping the rotary power of the lathe spindle is by means of flexible shafting. A flexible shaft is suitable for transmitting power over, under, around and even through obstacles that rule out the use of rigid straight lines [17, 18]. The flexible shaft method of power transmission is easy to install; maintain and is stable to vibrations.

The short comings of application of the flexible shaft method of power transmission include:

(i) its limitation to low power and speed requirements; and

(ii) it cannot be used to step speed up and down like in gear; belt and chain drive methods of power transmission.

Flexible shafting can be used to tap and transmit the lathes excess power either from the spindle or lead screw of the lathe.

3.6 CHOICE OF POWER TRANSMISSION METHOD TO DRIVE THE TEMPLATE OF THE NON-CIRCULAR BORING ATTACHMENT:

Despite the good advantages offered by gearing as a method of power transmission; the only probable point it can be used to tap and transmit the lathes excess power to drive the template is at the lead screw of the lathe machine. Even then the set-up arrangement as given in section 3.2 is not compact, efficient and economical.

Of all the processes used to shape metals. It is in machining that the conditions of operation are most varied. Many different machining operations are used involving cutting speeds as high as 600 metres per minute or as low as a few centimetres per several hours or interrupted in fractions of a second [30,36].

It is important that this variability be appreciated; therefore considering:

(i) the limitations of the flexible shaft to low speed and power requirements as a method of power transmission;

(ii) the occassional slippage associated with belt drives; and

(iii) the high efficiency of power transmission by chain drives (98 - 99%) over a wide range of speeds without slippage to interfere with machining operations, together with several other advantages, makes it more satisfactory, and it is therefore selected to tap and transmit the excess power of the lathe to drive the template at a desired spindle-template speed ratio. A 1:1 ratio is chosen for the non circular boring attachment. This is because the shape of a template will be reproduced on the workpiece only when the spindle-template speed ratio is 1:1.

3.7 POWER TRANSMISSION SET-UP USING CHAIN DRIVE:

Two possible set-up arrangements are envisaged for power transmission using the chain drive. These are as follows:

(i) the three-shaft arrangement; and

(ii) the single-shaft arrangement.

3.7.1 THE THREE-SHAFT SET-UP ARRANGEMENT:

In this arrangement, two equal size sprockets A and B are mounted as shown in Figures 3.1 and 3.2.

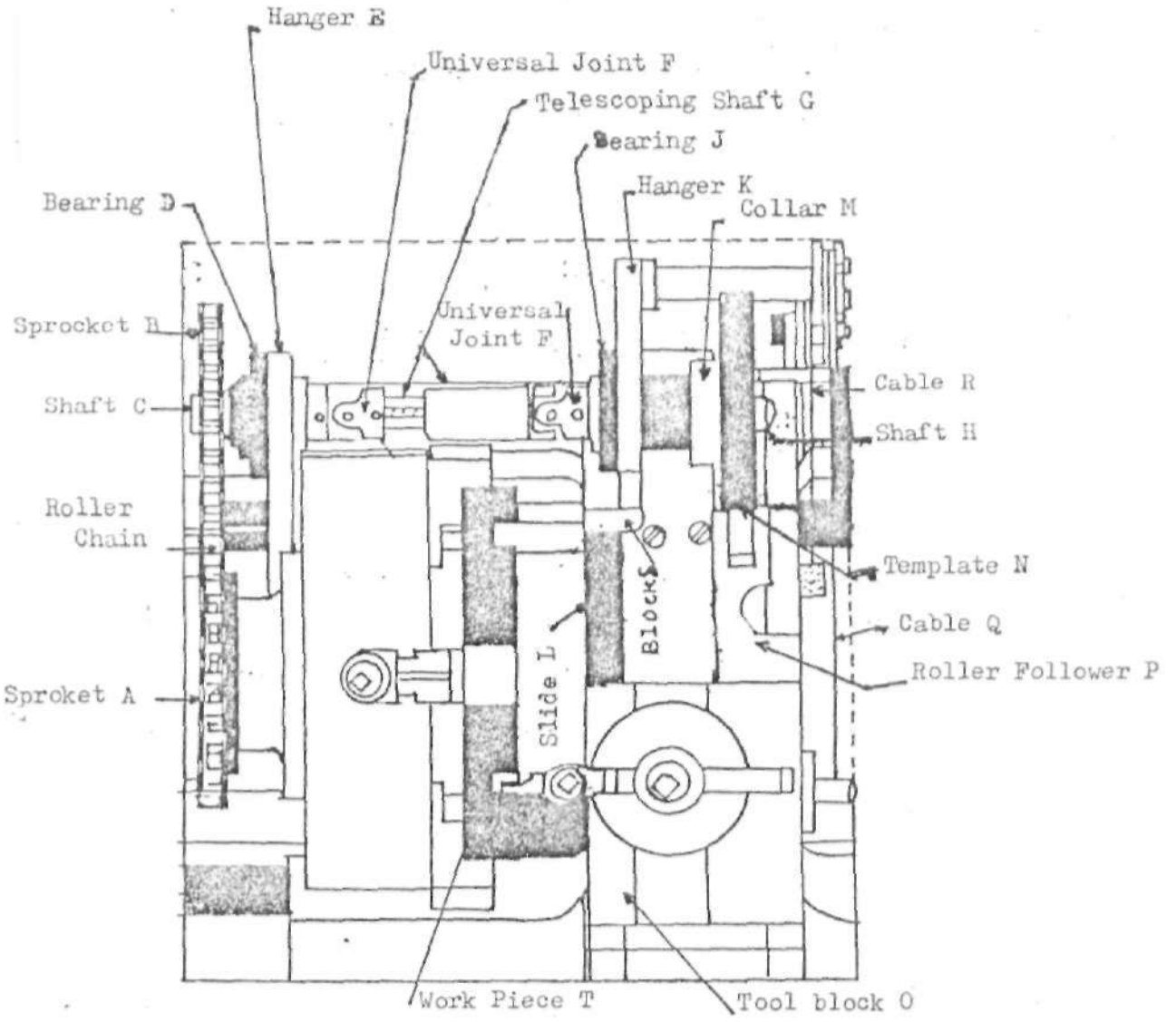


Fig. 3.1: Set-up for Non-circular boring on a lathe

Sprocket A is on a solid spindle friction clutch which is plugged with a tight fit into the lathe spindle, and sprocket B is on the shaft C. This shaft is supported in bearing D secured by screws to a hanger E, that is clamped to the bed of the lathe. Motion is transmitted by a roller type chain.

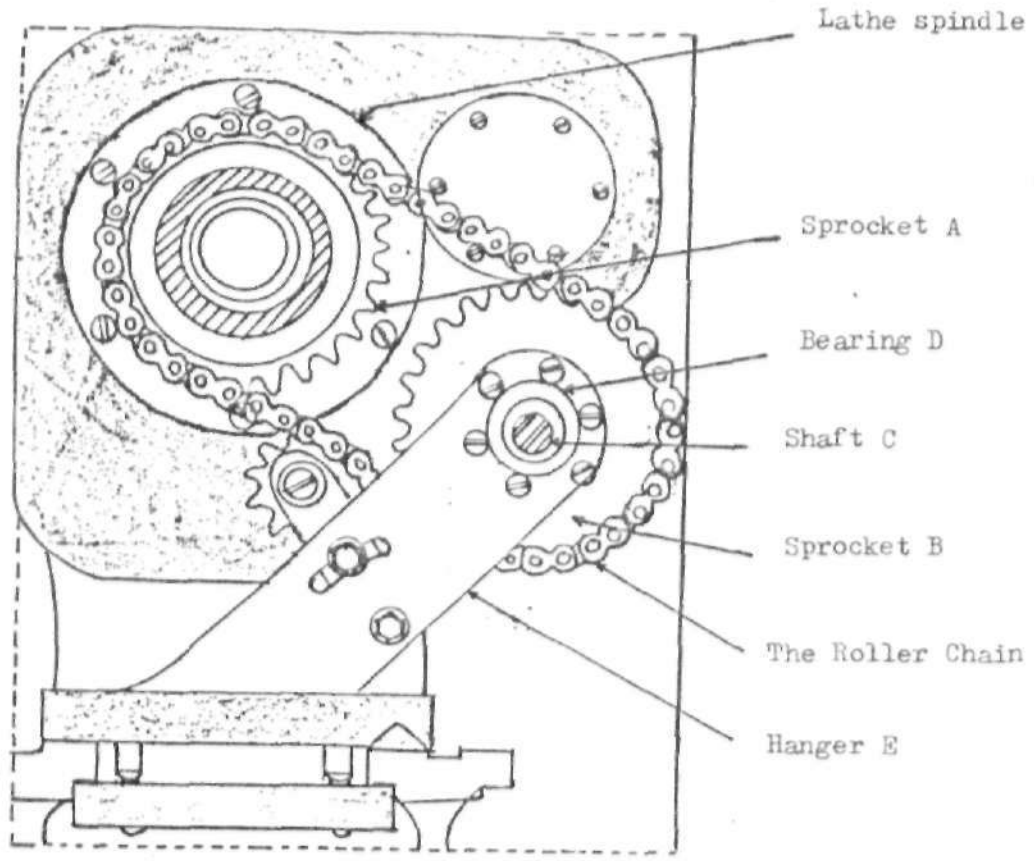


Fig. 3.2: Roller Chain and sprocket drive rotates the template at 1:1 ratio with the lathe spindle

Universal joint F and a telescoping intermediate coupling shaft G serve to drive shaft H while permitting both longitudinal movement of the carriage and lateral movement of the cross-slide. This arrangement allows shaft H to always rotate at a speed equal to that of the lathe spindle and in the same direction.

Shaft H is supported by bearing J in a hanger K fastened to a special slide L. A collar M is keyed to the shaft H, and the template N is attached to this collar with screws as shown in Figure 3.3 and 3.4. Slide L is fastened to the cross-slide in place of the compound.

Screws are used for this purpose. The tool block O is machined to fit slide L and has a T-slot for the tool post identical in size to that of the compound. However, this slot is made parallel, to the cross-slide for easier positioning of

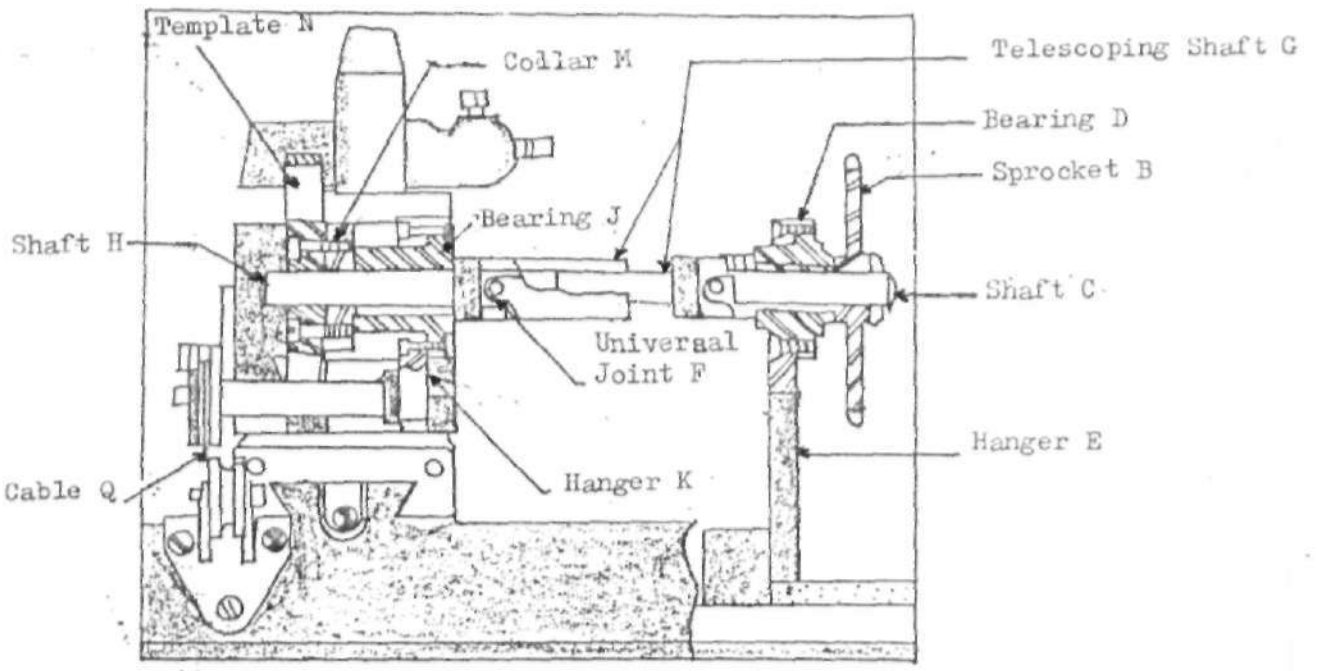


Fig. 3.3: Non-circular boring device as seen from rear of lathe. For clarity portions of the lathe have been eliminated

the tool. When the slide L and the block O are fitted together and mounted on the cross-slide, the top of the block O is at the same height as the top of the assembled compound.

The roller follower P is attached to the block O as shown in Figure 3.4. A weight secured to the end of the cable Q is used to keep a constant and even contact between the roller and template. A second weight attached to the cross-slide by cable R takes up any play between the cross-slide screw and nut. A block S which is machined to fit the dovetail slide of the saddle is fastened to

and supports the overhanging end of the slide L as illustrated

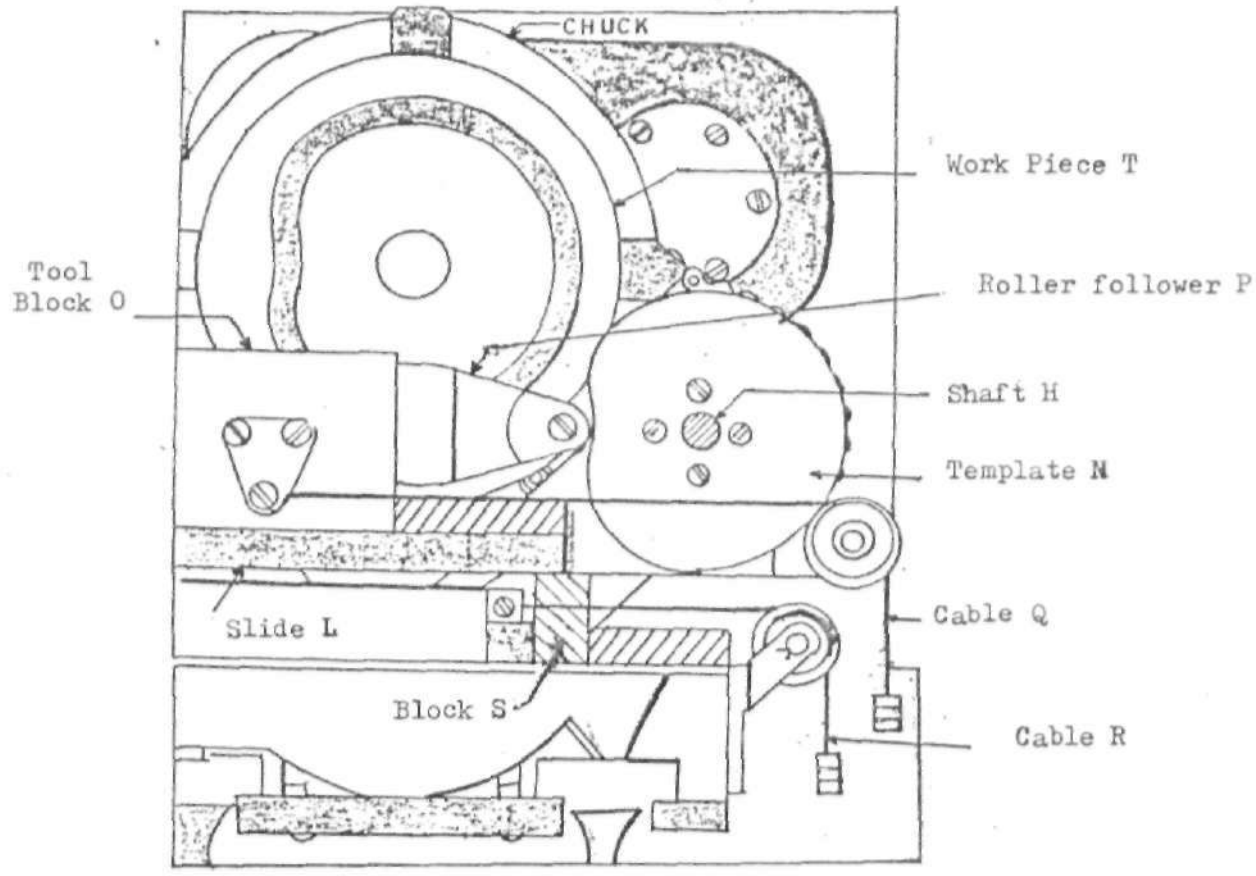


Fig. 3.4: A weight is attached to cable Q to keep the roller follower constantly in contact with the template N.

in Figure 3.4.

Since the two sprockets are equal in diameter and pitch and are coupled together by a roller chain, one turn of the lathe spindle will result in one turn of the template. When this template is rotated, a boring tool mounted on block O and guided by the template having the desired centre may be used to reproduce the shape of the template in the workpiece T .

3.7.2 SINGLE-SHAFT SET-UP ARRANGEMENT:

In a single shaft set-up arrangement, two identical sprockets S_1 and S_2 are mounted on shafts as shown in Plate I.

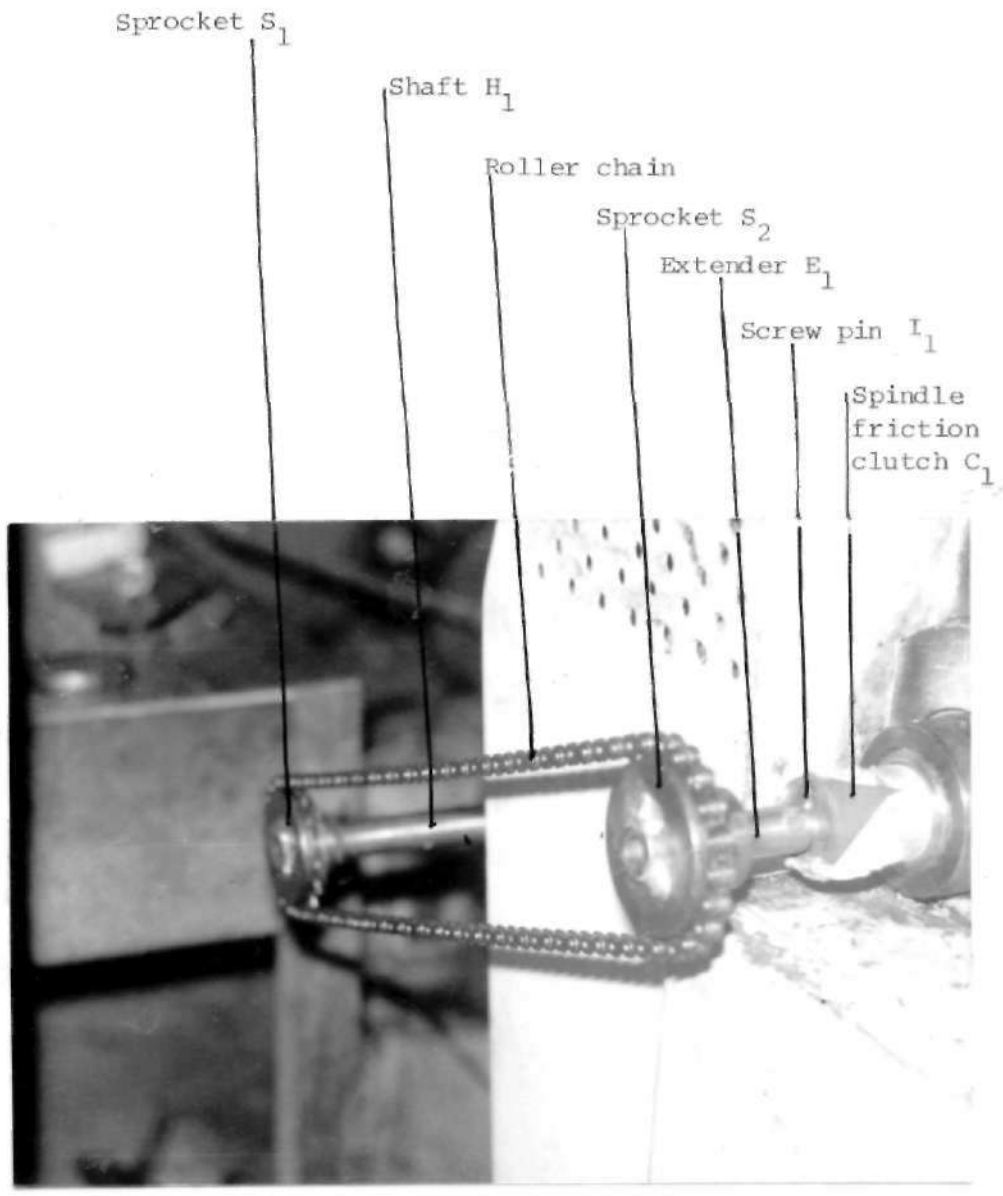
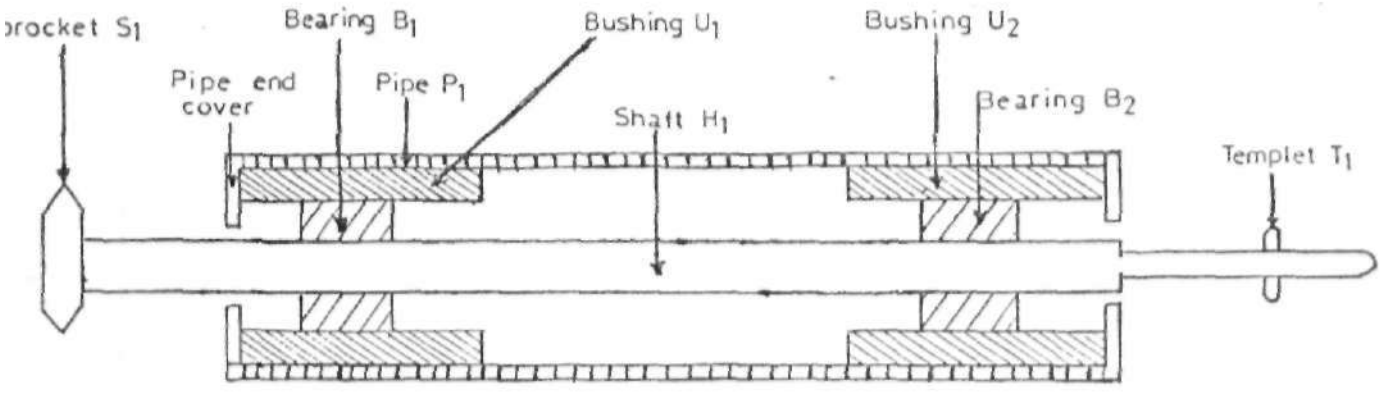


Plate I: Back view of the single shaft set-up arrangement.

S_2 is keyed to an extender E_1 which is connected to the solid spindle friction clutch C_1 by a screw pin I_1. The clutch is plugged with a tight fit into the lathe spindle. The clutch is made of a cylindrical steel part, and covered with friction materials. Since the outer layer of the clutch is made of friction materials, and the clutch is fitted tightly into the lathe spindle, it will not slip but become integral with it. This arrangement allows S_2 to take up and transmit the rotational speed of the lathe spindle when S_1 and S_2 are connected by a chain as shown in plate I.

S_1 is keyed to the end of shaft H_1. Shaft H_1 is supported appropriately in two bearings B_1 and B_2. Bearings B_1 and B_2 are fitted tightly into, and concentric with, the bores of identical bushings U_1 and U_2 respectively. Bushings U_1 and U_2 are again fitted tightly into, and concentric with, the bore of pipe P_1 of appropriate design length. The use of U_1 and U_2 may be omitted and the bearings supporting the shaft fitted tightly and directly into pipe P_1. This arrangement allows only the shaft to rotate integral with the bearings when it is rotated.

Pipe P_1 containing the assembly of shaft H_1, bearings B_1 and B_2, and Bushings U_1 and U_2 as described above and shown in Figure 3.5 is



Fig·3·5: Assembly of pipe, bushings, bearings and shaft.

Supported on an auxillarly bracket R_1 of the lathe as shown in Plate II. The wooden support D_1 is used to support the overhanging length of P_1.

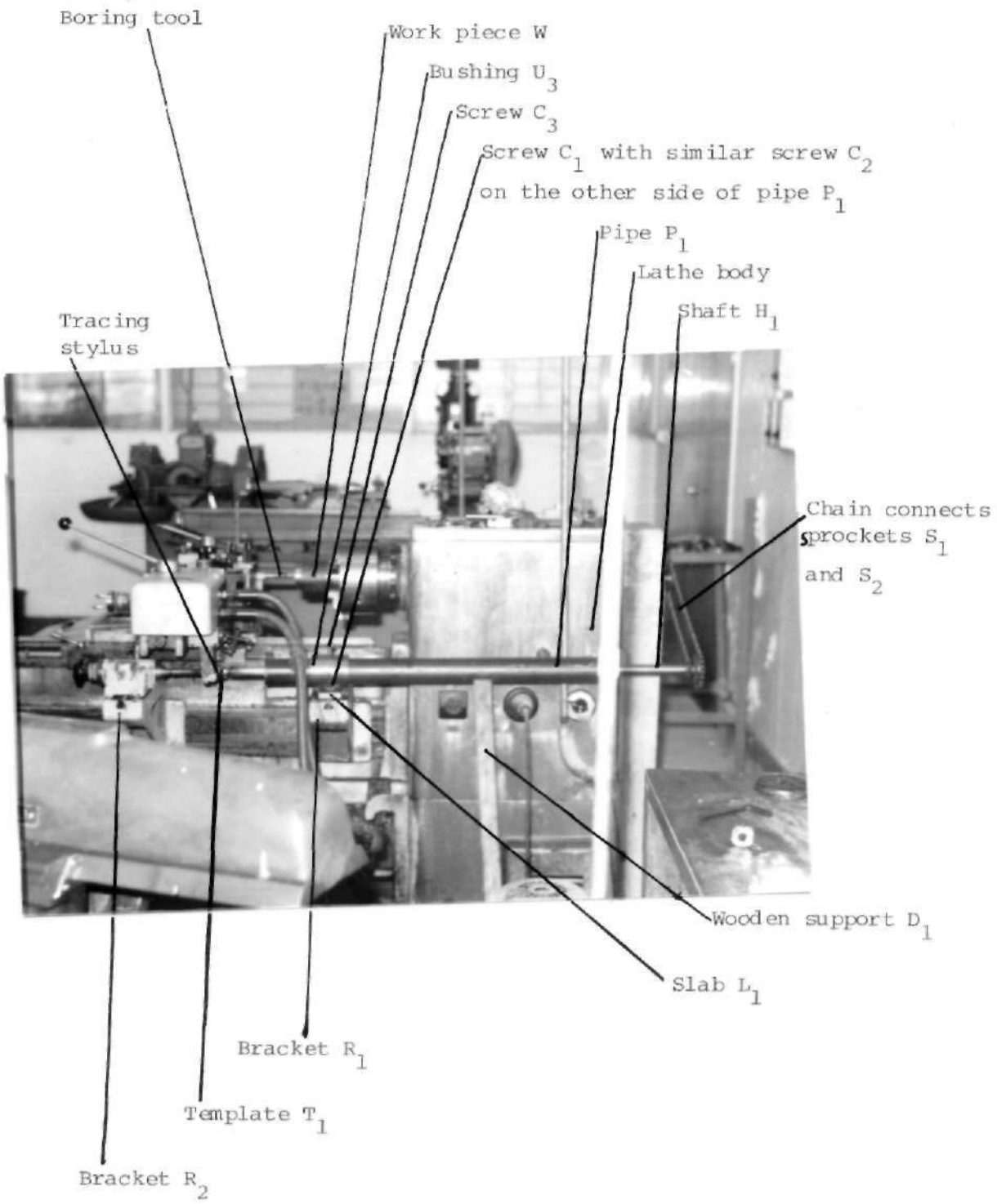


Plate II: Front view of the single shaft set-up arrangement.

Pipe P_1 is supported on bracket R_1 with a slidding fit in bushing U_3, to facilitate adjustment of the longitudinal position of the pipe. Bushing U_3 is welded to a steel slab L_1 to facilitate clamping of pipe P_1 on bracket R_1. Slab L_1 is provided with two screw holes, and two screws C_1 and C_2 as shown in plate II are used in conjunction with nuts for fixing slab L_1, which carries and support pipe P_1 in bushing U_3 on bracket R_1. The bracket is provided with a T-slot to facilitate this. Slab L_1 can be moved inward and outward from the main body of the machine on R_1 to adjust the contact between template T_1 and the tracing stylus.

U_3 is also provided with a screw C_3 for fixing the sliding fit of P_1 into a steady position at any of its longitudinally adjustable positions that may align S_1 with S_2 in a straight line so that the chain which connects S_1 with S_2 is not slanting but perpendicular to the shafts on which S_1 and S_2 are mounted.

A similar bracket R_2 to R_1 and adjacent to it is provided with a dead centre to support the end of H_1. H_1 carries template T_1 at a point on the shaft between R_1 and R_2.

Since the two sprockets are equal in size and pitch, the rotation of the lathe spindle synchronizes that of the template, when the sprockets are connected by a chain. T_1 is then used as input actuator to enable its shape to be reproduced on workpiece W, using the boring tool.

3.7.3 CHOICE OF SET-UP ARRANGEMENT:

It can be appreciated that the three-shaft set-up arrangement is bulky and not as compact as the one shaft arrangement, and is less economical. It involves the use of special and costly parts such as the universal joint and hangers. The one shaft arrangement involves the use of parts that can either be obtained locally or produced locally such as: bushings and pipes. Hence considering the

It is adopted and used as the set-up arrangement to transmit power to drive the template for the non circular boring attachment.

3.8 DESIGN CALCULATIONS OF SPROCKET DIMENSIONS:

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
Select a chain	ANSI 40 [16]	ASA 40 Trade (12.7mmx7.93). This was bought from the market.
P = 12.7mm	Chain pitch (P) = 12.7mm	P = 12.7mm
d_1 = 7.93mm [20]	Chain roller diameter (d_1) = 7.93mm	d_1 = 7.93mm
P = 12.7mm Assumme T=20	D_b < 45.2mm [16]	Take D_b = 25mm
D_b = 25mm	For roller chain ASA 40, $T_{min} = \frac{4D_b}{P} + 5$	
P = 12.7	$T_{min} = \frac{4(25)}{12.7} + 5 = 13$ [22]	Take T = 20

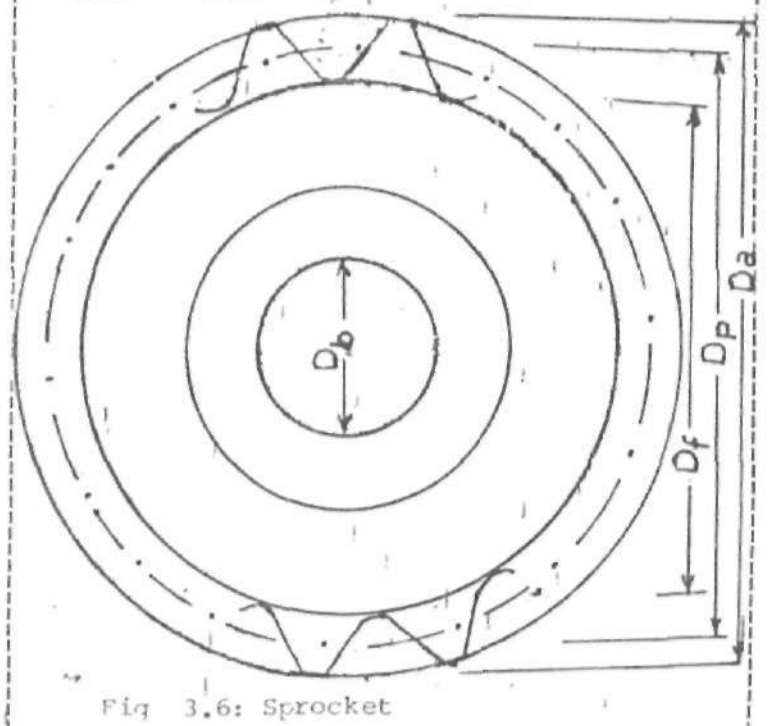


Fig 3.6: Sprocket

P = 12.7mm T = 20 D_p = 81.2mm	$D_p = \frac{P}{Sin(180^o/T)} = \frac{12.7}{Sin\ (180^o/20)} = 81.2mm$ [21]	D_p = 81.2mm
d_1 = 7.93mm P = 12.7mm T = 20	$D_f = D_p - d_1 = 81.2 - 7.93 = 73.3mm$ [4]	D_f = 73.3mm
	$D_a = P(0.6+\cot(180^o/T) = 12.7(0.6+\cot 9^o)$ D_a = 87.8mm [21]	D_a = 87.8mm

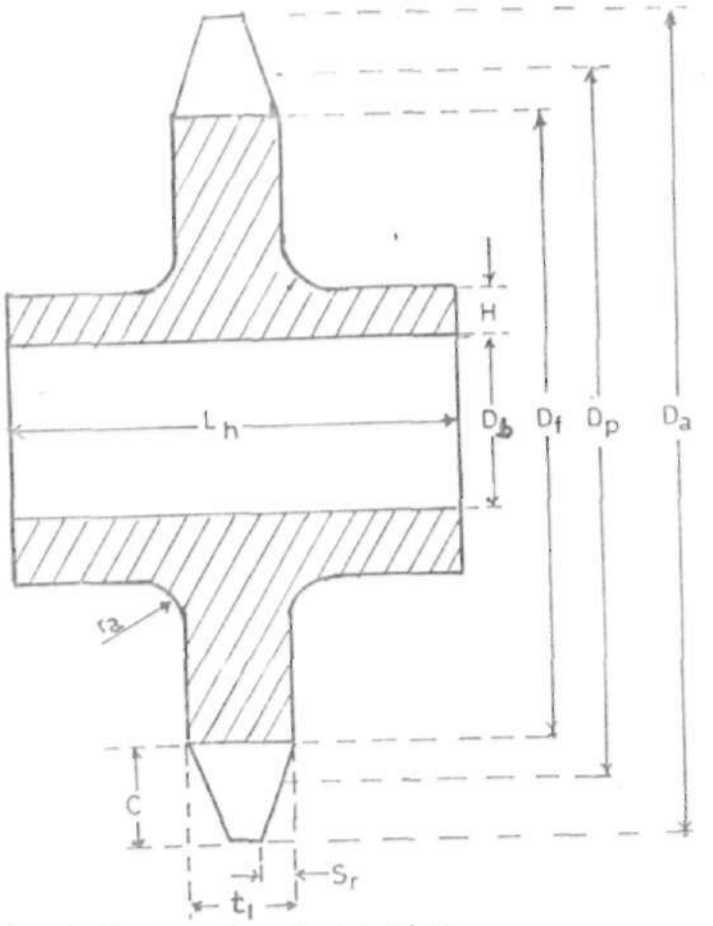


Fig. 3.7: Section of Sprocket

D_b = 25mm P = 12.7mm	$H = 4.75 + \frac{D_b}{6} + 0.01P$ [16]	
	$H = 4.75 + \frac{25}{6} + 0.01(12.7) = 9mm$	H = 9mm
D_b = 25mm H = 9mm	$D_h = D_b + 2H = 25 + 2(9) = 43mm$ [16]	D_h = 43mm
P = 12.7mm	$r_a = 0.4P \quad 0.4(12.7) = 5.1mm$ [21]	r_a = 5mm
P = 12.7mm	$C = 0.5P = 0.5(12.7) = 6.35mm$ [21]	C = 6.4mm
H = 9mm	$L_h = 3.3H = 3.3(9) = 29.7mm$ [16,21]	L_h = 30mm
b_1 = 7.93 [3]	$t_1 = 0.93b_1 - 0.15 = 0.93(7.93) - 0.15 = 7.2mm$	t_1 = 7.2mm
P = 12.7	$S_r = \frac{1}{8}P = \frac{1}{8}(12.7) = 1.6mm$ [16,21]	S_r = 1.6mm

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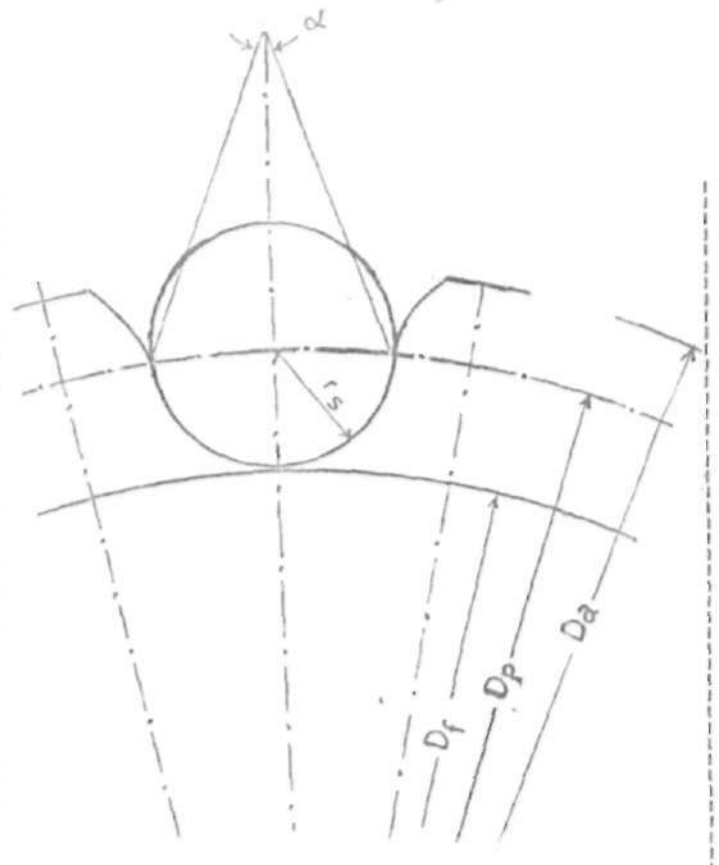


Fig. 3.3: Sitting of chain roller on the Sprocket.

d_1 = 7.93mm	$r_s = 0.502d_1 + 0.05 = 0.502(7.93) + 0.05$ r_s = 4mm [4,21]	r_s = 4mm
T = 20	$\alpha = 130^o - \frac{90^o}{T} = 130^o - \frac{90^o}{20} = 125.5^o$ [4]	α = 125.5^o
ρ_s = 7850 kg/m^3 D_h = 43mm D_b = 25mm L_h = 30mm D_p = 81.2mm t = 7.2mm	$M_p = \frac{\rho_s \pi (D_h^2 - D_b^2) L_h}{4} + \frac{\rho_s \pi (D_p^2 - D_h^2) t}{4}$ $M_p \approx \frac{7850\pi}{4}[(0.043^2 - 0.025^2)(0.03) + (0.0812^2 - 0.043^2)(0.0072)]$ $M_p \approx$ 0.352Kg	
M_s = 0.352Kg g = 9.8m/s^2	$W_p = M_p g = 0.352(9.8) = 3.45N$	W_p = 3.45N

3.9 POWER TRANSMISSION ELEMENTS AND THEIR ANALYSIS BASED ON THE ONE SHAFT SET-UP ARRANGEMENT:

The following assumptions are made for strength analysis of the power transmission elements:

(i) bending due to the side pull of the shaft and spindle clutch arm by the tension in the chain is neglected;

(ii) torsional effects in the shaft and spindle clutch arm due to the inertia of the sprockets are neglected;

(iii) the weight of the template is considered small and neglected;

(iv) the slip or pull out of the spindle of the friction clutch, if any is neglected;

(v) support of the shaft in the bearings is approximated to be simple supporting;

(vi) weight of the extender is considered small and neglected;

(vii) the weight of the shaft is assumed to act at its centre of gravity, and

(viii) the arm of the spindle clutch carrying the sprocket is likened to a cantilever.

3.9.1 SPINDLE CLUTCH ELEMENT:

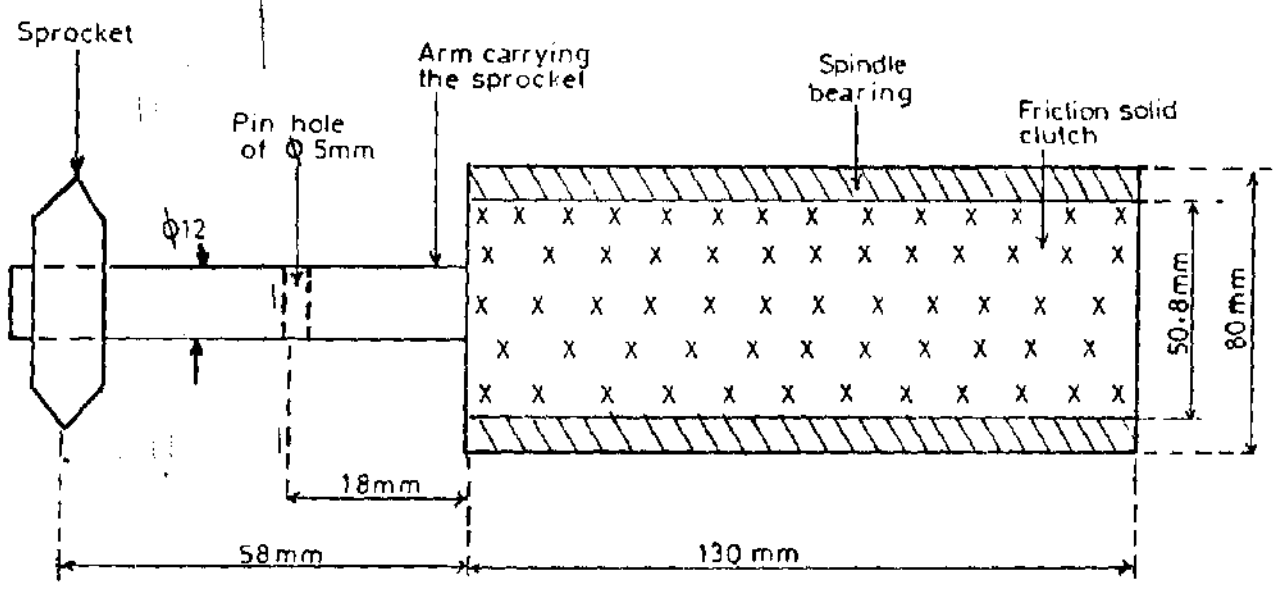
The spindle clutch element consists of:

(i) a sprocket of weight (W_p) = 3.45N;

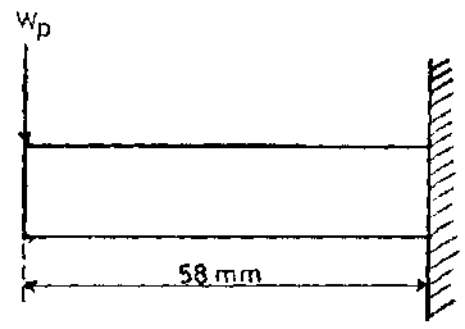
(ii) an arm carrying the sprocket at the end;

(iii) a pin, for joining an extender to the spindle clutch;

(iv) a solid friction clutch. ***These*** are shown in Figure 3.9.



Fig·3·9 : Spindle clutch element .



Fig·3·10: Free body diagram of the spindle clutch element.

Stress analysis

From Figures 3.9 and 3.10,

M_x = $W_p x$ ---------- (3.1)

M_I = 3.45(0.040) = 0.138Nm

M_{max} = 3.45(0.058) = 0.2Nm

σ_b = $\frac{M_x \bar{y}}{I}$ -------(3.2)

where

M_x = bending moment at an arbitrary position X from the end of the arm beam as shown in Figures 3.9 and 3.10

M_I = bending moment at the position of the pin.

M_{max} = maximum bending moment in the arm beam.

σ_b = bending stress in the arm beam

$\bar{y}$ = arbitrary distance from the neutral axis (stress free axis) of the arm beam.

I = second moment of area of the arm beam's cross section.

From equation (3.2), the maximum bending stress due to the maximum bending moment in the arm beam is

σ_m = $\frac{M_{max}\ \bar{y}_{max}}{I}$ where

$\bar{y}_{max}$ = $\frac{d}{2}$

I = $\frac{\pi d^4}{64}$;

d = diameter of the arm beam; and

$\bar{y}_{max}$ = maximum distance from the neutral axis of the arm beam.

Therefore $\sigma_m = \frac{0.2(0.012)/2}{\Pi\ (0.012)^4/64} = 1.2 MN/m^2$.

The maximum bending stress due to bending moment at the pin is

$\sigma_p = \frac{M \bar{y}_{max}}{I}$, where, $I = \frac{\Pi d^4}{64} - \frac{d_p d^3}{12}$

d_p = diameter of the pin = 5mm = 0.005m.

$\sigma_p = \frac{0.138(0.012)/2}{[\Pi(0.012)^4/64 - (0.005)(0.012)^3/12]} = 5.914 MN/m^2$

Therefore the overall maximum bending stress in the arm beam occurs at the pin and is $(\sigma_b)_{max} = 5.914\ MN/m^2$. For steel, the yield stress in tension $(\sigma_y) = 270 MN/m^2$ [22,23].

Therefore the overall maximum bending stress in the arm carrying the sprocket is far less than the yield stress of the arm material, hence the arm is safe.

Deflection

From equation (3.1), the deflection of the arm beam is determined as follows:

$$EI\frac{d^2y}{dx^2} = -3.45x \quad \text{-----} \quad (3.3)$$

$$EI\frac{dy}{dx} = -\frac{3.45x^2}{2} + C_1 \quad \text{----} \quad (3.4)$$

At $x = 0.058$, $\frac{dy}{dx} = 0$, $\rightarrow C_1 = 0.0058$

$$EIy = -\frac{3.45x^3}{6} + 0.0058x + C_2 \quad \text{------} \quad (3.5)$$

At x = 0.058, y = 0; $C_2 = \frac{3.45(0.058)^3}{6} - (0.0058)(0.058)$

$C_2 = -0.00022$

$EIy = -\frac{3.45x^3}{6} + 0.0058x - 0.00022$ ----- (3.6)

$y_{max} = \frac{1}{EI}\left[\frac{3.45(0)^3}{6} + 0.0058(0) - 0.00022\right]$

$= -\frac{0.00022}{EI}$, where;

y = deflection of the arm beam,

E = Young's modulus of the beam material

y_{max} = maximum deflection for mild steel, $E = 204x10^9 N/m^2$;

$I = \pi d^4/64 = \pi(0.012)/64 = 1 \times 10^{-9} m^4$

Therefore $y_{max} = \frac{-0.00022}{204x10^9 x10^{-9}} = 0.000001m = 0.001mm$

In the design of shaft, the deflection is specified to be limited to 0.83mm/Metre [21]. The arm beam is therefore safe.

3.9.2 The shaft

The shaft used was 1200mm long and 25mm in diameter. It was cut from a steel standard rod, and stepped to a diameter of 12mm for 134mm of its length at one end to facilitate entry and insertion of templates, which were made with a bore of 12mm.

Determination of the centre of gravity of the shaft

The shaft used to transmit power is shown in Figure 3.11 below.

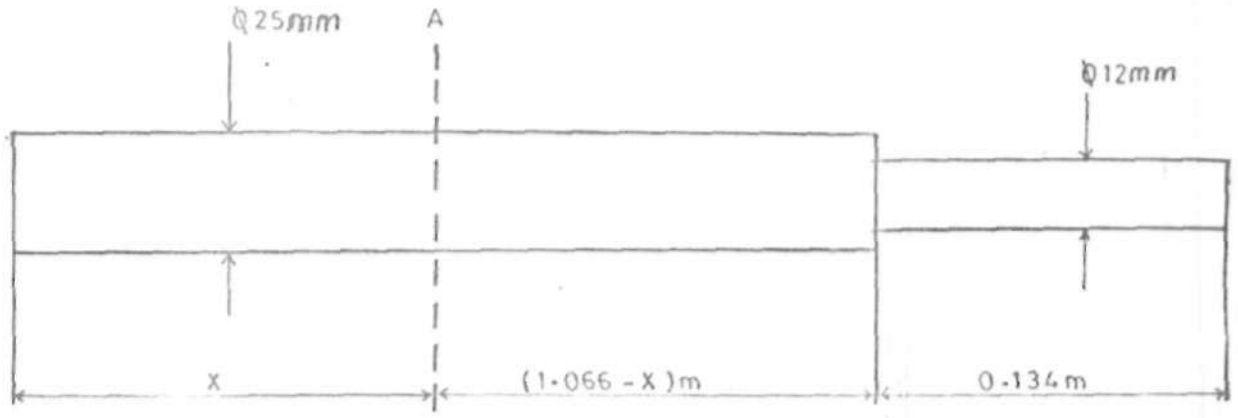


Fig. 3·11 : Shaft .

Density of steel (ρ_s) = 7850 Kg/m^2. From Figure 3.11,

ΣM_{AB} = 0 ------(3.7), where ΣM_{AB} is the sum of all force moments about section AB. From equation (3.7)

$$\Sigma M_{AB} = \frac{\Pi(0.025)^2(7850)(9.8)x^2}{4} - \frac{\Pi(0.025)^2(1.066-x)(7850)(9.8)}{4} - \frac{\Pi(0.012)^2(0.134)(1.134-x)(7850)(9.8)}{4} = 0$$

where 9.8 is the value of acceleration due to gravity.

$$\Rightarrow 0.025^2 x^2 = 0.025^2(1.066-x) + 2(0.012)^2(0.134)(0.133-x)$$

$$\Rightarrow x = 0.553\text{m}$$

The centre of gravity of the shaft is therefore 0.553m from its untapered end.

The total weight of the shaft(W_s) is given as:

$$W_s = \frac{1}{4}\left[9.8\Pi d_b^2 L_b \rho_s + 9.8\Pi d_s^2 L_s \rho_s\right] \quad \text{---------- (3.8)}$$

where d_b = diameter of the bigger portion of the shaft = 25mm;

L_b = length of the bigger portion of the shaft = 1066mm;

d_s = diameter of the smaller portion of the shaft = 12mm; and

L_s = length of the smaller portion of the shaft.

From equation (3.8),

$$W_s = \frac{1}{4}\left[\Pi(0.025)^2(1.066)(7850)(9.8) + \Pi(0.012)^2(0.134)(7850)(9.8)\right]$$

$$W_s = 41.36\text{N}$$

Forces acting on the shaft

The shaft was supported in two bearings 800mm apart. The static forces acting on it are shown in Figure 3.12. The forces are:

(i) the bearing reactional forces (R_1 and R_2),

(ii) force due to weight of the sprocket (W_p) and

(iii) force due to weight of the shaft (W_s).

The free body diagram of Figure 3.12 is shown in Figure 3.13.

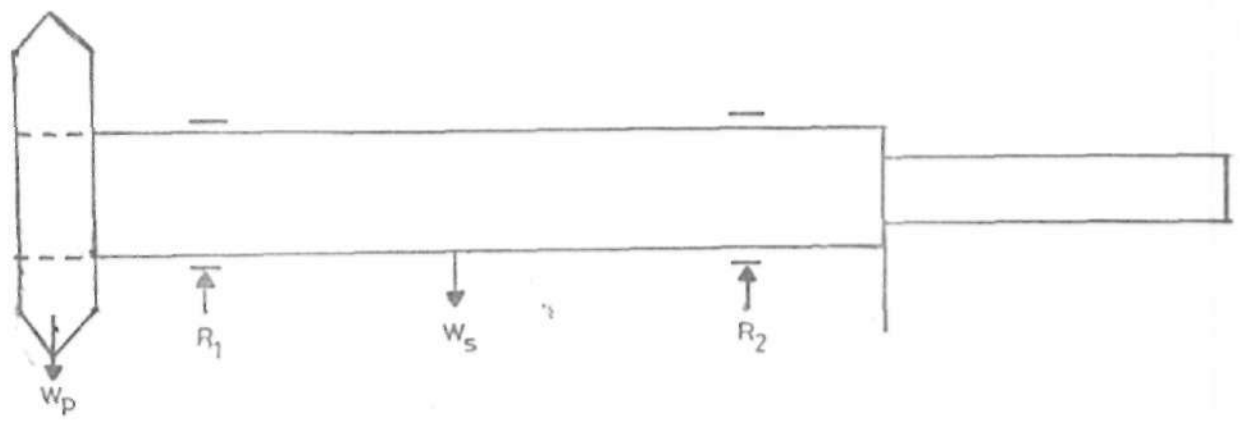


Fig.3.12: Forces acting on the shaft

For equilibrium, sum of all force moments about point D (ΣM_D) is 0.

Using W_s = 41.36N, and W_p = 3.45N.,

ΣM_D = 41.36(0.447) - 0.8R_1 + 3.45(1) = 0

$\rightarrow R_1$ = 27.32N.

For equilibrium, sum of all vertical forces (ΣV) is = 0.

$\Sigma V = 0 \rightarrow 41.36 + 3.45 - 27.32 - R_2 = 0.$ R_2 = 17.5N

Starting from the left end of the shaft shown in Figure 3.13,

The moment at section B is: M_{AB} = - 3.45x ------ (3.9)

The moment at Section C is: M_{BC} = - 3.45x + 27.32[x-0.2] ---(3.10

The moment at Section D is: ΣM_{CD} = - 3.45x + 27.32[x-0.2] -

41.36[x-0.553] --------(3.11

$M_{AB}|x = 0.2$ = - 3.45(0.2) = 0.69Nm

$M_{BC}|x = 0.553$ = - 3.45(0.553) + 27.32(0.353) = 7.7Nm.

The maximum bending moment in the shaft (M_{max}) is therefore 7.7Nm.

Using equation (3.2), the maximum bending stress in the shaft due to the maximum bending moment is $(\sigma_b)_{max} = \frac{7.7(0.025)/2}{\pi(0.025)^4/64} = 5.02MN/m^2$

For steel the yield stress in tension is 270MN/m^2. Therefore the maximum bending stress in the shaft is much lower than the yield stress of the shaft material, hence the shaft is safe.

Deflection of the shaft

From equation (3.11), the deflection of the shaft is determined as follows:

$$EI\frac{d^2y}{dx^2} = -M_x = 3.45x - 27.32[x-0.2] + 41.36[x-0.553] \quad ---(3.12)$$

$$EI\frac{dy}{dx} = \frac{3.45x^2}{2} - \frac{27.32}{2}[x-0.2]^2 + \frac{41.36}{2}[x-0.553]^2 + C_1 \quad ---(3.13)$$

$$EI_y = \frac{3.45x^3}{6} - \frac{27.32}{6}[x-0.2]^3 + \frac{41.36}{6}[x-0.553]^3 + C_1x+C_2 \quad ---(3.14)$$

where C_1 and C_2 are constants.

$y|_{x = 0.2} = 0$

Therefore, $0046 - 0.303 + 0.2C_1 + C_2 = 0.$

Hence, $C_2 = 0.303 - 0.0046 - 0.2C_1$ -----* -(3.15)

$y|_{x = 1} = 0$

Therefore, $0.525 - 2.33 + 0.62 + C_1 + C_2 = 0.$ ------(3.16)

Solving (3.15) and (3.16) simultaneously; $C_1 = 1.05$ and $C_2 = 0.089$

Therefore, $EIy = \frac{3.45}{6}x^3 - \frac{27.32}{6}[x-0.2]^3 + \frac{41.36}{6}[x-0.553]^3 + 1.05x+0.089.$

$y|_{x = 0.553} = \frac{1}{EI}[0.097 - 0.2003 + 0.581 + 0.089] = 0.567/EI$

$y|_{x = 0.57} = \frac{1}{EI}[0.1065 - 0.231 + 0.000034 + 0.6 + 0.089] = 0.565/EI$

$y|_{x = 0.553} > y|x = 0.57$. This means the maximum deflection occurs at $x = 0.553$, and is $0.567/EI$

$$I = \frac{\pi(0.025)^4}{64} = 0.96 \times 10^{-8}\ m^4$$

Therefore the maximum deflection of the shaft is

$$y_{max} = \frac{0.567}{204\times10^9 \times 0.96\times10^{-8}} = 0.0003\ m = 0.3mm.$$

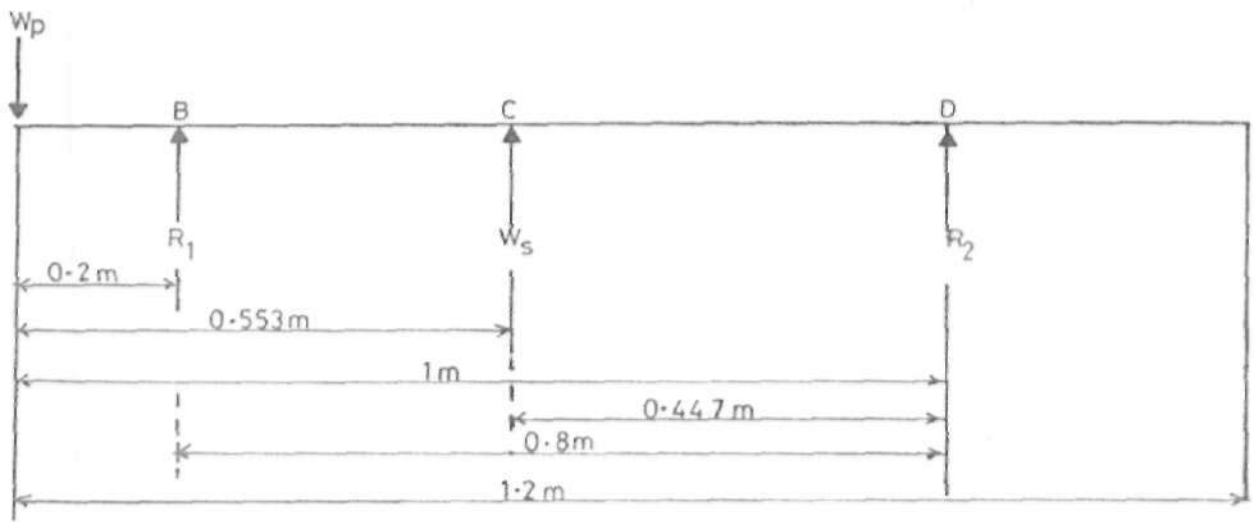


Fig. 3·13 : Free body diagram of forces acting on the shaft.

In the design of shafts, the deflection is specified to be limited to 0.83mm/metre [21]. Therefore a 0.3mm deflection has no effect on the shaft.

3.10 SELECTION OF BEARINGS:

Bearings are selected on the basis of shaft diameter. The selection of bearings for a particular use is governed by the following factors [5,20]:

(i) the radial load (N);

(ii) the thrust load (N);

(iii) the speed of the bearing;

(iv) the desired life of the bearing;

(v) condition of loading; and

(vi) the environment in which the bearing is to operate.

For the power transmission shaft used for non-circular boring on the lathe, the calculated maximum radial bearing load from section 3.9 is 27.32N. For the shaft, there is no thrust load, and for simple loading, bearing 25BC 10 was selected in accordance with international standards organization [4]. This is a deep groove ball bearing. It has the following specifications:

(i) outside diameter = 47mm;

(ii) bore = 25mm;

(iii) thickness of the bearings = 12mm;

(iv) basic load ratings are: Static (C_0) = 4900N and dynamic (C_d) = 7644N; and

(v) lubrication requirements for limiting speeds as: Grease for 15,000Rpm and oil 18,000Rpm.

3.11 BUSHINGS:

Three steel bushings were produced. Bushings U_1 and U_2 shown in Figure 3.5 have the following specifications:

(i) internal diameter = 47mm;

(ii) outside diameter = 60mm; and

(iii) length = 50mm

Bushing U_3 also shown in plate II has the following specifications:

(i) internal diameter = 81mm;

(ii) outside diameter = 91mm;

(iii) length = 120mm; and

(iv) a screw hole of 8mm in diameter at its mid length.

3.12 SLAB:

One steel slab shown in plate II was produced and has the following dimensions:

(i) length = 150mm;

(ii) width = 60 mm;

(iii) thickness = 10mm; and

(iv) two screw holes 8mm in diameter and 130mm apart along the length and each 10mm from the edge of the slab.

3.13 PIPE:

One cast iron pipe shown in plate IL and Figure 3.5 was produced from a standard pipe rod. It has the following specifications:

(i) internal diameter = 60mm;

(ii) length = 1000mm; and

(iii) outside diameter = 80 mm

3.14 KEYS:

Two identical rectangular parallel keys based on ISO 773 for a shaft diameter of 25mm were produced. The dimensions according to ISO 773 [24] are as follows:

(i) length of the key = 25mm;

(ii) width of the key = 8mm;

(iii) depth of the key = 7mm;

(iv) depth in the hub (sprocket) = $3.3\text{mm}^{+0.2}_{0}$

(v) depth in the shaft = $4\text{mm}^{+0.2}_{0}$;

(vi) tolerances of width of the key in the shaft = +0.018, and

(vii) tolerances of width of the key in the hub (sprocket) = -0.03.

3.15 CHAIN:

The chain used for power transmission is a roller chain ANSI 40, according to the American standards institute [16,21]. The chain has the following specifications:

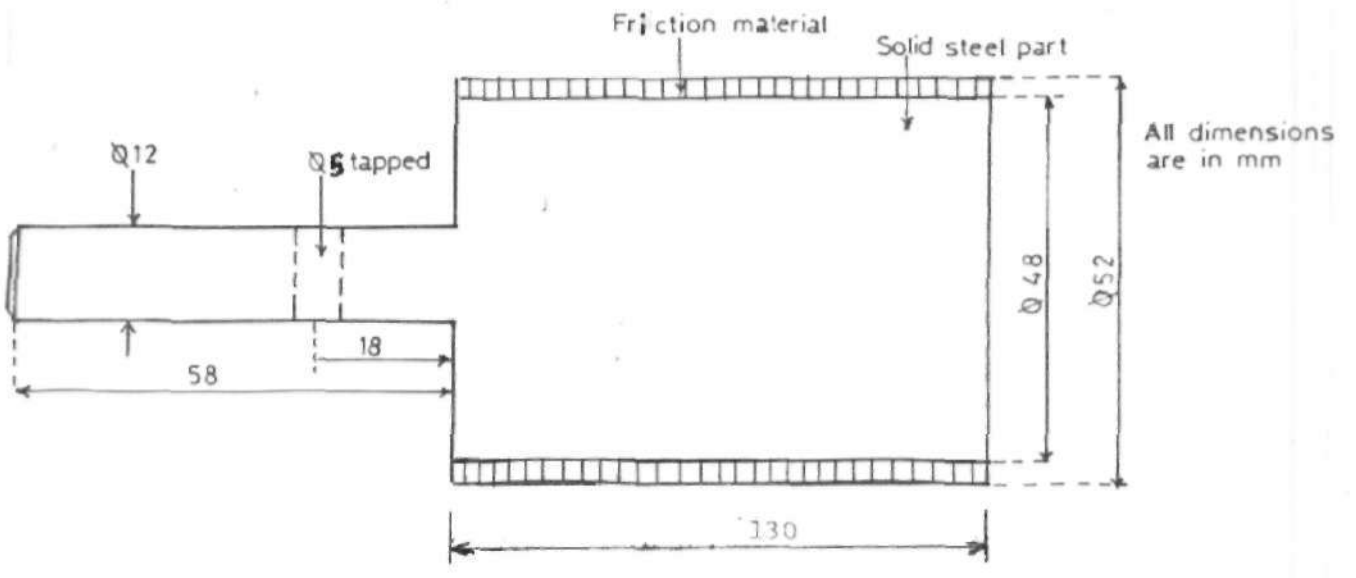
(i) pitch = 12.7mm;

(ii) number of links = 78; and

(iii) length = 0.99m.

3.16 SPINDLE CLUTCH:

The spindle clutch used for power transmission was produced using a solid steel part and friction materials. The dimensional specifications and items of the spindle clutch are shown in Figure 3.14. The friction materials were covered on the solid steel part with sufficient thickness to give a tight fit into the lathe spindle of diameter 50.8mm.



Fig·3·14: Spindle friction clutch.

3.17 THE EXTENDER

The extender used for power transmission and its diamensional specifications is shown in Figure 3.15. It was produced from mild steel.

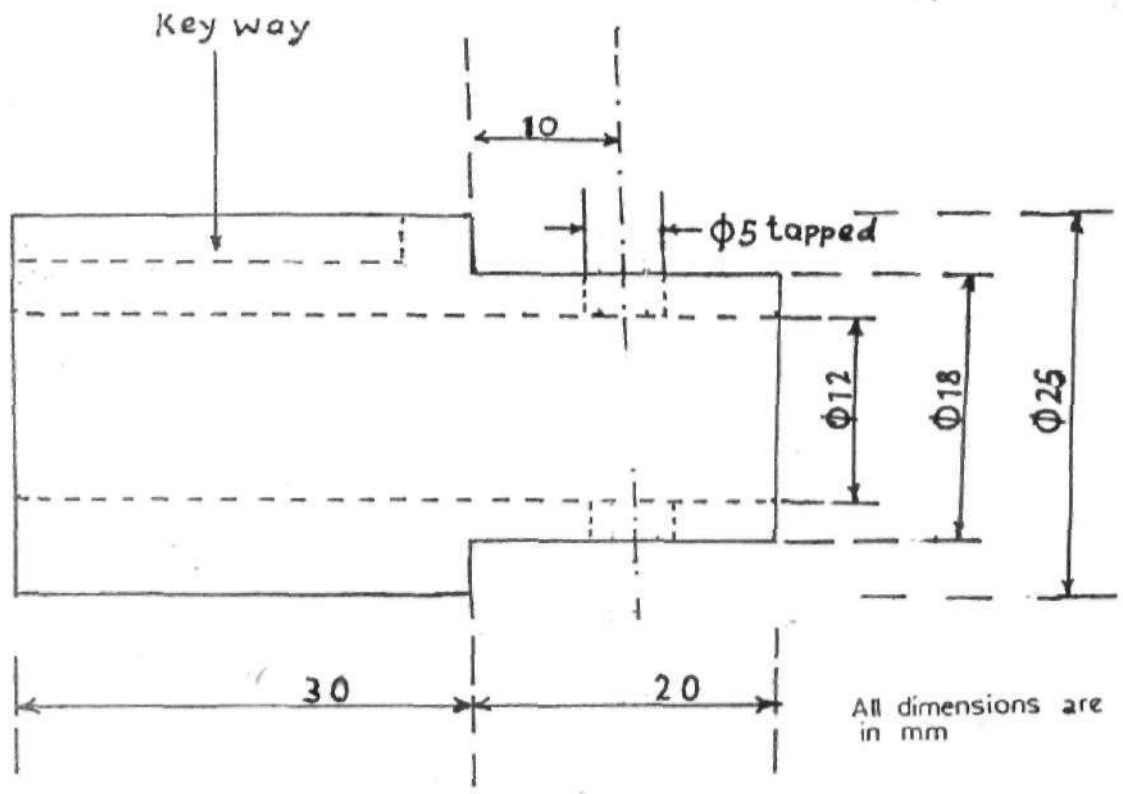


Fig. 3·15: Spindle clutch extender.

CHAPTER FOUR

THE PROPOSED NON-CIRCULAR BORING ATTACHMENT

4.1 INTRODUCTION:

The proposed attachment is essentially a slide positioning servo-system. The attachment consists of a hydraulic copying unit, various individual templates and a power transmission system. It is proposed to tap power from the spindle of the lathe using chain drive to drive a given template at the same

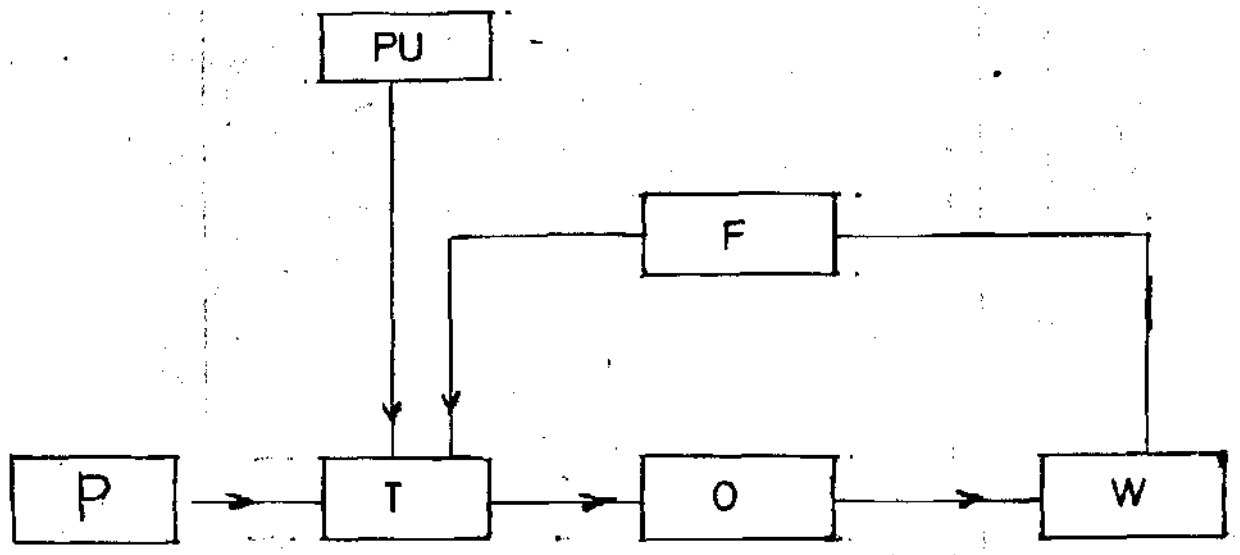


Fig. 4.1: Block diagram of a slide positioning hydraulic servo-system.

speed as the lathe spindle. The driven template is then used to actuate the boring tool through slide positioning in accordance with specifications as determined by the contour of the template. The programmed actuation of the boring tool of which will then be used to produce non-circular bores. The proposed operational principle is shown in Figure 4.1.

Figure 4.1 shows the programme medium P - the template, which specifies the mode of operation and action; pump PU, delivering a stream of hydraulic oil to the operative mechanism

(hydraulic power cylinder) O of the slide working member W; tracer T, designed as a directional valve admitting hydraulic fluid to one or the other end of the cylinder in accordance with the direction the valve is displaced by the programme medium; and a feed back F, rigidly linking the slide with the housing or the spool of the tracer.

4.2 HYDRAULIC COPYING UNITS:

Generally hydraulic copying equipments find wide applications in metal cutting machine tools. The most available copying units used in metal cutting are the hydraulic systems. Those used on the lathe are provided with features for mounting a boring bar to facilitate internal copying. A desirable and essential feature of the unit in such cases is the arrangement for limiting the back position of the slide to avoid damaging of boring bars and workpieces during withdrawal [4].

Advantages offered by hydraulic copying units and hydraulic copying systems are as follows [10,25]:

(i) they permit larger power and force to be transmitted by a hydraulic cylinder of comparatively small overall size;

(ii) they offer the means of obtaining infinitely variable rates of feeds thereby making available the most expedient cutting conditions and idle travel speeds and also permit cyclic re-engagement of the working feeds;

(iii) convenient positioning for hydraulic copying units in machine, regardless of the location of mechanical power transmission;

(iv) the simplicity of obtaining linear motions;

(v) frequent and rapid changes of linear and rotary motions;

(vi) smooth motions which increase the life of cutting tools and sometimes make possible the use of higher speed and feed rates;

(vii) the use of standard sub-assemblies and machanisma;

(viii) hydraulic copying units do not as a rule have parts subject to high contact stresses.

(ix) hydraulic copying units can be designed of standard elements which can be purchased from specialized plants;

(x) they make it easy for stepless regulation of speeds to be obtained, which is vital for efficient operation;

(xi) they permit the possibility of continuous supervision of a hydraulic copying system by means of simple and cheap instruments such as pressure gauges;

(xii) the copying units are rugged, accurate and free from both backlash and dead zones;

(xiii) hydraulic copying systems can have very high response rates and time constants of the order of 0.001 seconds can readily be achieved with them, even when forces of several Newtons have to be produced;

(xiv) hydraulic copying systems do not require amplification of the power of the signal.

One draw back of hydraulic copying systems common to all control systems with feed back in general is a tendency to instability when high accuracy and tracing speeds are required [25].

4.3 EQUIPMENT AND FACILITIES:

The following items of equipment and facilities exist in the production laboratory of the department of mechanical engineering, Ahmadu Bello University, Zaria, and were used.

(i) the universal lathe;

(ii) various boring tools; and

(iii) the hydraulic copying unit (type TKB10) with the following specifications:

Maximum turning diameter over screen	150mm
Entire travel of copying carriage along guides	80mm
Toolpost travel	25mm
Oil tank capacity	30 L
Pump drive motor power	0.55W
Pump motor synchronous speed	1500 Rpm
Pump output	5 L/Min
Oil tank weight without oil	54 Kg
Copying carriage weight	70 Kg

4.4 TEMPLATES:

The production of accurately formed templates with proper surface finish is the initial requirement for copy machining. The accuracy of the desired profile and good surface finish are of vital importance since templates can transfer surface undesirabilities to the produced forms on workpieces.

Templates themselves, could be complex shaped parts, therefore there is no single ordinary machining process of producing them. They can however be produced partly by some of the conventional machining processes such as sawing, shaping, slotting, planning, milling and then finishing manually by a series of combined sawing, chiselling, filling and rubbing with

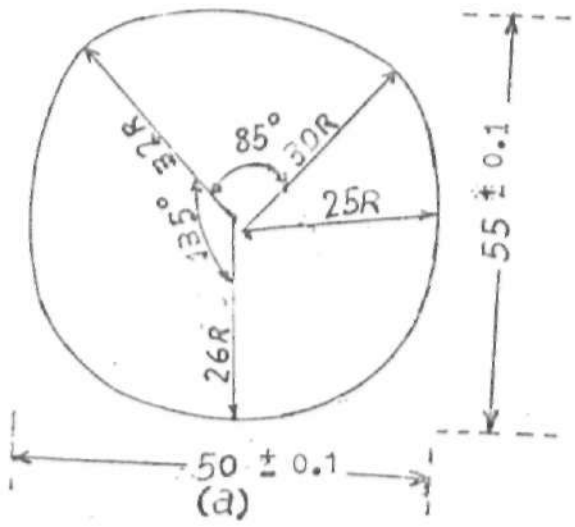
some sand paper till the desired shape and surface finish is obtained.

Advanced methods of producing templates is by numerical machining using numerically controlled machine tools, and of course by copy turning operations [34]. Templates can be made of metal or hard wood.

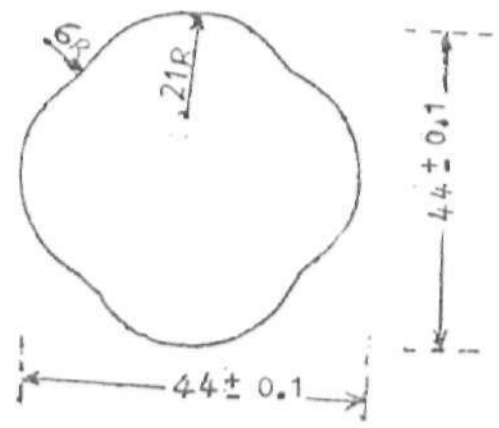
Three templates with profiles shown in Figure 4.2 were produced in the workshop of the department of Mechanical Engineering, Ahmadu Bello University, Zaria, and were used for non-circular boring on the lathe.

The templates were produced from mild steel using manual machining in conjunction with some conventional machining processes as given in paragraph two of section 4.4.

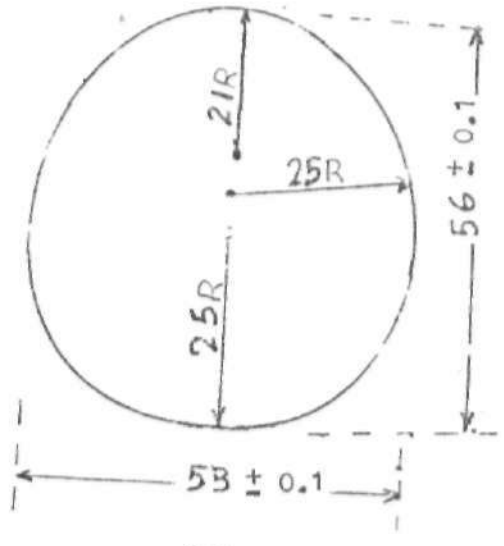
The choice of the sizes and profiles of the templates shown in Figure 4.2 is arbitrary. The templates were produced with a surface finish of 1.5μm.



(a)



(b)



(C)

All dimensions are in mm.

Fig·4·2: Profiles of templates

4.5 THE NON-CIRCULAR BORING ATTACHMENT:

The non-circular boring attachment is shown in Plates III and IV.

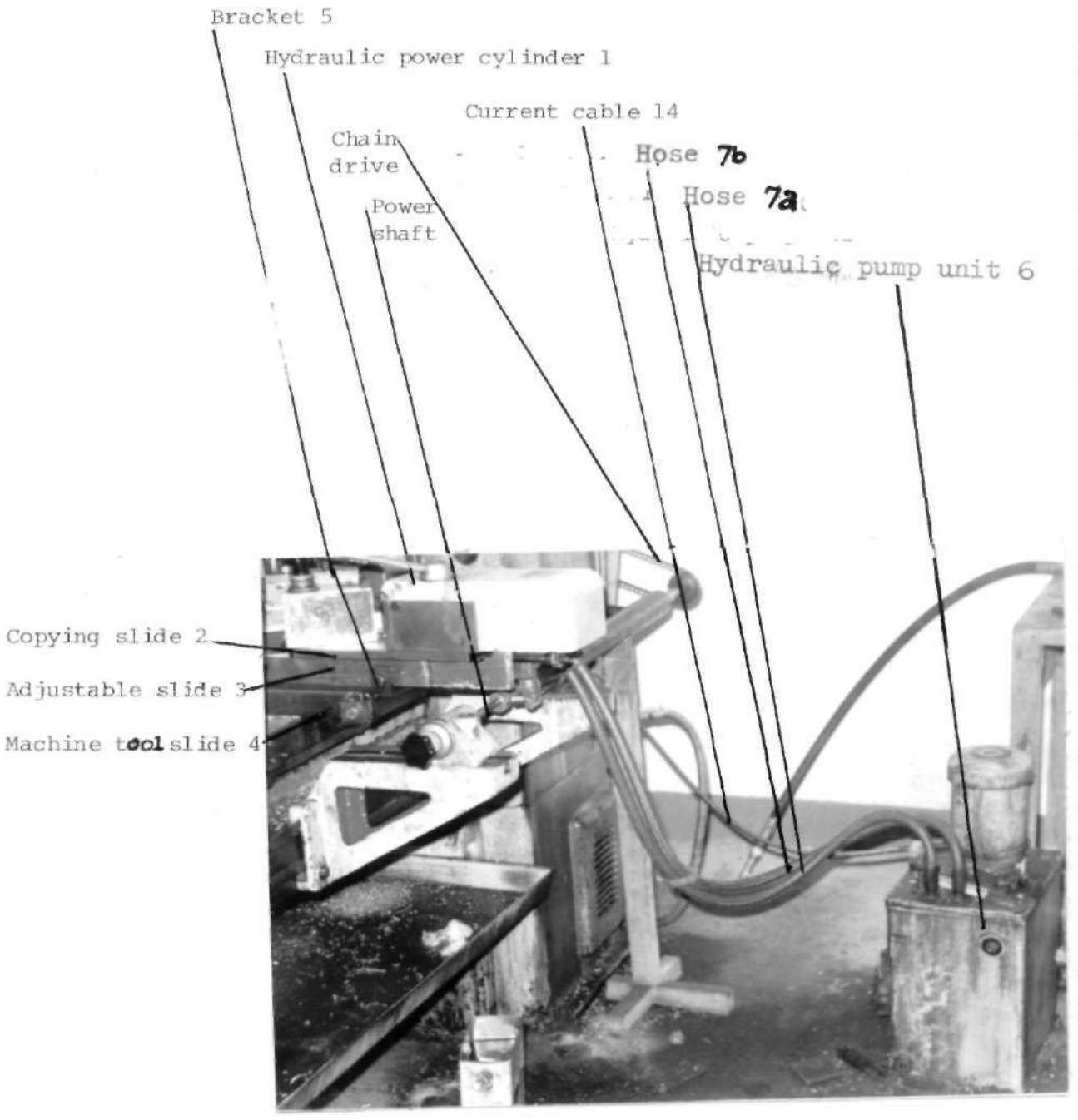


Plate III: Side view of the attachment.

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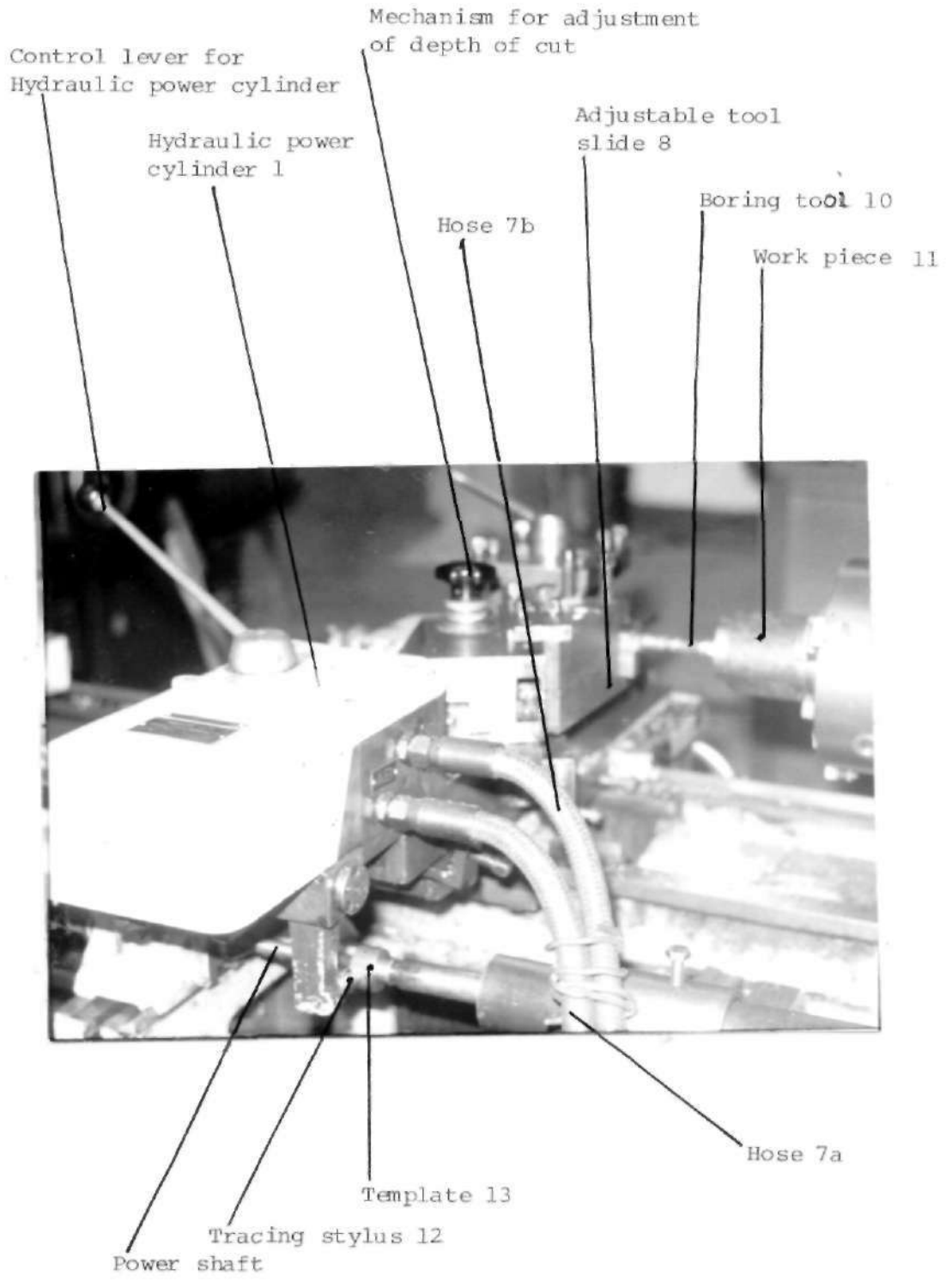


Plate IV: Back view of the attachment.

From plate III the hydraulic power cylinder 1 is made integral with the copying slide 2. Slide 2 was mounted on adjustable slide 3 by means of male and female dovetail way provisions on slides 2 and 3 respectively. This arrangement permits copying slide 2 to slide freely along the dovetail ways when operated by the power cylinder. Slide 3 was again mounted on the machine tool slide 4 (cross slide of the lathe) by means of T-slot provisions used in conjunction with bolts to hold the two slides together. Bracket 5 was also used in conjunction with bolts to hold slide 3 integral with machine tool slide 4.

The hydraulic pump unit 6 in the foreground contains the pump and tank, and the main relief valve. It is connected by two hoses 7a and 7b. One for delivering hydraulic oil to the power cylinder and the other for draining excess oil to the tank.

Adjustable slide 8 (plate IV) is mounted on the copying slide 2 by means of male and female dovetail ways. It is provided with features for mounting the boring tool and a mechanism 9 for adjustment of depth of cut.

The boring tool 10 was mounted on its post longitudinal-axially to the workpiece 11 which was held conventionally in the chuck before the boring operation commenced.

Before boring, tracing stylus 12 was arranged by adjustment of slide 4 to contact template 13, so as to follow in detail the templates contour from one end to the other along the feed direction of the boring tool.

4.6 THE ACTION OF TRACER CONTROL:

Based on the practical set-up arrangement described in section 4.5, the outline given in Figure 4.3 illustrates the principle of tracing control during the boring operation.

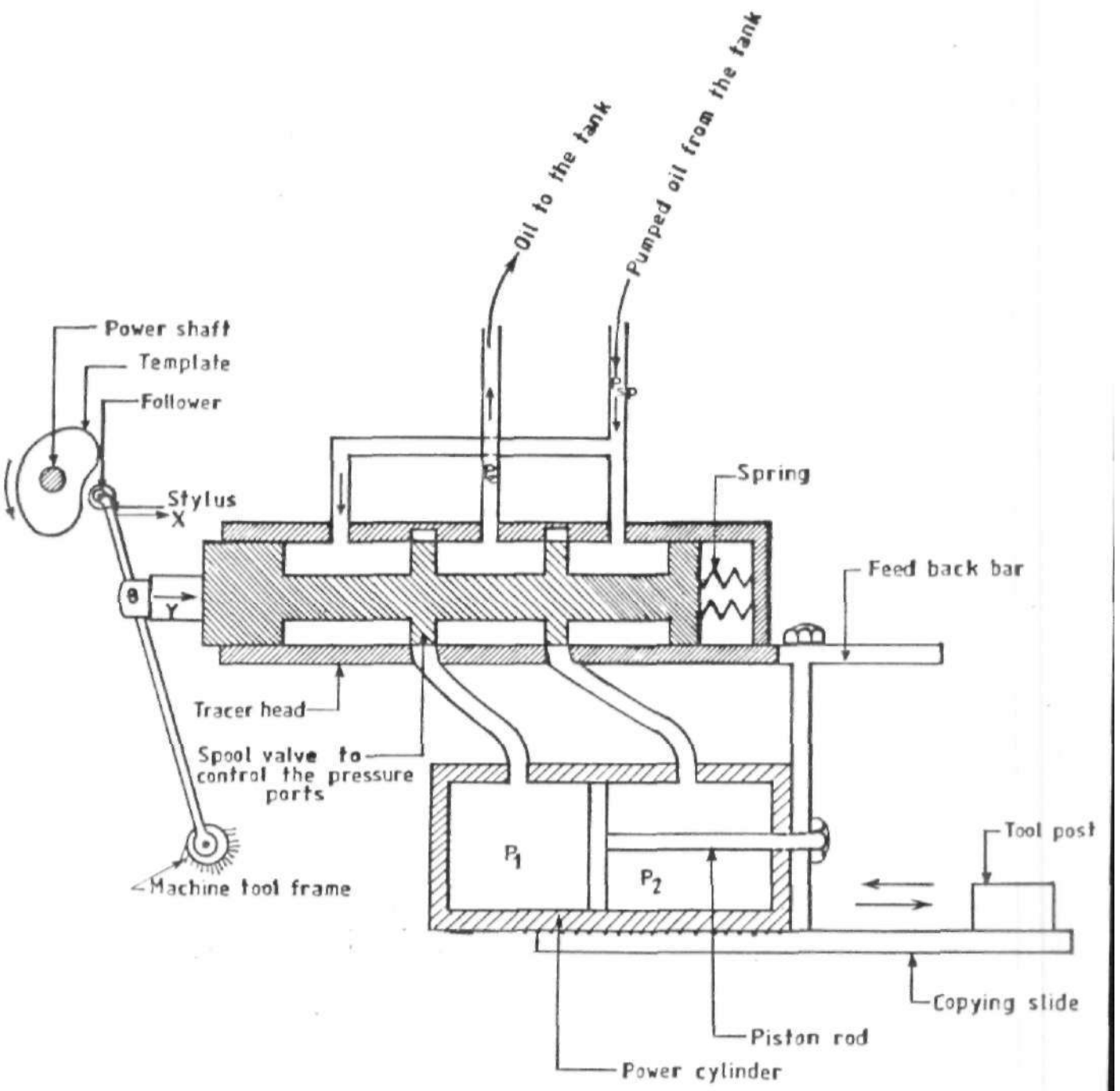


Fig. 4.3. Tracing control principle of the set-up arrangement.

The feed back as can be seen from figure 4.3 is formed by fixing the tracer head to the copying slide of the lathe, and functions when the stylus contacts the template to close the loop. The tracer head is mounted on a feed back bar bolted to the copying slide.

The system is in equilibrium when the stylus spool blocks the pressure ports as shown in Figure 4.3 and will remain so as long as the stylus is in contact with the parallel portion of the template. When the stylus encounters a ramp due to the rotation of the template, it moves to the right from the null point to open the left, port to oil under pressure. The main piston now moves to the right taking the slide with it, an action which in effect is an attempt to close the pressure port to restore the balance. That is the error of the stylus from the null position is endeavouring to zero the difference between the input and the output. The combined action is continuous until the stylus reaches the end of the ramp. The retraction of the stylus ceases thereafter and the slide closes the left port to zero the error, thereby restoring the balance for the stylus travel along the parallel portion of the template. When the stylus reaches a depression, the action is repeated but with the stylus and slide moving to the left. In practice the boring tool would have been profiling the workpiece when the longitudinal motion is provided by the machine tool slide.

4.7 TESTING OF THE NON-CIRCULAR BORING ATTACHMENT:

The boring operation was done by starting the hydraulic pump through the current cable 14 (Plates III and IV) by turning on the current switch. Individual depths of cut ranging from 0.1mm to 2mm together with individual feed rates ranging from 0.04mm/rev to 0.374mm/rev at desired spindle speeds such as: 22.4, 31.5, 45, 63, 90 and 180 revolutions per minute were taken for each cycle of boring operation. With several machining cycles and controls such as terminating the end of a boring cycle and restarting, the desired sizes, correct profiles and surface finish of the workpieces were obtained.

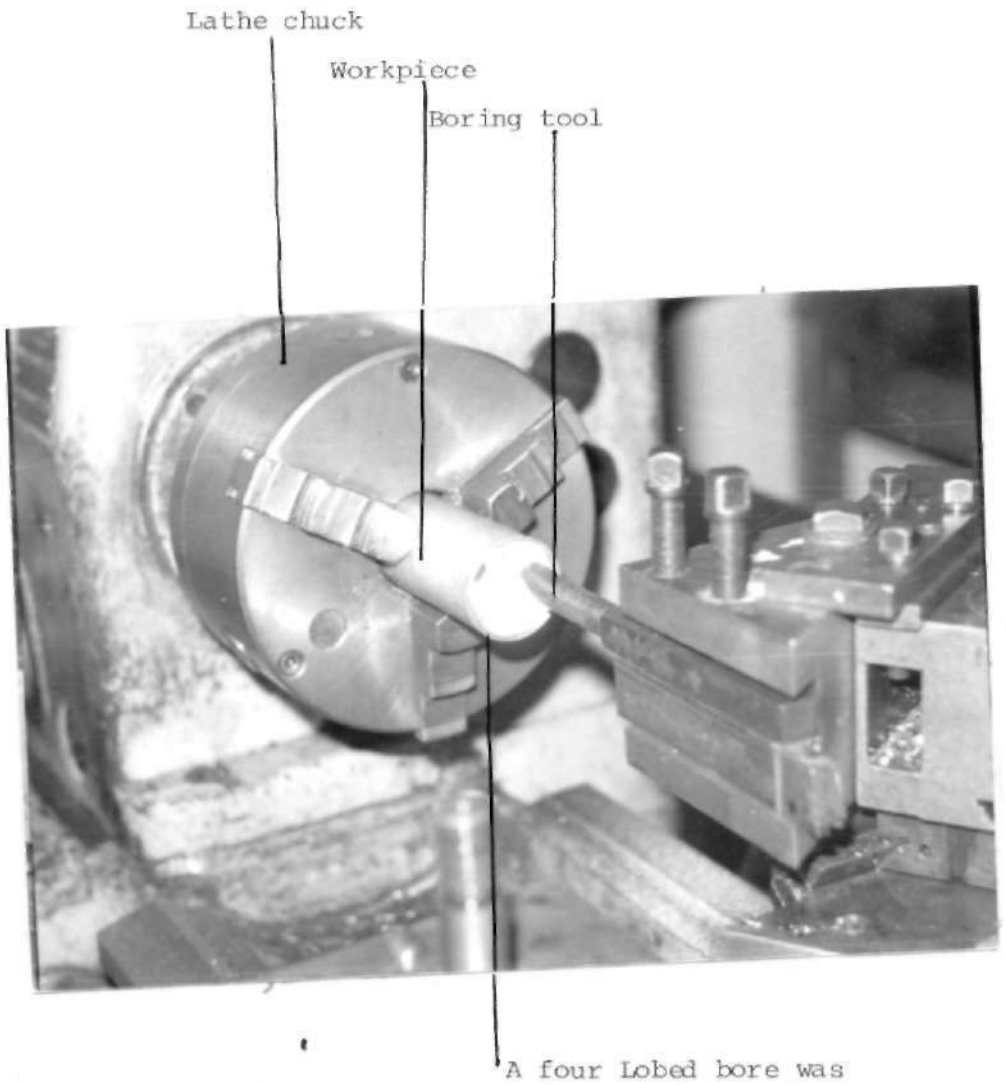


Plate V: An aluminium workpiece as it was being bored in the Laboratory.

Plate V above shows how an aluminium workpiece was being bored in the laboratory while Plate VI below shows various shapes of non-circular bores of uniform cross section produced from aluminium, brass and mild steel.

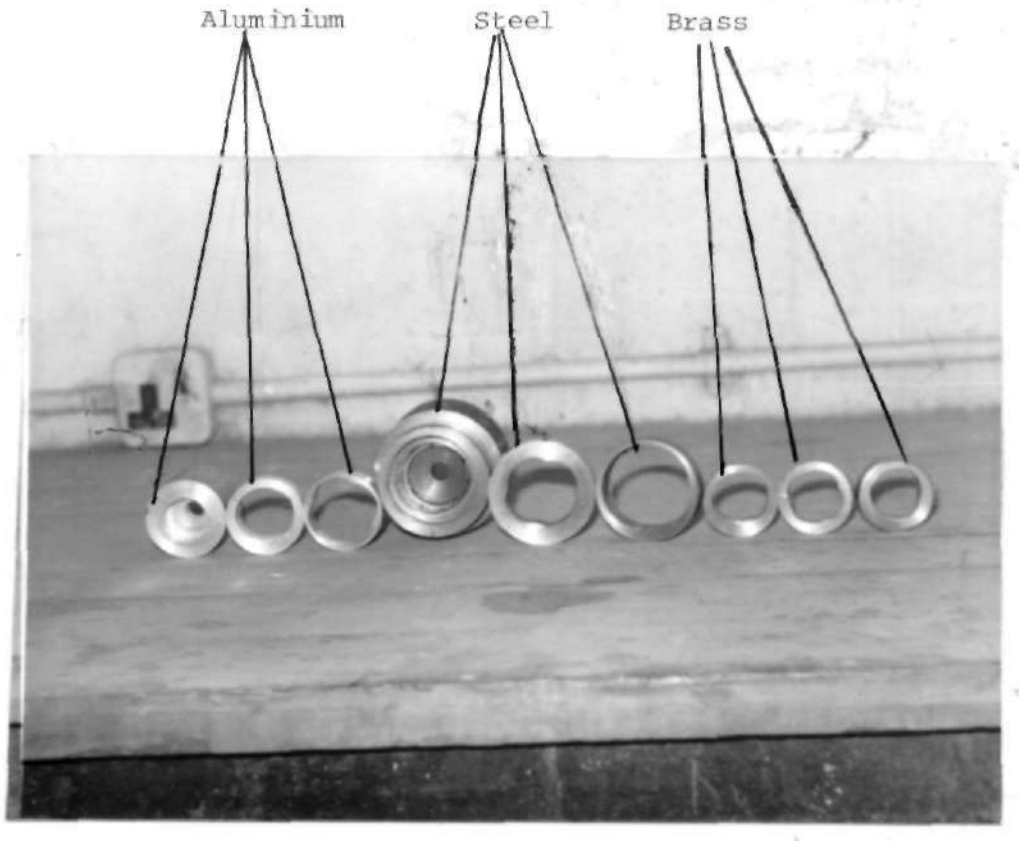


Plate VI: Shapes of some of the produced non-circular bores.

4.8 COMMENTS AND CONCLUSIONS:

It was observed during non-circular boring operations on the lathe, that the cutting action was not continuous at the start of boring which is the start of profile machining. The cutting action started at the points corresponding to the highest rise of the templates and proceeded gradually to the least rise. Thereafter the cutting action was continuous around the periphery of the bore, which is the full profile stage of machining. The bores were produced with either enlargement or reduction of the size of the templates. The size of a template is therefore immaterial to the size of a non-circular shape to be bored. One limitation imposed on the production of templates is that the curves and recesses forming the surface contour of the templates should not be too sharp or steep respectively, so

as to prevent the stylus from following in detail over the entire surface profile. It is preferable to use small-sized templates so that the rise of the boring tool shall not be too much for the pre-drilled holes which are small in diameter. For the non-circular boring on the lathe the pre-drilled holes had to be larger than the diameter of the individual boring tools so as to give room for the tool actuation according to the specifications of the template or programme medium.

Boring operations were attempted for all the twelve speeds of the lathe, from the least speed of 22.4 Rpm to the highest speed of 1000 Rpm. Increase in system vibrations and consquently the difficulty of the tracing stylus to follow exactly the contour of the template at high spindle speeds, limited actual boring operations to low spindle speeds such as: 22.4, 31, 45, 63, 90 and 180 revolutions per minute.

It is known that all servo-control systems with feed back are inherent to instabilities[25]. Therefore,the difficulty of the tracing stylus to follow exactly the contour of the template at high spindle speeds could mainly be due to increase in system vibrations which resulted to instabilities in the attachment which works on the principle of a servo mechanism.

The chain drive system operated at all the twelve spindle speeds of the lathe. The drive was very smooth, no slippage and clamping of the chain were observed during the entire boring operations. In fact the chain method of power transmission is reliable and meets all the speed demands for non-circular boring on the lathe. The observed speeds, attained to drive the template vary from 0 to over 1000 revolutions per minute.

Different shapes of non-circular bores of uniform cross-section from different workpiece materials have been produced.

CHAPTER FIVE

ANALYSIS AND MEASUREMENT OF FORCES

5.1 INTRODUCTION:

In order to put the analysis of the metal cutting operation on a qualitative basis, certain observations must be made before, during and after a cut. The number of observations that can be made during the cutting process are rather limited. One of the more important measurements to be made is the determination of the cutting force components [28].

The forces acting on the cutting tool are an important aspect of machining. For those concerned with the manufacture of machine tools, a knowledge of the forces is needed for estimation of power requirements and for design of structures so that they are adequately rigid and free from vibrations. Scientific analysis of metal cutting also requires knowledge of the forces [30,36].

Boring is a machining process of enlarging a drilled hole. In boring holes, the resultant cutting force F_R, can be resolved in three mutually perpendicular components. The force F_c which is the vertical component of F_R is the largest and the main cutting component; it determines the load on the speed gear box mechanism of the machine tool, the torque M_{tor}, the effective machining power P_{eff} and the amount of deflection of the boring bar in the vertical plane. The radial component F_r of the resultant cutting force F_R determines the amount of tool spring away from the work and the amount of the boring bar deflection in a horizontal plane. The axial component F_a is directed along the spindle axis and determines the load on the feed mechanism. The components F_c, F_r and F_a depend on the properties of the material being

machined, chip cross-section and the geometry of the cutting element on the tool. These components increase with the hardness and strength of the material, depth of cut and feed rate [26]. It has been found by studies and practice that the increase in the depth of cut has a considerably greater effect on the cutting force components than an increase in the rate of feed. In addition to the above factors, the components F_r and F_a are appreciably affected by the plan approach angle ϕ, side rake angle α_s, and the amount of wear δ on the flank and to a lesser degree, the nose radius η. When the plan approach angle is increased, the radial component F_r, decreases and the axial component F_a increases. An increase in the angle α_s diminishes F_r and F_a. More intensive wear on the flank δ tends to increase the forces F_r and F_a [26].

In the last ninety two years many dynamometers have been developed, capable of measuring tool forces with considerable accuracy [24,25]. In general dynamomenters must measure at least two force components in order to determine a two dimensional resultant cutting force. With boring, the force F_r has been found to be very small compared to F_c and F_a [24,39]. In this case the cutting operation is essentially two dimensional. Dynamomenters are available and can measure precisely the values of F_c and F_a. With the measured values of F_c and F_a, the resultant cutting force F_R, effective machining power P_{eff} specific cutting energy P_s, torque on the spindle M_{tor} and the rate of metal removal Q can be obtained as follows:-

$$F_R = \left[F_c^2 + F_a^2\right]^{\frac{1}{2}} ; \quad \text{----------(5.1)}$$

$$P_{eff} = F_c V_c ; \quad \text{----------(5.2)}$$

$$P_s = \frac{F_c}{f.d} = \frac{F_c}{A_c} ; \quad \text{----------(5.3)}$$

$$M_{tor} = F_c . D ; \quad \text{----------(5.4)}$$

$Q = f.d.V_c$; and --------(5.5)

$V_c = \frac{\Pi Dn}{60}$ ----------(5.6)

where:

F_c = vertical component of the resultant cutting forces;

F_a = axial component of the resultant cutting force;

V_c = cutting speed;

f = feed rate of the cutting tool;

d = depth of cut;

D = diameter of the hole being bored; and

n = spindle speed in revolutions per minute.

For the case where the boring tool does not cut continuously round the entire circumference of the hole being bored, per revolution of the workpiece as it occurs at the start of non-circular boring, equations (5.2) and (5.5) are modified to take the form:

$P_{eff} = K.F_c.V_c$ ---------- (5.7); and

$Q = K.f.d.V_c$ ---------- (5.8).

Where K is the proportion of workpiece-tool contact length to the circumference of the hole per revolution of the workpiece, K can be found by good observation and estimation during the boring process or by measurement.

5.2 MEASUREMENT OF CUTTING FORCES:

In general, unless some sort of mechanism is used, force measurement actually involves the measurement of a deflection with suitable calibration between force and the deflection it produces [28]. In most dynamometers the force is applied to some sort of spring and the deflection thus produced is measured.

Cutting forces were measured in the laboratory using the sigma cutting tool dynamometer type MK III. The dynamometer was rigidly mounted on the tool post and slightly modified to hold the boring tool rigidly and longitudinally to the the axis of the workpiece which was held conventionally in the chuck as shown in Plate VI below.

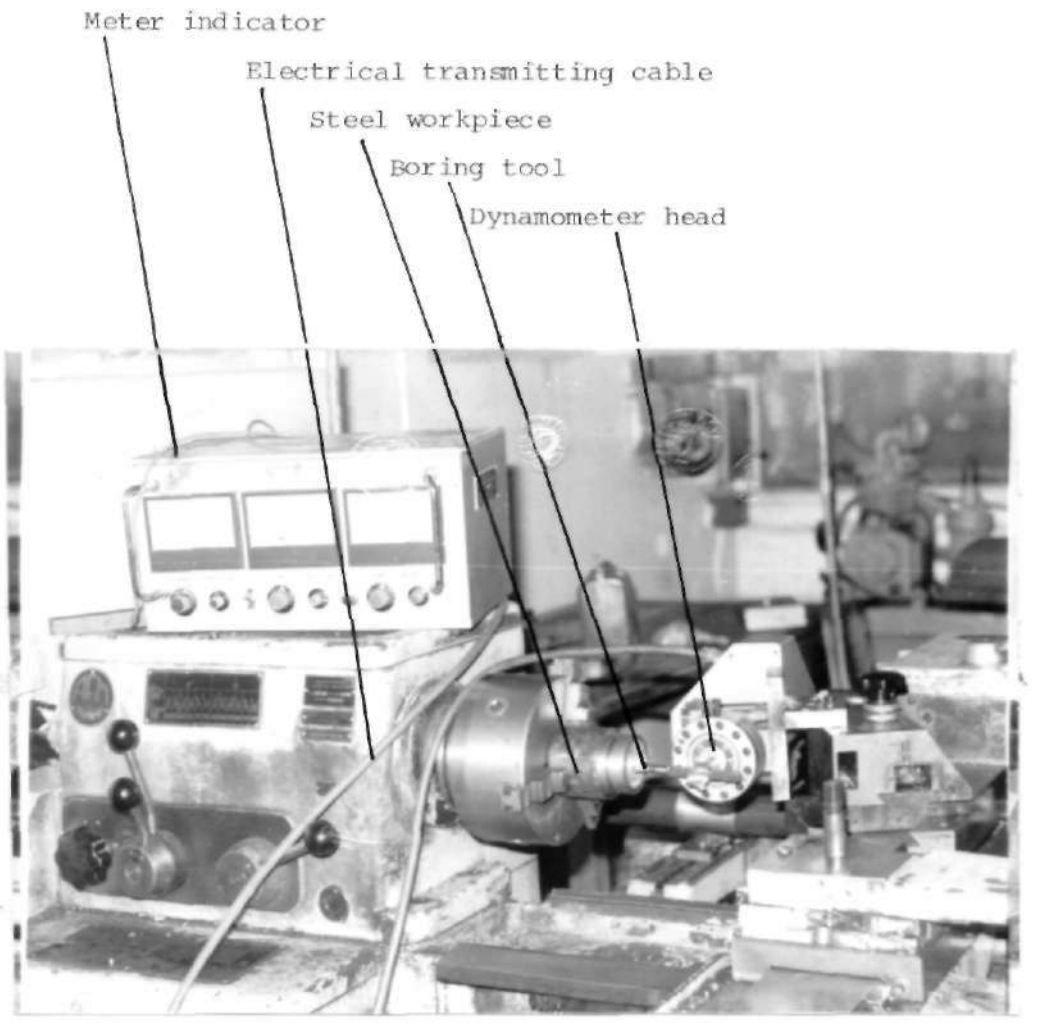


Plate VI: Laboratory set-up for measuring cutting forces using sigma cutting tool dynamometer.

The vertical and axial components of the resultant cutting forces were instantly recorded on the vertical and axial indicators of the meter during the cutting process.

5.3 RESULTS AND DISCUSSIONS

5.3.1 Results:

The results for the experimentally measured values of the cutting forces in Newtons(N) under different known cutting conditions of spindle speed, feed rate, depth of cut and hole diameter during non-circular boring operations, together with corresponding calculated parameters using equations (5.1) to (5.8) at the start of profile machining and full profile machining are tabulated in tables 1 and 2.

TABLE 1: CUTTING FORCES, MACHINING POWER, SPECIFIC CUTTING ENERGY AND METAL REMOVAL RATE AT THE START OF PROFILE MACHINING

(a) SPINDLE SPEED VARIATION: Feed rate = 0.067mm/rev

Depth of cut = 0.2mm

SPINDLE SPEED [Rpm]	F_c [N]	F_a [N]	F_R [N]	K	P_{eff} [W]	P_s [GN/m^2]	Q [mm^3/s]	V_c [m/s]	D [mm]
22.4	65	20	68	0.3	0.37	4.85	0.076	0.019	16
31.5	62.5	16	64.5	0.35	0.59	4.66	0.127	0.027	16.4
45	55	15	57	0.45	0.99	4.1	0.24	0.04	16.8
63	42.5	14	44.7	0.6	1.45	3.17	0.46	0.057	17.2
90	40	14	42.4	0.7	2.32	2.98	0.78	0.083	17.6

(b) DEPTH OF CUT VARIATION: Feed rate = 0.04 mm/rev

Spindle speed = 90 Rpm

Average cutting speed = 0.1036 m/S

DEPTH OF CUT [mm]	F_c [N]	F_a [N]	F_R [N]	K	P_{eff} [W]	P_s [GN/m^2]	Q [mm^3/S]	D [mm]
0.2	18	5	18.7	0.4	0.76	2.25	0.33	21.3
0.3	22.5	7.5	23.7	0.45	1.02	1.875	0.55	21.5
0.4	30	7.5	30.9	0.5	1.53	1.875	0.86	21.9
0.5	35	10	36.4	0.55	1.99	1.75	1.14	22.1
0.6	37.5	15	40.4	0.65	2.54	1.562	1.75	22.5

(c) FEED RATE VARIATION: Depth of cut = 0.1mm.
Spindle speed = 45 Rpm
Average cutting speed = 0.0895 m/S.

FEED RATE [mm/rev.]	F_c [N]	F_a [N]	F_R [N]	K	P_{eff} [W]	P_s [GN/m^2]	Q [mm^3/S]	D [mm]
0.067	17.5	5	18.2	0.2	0.31	2.61	0.12	13
0.127	30	12.5	32.5	0.3	0.81	2.36	0.34	13.4
0.214	37.5	17.5	41.4	0.35	1.2	1.75	0.67	13.8
0.291	45	20	49.2	0.5	2.01	1.43	1.3	14.2
0.374	52.5	22.5	57.1	0.6	2.82	1.404	2.0	14.6

TABLE 2: CUTTING FORCES, MACHINING POWER, SPECIFIC CUTTING ENERGY AND METAL REMOVAL RATE AT FULL PROFILE MACHINING

(a) SPINDLE SPEED VARIATION: Feed rate = 0.067mm/rev
Depth of cut = 0.2mm

SPINDLE SPEED [Rpm]	F_c [N]	F_a [N]	F_R [N]	P_{eff} [W]	P_s [GN/m^2]	Q [mm^3/S]	D [mm]	V_c [m/S]
22.4	72.5	25	76.7	2.25	5.41	0.42	25.5	0.031
31.5	70	25	74.3	3.01	5.22	0.58	25.9	0.043
45	62.5	20	65.7	3.9	4.66	0.83	26.3	0.062
63	50	17.5	53	4.4	3.73	1.2	26.7	0.088
90	45	15	47.4	5.76	3.56	1.7	27.1	0.128

(b) DEPTH OF CUT VARIATION: Feed rate = 0.04mm/rev

Spindle speed = 90 Rpm

Average cutting speed = 0.1625m/S

DEPTH OF CUT [mm]	F_c [N]	F_a [N]	F_R [N]	P_{eff} [W]	P_s [GN/m^2]	Q_3 [mm^3/S]	D [mm]
0.2	20	5	20.6	3.25	2.5	1.03	33.1
0.3	25	7.5	26.1	4.1	2.08	1.95	33.5
0.4	32.5	10	34	5.28	2.03	2.6	34.4
0.5	40	17.5	43.7	6.5	2.00	3.25	35.2
0.6	42.5	17.5	46	6.9	1.77	3.9	36.2

(c) FEED RATE VARIATION: Depth of cut = 0.1mm

Spindle speed = 45 Rpm

Average cutting speed = 0.0735m/S

FEED RATE mm/rev	F_c [N]	F_a [N]	F_R [N]	P_{eff} [W]	P_s [GN/m^2]	Q [mm^3/S]	D [mm]
0.067	17.5	7.5	19	1.3	2.6	0.15	30.4
0.127	30	12.5	32.5	2.2	2.36	0.95	30.8
0.214	35	15	38.1	2.6	1.64	1.57	31.2
0.291	47.5	22.5	52.6	3.49	1.63	2.15	31.6
0.374	55	22.5	59.4	4.1	1.47	2.75	32

The calculated parameters, for example were obtained as follows:

From table 1, for f = 0.067mm/rev, d = 0.2mm, n = 22.4 Rpm. The entire hole circumference was 50.24mm, workpiece tool contact length per revolution of the workpiece = 15mm, F_c = 65N, F_a = 20N, and D = 16mm.

$$K = \frac{\text{Workpiece tool contact length}}{\text{The entire hole circumference}} = \frac{15}{50.24} = 0.3$$

Using equation (5.1),

$$F_R = [F_c^2 + F_a^2]^{\frac{1}{2}} = [65^2 + 20^2]^{\frac{1}{2}} = 68N$$

Using equation (5.6),

$$V_c = \frac{\pi Dn}{60} = \frac{3.14(0.016)(22.4)}{60} = 0.019 \text{ m/S}$$

From equation (5.7),

$$P_{eff} = K.F_c V_c = 0.3(65)(0.019) = 0.37W$$

Using equation (5.3),

$$P_s = \frac{F_c}{f.d} = \frac{65}{0.2x10^{-3} x 0.067x10^{-3}} = 4.85 \text{ GN/m}^2$$

Using equation (5.8),

$$Q = k.f.d.V_c;$$

$$Q = 0.3(0.0167)(0.2)(19) = 0.019 \text{mm}^3/\text{S}$$

From Table 2a: for $F_c = 72.5N$; $F_a = 25N$; $n = 22.4$ rps

$f = 0.067$mm/rev.; $d = 0.2$mm; $k = 1$; and $D = 25.5$mm.

Using equation (5.1),

$$F_R = [F_c^2 + F_a^2]^{\frac{1}{2}} = [72.5^2 + 25^2]^{\frac{1}{2}} = 76.7N$$

From equation (5.6),

$$V_c = \frac{\pi Dn}{60} = \frac{3.14(0.0255)(22.4)}{60} = 0.031 \text{m/S}$$

From equation (5.2),

$$P_{eff} = F_c.V_c = 72.5(0.031) = 2.25W$$

Using equation (5.3),

$$P_s = \frac{F_c}{f.d} = \frac{65}{0.2x10^{-3} x 0.067x10^{-3}} = 5.41 \text{ GN/m}^2$$

Using equation (5.5),

$$Q = f.d.V_c = (0.067)(0.2)(31) = 0.42 \text{mm}^3/\text{S}$$

In a similar manner, all the other parameters given in Tables 1 and 2 were obtained.

Figures 5.1 to 5.15 show graphically the results of experimentally measured cutting forces, computed machining power, specific cutting energy and rate of metal removal for non-circular boring on the lathe.

5.3.2 Discussions:

Figures 5.1 to 5.3 show the effect of spindle speed, depth of cut and feed rate variations on the cutting forces at the start of non-circular boring when the boring tool was cutting intermittently round the hole circumference. Figure 5.1 shows that the cutting forces decrease linearly with increase in spindle speed for a given depth of cut and feed rate. The decrease of cutting forces with increase in spindle speed is due to the decrease in frictional forces between the tool and workpiece at higher spindle speeds, hence the efficiency of cutting from available effective machining power increases. Figures 5.2 and 5.3 on the other hand show that, at this stage of boring, cutting forces are directly proportional to increase in either the depth of cut or feed rate. The increase of cutting forces with either increase in depth of cut or feed rate is mainly because frictional forces between the boring tool and chips is higher at higher depths of cut or feed rates, thereby requiring higher forces to partly overcome the frictional forces in order to cut the metal.

The effects of spindle speed, depth of cut and feed rate variations on cutting forces at full profile stage of boring is shown in Figures 5.4 to 5.6. Figure 5.4 shows that cutting

GRAPHS OF CUTTING FORCES AT THE START OF PROFILE MACHINING: TABLE 1,

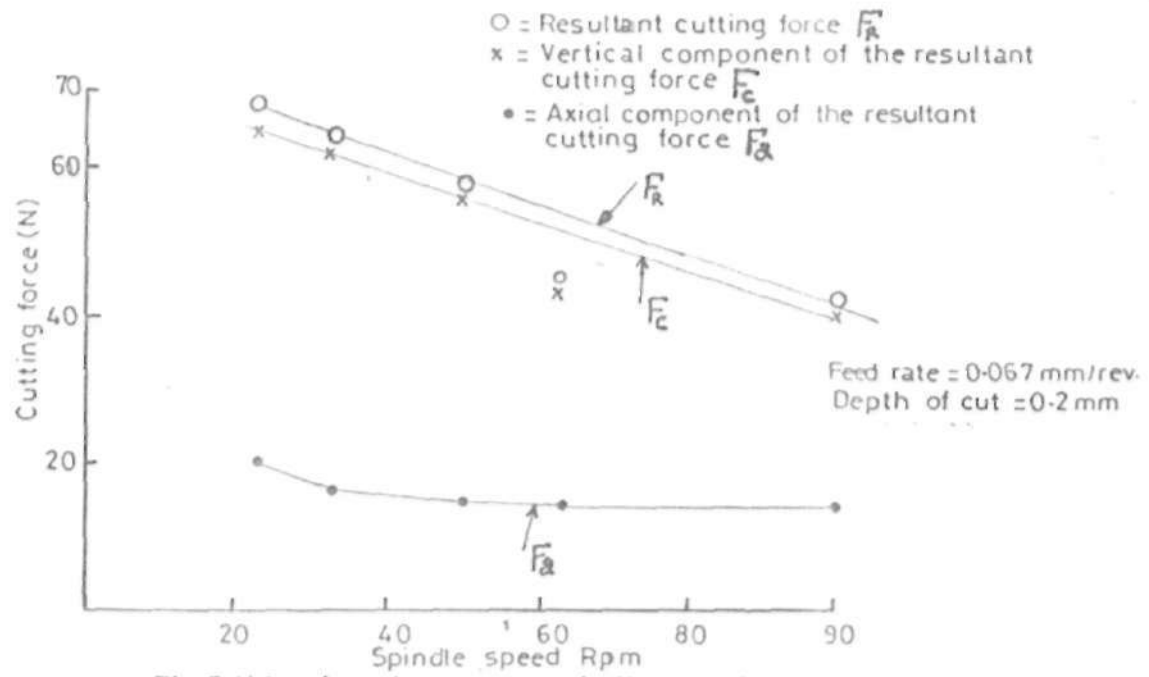


Fig.5.1: Cutting force vs spindle speed

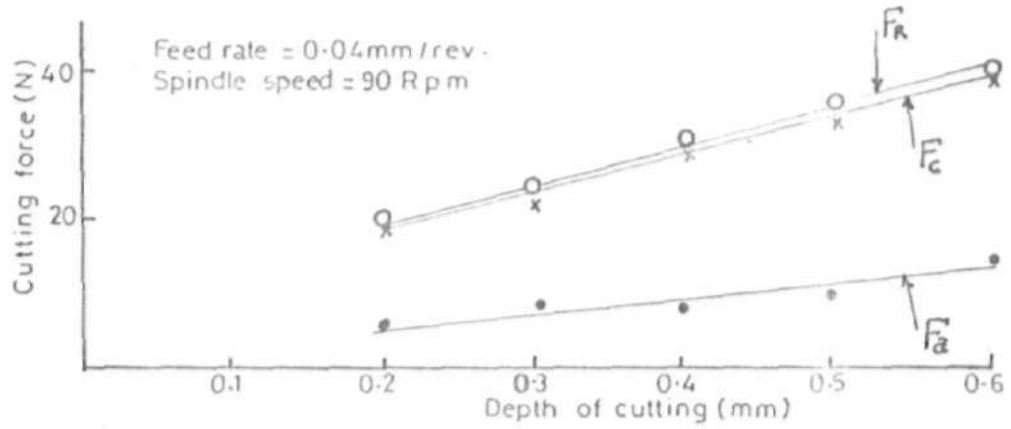
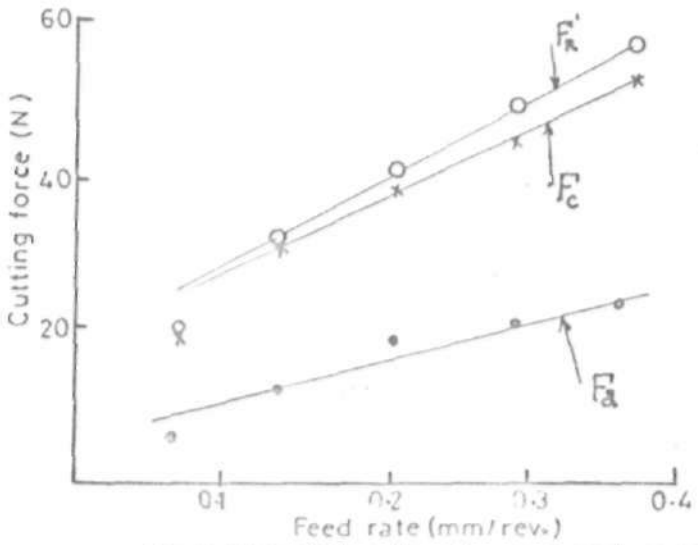


Fig.5.2: Cutting force vs depth of cut



Depth of cut = 0·1 mm
Spindle speed = 45 Rpm

Fig.5.2: Cutting force vs feed rate

GRAPHS OF THE CUTTING FORCES AT FULL PROFILE MACHINING ; TABLE 2.

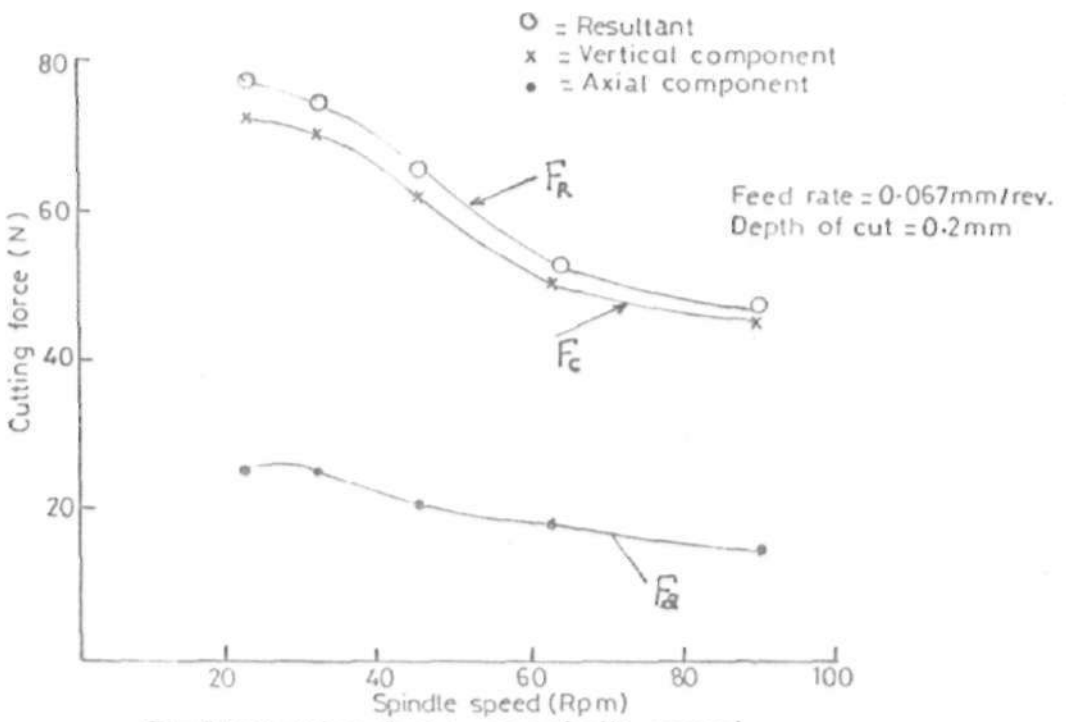


Fig.5·4: Cutting force vs spindle speed

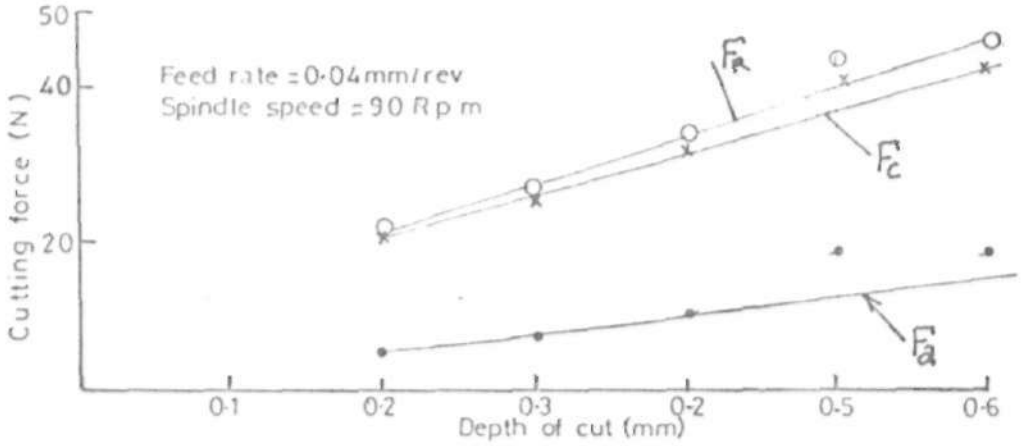


Fig.5·5: Cutting force vs depth of cut

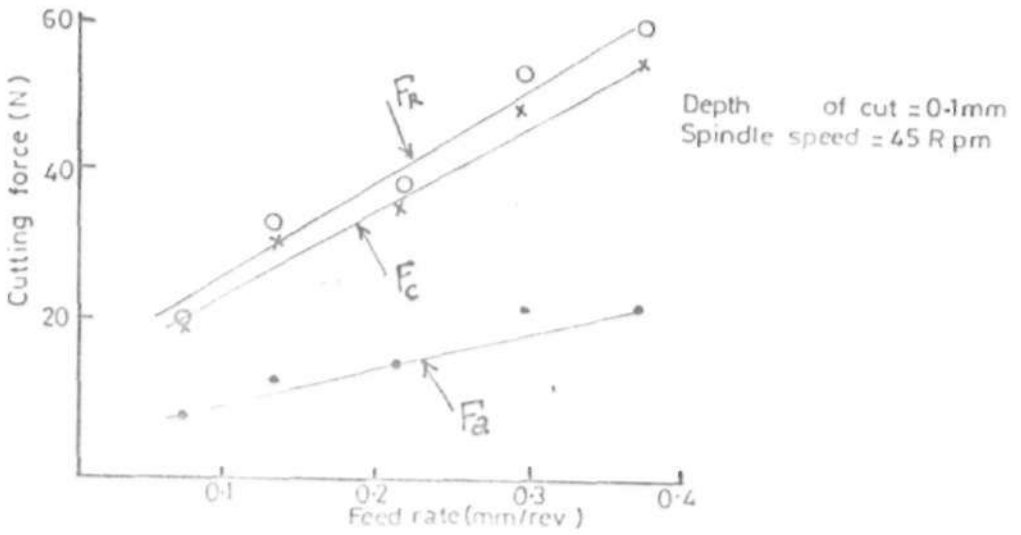


Fig 5·6 Cutting force vs feed rate

forces at this stage of machining also decrease with increase in spindle speed. The rate of decrease, as can be seen from Figure 6.4, reduces at higher spindle speeds. Figures 5.5 and 5.6 show that, cutting forces, at the full-profile stage of machining decrease linearly with increase in either the depth of cut or feed rate.

Effective power required to cut in non-circular boring operations on the lathe at the start and full-shape profile stages of machining is juxtaposed in Figures 5.7 to 5.9. From the Figures it can be infered that the effective machining power in all instances of spindle speed, depth of cut and feed rate variations is higher at the full-shape profile machining than at the start. This is mainly because the volume of metal removal per unit time at the full profile stage of machining is higher than that at the start, hence more power is needed to cut more metal per unit time at the full-shape profile stage of machining. From the Figures, effective power required to bore in all instances increase with either increase in spindle speed or depth of cut or feed rate.

Figures 5.10 to 5.12 shows the effects of spindle speed or depth of cut or feed rate variations on the specific cutting energy at the start and full-profile stages of machining. Figure 5.10 shows that the specific cutting energy decreases with increase in spindle speed. The decrease as can be seen from the Figure becomes less as the spindle speed increases further. The decrease in specific cutting energy with increase in spindle speed is because, cutting forces required to cut a given fixed cross-sectional area of cut decrease with increase in spindle speed. Figures 5.11 and 5.12 also show that the specific cutting energy decreases with increase in feed rate or depth of cut. The decrease here is mainly because the proportion of increase in length over which the cut is undertaken increases more than the corresponding increase in cutting forces.

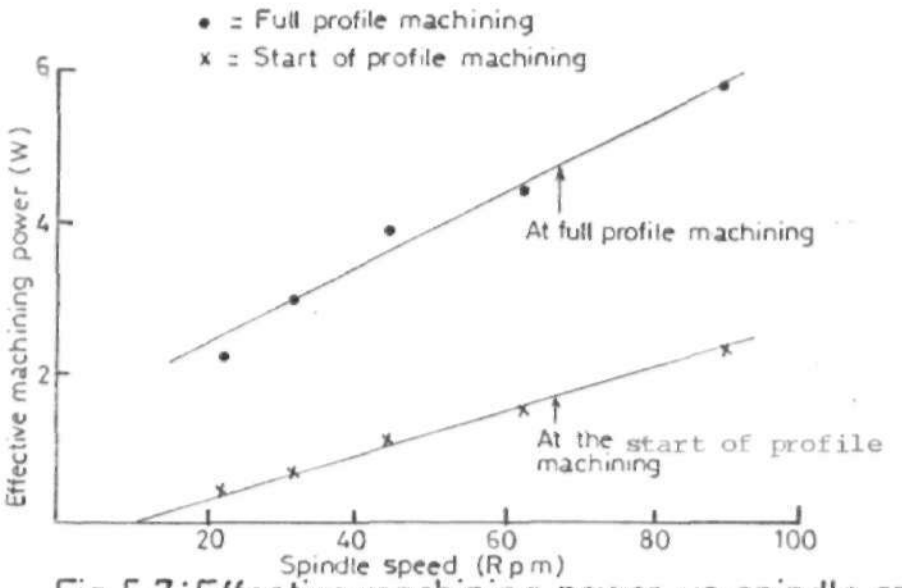


Fig.5.7: Effective machining power vs spindle speed.

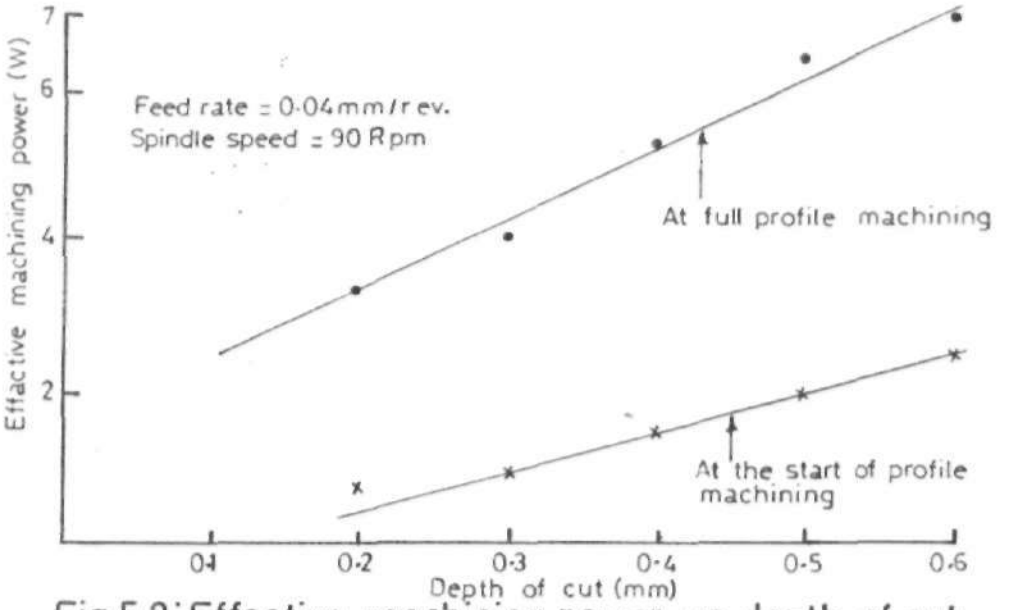


Fig.5.8: Effective machining power vs depth of cut.

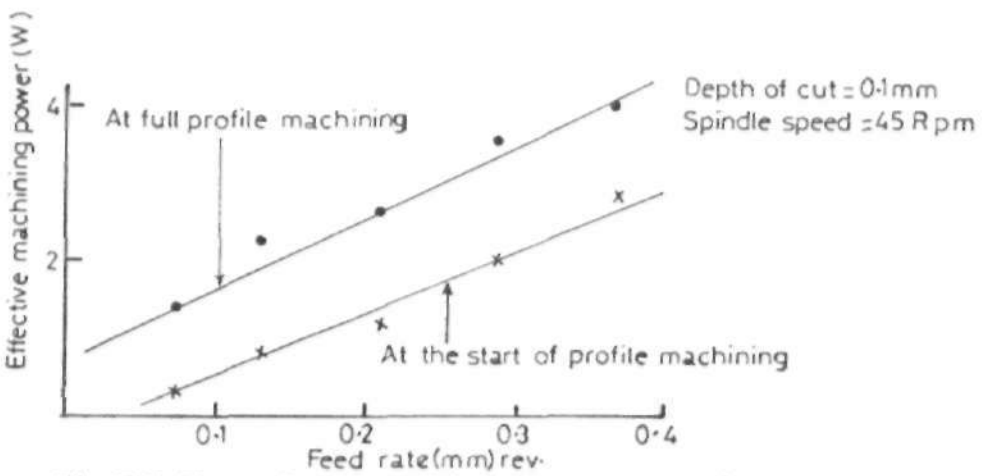
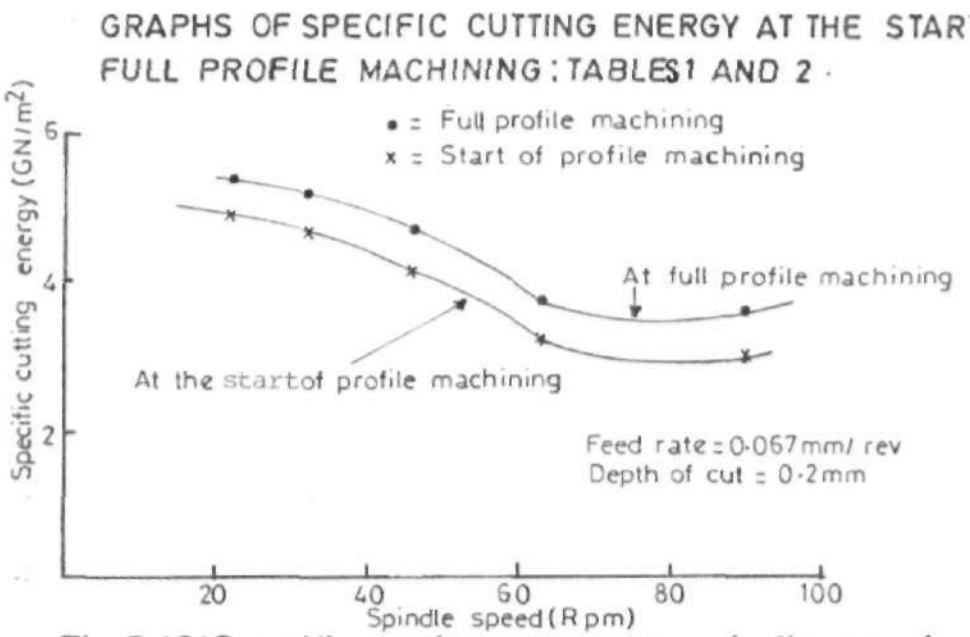
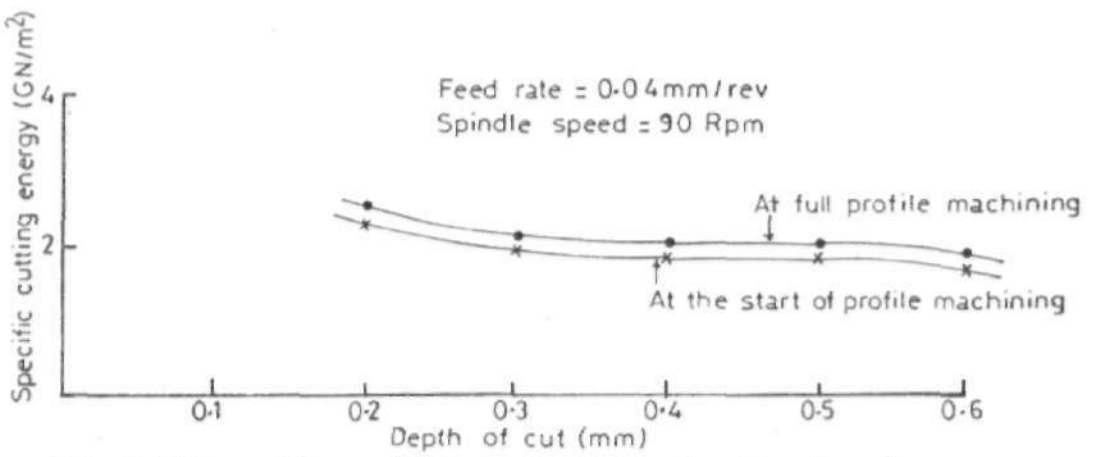


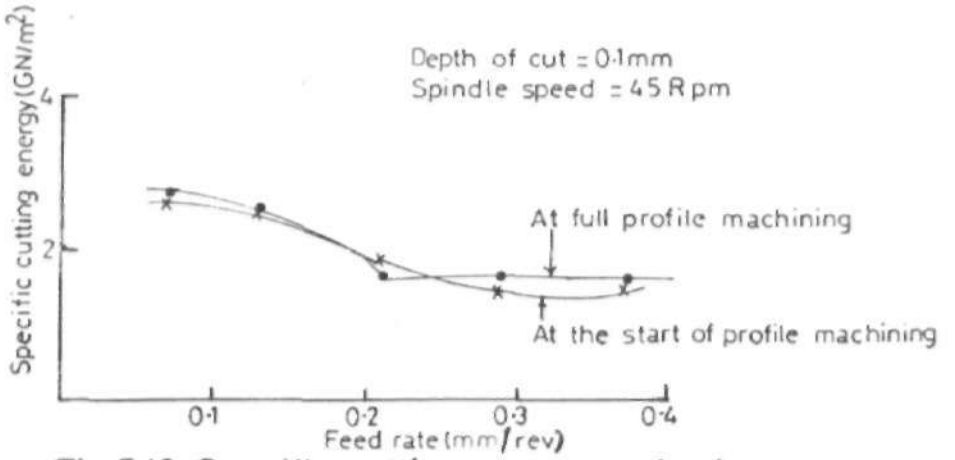
Fig.5.9: Effective machining power vs feed rate



Fig·5·10: Specific cutting energy vs spindle speed



Fig·5·11: Specific cutting energy vs depth of cut



Fig·5·12: Specific cutting energy vs feed rate

GRAPHS OF METAL REMOVAL RATE AT THE START AND FULL PROFILE MACHINING: TABLES 1 AND 2.

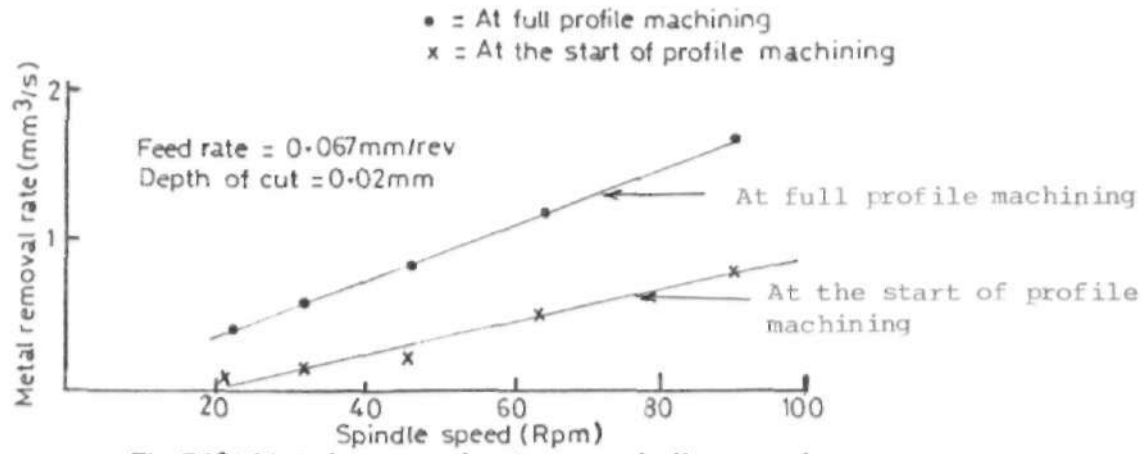


Fig.5·13: Metal removal rate vs spindle speed

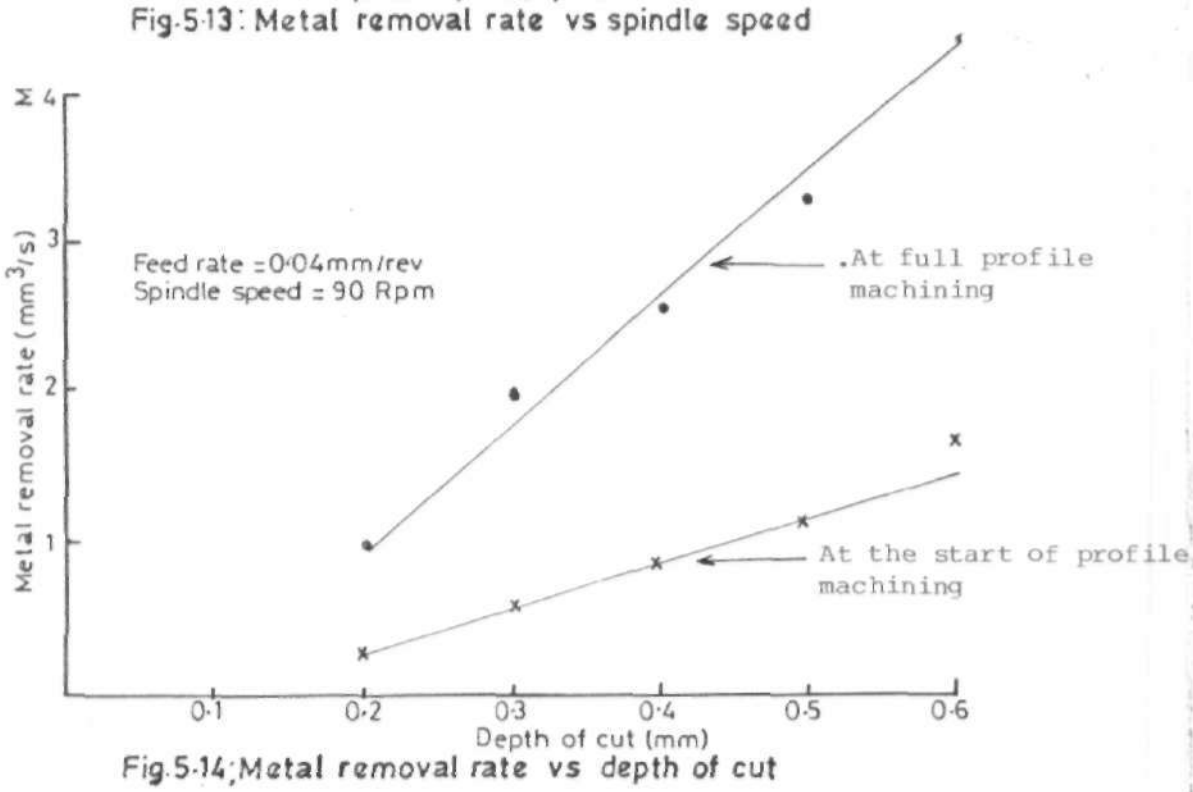


Fig.5·14; Metal removal rate vs depth of cut

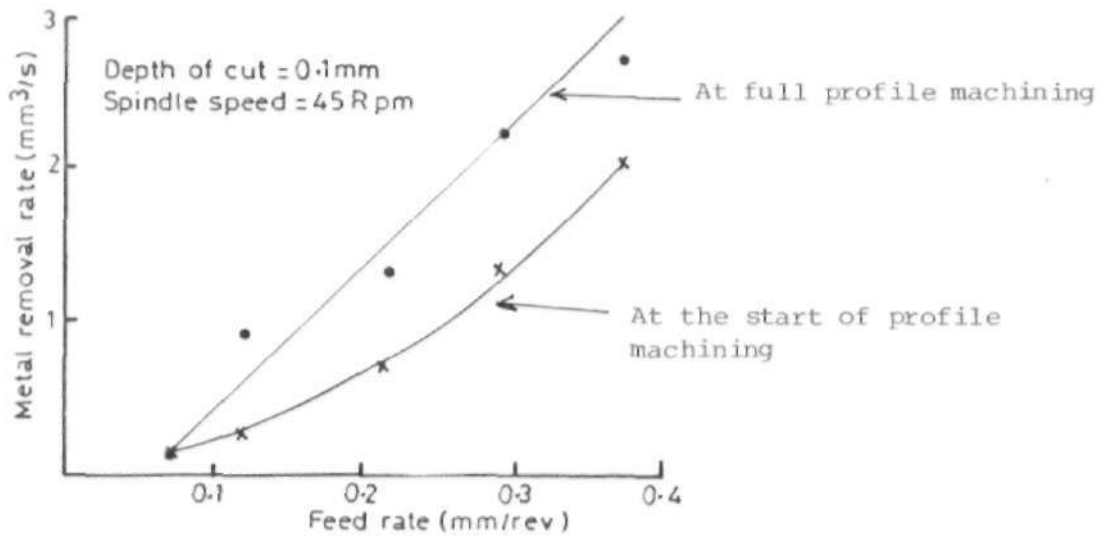


Fig.5·15: Metal removal rate vs feed rate

Finally Figures 5.13 to 5.15 show the effects of spindle speed or depth of cut or feed rate variations on the volume of metal removed per unit time in the non-circular boring operations. Figures 5.13 and 5.14 show that at both the start and full-shape profile stages of machining, the rate of metal removal increases linearly with increase in either spindle speed or depth of cut. For feed rate variation, Figure 5.15 shows that the rate of metal removal increases linearly with increase in feed rate at the full-shape profile stage of machining while it increases fast but in a non-linear fashion at the start of non-circular boring. The difference between the rate of metal removal at the start and full-shape profile stages of machining is because, at the start, there were times when the tool was idle whereas at the full profile machining stage, the tool was always engaged in cutting action with the workpiece.

5.4 FORCING FUNCTION ON THE BORING TOOL:

At the start of non-circular boring on the lathe, the boring tool does not cut continuously but intermittently until the full shape of the template is obtained. An osscilloscope was used to display the waveform of the intermittent cutting , using a cam type template shown in Figure 4.2c. This was done at a spindle speed of 22.4 RPM, depth of cut 0.2mm, and a feed rate of 0.04mm/rev. The corresponding vertical component of the cutting force was 55N. The pictorial wave form obtained is shown in plate VIII.

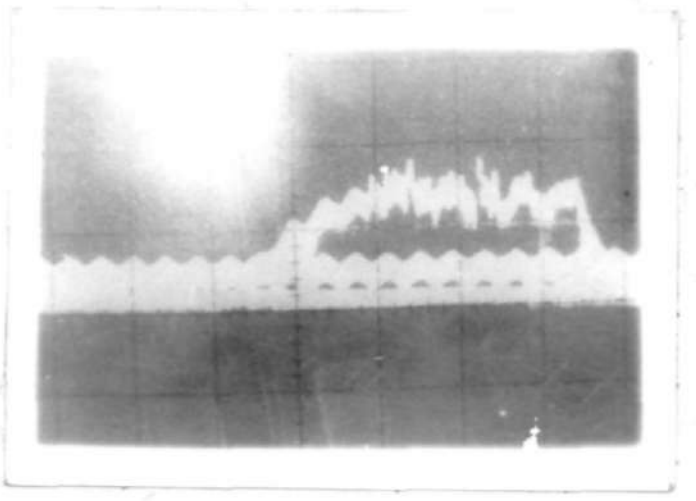


Plate VIII: Pictorial waveform of the forcing function.

The approximated waveform for one period of 2π is shown in Figure 5.16.

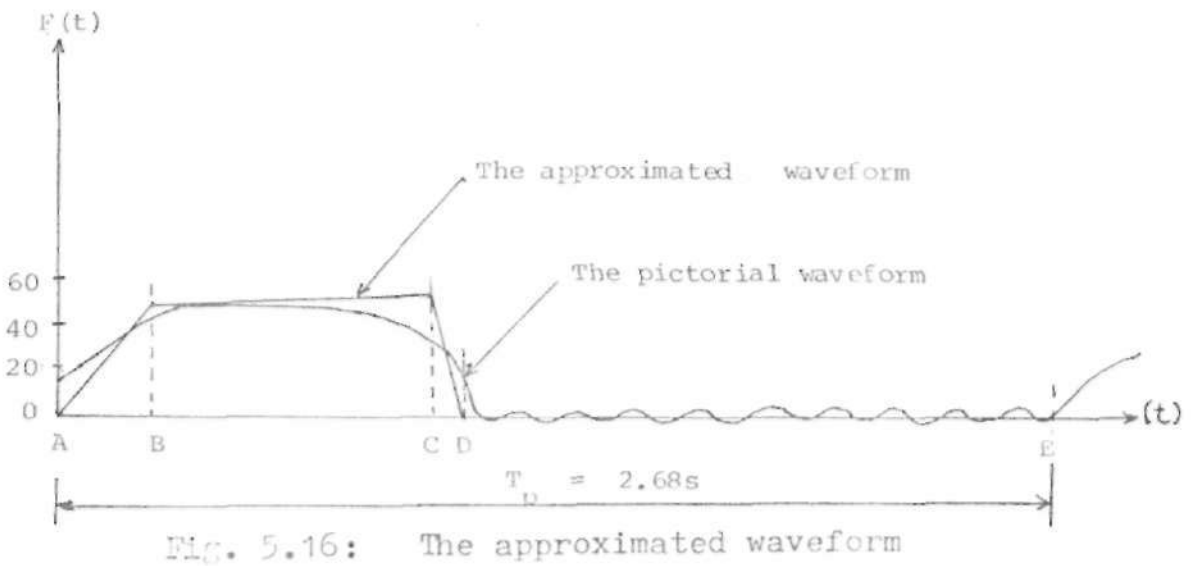


Fig. 5.16: The approximated waveform

Taking O as the origin the approximate equation of the wave form is obtained by dividing the time period (T_p) into 4 parts: AB, BC, CD, and DE.

$$F(t) = \begin{cases} 662.65t & \text{for } 0 \leq t \leq 0.083 \\ 55 & \text{for } 0.083 < t \leq 0.249 \\ 1300 - 5000t & \text{for } 0.249 < t \leq 0.26 \\ 0 & \text{for } 0.26 < t \leq 2.68 \end{cases} \quad \text{----------(5.9)}$$

$$T_p = 2.68s.$$

A periodic function like F(t) can be decomposed into Fourier Series of the form [29]

$$\frac{a_o}{2} + \sum_{n=1}^{\infty}\left(a_n \text{Cos}(2n\pi t/T_p) + b_n \text{Sin}(2n\pi t/T_p)\right) \quad \text{----------(5.10)}$$

where $$a_o = \frac{1}{T_p}\int_{-T_p/2}^{T_p/2} F(t)dt \quad \text{----------(5.11)}$$

$$a_n = \frac{2}{T_p}\int_{-T_p/2}^{T_p/2} F(t)\text{Cos}(2n\pi t/T_p)dt \quad \text{----------(5.12)}$$

$$b_n = \frac{2}{T_p}\int_{-T_p/2}^{T_p/2} F(t)\text{Sin}(2n\pi t/T_p)dt \quad \text{----------(5.13)}$$

From equation (5.11),

$$a_o = \frac{1}{2.63}\left[\int_0^{0.083} 662.65t\,dt + \int_{0.083}^{0.249} 55dt + \int_{0.249}^{0.26} (1300-5000t)dt\right]$$

$$= \frac{1}{2.63}\left[\frac{662.65(0.083)^2}{2} + 55(0.166) + 1300(0.011) - \frac{5000}{2}(0.26^2 - 0.249^2)\right]$$

$$= 4.37$$

Using equation (5.12),

$$a_n = \frac{2}{2.68}\left[\int_0^{0.083} 662.65t\text{Cos}(2n\pi t/2.68)dt + \int_{0.083}^{0.249} 55\text{Cos}(2n\pi t/2.68)dt + \int_{0.249}^{0.26} (1300-5000t)\text{Cos}(2n\pi t/2.68)dt + \int_{0.26}^{2.68} 0\text{Cos}(2\pi nt/2.68)dt\right]$$

$$a_n = \frac{6700}{\Pi^2 n^2}[\text{Cos}0.186\Pi n - \text{Cos}0.194\Pi n + 0.1325\text{Cos}0.062\Pi n - 0.1325] \quad \text{---(5.14)}$$

$$b_n = \frac{2}{2.68}\Big[\int_0^{0.083} 662.65t\,\text{Sin}(2n\Pi t/2.68)dt + \int_{0.083}^{0.249} 55\,\text{Sin}(2n\Pi t/2.68)dt$$

$$+ \int_{0.249}^{0.26} (1300-5000t)\,\text{Sin}(2n\Pi t/2.68)dt + \int_{0.26}^{2.68} 0\,\text{Sin}(2n\Pi t/2.68)dt\Big]$$

$$= \frac{6700}{\Pi^2 n^2}[\text{Sin}0.186\Pi n - \text{Sin}0.194\Pi n + 0.1325\text{Sin}0.062\Pi n] \quad \text{----------(5.15)}$$

The equation describing the forcing function $F(t)$ on the boring tool at the start of non-circular boring on the lathe is therefore given as:

$$F(t) = 2.185 + \frac{6700}{\Pi^2 n^2}\sum_{n=1}^{\infty}\{(\text{Cos}0.186\Pi n - \text{Cos}0.194\Pi n + 0.1325\text{Cos}0.062\Pi n - 0.1325)\text{Cos}(2n\Pi t/2.68) + (\text{Sin}0.186\Pi n - \text{Sin}0.194\Pi n + 0.1325\text{Sin}0.062\Pi n)\text{Sin}(2n\Pi t/2.68)\} \quad \text{----------(5.16)}$$

5.5 CONCLUSION

The cutting forces and machining power required for non-circular boring on the lathe has been measured or computed respectively under various cutting conditions. The results show that cutting forces decrease with increase in spindle speeds, but increase with increase in depth of cut or feed rate. Trent and Kronenberg [27,30] have observed for the case of conventional turning and milling operations that, at low cutting speeds, cutting forces are inversely related to cutting speeds, and in all instances the forces are linearly dependent on feed rate or depth of cut variations.

In all instances the computed machining power increases with increase in spindle speed or depth of cut or feed rate. Doyle and Kronenberg [15,27] have observed similar behaviour for the case of conventional cylindrical turning operations using different steels.

The cutting forces and machining power give an indication of the typical amounts required for non-circular boring on the lathe.

The waveform of the vertical component of the cutting force as revealed by the oscilloscopical display, shows that the cutting forces are dynamic. The forces depend upon the velocity response of the copying slide. Osman and Sankar [35] came to similar conclusion for the case of copy turning operations on the lathe.

CHAPTER SIX

VIBRATION ANALYSIS

6.1 INTRODUCTION:

One of the attendant adverse effects during the process of machining is vibrations. This can be particularly true for a machining method that has just been developed and tested, where substantial energy is being transfered in the absence of any mechanical damping.

Vibration is a nuisance to metal cutting and can be demonstrated on any chip producing machine tool. Metal cutting vibrations give rise to severe production problems from a number of perspectives. For example, vibration of the cutting tool relative to the workpiece can cause not only unacceptable surface imperfections but dimensional accuracy, tool life reduction, noise and even machine life. The literature accounts of the adversities and devestations caused by vibrations to engineering structures and systems is plentiful [11,12].

In the above light of the bad effects of vibrations in general and with particular reference to metal cutting in manufacturing, its analysis and measurement is necessary.

The analysis of vibrations and its entire ramifications is a topic of its own, is complex, and is not subject to simple analysis. We therefore consider the simplified analysis and measurement of the vertical vibrations of the boring tool.

6.2 VERTICAL VIBRATION OF THE BORING TOOL:

Vibrations to be measured can be classified as either:

(i) periodic;

(ii) shock or transient;

(iii) random or statistical.

Of these, periodic motion is best understood, and instruments for measuring frequency, amplitude, velocity and acceleration or wave slope are well developed [21]. In general peak accelerations are of prime importance.

Generally in boring operations, the bar holding the tool has to be long and slender and not as rigid as the thick and stocky tools and tool posts used for most turning operations. The tool tends to be deflected to a greater extent by the cutting forces and to vibrate. Vibration of the boring tool could also result from periodic fluctuations of cutting force that arise from discontinuous cutting, or from imperfections of gears or bearings in machines. In the developed auxillarly method of non-circular boring on the lathe, vibration of the boring tool could also result from any instability in the hydraulic servo-control system [3,28,30].

The analysis of the vertical vibration of the boring tool is more important because the deflection of the boring tool is greatest in the vertical plane due to the vertical component of the cutting force. Hence the tool tends to vibrate more in the vertical plane. Figure 6.1 below demonstrates the deflection of the boring tool under a vertical cutting load due to the excessive but necessary overhang of the tool during a boring operation.

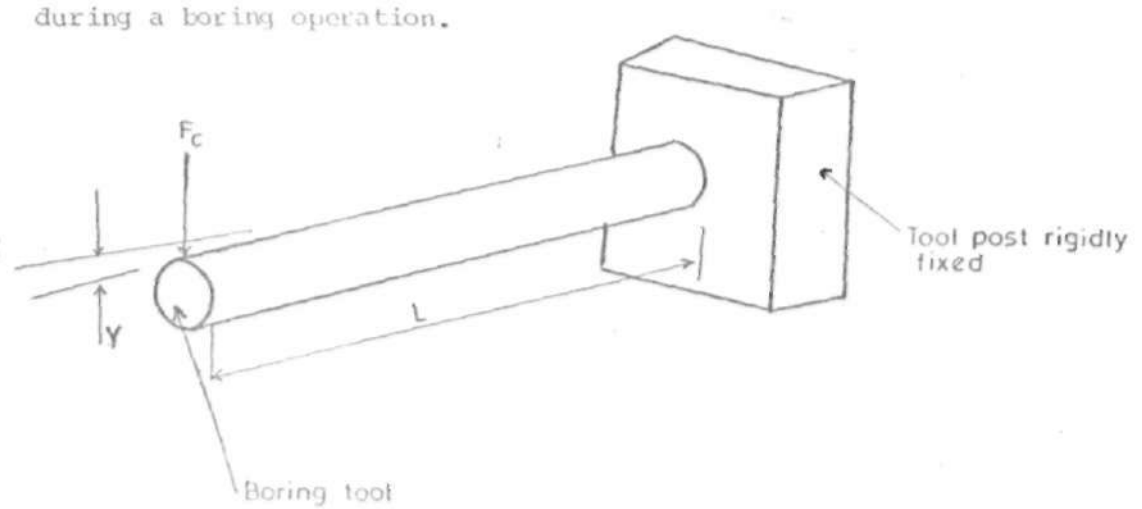


Fig. 6.1: Deflection of boring tool under vertical cutting load.

From elementary elasticity, the maximum deflection of the tool occurs at the end of the tool [33]; and is given by:

$$y = \frac{1}{3}\frac{F_c.l^3}{EI} \quad \text{----------(7.1)}$$

where $I = \pi d_t^4/64$ ----------(7.2)

Therefore, $y = \frac{64}{3E}\frac{F_c.l^3}{\pi d_t^4}$, ----------(7.3)

where:

y = deflection of the boring tool;

I = second moment of area of the tool's cross sectional area;

d_t = diameter of the boring tool;

F_c = vertical component of the cutting force;

l = overhang length of the boring tool;

E = Young's modulus of the tool material;

One of the boring tools used was a steel tool tipped with carbide and had an overhang diameter (d_t) = 15.5mm; $E = 20\times10^{10}\ N/m^2$ [21], and the overhang length = 80mm.

Therefore,

$$y = \left[\frac{64}{3\times20\times10^{10}}\frac{(0.08)^3}{\pi(0.0155)^4}\right]F_c = 3\times10^{-7}F_c \quad \text{----------(7.4)}$$

The frequency of vibration (ω) is given as [31,32]:

$$\omega = \frac{1}{2\pi}\sqrt{g/y}; \quad \text{----------(7.5)}$$

where, g is the acceleration due to gravity.

For example; from table 1a in chapter five, for the vertical component of the cutting force (F_c) = 65N,

$y = 3\times10^{-7}\times65m = 1.96\times10^{-5}m.$

Table 5 shows similarly obtained computed values of y.

From equation (7.5),

$$\omega = \frac{1}{2\Pi}\sqrt{\frac{9.8}{1.96x10^{-5}}} = 112.6HZ$$

When the boring tool is not cutting, its natural frequency of vibration (ω_n) is given as [31]

$$\omega_n = \frac{3.51}{2}\sqrt{\frac{EI}{mgl^4}} \quad \text{----------(7.6)}$$

where:

m = mass of the boring tool;

E = Young's modulus of the tool material;

I = second moment of area of the tool's over hang length's cross section;

g = acceleration due to gravity; and

l = overhang length of the tool.

From equation (7.2),

$$I = \frac{\Pi(0.0155)^4}{4} = 5.77x10^{-8}m^4$$

The steel tool tipped with carbide has the following specifications:

(i) overall length = 210mm;

(ii) shank length = 130mm;

(iii) shank section dimensions = 15.8mm by 15.8mm;

(iv) overhang length = 80mm;

(v) overhang section dimension = 15.5mm in diameter; and

(vi) density of tool steel = $7703Kg/m^3$

Therefore,

$$m = \frac{\Pi(0.0155)^2(0.08)(7703)}{4} + 0.0158x0.0158x0.13x7703$$

$m = 0.1162 + 0.25 = 0.366Kg.$

$g = 9.81m/s^2$, and $E = 20 \times 10^{10} N/m^2$

Therefore,

$$\omega_n = \frac{3.51}{2} \sqrt{\frac{20x10^{10}x5.77x10^{-8}}{0.366x9.81x(0.08)^4}}$$

$$\omega_n = 15546.23HZ$$

6.2.1 Measurement of vertical vibration of the boring tool:

The vertical vibrations of the boring tool at the start of profile and full profile machining were measured using a vibrations meter, type 1433 A+B, a preamplifier, type 1433/IC and an accelerometer type, CPZE 323F. Plate IX below shows the experimental set-up of how vibrations were measured in the laboratory.

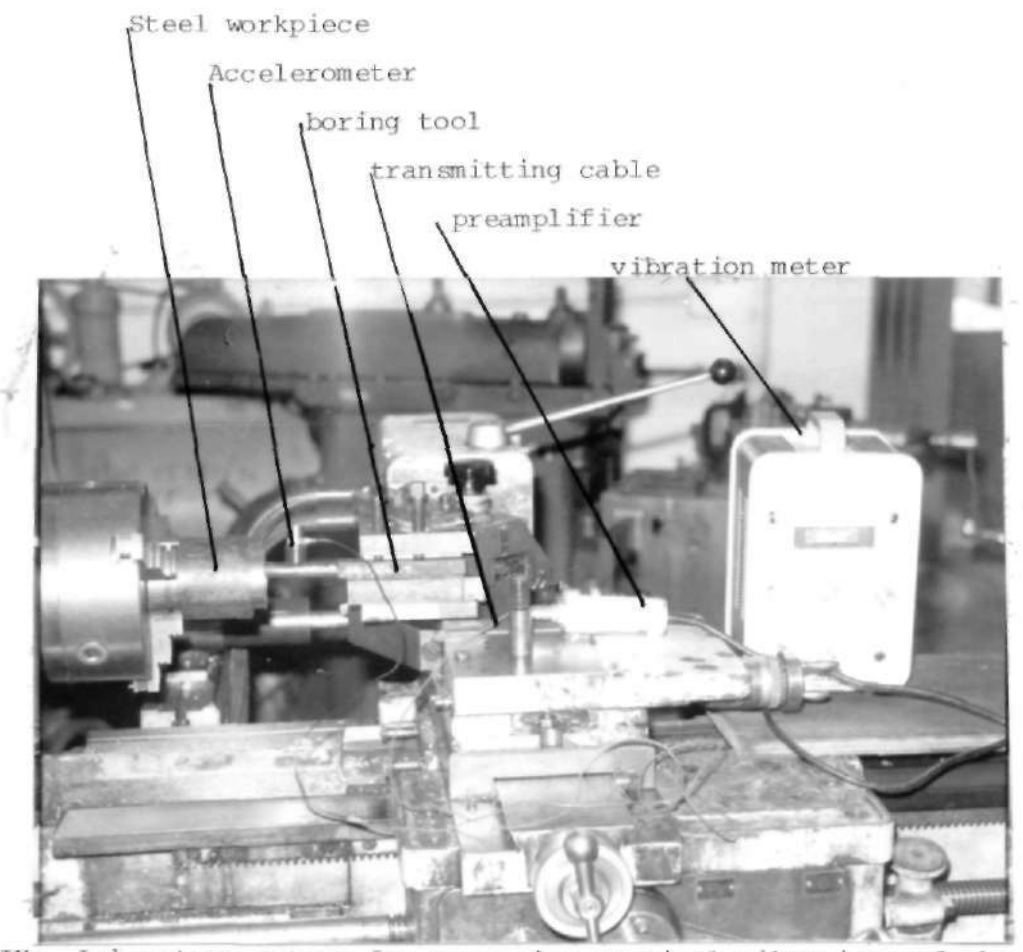


Plate IX: Laboratory set-up for measuring vertical vibrations of the boring tool.

The procedure was to mount the accelerometer which is of the magnetic type on the boring tool by magnetic attraction between them, and indicate vibrational displacement, velocity and acceleration during each cycle of machining. By selecting on the meter the type of vibration to be measured and adjusting the frequency and scale ranges of the meter, the meter reading was obtained. For each reading obtained, the frequency multiplication factor and the reading on the meter corresponding to the scale for which the reading was obtained were noted. The actual readings were obtained by multiplying the frequency factor with the corresponding meter readings according to the scale.

Vibrations were measured in terms of displacement, velocity and acceleration. This was done by varying one of the three machining parameters: speed, depth of cut and feed rates, and keeping the other two parameters constant. The measurements were taken at the start of profile machining and at full profile machining using mild steel as the workpiece.

6.3 RESULTS AND DISCUSSIONS:

6.3.1 Results:

The experimental results of the measured vertical vibrations of the boring tool are given in Tables 3 and 4. The computed values of displacement of vertical vibration using equation (7.4) compared with measured average values are given in Table 5. Graphical presentation of experimental results is shown in Figures 6.2 to 6.19.

TABLE 3: MEASURED VALUES OF THE VERTICAL VIBRATIONS OF THE BORING TOOL AT THE START OF NON-CIRCULAR BORING (START OF PROFILE MACHINING)

(a) SPINDLE SPEED VARIATION

Depth of cut = 0.2mm

Feed rate = 0.107mm/rev

SPINDLE SPEED Rpm	DISPLACEMENT $\times 10^{-6}$ [m]		VELOCITY $\times 10^{-3}$ [m/S]		ACCELERATION [m/S^2]	
	AVERAGE	RMS	AVERAGE	RMS	AVERAGE	RMS
22.4	1.5	0.9	1.9	1.6	1.3	1.4
31.5	2.8	1.2	3	1.4	3.4	3.1
45	4.2	3.1	4.2	3.9	6	5.8
63	6.1	6.2	7.1	7.5	8	8
90	10	9.5	11.6	11.4	8	10

(b) DEPTH OF CUT VARIATION

Spindle speed = 45 Rpm

Feed rate = 0.067mm/rev

DEPTH OF CUT [mm]	DISPLACEMENT $\times 10^{-6}$ [m]		VELOCITY $\times 10^{-3}$ [m/S]		ACCELERATION [m/S^2]	
	AVERAGE	RMS	AVERAGE	RMS	AVERAGE	RMS
0.2	0.35	0.28	0.65	1.4	0.9	1.3
0.4	0.75	0.8	1.7	2.2	2.4	2.4
0.6	1.3	1.3	2.3	2.8	3.6	3.9
0.8	1.3	1.2	3.2	3.8	4.9	4.6
1	2.1	1.9	4	4.3	4.6	5.2

(c) FEED RATE VARIATION

Spindle speed = 63 Rpm

Depth of cut = 0.1mm

FEED RATE [mm/rev.]	DISPLACEMENT $x10^{-6}$ [m]		VELOCITY $x10^{-3}$ [m/S]		ACCELERATION [m/S^2]	
	AVERAGE	RMS	AVERAGE	RMS	AVERAGE	RMS
0.06	1.1	0.8	0.81	0.92	3.5	3.5
0.160	1.7	1.5	2.6	2.8	4.8	4.9
0.214	1.7	1.4	3.2	3.2	5.9	6.3
0.241	2	2.1	3.9	4.3	6.5	6.7
0.267	2.6	2.6	4.8	5.5	6.7	7.1

TABLE 4: MEASURED VALUES OF THE VERTICAL VIBRATIONS OF THE BORING TOOL WHEN IT WAS CUTTING CONTINUOUSLY ROUND THE HOLE CIRCUMFERENCE (FULL PROFILE MACHINING)

(a) SPINDLE SPEED VARIATION

Depth of cut = 0.2mm

Feed rate = 0.107mm/rev

SPINDLE SPEED [Rpm]	DISPLACEMENT $x10^{-6}$ [m]		VELOCITY $x10^{-3}$ [m/S]		ACCELERATION [m/S^2]	
	AVERAGE	RMS	AVERAGE	RMS	AVERAGE	RMS
22.4	1.2	1.4	1.5	1.5	1.4	0.9
31.5	2.3	2.3	2.6	2.7	2.8	2.6
45	4	3.8	4	3.8	5.3	5.1
63	4.9	5.4	6.8	6.3	7.6	7
90	8.6	8.2	10.1	10.6	7.4	9.5

(b) DEPTH OF CUT VARIATION

Spindle speed = 45Rpm

Feed rate = 0.067mm/rev.

DEPTH OF CUT [mm]	DISPLACEMENT $x10^{-6}$[m]		VELOCITY $x10^{-3}$[m/S]		ACCELERATION [m/S^2]	
	AVERAGE	RMS	AVERAGE	RMS	AVERAGE	RMS
0.2	0.28	0.31	0.59	0.5	0.8	0.92
0.4	0.61	0.73	1.4	1.1	2.2	1.8
0.6	0.98	1.2	1.8	1.8	3.3	3.4
0.8	1.4	1.1	2.3	2.4	4.1	3.0
1.0	1.9	2.0	3.8	3.6	4.6	4.2

(c) FEED RATE VARIATION

Spindle speed = 63Rpm

Depth of cut = 0.1mm

FEED RATE [mm/rev]	DISPLACEMENT $x10^{-6}$[m]		VELOCITY $x10^{-3}$[m/S]		ACCELERATION [m/S^2]	
	AVERAGE	RMS	AVERAGE	RMS	AVERAGE	RMS
0.06	0.8	0.8	0.7	0.9	1.9	2.8
0.160	1.3	1.4	2.1	2.5	3.4	4.2
0.214	1.5	1.4	2.9	2.9	4.8	6.1
0.241	1.8	2.0	3.4	3.6	5.4	5.8
0.257	2.5	2.3	3.8	4.9	6.1	6.9

TABLE 5: MEASURED AND COMPUTED DISPLACEMENT VALUES OF THE BORING TOOL AT SELECTED CUTTING CONDITIONS

CUTTING CONDITION	F_c [N]	DISPLACEMENT [m]	
		COMPUTED USING EQUATION(7.4)	MEASURED (AVERAGE)
n = 90Rpm f = 0.04mm/rev. d = 0.2mm	18	5.4×10^{-6}	0.35×10^{-6}
n = 90Rpm f = 0.04mm/rev. d = 0.4mm	30	9×10^{-6}	1.7×10^{-6}
n = 22.4Rpm f = 0.067mm/rev d = 0.2mm	65	19.5×10^{-6}	2.9×10^{-6}
n = 90Rpm f = 0.04mm/rev. d = 0.6mm	37.5	11.25×10^{-6}	6.3×10^{-6}
n = 45Rpm f = 0.067mm/rev. d = 0.1mm	17.5	5.25×10^{-6}	0.32×10^{-6}
n = 90Rpm f = 0.04mm/rev. d = 0.3mm	22.5	6.75×10^{-6}	1.2×10^{-6}

6.3.2 Discussion of Results

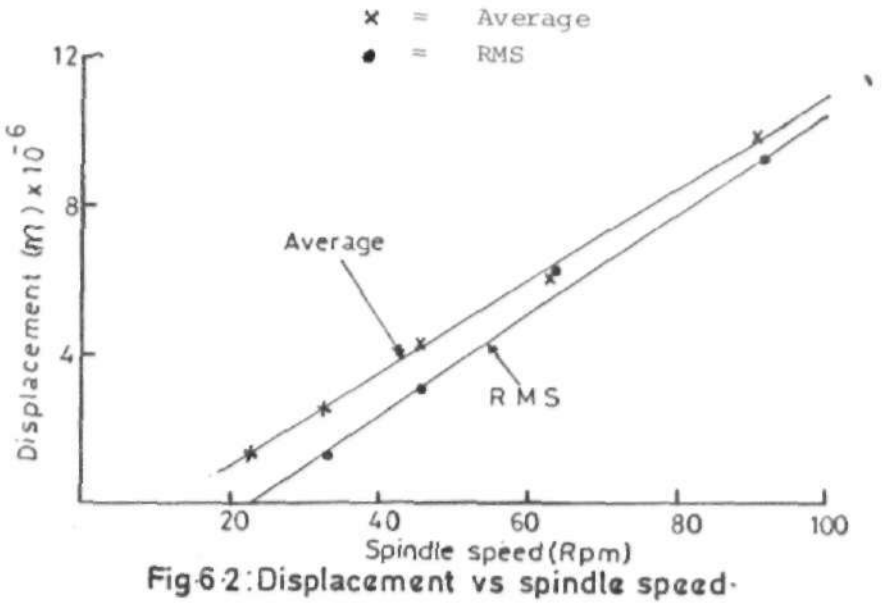
At the start of non-circular boring

At the start of profile machining, Figures 6.2 to 6.4 show the effects of spindle speed variation on the vertical vibrations of the boring tool. Figure 6.2 shows that the vertical displacement of the tool vibration increases with increase in spindle speed, the average values of which appear higher than the root mean square (RMS) values. From Figure 6.3, the velocity of vertical vibrations of the tool increases sharply and non-linearly with increase in spindle speed. The average velocity of vibrations as can be seen from the table and graph, appear a little higher than the RMS values. From Figure 6.4, the acceleration of tool vibrations also increases with increase in spindle speed; here the increase is non-linear but in a more relaxed form towards higher speeds compared to variation in velocity of tool vibrations with increase in spindle speed. The average values of the acceleration of tool vibrations appear to be the same with the RMS values.

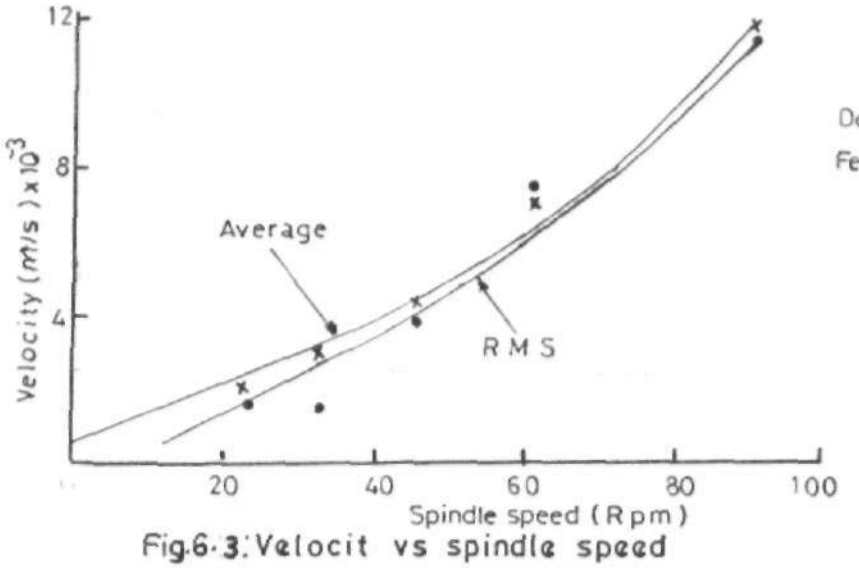
From Figure 6.5, the displacement of vertical vibrations of the tool increases linearly with increase in depth of cut. Figure 6.6 also shows that the velocity of vertical vibrations of the tool increases linearly with increase in depth of cut, the RMS values of which appear higher than the corresponding average values. The acceleration of vertical vibrations of the tool as can be seen from Figure 6.7 increases rapidly and is directly proportional with increase in depth of cut.

Figures 6.8 to 6.10 show the effects of feed rate variation on the vertical vibrations of the boring tool. As can be seen from Figure 6.8, the displacement of vertical vibrations of the tool increases with increase in feed rate. The increase is linear

GRAPHICAL PRESENTATION OF THE MEASURED VIBRATION AT THE START OF PROFILE MACHINING ; TABLE 3 ·

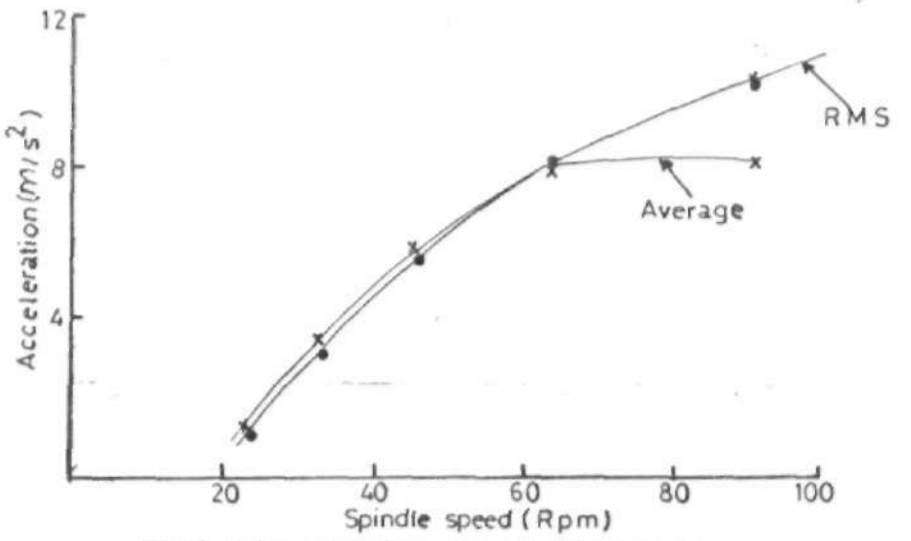


Fig·6·2 : Displacement vs spindle speed·



Depth of cut = 0·2mm
Feed rate = 0·107mm

Fig·6·3 : Velocit vs spindle speed



Fig·6·4 : Acceleration vs spindle speed

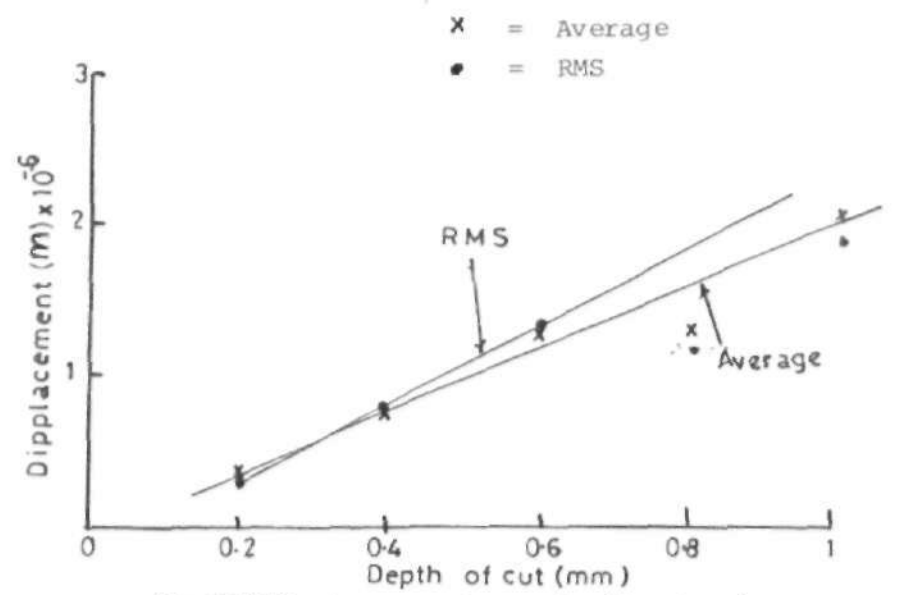
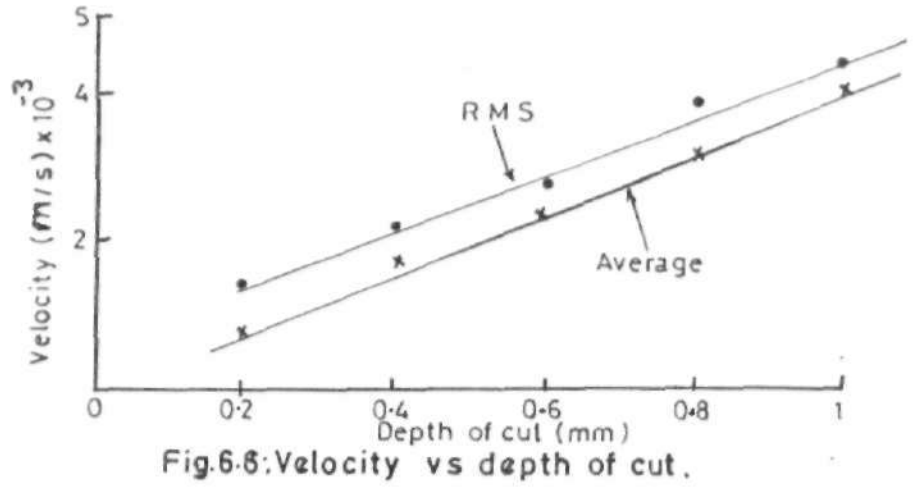


Fig.6·5: Displacement vs depth of cut.



Spindle speed = 45 Rpm
Feed rate = 0·007 mm/rev.

Fig.6·6: Velocity vs depth of cut.

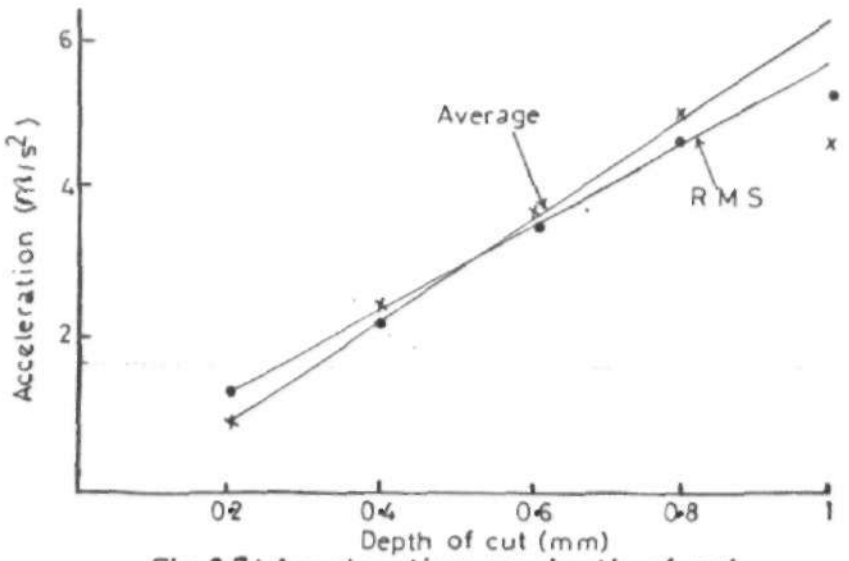


Fig.6·7: Acceleration vs depth of cut

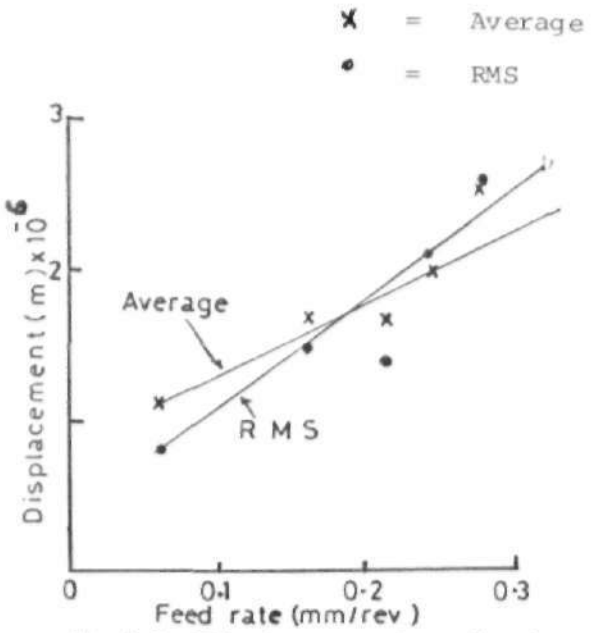


Fig 6 8 Displacement vs feed rate

Spindle speed = 63 Rpm
Depth of cut = 0.1mm

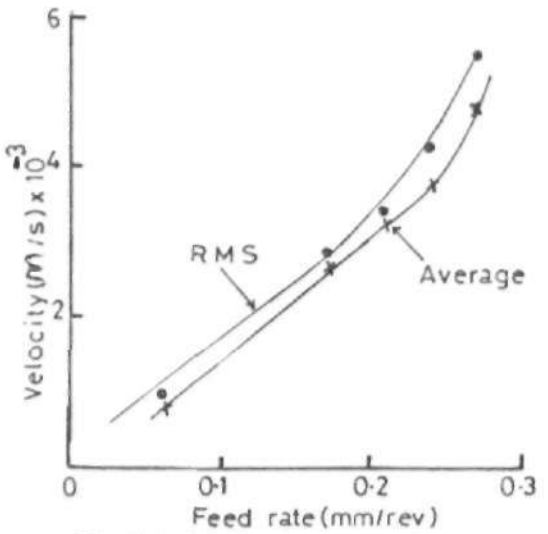


Fig 6 9 Velocity vs feed rate

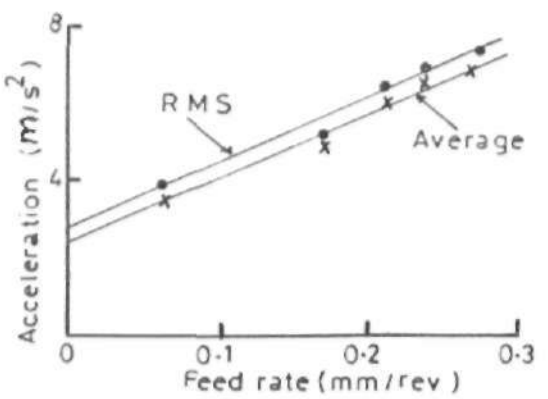


Fig.6·10. Acceleration vs feed rate

and rapid as can be seen by the slope of the graph. The average displacement of tool vibrations appear higher than the corresponding RMS values.

Figures 6.9 and 6.10 show that the velocity and acceleration of the vertical vibrations of the tool increase linearly with increase in feed rates. The average values for both cases appear to be less than the corresponding RMS values.

At full profile machining

At the full profile stage of machining when the boring tool was cutting continuously round the hole circumference, Figures 6.11 to 6.13 show the effects of spindle speed variation on the vertical vibrations of the boring tool. The Figures show that the displacement, velocity and acceleration of vertical vibrations of the boring tool, each increase linearly with increase in spindle speed.

Figures 6.14 and 6.15 show respectively that the displacement and velocity of the vertical vibrations of the tool increase linearly with increase in depth of cut. From Figure 6.16, it can be observed that the acceleration of tool vibrations increases non-linearly with increase in depth of cut.

Figure 6.17 shows that the effects of feed rate variations on the vertical displacement of tool vibrations. The vibrations as can be seen increases with feed rates, the increase however being more pronounced at higher feed rates. Figures 6.18 and 6.19 on the other hand show that the velocity and acceleration of vertical vibrations of the tool both increase linearly with increase in feed rates.

GRAPHICAL PRESENTATION OF THE MEASURED VIBRATION FOR PROFILE MACHINING: TABLE 4.

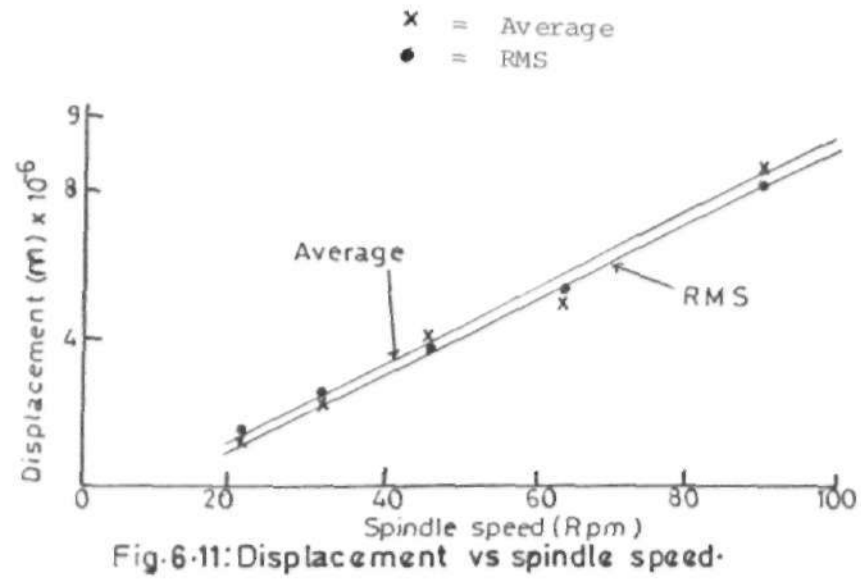


Fig.6.11: Displacement vs spindle speed.

Depth of cut
= 0.2mm
Feed rate
= 0.107mm/rev.

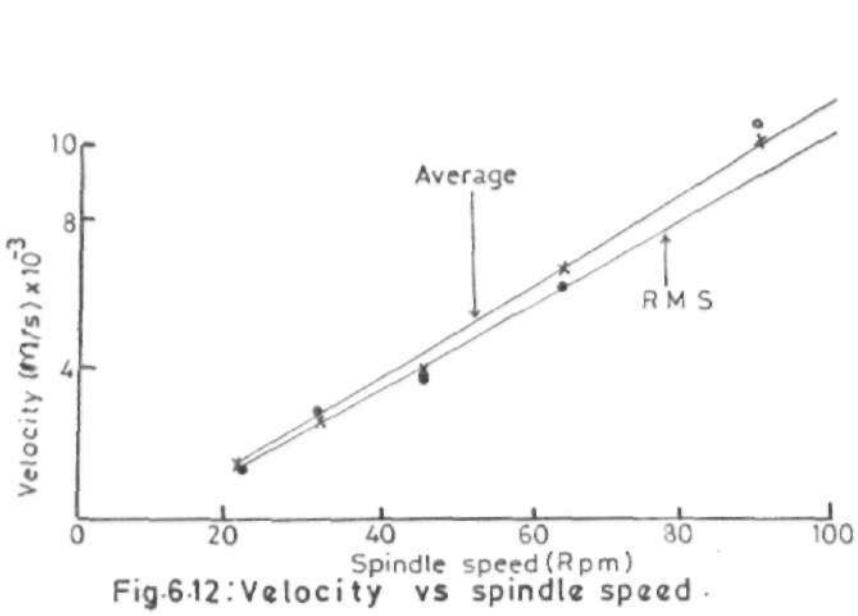


Fig.6.12: Velocity vs spindle speed.

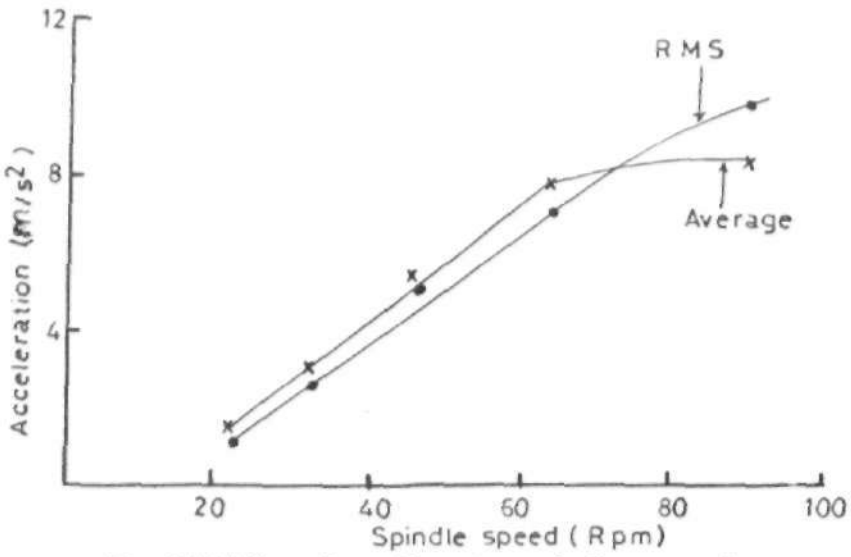


Fig.6.13: Acceleration vs spindle speed

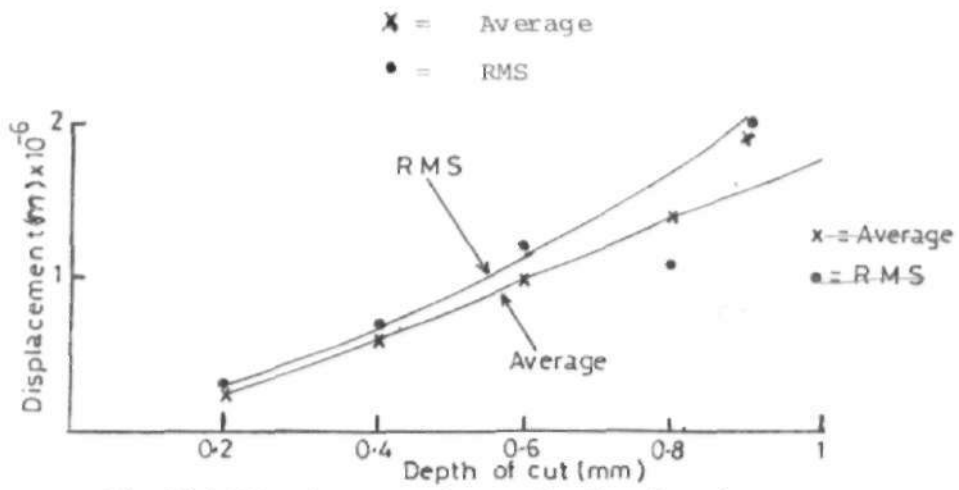


Fig.6.14: Displacement vs depth of cut.

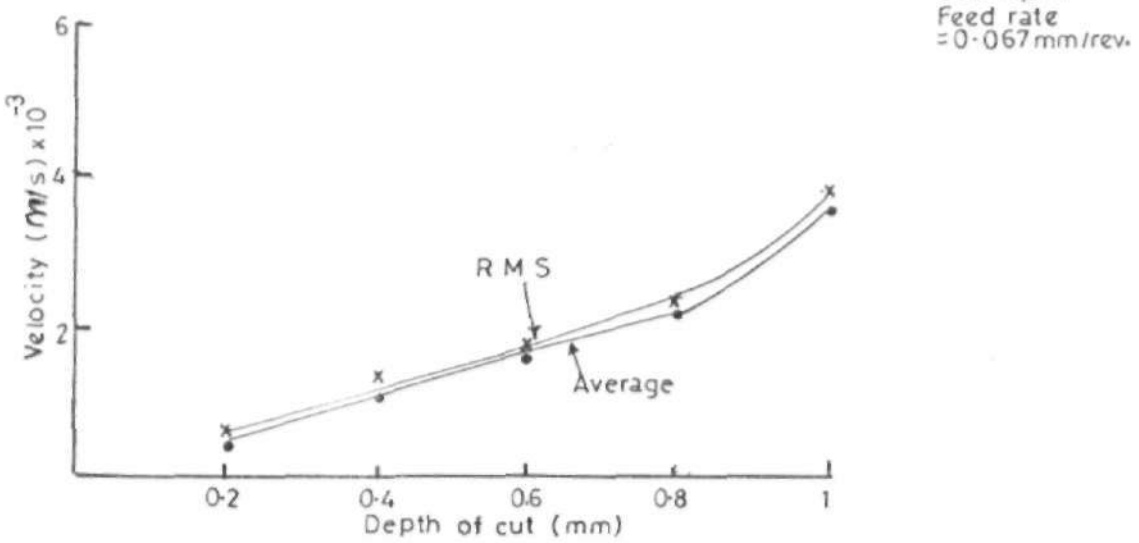


Fig.6.15: Velocity vs depth of cut.

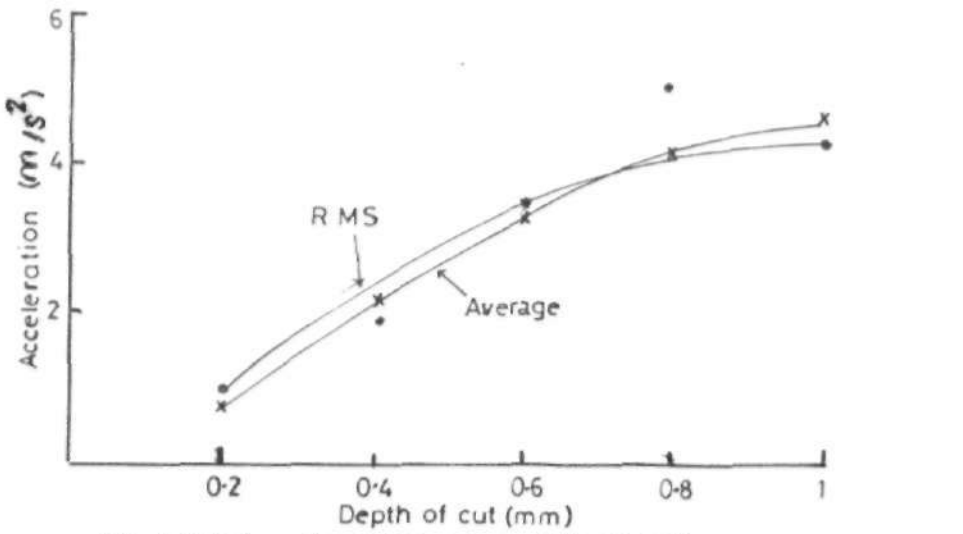


Fig.6.16: Acceleration vs depth of cut.

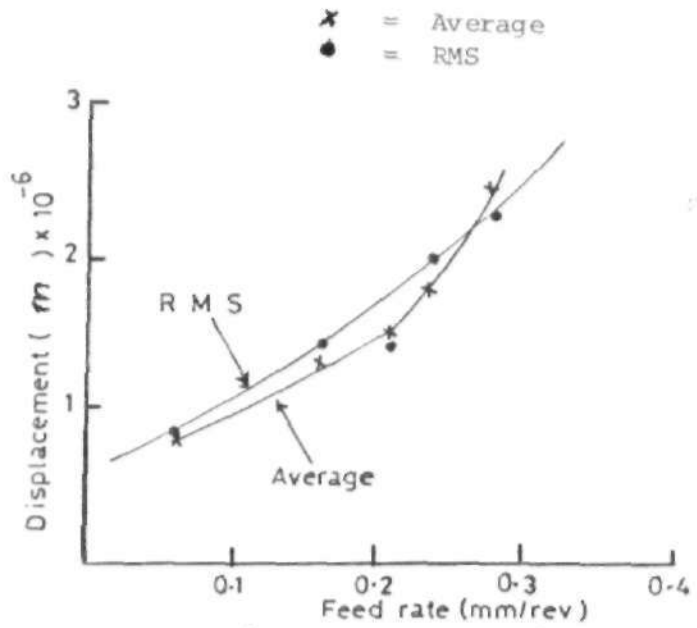


Fig.6.17: Displacement vs feed rate

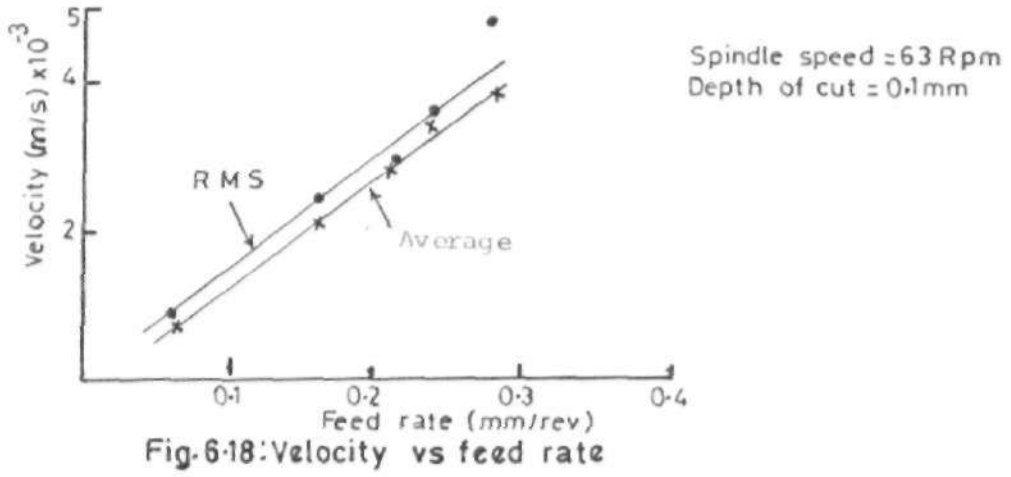


Fig.6.18: Velocity vs feed rate

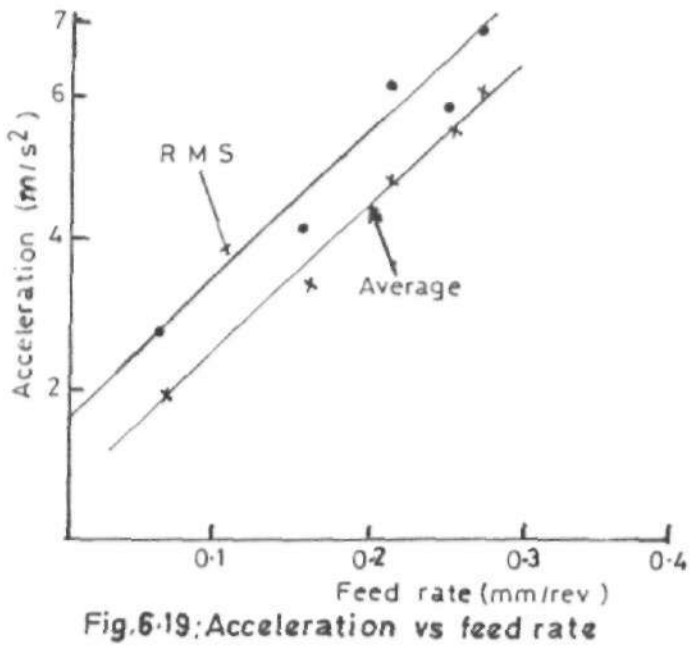


Fig.6.19: Acceleration vs feed rate

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6.4 CONCLUSIONS:

Generally, vertical vibrations of the boring tool increase with either increase in spindle speed or depth of cut or feed rate. Shaw [28] observed similar behaviour for the case of conventional milling and turning operations. One of the reasons that may be attributed to this is that cutting forces as can be seen from tables 1 and 2 in Chapter five increase with increase in depth of cut or feed rate, consequently the tool tends to be deflected more and to vibrate at lower frequency values. In the case of increase in spindle speed, the cutting forces decrease, however tool vibrations increase because of the forcing effects on it at higher speeds.

From the overall results, the vertical vibrations of the tool at the start of profile machining when the tool was cutting intermittently round the hole circumference appear higher than the corresponding values at full profile machining when it was continuously engaged in cutting the workpiece during boring operation. The reason that may be advanced for this is the idle times the tool had to traverse prior to another cut in the intermittent cutting, thus giving room for excitation of vibrations imparted on the tool in the previous cut.

The computed values of the boring tool displacement using simplified analysis agree well with the measured average values as shown in table 5.

For a cutting tool, the higher its natural frequency of vibration the better it is. The calculated natural frequency of vibration of one of the boring tools used is 15546.23HZ. This tends to decrease rapidly with increase in cutting forces. The higher the vertical component of the cutting force, the lower is the frequency of tool vibrations. The low er frequency vibrations have worse effects in metal cutting manufacturing than the higher frequency vibrations.

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CHAPTER SEVEN

SURFACE FINISH MEASUREMENT OF THE PRODUCED WORKPIECES

7.1 INTRODUCTION:

By surface finish it is meant the surface texture left after machining and to the condition of the surface with regard to irregularities forming valleys [8,33]. It can be appreciated that each chip-producing forming method imparts some characteristic quality to the structure of the surface layer of metal. A machined part that leaves some surface defects like flaw, lay, profile, chatter marks, roughness and waviness of excessive magnitude may not only increase the cost of production but find little demand for many applications [33].

Variations in the texture of a critical surface of a part influence its ability to resist wear and fatigue; to assist or destroy effective lubrication, to increase or decrease its friction and/or abrasive action on other parts and to resist corrosion as well as affect many other properties that may be critical under certain conditions [3].

Certain qualities in the surface are important. For example [8,21]:

(i) the reliability of a force fit and its approach to theoretical conditions is largely dependent on surface quality and finish,

(ii) smoothness is often important since in highly stressed parts, fatigue cracks often originate from surface blemishes, and under corrosive influence, a high quality surface may be more durable than one less well-finished,

(iii) every surface more or less is composed of minute hills and valleys, and when the condition of service requires that two of such surfaces shall operate one against the other, the early stages of the action will result in the levelling down of the hills on each member, so that the eventual conditions after one of the surfaces has settled down will depend on both the initial fit and the quality of the operating surface finish.

In view of the above discussion it can be appreciated that the analyses and measurement of machined surfaces is important for the control of

(i) those parts where surface roughness must be held within closely controlled units for optimum performance, and

(ii) parts where surfaces must be made as smooth as possible for optimum performance regardless of cost.

The general practical values of surface finishes obtained from some machining operations are as follows [1,6,21]:

(i) boring: from 0.5μm to 10μm

(ii) drilling: from 1μm to 10μm

(iii) planning and shapping: 0.5μm to 30μm and

(iv) grinding: from 0.1μm to 2.5μm

Surface finishes of the produced non-circular bores from workpiece materials of different physical properties common to engineering use have been measured and presented in this chapter so that appropriate machining conditions should be chosen when planning for the production of non-circular bores of desired surface finish using the non-circular boring attachment.

7.2 MEASUREMENT OF SURFACE FINISH

Surface finish of the produced workpieces was measured using an intricate device called profilometer. The trade name of the device is "Surtronic".

Plate X shows the experimental test arrangement of how surface finish was measured under laboratory conditions.

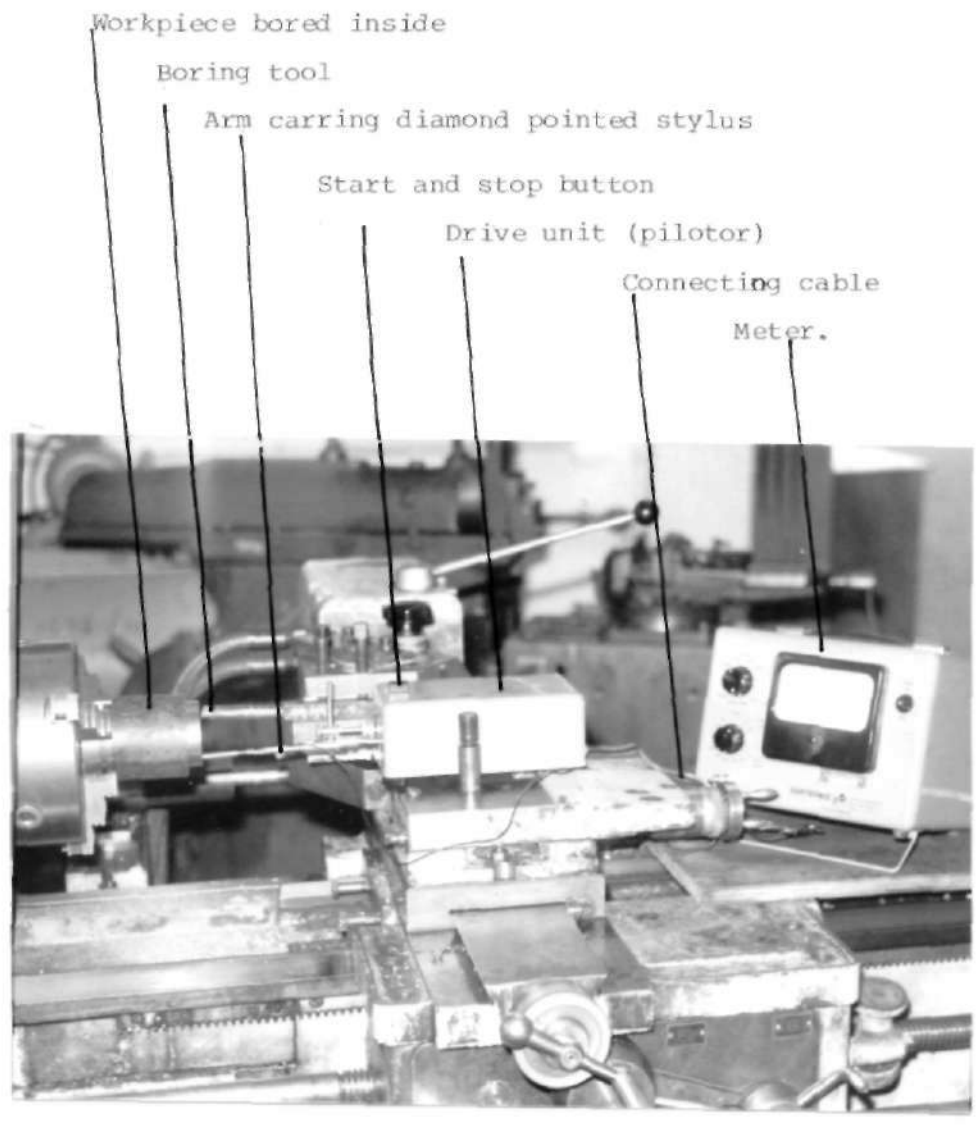


Plate X: Set-up for measuring surface finish.

The procedure of measurement was to vary one of the machining parameters, spindle speed or depth of cut or feed rate and keep the other two constant. After each cycle of machining, the boring tool was withdrawn, set aside and the surface finish measured. The measurement was done by passing the diamond pointed stylus of the device carried at an arm over the bored surface, so that when the operating button was started, the stylus moved across the surface ascending and descending faithfully with the surface irregularities as corresponding surface roughness were shown on a clearly marked meter. In that manner the surface finish of the produced workpieces was measured accurately in micrometres |µm|.

The results obtained for the test with brass, steel and aluminium workpieces under different machining conditions of spindle speed, depth of cut and feed rate are given in table 6, and graphs of the measured surface finishes are shown in Figures 7.1, 7.2 and 7.3.

Table 6: RESULTS OF THE EXPERIMENTALLY MEASURED SURFACE FINISH OF THE PRODUCED WORKPIECES

(a) SPINDLE SPEED VARIATION:

Depth of cut = 0.2mm

Feed rate = 0.107mm/rev

WORK PIECE	SPINDLE SPEED [Rrm]	SURFACE FINISH [µm]
BRASS	22.4	3
	31.5	3
	45	2.6
	63	3.5
	90	4
STEEL	22.4	4.4
	31.5	4
	45	3.6
	63	4.1
	90	4.8
ALUMINIUM	22.4	6.5
	31.5	5
	45	4.3
	63	4.7
	90	5.1

(b) DEPTH OF CUT VARIATION:

Spindle speed = 63Rpm

Feed rate = 0.04mm/rev

WORKPIECE	DEPTH OF CUT [mm]	SURFACE FINISH [µm]
BRASS	0.4	3.1
	0.8	3.2
	1.2	3.6
	1.6	3.6
	2.0	4
STEEL	0.4	4.1
	0.8	4.3
	1.2	4.3
	1.6	4.7
	2.0	5.9
ALUMINIUM	0.4	4.3
	0.8	4.5
	1.2	5
	1.6	5.8
	2.0	7

(c) FEED RATE VARIATION:

Spindle speed = 45 Rpm

Depth of cut = 0.2mm

WORKPIECE	FEED RATE [mm/rev.]	SURFACE FINISH [μm]
BRASS	0.107	2.1
	0.127	2.6
	0.160	2.7
	0.241	2.9
	0.371	3.4
STEEL	0.107	3.4
	0.127	3.7
	0.160	3.9
	0.241	4.6
	0.371	4.9
ALUMINIUM	0.107	4.4
	0.127	4.5
	0.160	4.8
	0.241	5.4
	0.371	5.8

GRAPHS OF THE MEASURED SURFACE FINISH

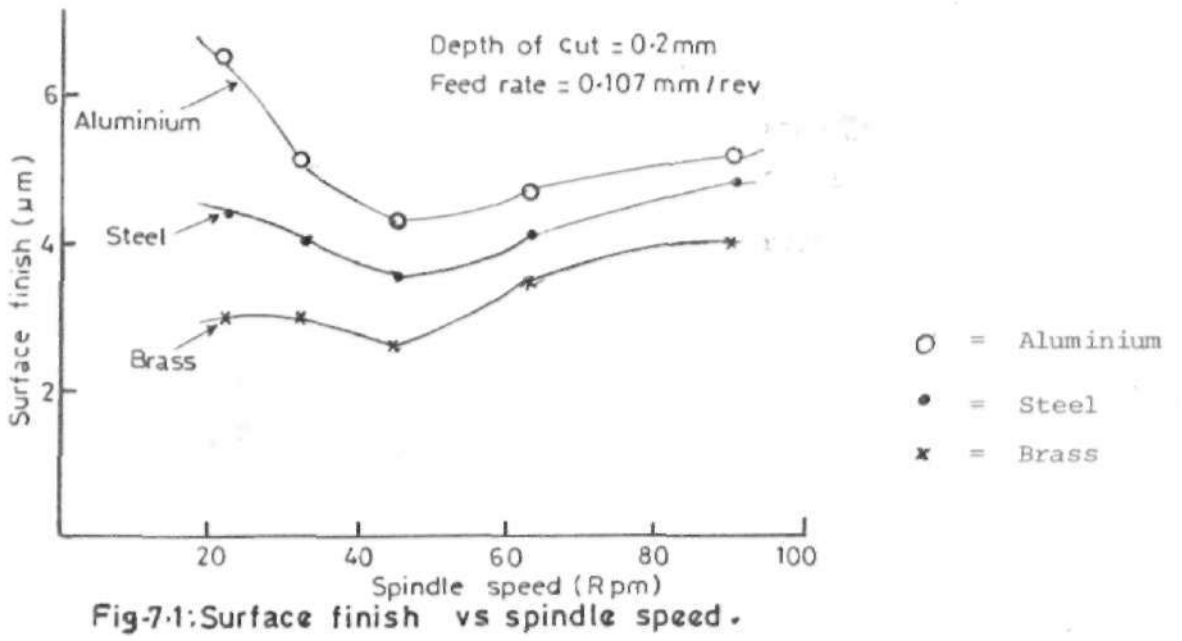
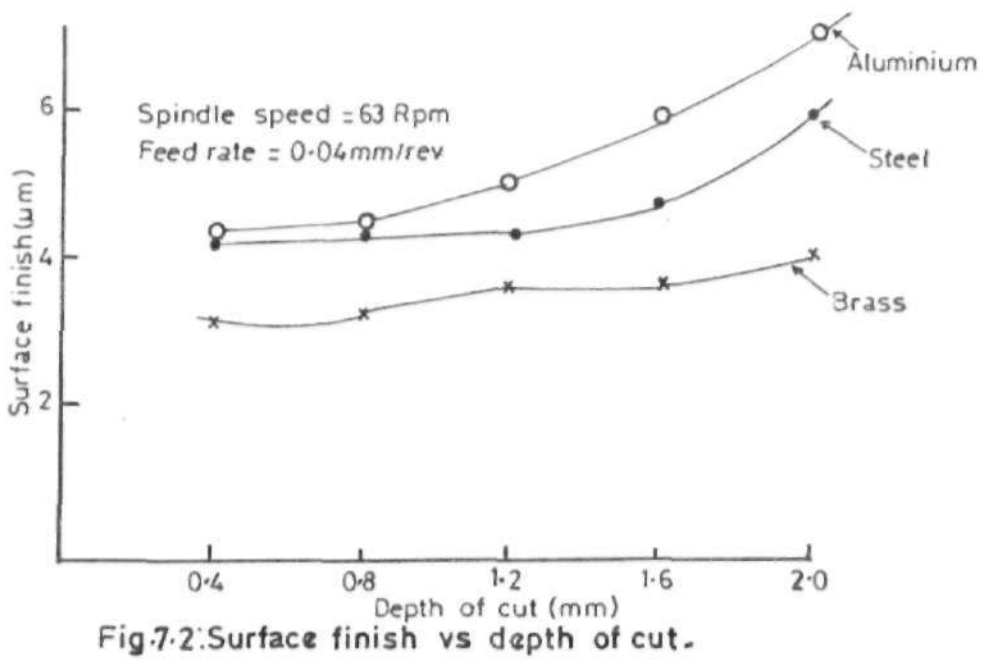
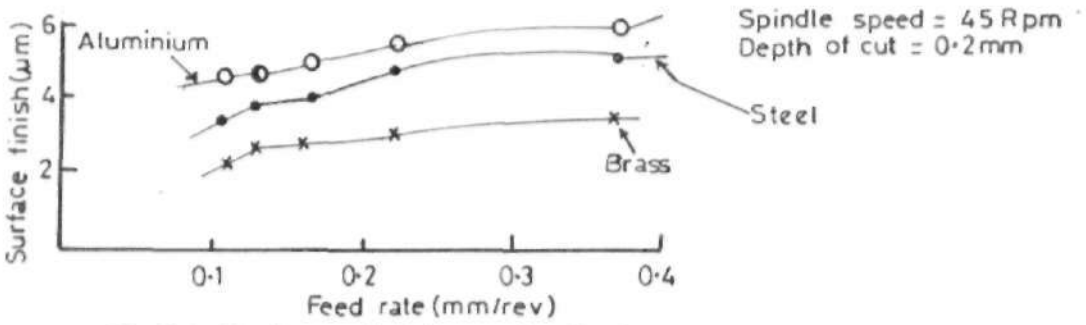


Fig-7·1: Surface finish vs spindle speed.



Fig·7·2: Surface finish vs depth of cut.



Fig·7·3: Surface finish vs feed rate.

7.3 DISCUSSION OF RESULTS:

From the experimental results of surface finish of the produced workpieces presented in Table 6 and graph for Tables 6a, 6b, and 6c shown in Figures 7.1, 72 and 7.3 respectively, it can be observed that for each workpiece material, surface finish deteriorates with increase in either the depth of cut or feed rate. Shaw [28] made similar observation for the case of milling and grinding operations. For the increase in spindle speed, the surface finish for each workpiece material improves up to 45Rpm. Thereafter it deteriorates with further increase in spindle speed. Doyle [15] observed that the surface finish of a machined part improves with all values of increase in spindle speed for a given depth of cut and feed rate.

Theoretically better surface finish of a machined part is expected at higher cutting speeds for a given depth of cut and feed rate; and light cuts for a given cutting speed [6,28] . This is because the coefficient of friction between the cutting tool and workpiece is decreased, resulting in a decreased tendency to form built-up edge chip as the cutting forces and strain in the chip are decreased [28].

Within the ranges of cutting conditions the experimental test was conducted, brass gives better surface finish than steel and aluminium. The difference in surface finish of the three metals is mainly due to the nature chip formation during machining.

The onset of deterioration in surface finish after the spindle speed of 45Rpm could be due to one or more of the several factors that may affect surface finish of a machined part, such as vibration and skill of the operator.

Generally the side and end cutting edge angles of a single point cutting tool have great influence upon the theoretical surface finish of a material. Shaw [28] has shown that the maximum amplitude of surface roughness of a machined part h is a function of the feed f, side cutting edge angle C_a and cutting edge angle C_e as follows:

$$h = \frac{f}{\tan C_a + \cot C_e}$$

This the theoretical surface roughness increases linearly with the feed and decreases with increased C_a or decreased C_e.

The workpiece material can also affect surface finish due to the difference in chip formation by different materials.

The evidence is that the quality of a machined surface deteriorates with increase in the amount of attendant tool vibrations relative to the workpiece [11]. From the results of measured vertical vibrations of the tool presented in tables 3 and 4, it can be observed from able 6 that, as tool vibrations increase with increase in depth of cut or feed rate or spindle speed, the surface finish of the produced workpieces deteriorates.

7.4. CONCLUSIONS:

Surface finish of the produced workpieces has been measured, presented and analysed. The surface finish obtained lies within the range of the genergal practical values obtained from boring operations. The spindle speed of 45Rpm, together with light cuts will produce smoother surface finishes if desired when using the non-circular boring attachment for producing non-circular bores.

CHAPTER EIGHT

GENERAL SUMMARY AND COMMENTS, CONCLUSIONS, AND SUGGESTIONS

8.1 GENERAL SUMMARY AND COMMENTS:

The developed auxillarly method of producing non-circular bores on the lathe consists of four stages. These are:

(i) acquisation of copying units;

(ii) production of templates;

(iii) development of power transmission method to drive the template; and

(iv) mounting of individual boring tools on the post and other arrangements.

8.1.1 Copying units

Copying units are accurately designed and special parts. They can only be got from the manufacturers or marketing dealers of such parts. The TKB10 hydraulic copying units were used for the non-circular boring attachment.

One of the problems observed while using the TKB10 copying units was the leakage of hydraulic fluid during boring operations.

8.1.2 Templates

A template is a shaped part with a profile replica of the desired form to be machined on workpieces, used in conjunction with copying units to form a copying system. Templates can be made from hard wood or metal. Three templates with profiles shown in Figure 4.2 were produced from steel metal.

8.1.3 Power transmission

A copying system incoporating a template as the programme medium, functions only when the template is given a steady rotation during machining operations. In achieving power transmission to drive the template during boring operations, economy and optimization of

demand were considered, and the chain drive method of power transmission based on one shaft set-up arrangement was found to be best for non-circular boring on the lathe. Two sprockets were designed and produced; Also three bushings, one spindle friction clutch, one steel slab, one power shaft, one extender and a housing pipe were designed and produced using local materials. Standard parts like bearings and a chain were bought from the market.

Although the developed chain drive method of power transmission can satify all speed requirements to drive the template for non-circular boring of different metals on the lathe, system vibrations and difficulty of the tracing stylus to following exactly the profile of a template at high speeds, as it was observed, limit boring operations to low speeds. Certain ductile metals like aluminium require high speed machining to give smoother surface finishes.

8.1.4 Mounting of the boring tool on its post:

The mounting of the boring tool was made to ensure no damage was done to it during boring operation. One of the differences between conventional cylindrical boring and non-circular boring is that; in the conventional case, the hole to be bored is smaller than the diameter of the boring tool; whereas in the non-circular case, where the boring tool need to be actuated constantly in a timed programme, the hole to be bored need to be larger than the diameter of the boring tool. There is thus a limit in non-circular boring of a hole with a particular boring tool.

In some instances where the clearance between the walls of the hole and the boring tool was not enough, there was rubbing of the tool body on the walls of the hole, thus contributing to poor surface finish. Arrangements were made to ensure the holes had

adequate clearance space between its walls and the boring tool to avoid the rubbing problem. For example, for one of the boring tools with a diameter of 15.5mm, a hole of at least 25mm was needed to overcome the rubbing problem using the various templates of Figure 4.2.

8.1.5 Measurement:

In measuring surface finish, cutting forces and vibrations, it was observed at times in some instances that the meter reading indicators were not giving steady readings. In such instances, the average values of the meter readings were assumed. The Oscillations of the meter reading indicators about a mean value, particularly when cutting forces and vibrations were being measured is due to the dynamic nature of the cutting forces [35]. However, the table data of the measured surface finish, tool virbations, cutting forces and its derivatives provide a true insight of the practical encounter with non-circular boring on the lathe.

8.2 CONCLUSIONS:

The following conclusions are drawn from this work. They are:

1. The auxillarly method of producing non-circular bores on the lathe has been successfully developed and used. Non-circular bores have been produced and tendered as exhibit;
2. The chain drive has been developed and used to drive the template;
3. Surface finish of the produced bores is similar to the general practical values obtained from boring operations, and is therefore good for normal engineeering and other users.

4. The measured values of cutting forces and corresponding calculated effective machining power give an indication of the amounts needed for non-circular boring on the lathe under various cutting conditions. The forces and power required to bore are higher at full-shape profile machining.

5. Vibrations exist in the system as shown in Tables 3 and 4 of the measured values of the vertical vibrations of the boring tool and is higher at the start of non-circular boring than at full-shape profile machining. In all instances these vibrations increase with increase in spindle speed, or depth of cut or feed rate.

8.3 SUGGESTIONS FOR FURTHER WORK:

The following suggestions for further work are made:

1. To investigate the effects of non-circular boring on the lathe with variable spindle-template speed ratios using chain drive and decide if any of the most economical speed ratio to be used.
2. To investigate some of the causes and possible ways of reducing vibrations in the system.
3. To look at the ways of controlling noise of the hydraulic system for silent operation.
4. To investigate the effects and possible ways of reducing , if any, dry friction in the copying slides.
5. To look at the different ways of controlling the inherence to instability, of hydraulic copying systems.
6. To investigate the causes and possible ways of preventing the difficulty of the tracing stylus in following exactly the contour of a template at high spindle speeds while using the non-circular boring attachment.

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