DEPARTMENT OF MECHANICAL ENGINEERING
AHMADU BELLO UNIVERSITY, ZARIA

DESIGN AND PRODUCTION OF MULTI-SPINDLE ATTACHMENT TO THE UNIVERSAL LATHE

BY

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DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my research work.

It has never been presented nor accepted in any previous application for higher degree.

Sources of all quotations and other non-original pieces of information are specifically acknowledged by means of references.

F. A. Oke.

11th January, 1984.

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

T = Torque.

N = Number.

n = Number.

D = Diameter.

d = Diameter.

r = Radius.

η = Efficiency.

S = Stress.

f = Coefficient and other factors.

F = Force.

PCD = Pitch Circle Diameter.

h.p = Horse Power.

rpm = Revolution per minute.

M = Bending moment.

n = Factor of safety.

R = Reactions.

T_e = Equivalent Torsion.

π = $\frac{22}{7}$

w = Width.

l = Length.

h = Height/depth.

t = Time.

W = Weight.

Q = Rate of Production.

b = Thickness.

μ = coefficient of friction

SUMMARY

The project is the design and production of Multi-Spindle Output Attachment to the Universal Lathe Machine.

The decision to embark on this project was out of the consideration for better productivity of the lathe machine.

Before the design project was started, Machine shops of some industries in Lagos, Port-Harcourt and Ibadan were visited along with some production workshops. It was discovered that the most common of the lathe machines in use are medium-sized lathe on which full capacity work-pieces are machined less than 20% of their working periods. During the majority of their working lives, they are under-utilized with small jobs that are usually required in small lots. Since these items are not mass-produced, it would have been wasteful to invest on multi-spindle lathes which are very costly. A simple attachment that can temporarily turn a single spindle lathe to a multiple spindle output would therefore be very useful for these machine shops.

Multi-spindle lathes are not available in the local market since there is virtually no market for them. It is envisaged that multi-spindle attachment will have a large market in this country as well as other countries (even developed countries).

In order to have a good idea of the design, a good knowledge of all the various types of lathes, especially multi-spindle lathes and their attachments, was necessary. To obtain this knowledge, periodicals on machine tools and machine designs as well as related books found in the libraries of University of Lagos, Ahmadu Bello University and University of Ibadan were read in conjuction with brochures, write-up, manuals and drawings sent on request by machine tools industries in the United Kingdom, United States of America and Western Germany. The earlier parts of this thesis are therefore on these lathes.

There is a brief history of lathe machines from the original tree lathe to the present types. The various stages of its development are presented.

After this, a full study of various types of single spindle lathes is presented. Various designs of the parts and members of these machines as well as their tools and the operations that can be performed on them along with attachments that are used on the lathes are fully described.

Because of the high productivity of Capstan and Turret lathes and the efficient tooling requirements, these types of single spindle lathes are given full descriptions in one chapter. Emphasis is placed on their tools, tool-indexing mechanisms

and work-holding devices.

The various types of multi-spindle lathe machines are described in anotner chapter. A detailed study of their operating sequences, tooling, work-indexing mecnanism, cammings as well as various types of attachments used with them is also presented.

The knowledge presented in the first four chapters is used as bases for concluding on the design of an attachment to lathe machine. A brief description of the attachment is made along with its maintenance and expected tooling.

Design calculations were made using engineering standard books like Standard Handbook of Engineering Calculations (by Hicks) and Machinery Handbook (19th Edition), along with some design books.

The production of the prototype, the modifications carried out in the design during its production, the factors limiting the accuracy of the prototype, and the cost of its production, are presented in a chapter. The cost is used as base for the computation of the expected cost of the attachment when it is produced for marketing.

The test carried out on the prototype and the problems encountered while producing it are described before a conclusion on the viability of the project is reached.

Drawings and sketches were made. Drawings are attached.

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CHAPTER ONE

1 - INTRODUCTION

Machine tools are parents of all machines, since any otner machine is produced by machine tools. They are therefore bases of mechanised society and the foundations of industrial civilization.(1) In simple terms, a machine tool is a power driven machine designed to cut metals to shape.

It is not known when the first machine tool was made, but archeologists have discovered an object which appeared to have been machined with a lathe about 1500 B.C.(2) Lathe is believed to be the oldest machine tool and the earliest knowledge of it started from the tree lathe which was powered by a rope passed round the work a few times, while the other end was attached to a springy tree branch overhead. The work piece was supported by two dowels stuck in adjacent trees as shown in Fig. 1. The operator's foot supplied the motion which was intermittent and fluctuating, while the tool was held in his hand. Later, a strip of wood called lath was used to support the rope, and the machine was named Lathe.(1) The primitive pole lathes are said to be still in use in parts of Asia, though they disappeared in Europe in the 19th century.

Lathe evolved over a period of more than two centuries to what we now know it to be. At the beginning of the 18th century, the lathe was made almost entirely

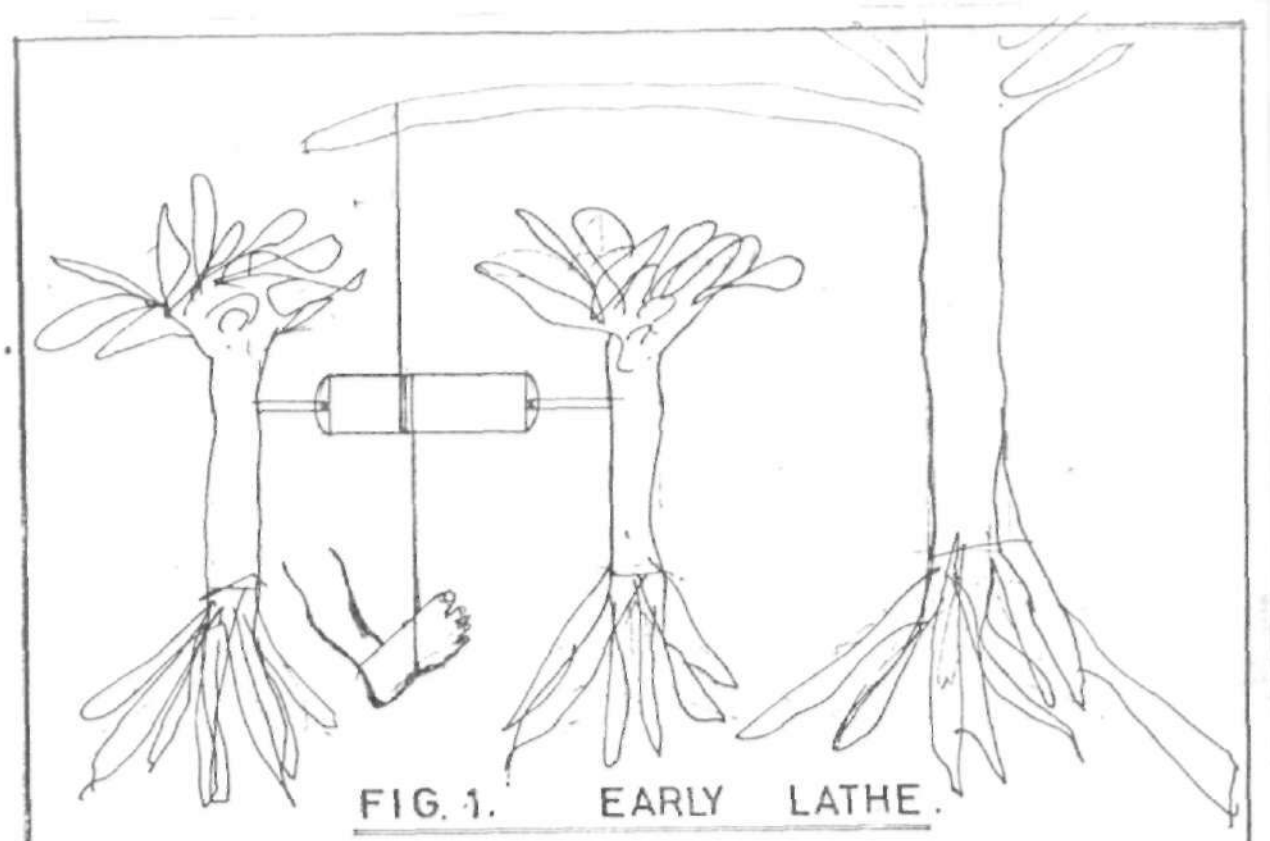


FIG. 1. EARLY LATHE.

of wood. It had no slide rest and no self acting feeds. Before 1770 lathe could not turn metals because of lack of power and strong holding device to guide the tool. In 1770, the first engine lathes were produced. These were driven by central steam engine through a line shaft and belts, and in 1776, John Wilkinson produced the horizontal boring mill at Bersham Iron Works, England.(2) The first screw cutting machine with slide rest, lead screw and change gears, was made by Henry Mandslay in 1797, in England.(1)

From this period, lathe started to develop and the concern was not only with producing but with making

products faster and more economically. By the first half of the 19th Century, Turret and Capstan lathes were developed. They became available for sales during the second half of the century. The earliest automatic lathe (for turning wood screws) was made in 1842 by Cullen Wipple of New England, America. The first bar automatic lathe was produced in 1879 by C. W. Parker in Leeds, England, and the first automatic Turret lathe was produced in 1893, by Pitler of Germany.

By the beginning of the 20th century, custom-built lathes had started appearing and in 1900 A.D., the first multi-spindle automatic lathe was produced in Cleveland, U.S.A. During the first half of the 20th century, attention was focussed mainly on types of controls for automatic machine tools, while investigationsinto various types of turning tools for fast production of parts were intensified. Thus there were HSS tools, later carbide tipped tools, ceramic toos, etc.

1.1 FEATURES OF MODERN LATHES

The modern lathes are designed to be easy to operate and can be operated by semi-skilled operators; thus we now have the following:

1. Easy gear changing control levers that are grouped in a position easily accessible to the operator.
2. Saddles and other feed moving parts coming against stops which operate clutches or other controls to stop feed or spindle.
3. Hydraulic or fully electric method for feed instead of feed screws (which are still very popular).

4. Infinite variable speed gear-boxes [illegible] instead of stepped gear-boxes involving shift gears.

5. Pneumatic hydraulic and magnetic operated chucks with safety interlock against malfunction.

6. Numerical control of machine tools.

Apart from Ergonomics which concern the use of less effort by machine operator for more production as well as increased productivity, researches and development of machine tools are on to improve the accuracy of the machine (by improving the bearing precision, the spindle material, the bed castings/ materials and by limiting vibration to avoid chatter in the common range of machine tool operations); and reducing noise level. Steps are also being taken to improve the measuring and setting devices.

Attachments to make machines more versatile have always been made. These attachments used on various types of lathes include drilling, reaming, grinding, taper turning, threading and copying attachments. It is interesting to note that in 1967, an attachment for converting six spindle bar automatic lathe to a ten spindle machine was made by Wickman Machine Tools Limited, Coventry, England.(3)

Apart from numerical controls and other forms of electronic/computerised control used on individual machines, the invention of transfer machines has given rise to group engineering technology, where a group of machines - drilling machine, shaper, lathes, milling machines, etc., form a working station that is controlled centrally. Once a work piece goes in, the operator

only needs to collect the finished product, despite the fact that all the machines in the group might have worked on it.

Machine tools have continued to develop but there these developmens are concentrated in the advanced countries of the world. It is of great concern that developing countries are still in the basic stages of machine tools utilization. For example, there is no evidence to show that there is any multi-spindle lathe machine in this country while only few industries have Capstan or Turret lathes. This inhibits production of machine elements, thus making simple engineering parts very expensive.

Even in developed countries, while many workshops can afford to have universal lathes, few of them have multi-spindle lathes which are very expensive and uneconomical to use for short run jobs. The universal lathes are therefore made to do a lot of repetitive jobs. There is therefore a need for mass producing attachments like the proposed multi-spindle attachment which will temporarily turn a lathe to a multi-spindle unit. This need is more in developing countries.

CHAPTER TWO

2 - THE LATHE

The main purposes of the lathe machines are to machine external, internal surfaces on solids of revolution and also to cut threads on them.(4) It can therefore be defined as a machine tool which holds work in a revolving chuck or between revolving centres against a rigidly held tool that can be fed along or across the work to form a cylindrical section. The section may form contour, taper or thread but it is symmetrical.(1) It is a basic machine tool and the most important. Its usual operations include turning, facing, boring, drilling, threading and parting off. Apart from these, it can be made to mill, shape, gear cut, flute cut, slot, spin, lap, buff, polish and grind, thus combining the functions of many other machine tools. This makes it universal and important, as other machine tools cannot do as much. When it is turning between centres, it is called Centre Lathe; when the workpiece is bar, which is held by collets, we have Bar lathes; when the workpiece is held only in chucks, it is called Chucking Lathe. The centre lathes are the most widely used. They are made in considerable range of sizes with variation in designs, tools and attachments to suit different duties. Their feeds, loading and unloading can be automatic. If these are done, they become automatic lathes.

It is common to refer to lathes as Engine Lathes because the early lathes were driven by central steam engines through line shafts and belts. All modern machines have individual drives and some even have separate drives for some functions, like coolant and lubrication pumps. However, engine lathe is now a general name which is hardly used since various modifications have taken place and the lathes are now being called by their specialized functions, like centre lathe, chucking lathe, bar lathe, multi-tool lathe, etc.

All lathes have four basic units:

1. The bed, the supporting member to which the headstock and tailstock are secured.
2. The headstock or work driving member which usually houses the speed gear-box and the feed gear-box.
3. The carriage for tool support and feed.
4. The tailstock which carries work supports and some end working tools.

1 SIZES OF LATHES

There are many ways of giving the sizes of lathes. One method is to give the centre height of the lathe. This is the height of the spindle axis above the bed. The second method is to give the maximum diameter of workpiece that can be swung over the bed. The third method is to give the maximum diameter of workpiece that can be swung over the carriage.

The length of a centre lathe is given by the distance between the centre in headstock and the other in

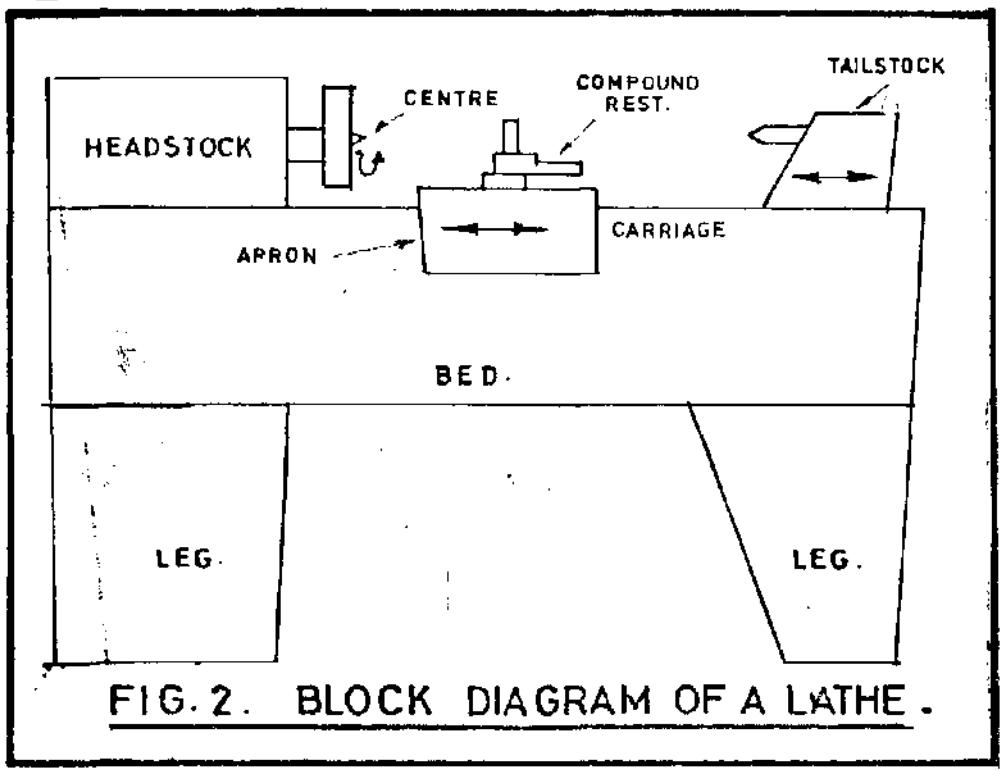


FIG. 2. BLOCK DIAGRAM OF A LATHE.

tailstock when the tailstock is at the extreme position (without over-hanging). This represents the maximum length of the workpiece that can be machined. In chucking machine, the length is given by the length of the bed.

Bar machines are sized according to the maximum diameter of bar they can admit.

2.2 MAIN DRIVE

Most modern lathes are driven by a 3-phase single speed squirrel caged induction motor through vee belts and stepped type mechanical gear-box housed in the head-stock. Some lathes are now designed that have infinitly variable spindle speeds. These are got by using:

(a) Variable speed D.C. motors. This method is hard to justify as it requires the use of Motor/Generator (M.G.) or Ward-Leonard Set for the convertion of local alternating current supply to direct current or the use of converters and thyristor drives.

(b) Variable speed gear-boxes (Carter, Kopp or Croft types), and

(c) Variable speed pulleys.

Some lathes use double speed and other multi-speed motors for the purpose of increasing the range of number of spindle speeds available.

2.3 THE BED

It is usually a box casting with machined and ground ways on its upper surface. In most lathes, it is bolted to a heavy box or leg which provides trays for cutting fluid and swarf collections. It supports the tool and work. Because it supports the carriage (and thus bears the pressure of cutting tool) as well as the headstock and tailstock, which in turn support the workpiece, it is the backbone of the lathe, contributing to the strength, accuracy and rigidity of the machine. To be accurate, it must resist the torque developed when turning. If the bed deflects, the accuracy of machining suffers because it diverts the cutting tool from its true geometrical path. Its deflection also results in vibration, which increases as deflection increases until natural frequency, which is a function of $\sqrt{\frac{\text{stiffness}}{\text{mass}}}$ (5) is reached and resonance occurs

leading to chattering. Increasing rigidity does not only reduce the chances of vibration, but also increases the frequency that will produce resonance, thus reducing the chance of chattering at normal operating speed.

2.3.1.1 Slide Ways

On the bed are the ways over which the carriage, tailstock and other feeding elements move. They are normally well lubricated, since they are bearings for linear movement. They provide alignment, fit and load carrying capacity. They should have no tendency of stick-slip jerk and they usually have adjustment for wear. They should allow for instant and accurate motion. Since the slides of the carriage (and tailstock) and the slide ways on the bed bear on high sports which are flattened plastically by load when slides want to move, there is a resistance from the micro weld requiring increased effort to be applied to make the motion. The piling energy shears through the micro weld and jerks the slide forward. This is called stick-slip and it is repetitive and more pronounced at slow speed. The slides are therefore separated by lubricants so that shearing occurs in the lubricants rather than through the micro welds to avoid stick-slip situations. Roller chain slides are now being used since rolling friction is very much smaller than sliding friction for the same reaction load. They slide inside a chain track in the bed.

2.3.2. Types Of Slides

The simplest types of slides are the flat slides which have large bearing areas and can be of low wear, if closed grain cast iron that is flame hardened is used. They lack positive guide and cannot be adjusted. The rectangular, dovetail, vee and inverted vee types of ways are now common, since they allow for guidance. With these, except for the inverted vee types, adjustable wear strips can be incorporated. These can be in the form of wear plates or rails, bolted to the bed so that they can be easily changed. In modern designs, they are made as plastic insertions which, apart from acting as bearings, help as vibration dampers to reduce chatter in the machine tool. Plastic insertions also insulate the slides from thermal effect and provide floating effect when the slide ways are lubricated under pressure.

The inverted vee is, however, self-adjusting and requires no wear strips. It is an efficient narrow guide ensuring smooth and accurate motion. It wears quickly and requires being changed constantly. The two mating parts of the ways where wear strips are not used are made of two different materials with the part easier to remove, made of softer material. For vertical lathes and other machine tools which use columns, either the barrel has wear insertion or if there is no insertion, the shaft is made of softer material since it is easier to remove.

The contacting ways are hardened and ground. With grinding generating lots of heat which affects the properties of the slide ways materials, scraping in well controlled manner are performed instead of grinding in precision lathes. In some cases, the ways are not hardened but left as cast with the impression that the constant sliding between them will produced a work hardening effect. It is difficult to control wear in this case and this method is used where the efforts required to change the slide and the slide ways are almost equal. Some beds have detachable slide ways that can be renewed when worn. A great problem to the slides is swarf collection which, if allowed to gather on the way, can trap and scotch them. To avoid this, scraper belts are usually used to clean ahead of slide movement.

2.3.3. Bed Sections

Various researches have been made on the section of beds that will produce the highest rigidity and yet allow for easy chip disposal and coolant flow. Since deflection decreases in proportion to the cube of the depth of section in the direction of applied force

$$\delta \propto \frac{1}{t^3}$$

δ = deflection

t = thickness in the direction of force

machine tools beds are therefore designed thick in direction of main cutting force and to resist forces from other direction they are wide and ribbed. The

double I section which was the original bed section has been replaced by box section and where they are used, they are ribbed in Zig-Zag manner. The ribbed sections are, however, being retained because of the ease of chip and coolant disposals in them. The new design that combines rigidity with easy swarf disposal is the box type with slanting top, shown in Fig. 3.

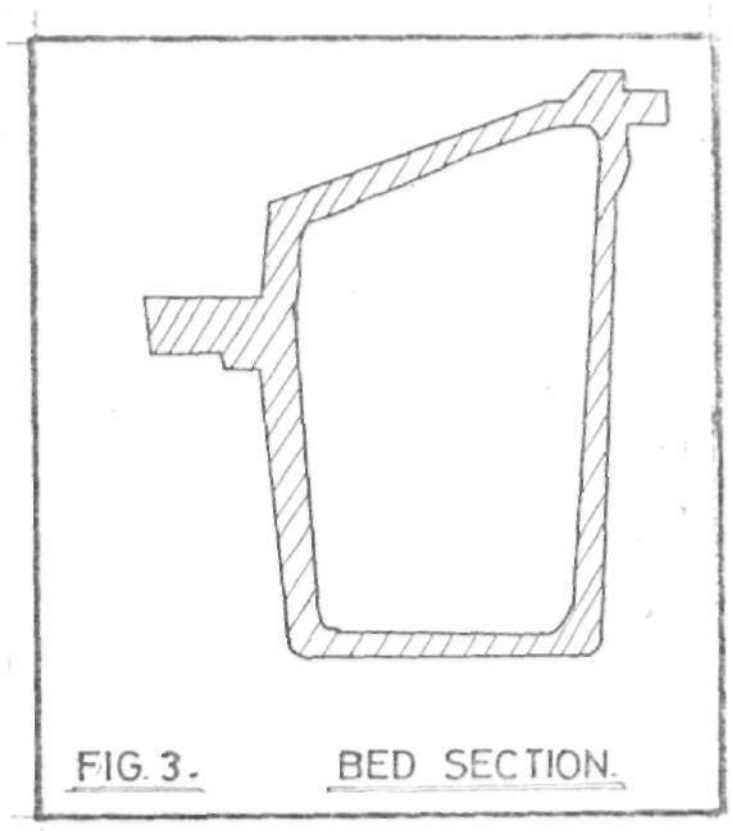


FIG. 3. BED SECTION.

There is need to control the foundry process of bed castings. The metal should be close grained and well dispersed for even strength.

2.4 THE HEAD STOCK

This is a rigid and accurately machined casting secured to the machine bed. It carries bearings in which spindle and other shafts revolve. The bearings

are lubricated through a lubrication pump. The shafts carry the change gears and other power transmission mechanisms required for driving the spindle and generally, other moving parts of the machine. In other words,the headstock is a gear-box for transmitting power and torque required for cutting processes to the spindle. It provides for engagement, disengagement and reversal of spindle rotation and it is designed to ensure smooth and accurate rotation of the spindle at all available speeds. In some smaller lathes, especially small lathes of high precisions, changed gears are not used but speed variations are done through sets of coned pulleys to reduce vibration, which is usually magnified by gear trains, to the karest minimum. The speed change is done by selecting from a pair of pulleys to the other with different pulley diameter ratios in a cluster of pulleys (coned pulley) mounted on motor and headstock shaft as shown in Fig. 4.

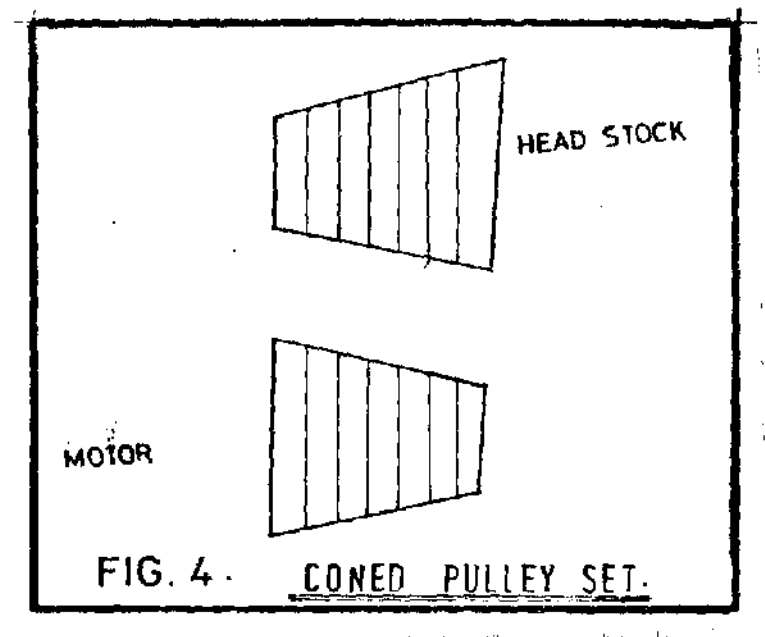


FIG. 4. CONED PULLEY SET.

The motor generally is mounted at the base of the headstock, but in some very small lathes with gear trains, the motor is flanged mounted directly to the headstock.

In large lathes, owing to the amount of power transmitted, many vee belts in a matched set have to be used to transmit power from the motor to the headstock. This disallows the use of variable ratio pulleys. The speed change is done through gear train, which though is more costly initially than belt, provides better speed variation, a higher output (since speed charges are easy through lever), lower maintenance and less risk of danger as in belt manipulation. Gears changes can only be done when gears are stationary, so clutches and brake are incorporated to reduce over-run when speed changing, braking and declutching are being done simultaneously through a lever which can also engage forward or reverse clutches. The clutches can be arranged to slip after a certain amount of torque is transmitted to protect the machine from overload.

2.4.1. Clutch Designs

These are usually multi discs type that can be dry-made of alternate carbon steel and fabric or wet-made of alternate carbon steel and phosphorous bronze, but with the flood lubrication arrangement of the headstock, wet type of clutches are used. For a single friction plane, torque transmitted, T, is given by

$$T = \mu P \frac{D + d}{4} \text{ lb-in} \quad (7)$$

D = the outside diameter of the plate

d = the inside diameter of the plate

μ = the coefficient of kinetic friction which between wet plates is between 0.1 and 0.2

P = load on the plate and it is given by

$$P = \rho \frac{\pi (D^2 - d^2)}{4}$$ where ρ pressure of plate (5) in lbs/in^2.

For N = number of plates.

$$T = \mu NP \frac{D + d}{4} \text{ lb-in}$$ (5)

The plate is always calculated to about 250 - 300% of the maximum torque required.

2.4.2. Gearing

The design of lathes is to cope with their versatility. This always takes into consideration the range of sizes of workpiece that may be machined, the speed range expected and maltreatment expected on the machine. For gears, Torque x Speed = H.P. available at gear which, depending on frictional and other losses, is a percentage of the motor output power. This is the base for gear designs.

The largest torque on workpiece is given by

$$Tmax = \frac{Dmax}{2} \times Ac \times f$$ (6)

where

Dmax is the maximum swing of the lathe

Ac = area of cut

f = specific cutting pressure.

The power at the spindle is limited by power output of the main drive motor and it is found to be about 70% of this power. Since HP = Torque x Speed, it follows that at low speed, torque can be very high, but

this cannot be fully utilized, owing to limitation imposed by strength of gearing and shafting.

In some rare situation where heavy lathes require high precision, the gear-box is housed outside the head-stock. The speed changes are done in the gear-box which is only connected by pulleys and belts to the spindle housed in the headstock. The pulley in the headstock is mounted on anti-friction bearings to relieve driving shaft of bending stresses due to tension on pulley. Since all feeds are taken from the spindle, the spindle drive is taken to the feed gear-box in these lathes through vee belts.

With shift gears, splinned shafts are generally used. The shafts are made as short as possible to avoid deflection, but where they are long, they are generally supported by bearings mounted at the ends and in the middle. The general method of transmission is to transmit motion from the motor to a shaft which in turn transmits X number of speeds to another shaft through change gears. The second shaft transmits Y number of speeds to a third gear. The values of X and Y and the number of intermediate shafts depend on the number of speeds that the machine is designed to have. Take a simple case of 6 spindle speeds. If the designer wants to use 3 shafts, the first shaft can be designed to give 2 speeds to the second while the second is designed to give 3 speeds for each of its speed to the third shaft, the combination is thus 3 x 2 = 6.

2.4.2.1. Gear Ratio

If maximum speed is N_{max}, minimum speed is N_{min} and n is number of speed, then r, the gear ratio is given by

$$r = \sqrt[n-1]{\frac{N_{max}}{N_{min}}} \quad (5)$$

when

n = number of speeds = 6

$$r = \sqrt[5]{\frac{N_{max}}{N_{min}}}$$

standard tables are available to give preferred gear ratios and speed numbers.

A typical gearing diagram for six spindle speeds with ratio r is given by Fig.5:

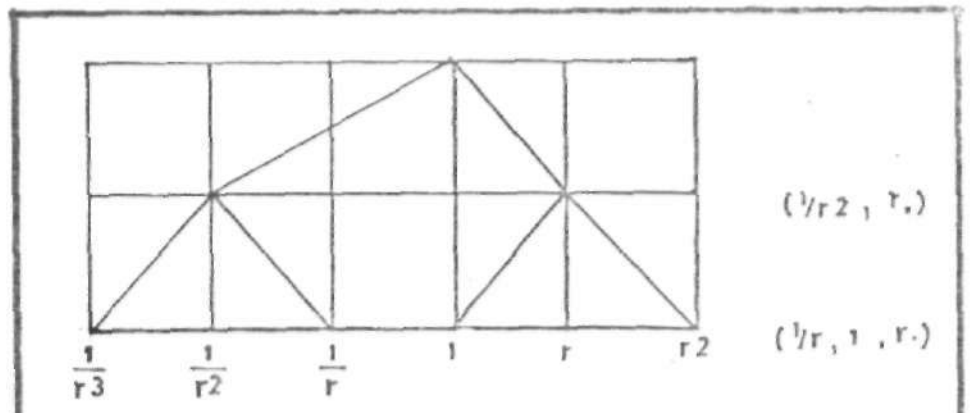


FIG.5 GEAR DIAGRAM.

and the gear layout is given by Fig. 6. The gears are arranged in such a way in the gear box that space economy is taken into consideration. Speed change is done by shifting cluster gear A and B to mesh with the required gears. Other methods of gearing are:

1. Tumbler gearing where a cone gear (a group of gears arranged as a cone) is engaged by a tumbling pinion which

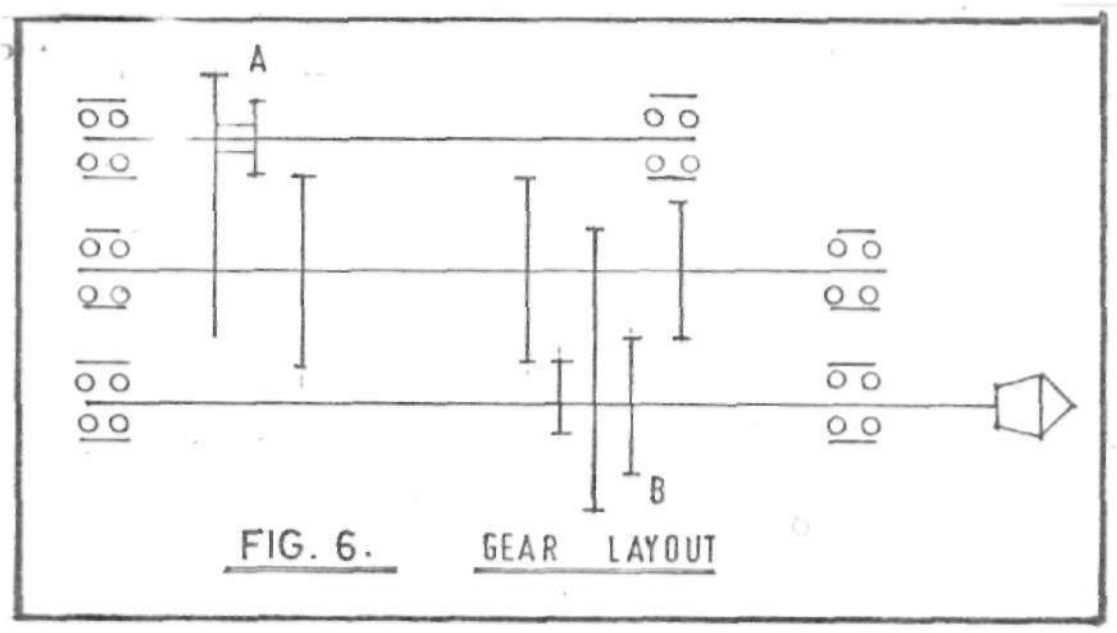
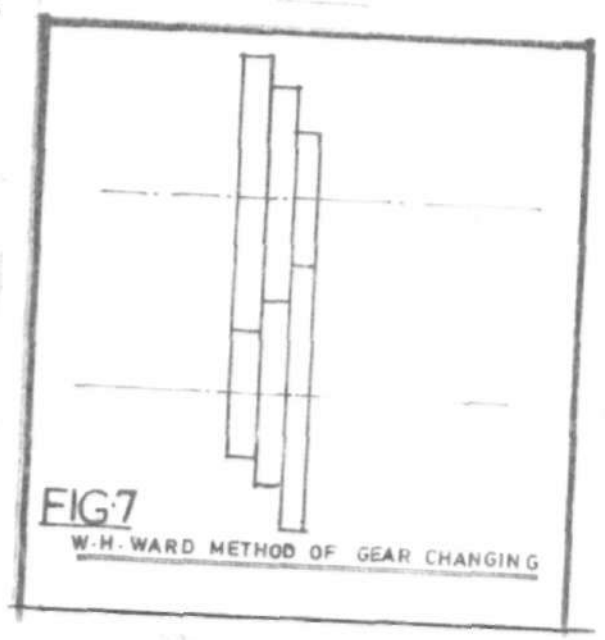


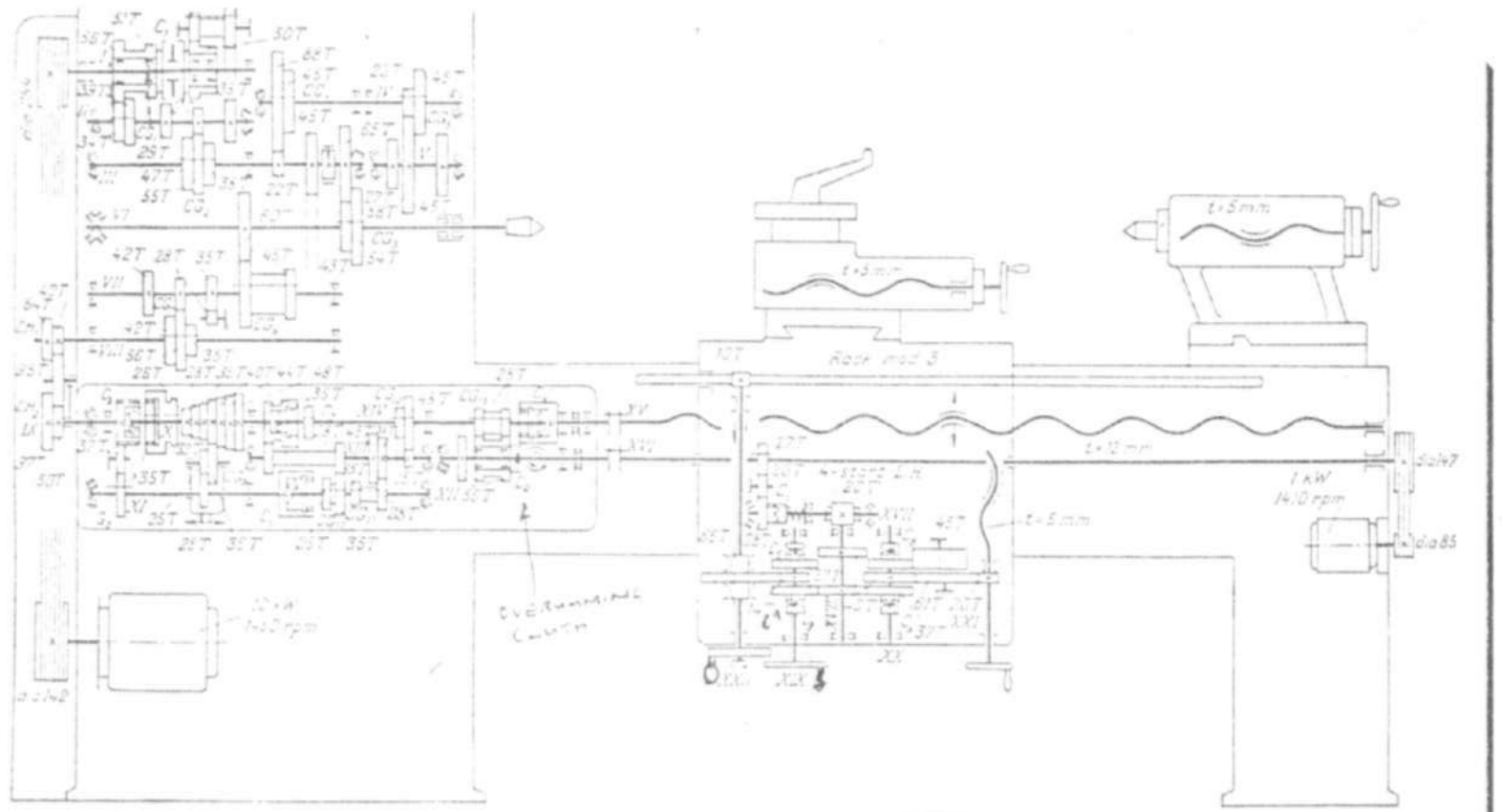
FIG. 6. GEAR LAYOUT

swivels to locate and engage any gear chosen. The pinion drives a shaft through a sliding key that moves in a keyway on the shaft.

2. W. H. Ward and Co. method: Here, some pairs of gears are constantly meshing and a sliding key is used to engage anyone required to drive the driven shaft (Fig. 7). This is an easier method than the tumbler method.



FIG·7
W·H·WARD METHOD OF GEAR CHANGING



FIG·8 TYPICAL GEARING LAYOUT OF A LATHE

2.4.2.2. Typical Gearing Layout of a Lathe

For further illustration, typical gearing layout of a lathe is shown in Fig. 8.

The first shaft is driven through vee belts from an induction motor housed at the left leg of the bed. Shaft I carries the friction clutch C1 for engaging and disengaging forward and reverse rotations of the spindle - for forward motion the Shaft II is engaged through cluster gear 56T and 51T at the left side of the clutch and the reverse is through the gear cluster 24T and 36T at the right hand side of the clutch. Through sliding cluster gears CG1 and CG2 six forward and six reverse speeds are transmitted to Shaft III. Power can be transmitted from Shaft III to the spindle along 2 gear trains by shifting cluster gear CG3 to the left or right. At the left, a direct drive is taken from Shaft III to spindle shaft. This gives the higher speeds. If it is at the right, the drive goes through shift gears CG4 and CG5 giving four gear train combinations,

1:1. 1:4, 1:4 and 1:16.

to give 3 lower speeds combinations, which, through the six combinations in III, give 18 speeds. These

combine with the six higher speeds through the overdrive to give 24 spindle speeds in forward and 24 in reverse. In Shaft III, there is a brake mechanism interlocked with the clutch C1 for immediate stopping of spindle.

2.4.3. The Spindle

The final drive in a headstock set-up is the spindle which extends out of the headstock and carries a chuck, collet, or a face-plate for work holding. The spindle is hollow to allow for bar feed and the nose bore is tapered to receive tapered sleeve for holding morse centre or collets. The nose can either have thread or flange for chuck attachment. The threaded type is the more common and it usually has spigots for accurate location. The thread is therefore easy-fit to allow for positive location of chuck on spigot and face and not on threads. In the flanged type, a recess in the chuck back locates on the flange and they are held togetner by axial bolts. The spindle is made of high tensile steel usually carbon alloy or nitralloy steel but recent designs use spheriodized cast iron. Gears, pulleys and chucks are positioned on the shaft, close to bearing support

to minimize bending moment and produce pure torque. The spindle must run true with minimum deflection under the action of radial force and cyclic loads so the bearing must be as rigid as possible while the spindle must be made short and stiff. Where it is not possible to have short spindle, the spindle is supported in the mid-length by a third bearing.

2.4.3.1. Spindle Bearings

For heavy duty lathes used for roughing jobs, solid bearings in form of phosphorous bronze are usually used. These are simple and they have vibration damping ability, but for high speeds, ball and roller bearings are preferred because only small clearance can be tolerated between moving parts. Ball and roller bearings can be pre-loaded to avoid slackness. Since accuracy of the job produced depends on the bearing runnings, for high precision lathes, high precision bearings that are made to very close tolerancings are used. Roller bearings are more rigid than ball bearings which tend to be springy, so most lathes now use roller bearings. The usual arrangement is to have one of the bearings spherical roller and the other a thrust bearing; where no thrust bearings are used, it is usual to take off the thrust produced during cutting action by thrust washers.

2.5 FEED DRIVE

The drive for feed shaft and lead screw are taken off the spindle through a gear-box with change gears.

This provides power travel of the cutting tool clamped on the carriage. Since the source of motion to the feed gear train is the spindle, we can measure feed in mm/rev of spindle. The feed gear-box which is usually housed in the headstock, should provide for:

(1) engagement and disengagement of feed without stopping spindle rotation;

(2) forward and backward feed motions with spindle rotating in only one direction;

(3) changing of rate of feed.

2.6 THE CARRIAGE

It supports, moves and controls the tool. The feed from the feed gear train is transmitted to the tool through the carriage. It consists of apron, saddle, compound rest and tool post. The apron is its vertical portion which houses the control and gear trains for tool movement. A hand wheel allows for moving the carriage and the tool quickly back and forth along the slide-way. A cross feed handle moves the tool back and forth across the saddle at right angle to the movement of carriage. The saddle goes across the slide-way and supports the apron. On it is a slide for the cross feed on which is mounted the compound rest which has a swivel base with dovetail. The tool post is mounted on the compound rest which can be positioned at any angle with a handle moving the tool forth and back along this angle for short taper turning. Attachments like taper turning, copying are usually attached to the saddle.

Either the cross or longitudinal motions can be done through power feed, but the two cannot be power-fed simultaneously. The compound rest feeds are generally manual with a scaled dial mounted on its feed screw giving the amount of travel. In some heavy lathes, arrangements have been made to have them on power feed. A feed selection lever allows power feed selection for either cross or longitudinal motions.

2.6.1. Turning And Threading Feed

For turning feed, the drive is taken from a key (or spline) within a gear wheel mounted on feed bar, so that the key turns with the feed bar which has a key way (or a spline) along its length, to give motion along the length of the bar. But in cases where the carriage moves within restricted area of the bed, the key way is cut to correspond with this movement. The wheel through a clutch engages a series of reduction gear to a pinion which engages a stationary rack mounted beneath the slideway for longitudinal movements of the carriage in the direction determined by the direction of rotation of the feed shaft that runs along the front of the bed. Rate of feed is selected through change gears at the gear-box which controls the speed of the shaft. The key slides along the feed shaft as the carriage moves. The cross feed takes its power drive from the feed shaft through another set of gears. A lathe normally has the feed shaft for turning feed and the lead screw for thread cutting, but owing to space economy, the smaller lathes

have lead screw combining the job of a feed bar by having a key way along its whole length. Threads in the lead screw are used for thread cutting while the key way is used for power transmission since the thread will wear if used frequently as feed mechanism. Half nuts engage the thread for thread cutting. A lever is used to engage or disengage the nuts. A threading dial is used to give when to engage thread nut, so that threading tool enters a cut at any point without damaging the thread. The dial gauge is a form of indexing mechanism with its single turn corresponding to n turns (usually 4) of lead screw. Carriage return is usually manual through a hand wheel that engages the pinion. In some large lathes, separate high speed return motors are incorporated. The cross feed motion is through a screw and a nut arrangement to allow linear movement. The cross slide is attached to the nut and it moves along a dovetail slideway. A micrometer is usually attached to show the feed.

2.6.2. The Compound Rest

The compound rest is similar to the cross slide (except that it is rarely power feed) but its movement is much shorter and can be set to produce angle cuts and short tapers. Graduations in degrees are provided to give the set angle.

For further illustration in Figure 8, motion is transmitted through sliding gear (27T) that slides through splined shaft (in most machines this is through

sliding key in the feed bar key way); through clutch Cs to worm wheel(20T) meshing with a 4 start L.H worm. From this worm, motion can be through either C6, C7, C8 or C9 to the 10T rack for longitudinal feed or 20T gear mounted on the cross feed screw for cross slide power feed. The operation of cross power feed and longitudinal feed cannot be done simultaneously as they are interlocked to avoid conflicting engagements. When hand wheels are used, the power feed levers are put in neutral position. The hand wheel for longitudinal movement is attached to Shaft XXII while that for transverse movement is attached to Screw XXI. Clutch Cs is a safety clutch that protects feed gear train against overload and the machine can therefore be used in turning to a positive stop. The clutch has a spring adjusted in such a way that the clutch rachets after a safe torque is exceeded.

2.6.3. Idle Motion

For idle motion which is usually done at high speed, some modern lathes have separate motors. These motors are high speed drive and can be used for carriage return (in Figure 8 the motor is mounted at the tailstock end of the bed and it is connected to the feed bar through vee-belts). When to be used, a clutch can be interlocked with the switch to disengage feed gear-box and if this is is not done, an over-running clutch like Co in Figure 8 can be used. This clutch transmits only low speed from the feed gear-box and at high speed it rachets over the gear-box shaft.

It consists of an outer shell A attached to the feed gear-box snaft and inner shell B attached to the feed rod (Fig. 10). Two spring D pushes the roller C to a jammed position when outer shell A moves relative to B thus moving it along.

When B moves faster than A, there is no jamming effect of the ball and tne outer shell A as well as the feed gear-box is disengaged.

2.6.4. The Tool Post

The final element of the carriage is the tool post. The earliest types are the double clamp type, where four vertical bolts that are spring loaded for quick clamp release hold two flat bars which are used to clamp the tool to a well machined square surface held on the compound rest - Fig. 11. At the otner end of the bars are packings to allow for good clamping of the tool. Tool change is therefore not easy but it holds tool firmly. It is still in use for heavy duty lathes.

This was refined to a triangular clamping plate swivelling on a central bolt that is spring loaded. At the apex of clamp is a jacking screw to avoid use of packing. The nut on the centre bolt clamps the plate on to the tool which is at the base of the triangle.

2.6.4.1. The Four Station Turret Tool Post

The four station tool post or four station Turret is now standard equipment on lathes. It comprises a square block of steel with a slot milled along each vertical face for accommodating cutting tools. There are sets of screws on the upper edge of the block for tool clamping. It is mounted so that it can be positively located by spring loaded plungers in four positions, so that tool is brought in succession without tool changing. The Turret can be unlocked by turning the locking handle (or lever) and indexed by hand. In some types, turning the clamping lever anti-clockwise unlocks the Turret and indexes it to bring one of the cutting tools to cutting position, while clockwise rotation locks it in position. The Turret can be locked in any angular position without the plunger locating if desired. Some lathes have one or two faces of the tool post designed to receive a drill, reamer or boring bars, so that end work can be done from them. The square turret was originally used in the early Turret lathes. It allows for tools pre-setting, a basic ingridient of batch production. It also offers a firm and vibration damping hold for cutting tools.

A further development of square turret uses the quick change holder. Here the holder, complete with tools (not the tools) is attached to a square faced block which can be swivelled and locked like the other square turrets. The tool holder is positively located either by dowels or semi-circular grove to take corresponding projection from the block. Most of the tool holders have height adjusting screw. They also can take end working tool holders and can be swivelled and locked in any angle. The pre-set is easier since both tools and holders are removed.

2.6.4.2. The Pillar Tool Post

Another form of tool post is the pillar type which has a pillar with a vertical slot for holding the tool holder. It is held in a tee slot in the compound rest. The clamping bolt extends to the top of the pillar. The tool holder is usually on a boat-shaped piece which sits in a part - spherical seat in the tool post. This is used for height adjustment of the cutting tip. The tool holder is made of forged steel and has square section hole for taking square section tool bits. The angle of tool presentation is such that top rake is provided without grinding. It is economical for light cuts and can be easily adjusted. Tools are always efficiently presented to workpiece and no loose packings are necessary. Its holding power on tool bits is poor and it does not allow for tools pre-set. The top rake angle cannot be sufficiently varied (in tool bits) and

this leads to little control over cutting characteristics.

There are some other types of lathe tool posts. Some handle one tool at a time while some handle two tools swivelling through 180° for tool presentation.

2.7 THE TAILSTOCK

The tailstock is to house the centre which is used to support an end of workpiece. It also carries various end working accessories. It can be slid along the slideway to a desired position where it is clamped to the lathe bed by means of an eccentric clamping lever. In some larger lathes, owing to the mass of the tailstock, the sliding is done through rack and pinion arrangement. The centre can be replaced with drill chucks or tapered shank drills, or reamer, for making holes concentric with a machined diameter and square with the face of work. It has a spindle which is bored. The end of the bore is tapered to morse taper to take the centre and end working accessories. The spindle is moved in and out of tailstock body by a hand wheel which turns a screw. The screw turns a nut that is restricted from turning, so that it only has linear movement between slides and thus moves in and out. This nut is attached to the spindle. A clamping lever is provided to lock spindle in the body of the tailstock once it has reached the required position. The movement of the spindle is calibrated to show depth of feed. It is possible to have the movement power driven, though its limitation is the amount of feed which is very short.

The tailstock can be off centred from the axis of the lathe spindle by means of some adjusting screws to give a taper turning arrangement. The taper is short and slow. When dead centres (fixed - not rotating) are used, it must be lubricated to avoid burning it or the workpiece, but production lathes usually have live centres that rotate with the workpiece. The centres and other tools held in the tailstock are removed by withdrawing the spindle until the shanks jam against the screw which pushes them out as the spindle withdraws further.

2.3 WORK HOLDING

All work must be rigidly held before machining. Standard work holding devices incorporate quick and easy clamping features. Depending on shape and size, work can be held in chucks, between centres, on face plates, in collets or on madrels. The most common method is to clamp workpiece in a chuck. Where the work is long, it is clamped in a chuck and supported at the other end with a centre held in the tailstock. Chucks can be manual, pneumatic, hydraulic, or magnetic. There are many types of manual chucks. They can be:

2.3.1. Manual Chucks

(a) universal or self-centering - these are generally 3-jaws design, though there are some 4-jaws. They are used for round, hexagonal bar stock or other symmetrical workpieces. All jaws move together towards or away from the centre. The body of the chuck is a hollow casting with an internal boss forming a bearing for the bore of a scroll plate. One side of the scroll plate has teeth

forming a bevel gear that meshes with three(or four) pinions equally spaced around the body. Each pinion has a key hole for turning. The other side of the plate has a scroll which is a continuous spiral groove of square section extending from centre outwards. The jaws have arch-shaped teeth on their back-faces to mesh with the scroll thread. Rotating the plate converges or diverges the jaws which are restricted to linear motion by guide slots. The jaws are irreversible but are made to have either inwards steps for outer diameter holdings or outwards steps for bar and inner diameter holdings. It is standard to supply each set of jaws with the chuck. Bar work is made to pass through the spindle bores.

(b) Independent - These are 4-jaw designs, used for rough castings, square octagonal or non-symmetrical workpieces. The jaws are set independently and they are reversible for inside or outside work holdings. They are hardened to resist deformation. They have half nuts that engage in square thread of screws that protrude out of the chuck body for turning. The body has slots along which the jaws move in or out. The

jaws are retained axially by thrust plugs or clamping bolts and their vertical faces are ground so that jobs pushed against them run true in vertical plane, though they may run eccentrically in relation to lathe axis. This eccentricity is taken off by adjusting individual jaws.

(c) Combination - These are 4-jaw chucks that can be moved separately or together. They are operated from one socket as independent and from another socket as self-centring.

(d) 2-Jaw - These are used for very irregular work-pieces and they are independent. They usually hold adaptors or fixtures which hold the workpieces.

2.8.2. Pneumatic Chucks

Pneumatic chucks are usually used in establishments with central services departments. Where this is not existing, a small compressor with accumulator or receiving tank is necessary to give a bank of pressure. The system incorporates pressure regulators and pressure gauges. A warning bell is needed to warn when pressure falls below a safety pressure, so that machine is stopped before the chuck looses its grip. It is, however, usual now to have interlock valve to prevent escape of pressure from chuck cylinder, even when the line pressure is lost. The chuck consists of a cylinder with its piston connected to a bar that passes through

the spindle bore which operates a toggle finger that opens and closes the chuck. The operation of the cylinder is controlled through a valve that can be lever, solenoid, or pilot air operated.

2.0.3, Hydraulic Chuck

This incorporates a pump with its motor and where necessary an accumulator. The pump pumps oil through the control valve to the cylinder which is similar to the pneumatic cylinder except that it is more robust for more power transmission. It also incorporates interlock valves to ensure that chuck does not loose its grip when pump fails and thus making it unnecessary to leave the pump running continuously. Pressure regulators and gauges are standard parts of the equipment. The operating method is similar to those of pneumatic but the parts are more robust and they are used for heavy machinery.

2.0.4, Magnetic Chuck

Magnetic chucks are either electromagnetic or permanent magnetic types. The recent trend favours the use of permanent magnets instead of electromagnets, especially in countries with unreliable power supply, though electromagnets develop very high clamping forces and can be regulated. This is because workpiece hold is lost when there is power failure in electromagnetic chucks, thus giving a risk of workpiece flying out or being out of set-up for further machining when power is restored. Electromagnets are, however, easy to operate and work is released by switching off power to the coils.

Varying the power supplied varies the gripping power and allows for setting up of the workpiece with ldw clamping forces. In permanent magnets, magnetic field is directed through workpieces when hold is necessary and when unloading, the workpiece is by-passed by diverting the field through iron core, which is passed between the magnet and the workpiece . A shifting mechanism for the iron or the magnet is provided. Magnetic holding devices are not common with lathes as with other machine tools because in lathes workpieces are rotated.

2.8.5. Centres

When a workpiece has a lot of over-hang from the chuck, lathe centres are used to support the work. Some workpieces are not held in the chucks but are held between centres fixed into the headstock and tailstock spindles. Centres have shanks that are tapered to a morse taper like drills, and reamers shanks and these fit into tapered holes in the spindles. They are usually mounted in lathe spindles and ground true. The centre head usually has a conical angle of 60^{o}. When workpiece is to be held between centres, they are centre-drilled at both ends to give seats for the centres. There are centre drills of various shapes corresponding to the various shapes of centre heads. Centres can be dead (stationary) or live (revolving). They are made of tool steel hardened and tempered. If centre is dead, it must be adequately lubricated, and to avoid damaging the head, carbide tipped heads are usually used.

Revolving centres have centre points integral with shanks running in precision ball or tapered roller bearings, thus rotating with the work. The bearing is held in the outer housing which has tapered shank for the spindle or tailstock holes. For positive location and to avoid catching, there is a clearance hole in the workpiece for the tip of the centre, as in Fig. 13.

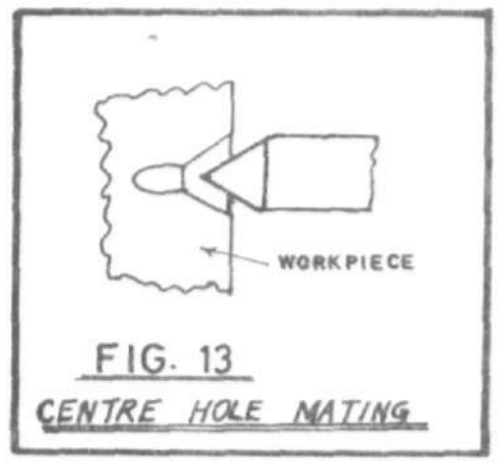


FIG. 13
CENTRE HOLE MATING

Motion of the spindle is transmitted to workpiece held between centres by the means of a dog clamped on one end of workpiece with its tail in a face plate on the spindle.

The centres and centre holes are chosen to carry weight of workpiece and size of cut. This method of work holding (i.e. holding work between centres) has the advantage that work can be removed and replaced without resetting and yet run true, and also it may be transferred from a lathe to other machine tools like milling machine and it will run true. It is, however, impossible to end work and it is unsuitable for castings and forgings, except the simple types.

2.8.6. Face Plate

Very large workpieces that cannot be held in chucks and workpieces of unsymmetrical shapes are usually mounted

on a face plate by the use of clamps or fixtures clamped to the face plate. The work can be recentred and clamped in different locations with the use of clamp bolts, brackets or screws. The face plate is a large piece of flange mounted on the spindle with many slotted holes for different types of work clamping. Flat plates can easily be clamped onto it.

2.5.7. Collets

Though chucks are used for bar works, the most accurate holding devices for bars are collets. The bars can be round or polygonal and the shapes of the bores of the collets are those of the material they are holding. Collets are in different sizes and they can only hold specific sizes. They are therefore usually used for bars that have small variation in sizes like bright mild steel bars. It is necessary to have a large number of collets for a machine to accommodate a range of sizes within the machine's capacity. Because of their accuracy and the fact that they do not require setting up, they are used for mass production.

They are hardened steel sleeve split (with 2, 3, or 4 slots) for about ⅔ (two-thirds) of their lengths, having tapered external portion at the split ends. They are heat treated to provide springy qualities. The tapered portion sits in a collet adaptor with corresponding taper mounted on the spindle nose. Arrangements are made to draw or push the collect into the adaptor (depending on the type of tapers of the

collet, Fig. 14) for closing up the collet onto the workpiece. As soon as the tapered end of collet is away from the mating part, it springs open to release the workpiece.

The more common type is the draw type where a draw tube is screwed to the parallel end of the collet and the tube passes through the spindle hole to the back of the lathe, where draw mechanism which can be a lever, a cone or a handwheel is fixed. The push type also has a thrust tube fixed into the end of the collet. The tube also passes through the spindle bore to the back of the lathe where pushing mechanism is fixed. In some lathes, the pushing and drawing are done at the work end of the spindle. This requires a bogus collet adaptor, but has the advantage of taking a larger size of bar. When collets clamp bars, the positions of grips shift slightly and the protruding lengths vary. In cases where lengths are determined by length stops and these lengths should be accurate, a special type of collet called the dead length collet is used. This has a feature that disallows relative movement between bar and collet. Operating mechanism for collet is hydraulic, or pneumatic in automatic machine tool. Some collets are made to carry pads or lines so that they can accommodate a range of bar sizes.

2.8.8. Mandrels

When workpieces have centre holes that can be used as datum, they are mounted on mandrels. The simplest

form is a bar with centring holes at both ends and a flat for clamping a lathe dog. They are used where holes are made to narrow tolerances and the workpiece forced on the mandrel is held by friction. This limits the amount of cut that can be taken. It is usual to make these types of mandrels with slightly tapered outside diameter to increase the frictional grip. Excessive taper will damage the workpiece bore. They are generally made from case hardened steel and they are in sizes. Because they are usually hammered into workpieces, the centre holes are counterbored to avoid damage.

2.8.8.1. Expansion Mandrels

If the bores of workpieces vary slightly, expansion mandrels are used. Some are made of a circular bar on which are machined four equispaced slots. The bottom faces of the slots are inclined to bar axis so that four blocks or jaws fitting in them project a greater distance from the bar periphery at one end than the other. The jaws are carried by a sleeve and their outer surfaces grip the bore of the workpieces as the sleeve carrying them moves up the sloping slots (by means of screw and nuts). The jaw bearings on the work are always parallel. Where very large cutting forces are envisaged, mandrels are bolted to the workpiece.

2.8.9. Work Rests

Where work is slender and requires intermediate support, rests are used. There are two types of rests- steady rests and travelling rests. The steady rests are clamped like the tailstock onto slide ways.

They have three supporting fingers (equally set about the work) which usually carry removable bushes. Travelling rest travels with the tool and it is fastened to the saddle. It usually bears on the work at 2 points behind the cutting tool to support work when cutting force is applied and thus avoid springing of work. Rests can be used between centres or after a chuck. Stationary rests can be made to give support near the end of workpieces to allow end workings on the work.

2.9 LATHE TOOLS

There are many types and shapes of tools, though attempts are being made to standardize them. Tools are either roughing or finishing. The roughing tools take heavy cuts while the finishing tools take light cuts at higher speeds. The tool can be single point or form tools. Form tools are made to give the required shape at a feed of tool. Angles of tools are ground to different shapes in accordance with workpiece materials. Some of the tools are:

(a) Front roughing tools: These are commonly used and have different approach angles. They are made from tool steel or could be made to have ceramic or carbide cutting tips.

(b) The Klop stock tool is not widely used. It is designed to give very small heating zone as the top which the chip impinges on is ground away to leave a narrow lip around the cutting edge.

(c) Chip breaker tools where a chip breaker in form of holes, ridges or vibrator, is made on the top of the tool. These avoid the formation of long chips which can be harzaduous to the operator as well as/heat jacket acting as

(d) Side facing tools which are made with the cutting edge bent away from the main body (Fig.16).

(e) Knife tool which is a form of narrow cutting tools with long cutting edge.

(f) Parting tools: These are used for cutting off workpieces - they are made narrow but from high strength materials. The cutting edges are cranked slightly to allow for proper cutting action (Fig. 17).

(g) Screw cutting tools are single point tools that are ground to give the correct shape of the thread to cut.

(h) Boring tools: these can be in form of tool bit held in a boring bar or they can be made with the bit integral with the bar. They are well relieved and usually much longer than other tools.

(i) Form Tools: Shapes other than cylinderical and conical are generally obtained by means of form tools made to the required profile so that work is direct copy of tool - such tools are radially fed to workpiece and are never moved axially. They can be flat or circular and they are held in rigid tool holders. Since the area of tool in contact with workpiece is large, the force of cut is large and speed of cut should be low.

2-10 LUBRICATION AND COOLANT FEED

Coolants which are in form of soluble oil mixed in water are pumped from a sump within the bed casting to the cutting tool or tools. They drain and collect back to the sump which is placed in the lowest part of the bed base. The pump can be driven by separate motor or from the gear-box through chain drives. Lubrication is very essential to machine tools. Apart from gear-box which is usually forced fed from a lubrication pump that can be driven by separate motor or through chain connection from feed gear-box, the slides are lubricated. While oil is pumped to the bearings and the top of the gears, in many cases they are allowed to drop on the slides. In some cases, the lowest gears are made to pick oil from a sump in the gear-box. This is splashed into the top gears and the bearings. In these cases, the slides have oil points for manual lubrications.

2.11 OPERATIONS PERFORMED ON LATHES

Lathes perform lots of operations and these make them universal. Some of the operations can only be performed with the use of special attachments.

Some operations performed on lathes are:

(a) Turning - removing materials from outside diameter of workpiece.

(b) Facing - removing materials from end of workpiece.

(c) Drilling - making hole in workpiece where non existed before.

(d) Reaming - enlarging a hole to accurate size.

(e) Boring - enlarging an existing hole with single point tool.

(f) Counter-boring - boring of hole to more than one diameter, generally with the larger diameter on the outer face. A counter-boring tool which is a steeped drill or a single point tool can be used.

(g) Thread cutting - cutting of internal or external threads with single point tool.

(h) Thread rolling - forming of threaded shape on a workpiece. The tool is held at the cross slide.

(i) Die threading - forming of external thread with a Die which is fed from the work end.

(j) Thread tapping - forming of internal thread with a tap which is fed from the work end.

(k) Spring winding - coiling of spring round a mandrel. It is almost of the same principle as thread cutting.

(l) Polishing - removing of very thin layer of material with the purpose of attaining high surface texture. This is a final operation on a workpiece. Abrasive materials are held against workpiece as it rotates on high speed.

(m) Spinning - forming of contoured, cylindrical, or conical parts from flat sheet metal which is cold worked over a suitable mould held in headstock.

(n) Roll flowing - similar to spinning but involves high pressure and harder tools.

(o) Milling - this is done with milling cutter held in headstock while workpiece is held in a milling vice attached to the compound rest.

(p) Grinding - removing of small layer of metal from workpiece. Grinding wheels are mounted in place of tool post and they can be stationary or rotating while they are fed along rotating workpiece.

(q) Knurling - this is plastic displacement of metal into a pattern. Hardened rollers with the required pattern are pressed against the workpiece.

(r) Gear cutting - this is similar to milling but workpiece is held in a dividing head while the cutter is held in a mandrel supported by the chuck and the tailstock centre.

(s) Lapping - this is usually done on a face plate lathe or in vertical boring machine. One of the two faces is held in the chuck while the other is held in a fixture attached to the tool slide. The chuck is rotated at very slow speed.

(t) Honing - this is the same as polishing, but it removes more metal. The stones are rougher and require more force.

(u) Slotting - cutting of straight grooves along the inside or outside diameters of workpiece. This is done with the spindle stationary with the slotting tool being fed into it.

(v) Broaching - this is similar to slotting.

(w) Buffing - this is idential to grinding but the buffing head is always rotated.

(x) High-Speed Drilling - the drill is rotated at opposite direction to the spindle rotation, so that the relative speed is high. It usually has its own fixture with motor attached to the compound rest.

Operations (k) to (x) described above require the use of attachments on lathes. Some of the attachments are fixtures for holding the tool, e.g. grinding wheel, while others are for holding the work, e.g. gear milling dividing head. Apart from these, there are other attachments that help in increasing the efficiency of lathes. Some of the attachments are:

2.11.1. Tailstock turrets: These are turrets attached to the tailstock carrying boring, slotting, reaming and cutter relieving tools which are indexed into work as required. Some turrets carry four tools while some carry 2, 3, 5 or even up to six tools.

2.11.2. Dead stops: These are used for determining the position of saddle along the bed. They are usually used for turning and boring to the same length, similar workpieces. The stop is clamped to the bed slideway and has micrometer collar for fine adjustment of cut length. They can be made to trip a clutch, or switch off an independent feed motor so that power feed is off. In single spindle lathes, they are made in such a way that they stop the feed, ahead of the required position which is finally reached by manually turning the saddle wheel.

2.11.3. Taper turning attachments: There are many methods of turning tapers on the lathe, some of which are:

(a) Swivelling the compound rest to an angle. The length of taper is limited to the travel of the compound rest slide.

(b) Using two feeds - cross feed and compound rest feed - this produces rough tapers.

(c) Setting the tailstock out of alignment with the lathe axis. This is used for turning shallow tapers of short lengths, and where accuracy is not required as the misalignment makes the centre hole wear rapidly.

2.11.4. Taper turning attachment: This is the most accurate method and the easiest to operate. The simplest type consists of a guide bar fastened to a bracket attached to the rear of the bed (Fig. 19). The guide bar is set to the angle required. A guide block attached to the slide, slides in the guide bar. The cross slide is free to move crosswise as the cross feed screw has been taken off. As the carriage moves, it carries the guide block which then moves the tool in and out as set by the bar. The length of taper cannot be more than the length of bar. There are more complicated forms that allow the turning of cylindrical and tapered sections one after another. Various machine tool manufacturers also vary the design of their attachments but the basic principle is still retained.

2.11.5. Copying attachment: Though there are copying lathes a centre lathe can be used to copy a template or a masterpiece by using copying attachment. If the guide bar of the taper attachment is replaced by a template and the slide block is replaced by a stylus which is made to follow the profile of the template (by spring loading or other arrangements), a copying attachment is

made. If the template is replaced by a masterpiece, it is possible to reproduce this masterpiece.

2.11.6. Spherical Turning Attachment

For spherical turning, a circular template is attached to the tailstock. The tool post with the tool is pressed against this template through a roller (Fig. 20).

The saddle feed is disengaged so that the saddle is free to move and the cross slide is power-driven. As the cross slide moves, the carriage is pushed by the action of the template on the roller thus producing the contour. Problems about mechanical tracing methods are the difficulties in making a template sufficiently accurate and strong to withstand the cutting force. Even when they are made strong, they wear rapidly. Hydraulic, electrical, electromagnetic and pneumatic methods are now used in copying lathes, so that the stylus moving over the template carries no cutting force, but only transmits commands to the operating units (hydraulic cylinder or pneumatic cylinder, etc.) which effect working feed of tool. This allows the use of a workpiece for duplication and duplicating at high speed. The stylus is usually nip-ended to allow for intricate contours to be read. This also allows the use of sheet or magnetic tapes as templates.

2.12 TYPES OF LATHES

There are many types of lathes and these are named either by their specialized functions or by their peculiar designs. These are:

2.12.1. Speed Lathe: This is the simplest lathe made up of a headstock, a tailstock and a tool post. It has no gear-box nor carriage. It is generally used for wood turning and metal spinning or polishing. The headstock can hold workpieces at either the right or left ends. The left end is used for workpieces of very large diameters and because there is no tool post at this end, tools are supported by hand. It has very high speeds.

2.12.2. Tool Room Lathes: These are lathes equipped with accessories for accurate tool room works. They have wide range of spindle speeds, especially at higher speed levels and their beds are very short. They are accurate and precise (an essential requirement for tools making). They usually have threading dial, micro-meter stop, collet sets, chucks, taper and other attachments. There is a type of tool room lathe called Relieving Lathe, used to relieve teeth or cutting edge of tools. Here, a reciprocating motion is imparted to the tool slide, which holds the tool to relieve. The motion has slow forward motion for cutting and rapid return after-cut. The motion is through a cam on cam-shaft that is driven from the main drive.

2.12.3. Gap Lathes: These are used to swing very large diameter workpieces. The beds and their ways are stopped short of headstock to give a gap. Some lathes have detachable beds so that they can be used as gap lathes. The workpieces are usually short because there is a limit to the overhang of tools and also the gap lengths are limited. The usual operations on them are facing and boring.

There is a problem presented by this machine in that if gap is too narrow, its usefulness is limited and if it is too wide the tool overhang for jobs close to spindle face, becomes a problem, so the detachable gap-piece provides a compromise but not without presenting its own problem of alignment with the rest of the bed.

2.12.4. Plain Turning Lathes: These have no lead screw and can therefore not be used for single point tool thread cutting. The absence of a lead screw simplifies the feed mechanism.

2.12.5. Facing Lathes: These are also used for turning work with large diameters but short lengths. They have large face-plates and they are much shorter than ordinary lathes. Works are clamped to face-plates by clamping straps and bolts. It is usually used for turning external cylindrical and tapered surfaces, facing, groove cuttings and borings. A typical design has a base plate with slots onto which is mounted short bed that carries the carriage. If a tailstock is fitted, it is mounted on another set of slots. The headstock is rigidly screwed to the base plate while the bed can be positioned as required on the base plate and clamped with three bolts. The feed gear train is driven by separate motor (see Fig. 21). Some other facing lathes have no power feed, but the tool is mounted on base that can be tilted.

2.12.6. Duplicating or Copying Lathes: Many standard lathes can be adapted to copy-turning lathe by the use of copying attachments. There are, however, many lathes designed to copy profiles from templates or master

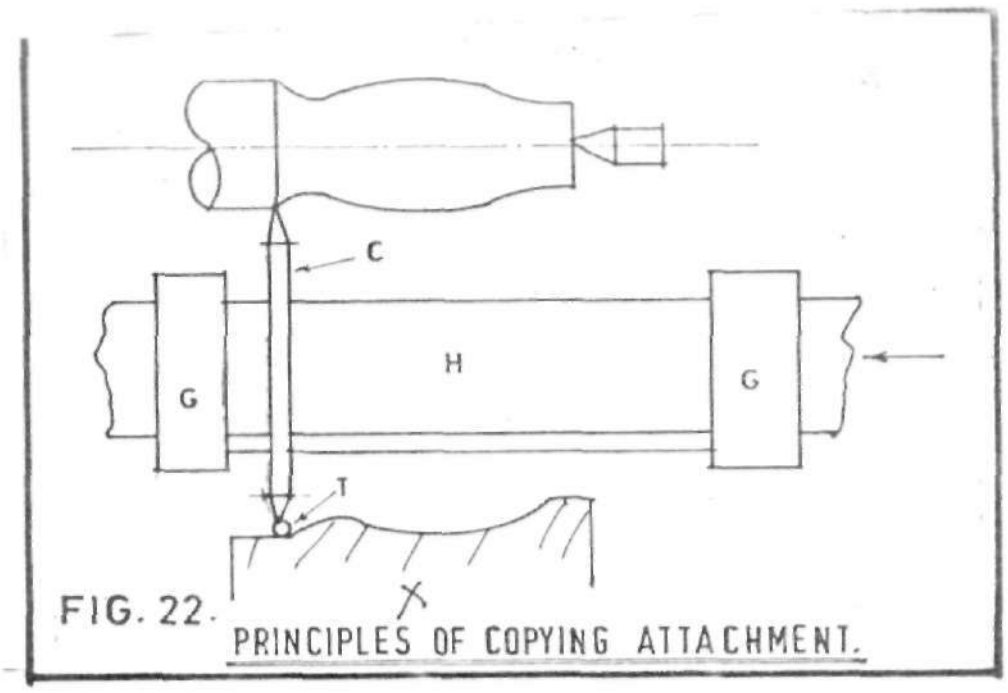


FIG. 22. PRINCIPLES OF COPYING ATTACHMENT.

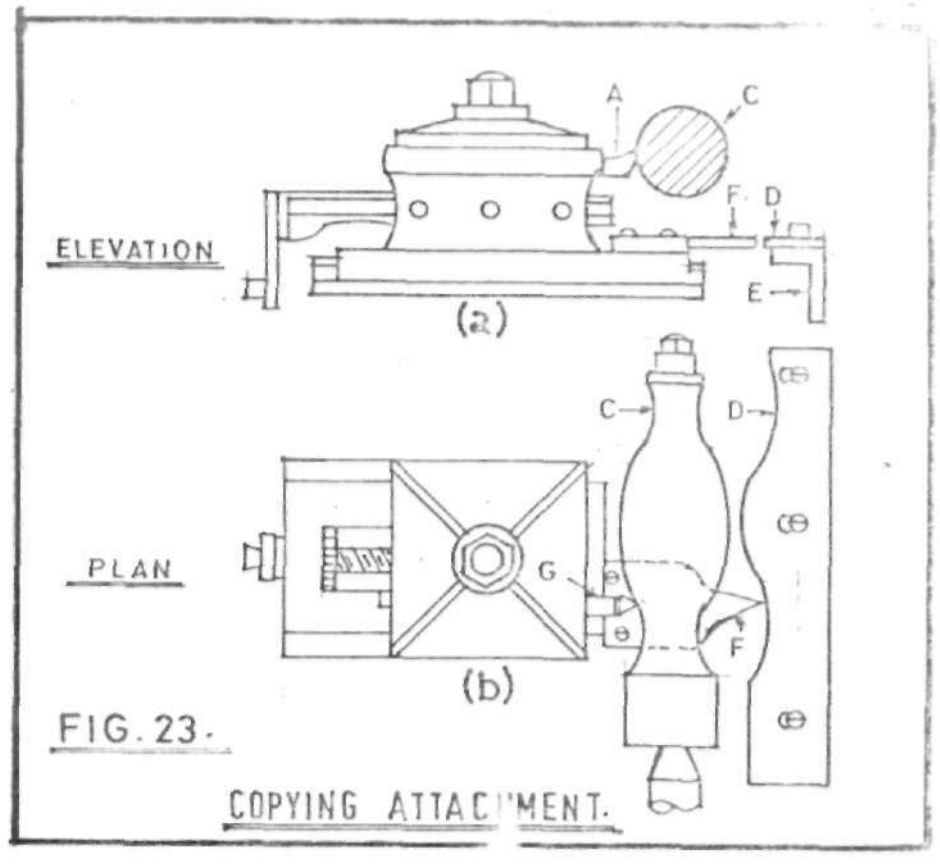


FIG. 23. COPYING ATTACHMENT.

components. These are copying lathes. A follower on the machine moves along the template and by suitable mechanism (which can be mechanical, pneumatic, hydraulic, electrical, electromagnetic or a combination of any of these), the cutting tool is made to reproduce the profile of the template on the work. The template can be full size or the work can be scaled up or down to any suitable ratio by the use of mimograph. The template is usually mounted to the rear of beds except for small workpieces.

The principle is as shown in Figure 22. Template X is secured to the bed. Tool C and a tracer (or follower) T are mounted on the holder H which is arranged to slide in a guide G at right angle to the axis of rotation of spindle. The unit comprising G and H can be moved along lathe bed in the same manner as lathe saddle and can be hand or power fed. As the unit moves left, the tracer follows the contour of template and the tool point describes a similar path on the workpiece, thus producing the contour. Arrangement has to be made to pressurize the tracer on the template and this can be done by the use of spring attached to overhang weight. This is basically a mechanical copying unit and the principle is adapted for other types. An example of a simple copying lathe is given by Figure 23.

The round bar C is to be turned to the profile of template D which is a plate screwed to an angle bracket E attached to the rear of the lathe bed and set as close as possible to slide to avoid vibration. The screw of the

cross slide is removed and the compound slide is swivelled as shown in (b). A weight (not shown) is attached to the cross slide in such a way that the slide is pulled to the template. To this slide is screwed the follower (tracer)which is always in contact with the template, by virtue of the weight pressure. The saddle is power fed along the bed. The follower traces the contour of the template and gives this to cross slide which then impacts it through the tool in the tool post to the workpiece. The compound rest is fed into the workpiece at the initial stage to give the base diameter. For repetitive job, a stop is incorporated in the compound rest to set the amount of feed that produces the base diameter. The follower point is hardened and the weight should be enough to overcome the cutting reaction.

All shapes can be copied but usually sharp angles and shoulders are avoided. Some can produce squares, hexagonal, elliptical and other grooves in the face of a workpiece. Work can be chucking or between centres. Masterpiece can also be held between centres. When machining steep slopes of curves, to ensure uniform quality of surface finish, the rate of feed is reduced. Copying can be done on internal surfaces as well as on external surfaces.

2.12.6.1. Hydraulic, Pneumatic and Other Non-Mechanical Copying Lathes

In the mechanical copier, the follower bears a lot of pressure on the template. Thus, the template and the follower are hardened. In Hydraulic, pneumatic, electric and other cases, pressure of contact between the stylus (follower) and the template

is very light and the template can, therefore, be a fully machined workpiece or a thin sheet of metal. Using original workpiece is always preferred. The hydraulic machine has an hydraulic pump and reservoir (or accumulator) which supplies the operating pressure. A stylus attached to the tracer valve is moved along the template. The stylus is lightly spring-loaded to the template. The valve meters oil according to the stroke of the stylus, into a cylinder which controls the movement of the tool slide.

The air tracers of many pneumatic copier are not made to follow the profile of the template, but are set to travel parallel to the axis of the lathe. Air nozzles are used and this allows air to escape and the pressure drop is proportional to the distance between the nozzle and the template, which changes as the stylus moves along the bed. The pressure drop is amplified and fed into a relay for tool control.

The electromagnetic mechanism also uses the same principle, the change of air diaelectric between the stylus and the template is used to control the tool movement.

2.12.7. Multi-Purpose Lathes: These are lathes designed to do other machining operations like milling, shaping, slotting and sharpening. They can incorporate a dividing head. Tools as well as workpieces can be held in the chuck which can also grip arbor for milling works. The saddles normally have provisions for vertical adjustment. The tailstock is made to have identical spindle nose as

the headstocks, Chucks,face-plates as well as collets can be mounted on them. Provisions are made for cross movement of taistocks so that they can be off-set to headstock axis. The dividing head allows for holes on pitch circle diameter to be machined concentric to the axis of workpiece.

2.12.8. Screw Cutting Lathes: These are designed mainly for screw cuttings. They have lead screws only and they are very accurate. A lot of them like the Swiss screw cutting lathes, are fully automatic. They have lots of accessories for their operations.

2.12.9. Electric Lathes: In these lathes, all movements are controlled by limit switches, electromagnetic and other electrical devices. They have no trip dogs, levers nor any mechanical controls. They are very accurate and sensitive. They are usually automated since automation is easily achieved. Other pressures, except the cutting pressures, are very low. The machines appear like any other lathe, except that they usually have two independent tool slides - one in front and the other at the rear. Each of the slides can carry many tools and can move in different directions unlike in other lathes with such slides. The carriages are fed from separate feed gear-box. The clutches and brakes are magnetic and this made their actions quick. Limit switches replace stops and no cams are employed. The lathe is not yet very popular but it is gaining grounds in developed countries.

2.12.10. Custom Lathes; These are special lathes built and adapted for special purposes, for example, the turbine turning lathes for shipyards, wheel lathes for locomotive wheels, T-lathes for jet engine rotors and crankshaft turning lathes. Their constructions have been helped by the availability of standard units that can be assembled to suit any required set of conditions.

2.12.10-1. Wheel Lathes - The wheel lathes have two headstocks with workpieces being driven by each through chuck jaws. Each headstock has its own motor - one of the headstock can be moved along the bed to accommodate variation in length. They have at least two tool posts one for each wheel. The horse power required is very high.

2.12.10-2. Tee-Lathes - Rotors for jet engines are machined on T-lathes. Their carriages are mounted on ways perpendicular to the headstock axis. They are chucking machines with very large swings. They are generally for facings straight and taper turnings and borings.

2.12.10-3. Crankshaft Turning Lathes - There are two types of crankshaft turning lathes. In the first type, the tailstock spindle is driven at the same speed as headstock spindle. To turn the main journal, the crankshaft is held between centres and turned normally. Other journals are turned by setting their axes coaxial to the spindle axis, as in Figure 24. In the second type, the shaft is set with its main journal coaxial with the spindle axis and the carriage in which the tools are

clamped travels in a circle whose radius is equal to the throw of the crankshaft part to be machined (i.e. synchronously with crank rotation) as in Figure 25.

2.12.11. Floturn Lathes: These are used for spinning and forming. They are not chip producing machines and are therefore not lathes in the strict sense, though they have all the essential features of one. Their tools are for cold forming of metals into shapes on mandrels. The materials are usually flat sheets of metal and thickness up to 5/16" (if themetal is stainless steel). The mandrel is held in chuck. As it rotates, the material is spinned on it. The speed is low (average is 300 rpm). The microfinish can be very good, depending on the applied pressure as the material is sheared before flowing out plastically.

2.12.12. Vertical Lathes or Boring Mills: These are lathes with vertical axes. The spindles rotate in horizontal planes about vertical axes. They usually have no tailstocks, but arrangements can be made to support long parts at upper end by air operated revolving centres mounted on cross beams or other frames. The spindle carries a chuck or a table (which corresponds to the horizontal lathe face-plate). The saddle and slide of horizontal lathes are replaced by cross beam and tool head, while the bed is replaced by column. The tool head can also have turret arrangements. The tool feed is vertical along the column, though special arrangement for horizontal feed is possible, especially where there are no cross beams, which are used for work-in-feed. The

feed gear-boxes are generally mounted above the column while the headstocks are at the base. They usually use cemented carbide tools and are very robust and strong. The driving motors are very powerful. They have many advantages over the horizontal lathes in that they save plan space and they can be easily used for heavy jobs, since the weight reaction can be better supported through thrust bearings, washers, or roller contacts. Loading and unloading are easier through cranes, forklifts, and other lifting tackles and workpieces can be easily set up.

2.12.13. AUTOMATIC LATHES ..

A fully automatic machine tool is that in which all working and auxiliary motions required to carry out a definite sequence of machining operation, including loading and unloading of workpieces, are performed automatically. All that an operator needs do is to load new blanks into magazine or hoppers, or to feed new bars into the bar feeder. Semi-automatic machine tools perform the same function but the loading and unloading of workpieces into the machine's work holding are done manually. These machines usually stop automatically after the machining sequence is completed to allow for unloading and loading of work. The start push buttons or levers have to be operated to re-start the machining sequence.

Lathes are available in various degree of automation. To increase output, it is necessary to increase degree of automation. The bar lathes are usually fully automatic, while the chucking types are usually semi-

automatic. To make chucking lathes fully automatic, loading hoppers or transfer fingers should be incorporated. A universal lathe can be made partially automatic by using pneumatic or hydraulic chucks, air or hydraulic pushing device for tail spindle, positive stops, indexing adjustable stops and loading as well as unloading devices.

2.12.13.1. Types Of Automation

The operating cycle of lathes is automated using mechanical, hydraulic, electrical, electronic or pneumatic controls or any combinations of these. The mechanical types, usually cams and levers, are productive and reliable in operation, but much time is spent in setting up jobs. They are, therefore, used in mass production. The semi-automatic mechanical types are used in lot and large lot productions. Lathes controlled by other means are easier to set up and are therefore used in batch production. The numerically controlled lathes, where a pre-programmed tape or punched card dictates the control, are flexible and can be easily set up to give both batch and mass production.

To operate automatic lathes, semi-skilled operators can be used while the tools are pre-set in a pre-setting bay. When tools are worn, they are changed with the pre-set head and the head with the worn tools are sent for regrinding and pre-setting.

In automatic bar turrets, the operations performed by the machine include gripping the bar and stock feeding through the hollow spindle to a length stop as soon as the previous workpiece is parted off and bringing the respective tools up to the workpiece in proper sequence.

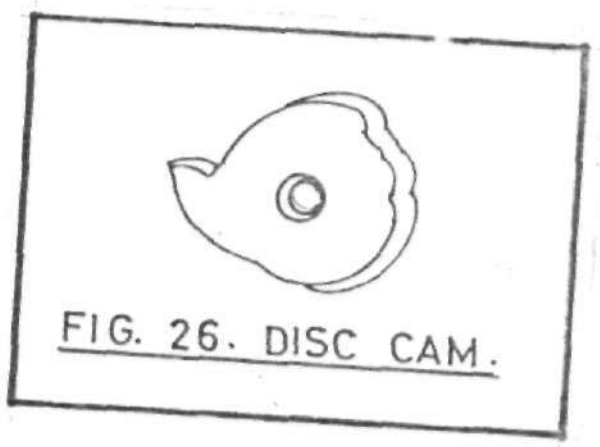


FIG. 26. DISC CAM.

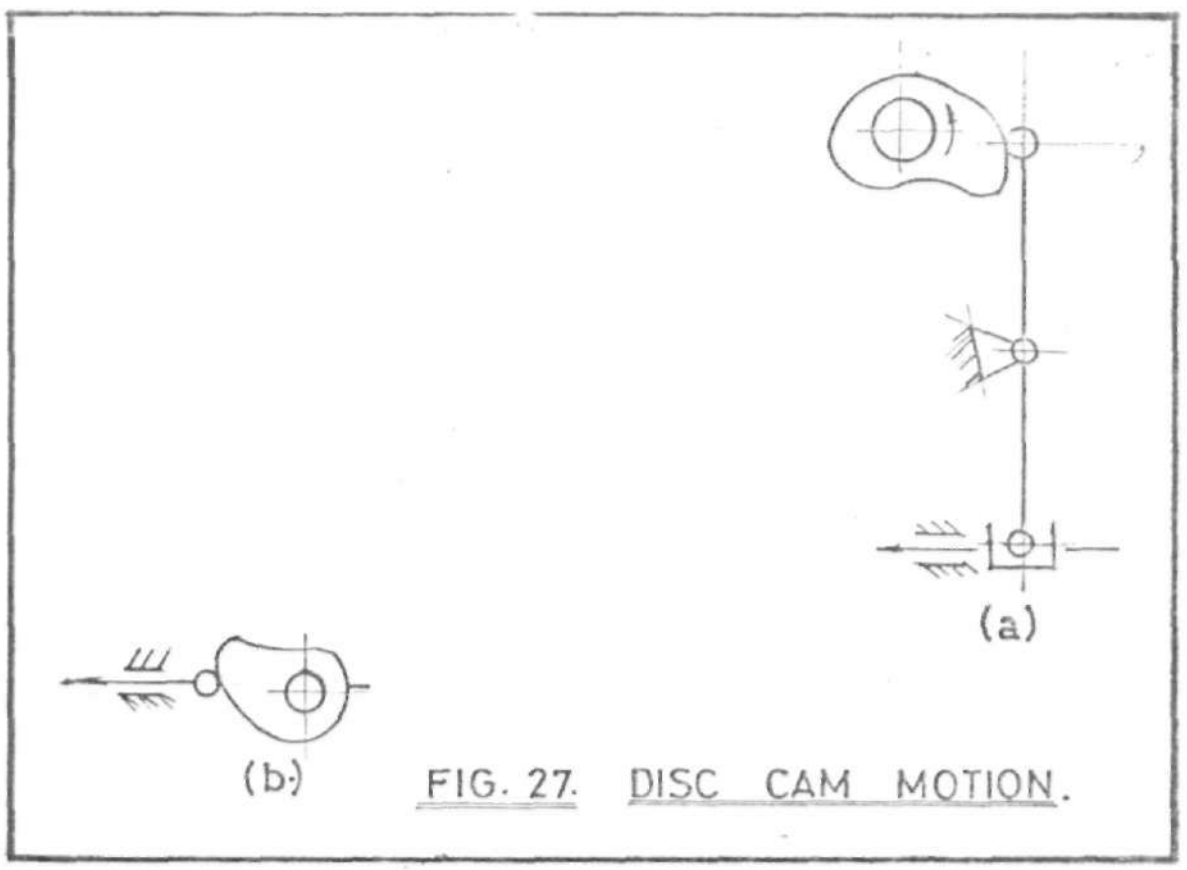


FIG. 27. DISC CAM MOTION.

The cross slide is brought in when necessary.

2.12.13.2. Classification of Automatic Lathes

Automatic and semi-automatic lathes are classified according to various features like:

(a) Purpose: General (or universal) and single purpose (or custom built);

(b) Type of blanks: Bar or chucking;

(c) Number of Spindles: Single or multi-spindle;

(d) Arrangement of Spindles: Horizontal or vertical.

There are also some other minor classification like indexing method, and others.

Single spindle automatic lathes are most common, but for higher production rates, multi-spindles are employed. Many capstan/turret, multi tools and multi-spindle lathes are automated either fully or partially.

2.12.13.3. Mechanical Automatic Lathes

In mechanical automatic lathe, usually a camshaft carries cams of various designs linked through a system of levers, gears, chains, pulleys and other transmission mechanism to the operating mechanisms like slides, indexing, clamping and feeding mechanism. The cams rotate with the camshaft and actuate followers linked to the required mechanism. The sequence of motions depends on the arrangement and the layout of the cams. One workpiece is usually completed at a revolution of the camshaft. There are three major types of cams - disc (or plate), cylindrical (or drum) and edge type. The disc type cams (Figure 26) are used to transmit motions with short strokes in a plane perpendicular to

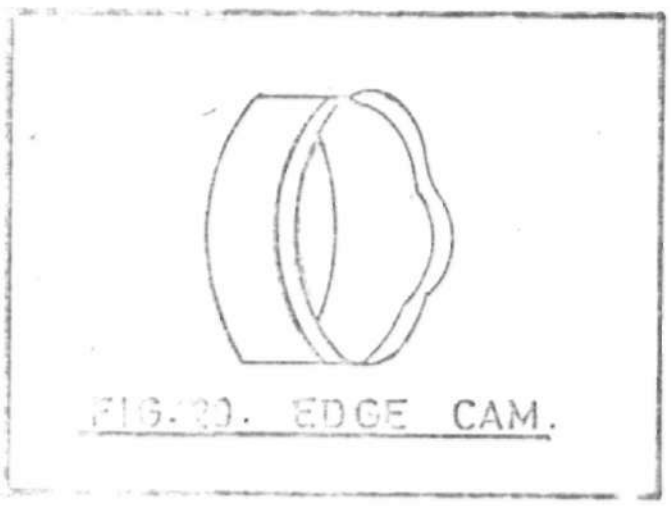


FIG. 30. EDGE CAM.

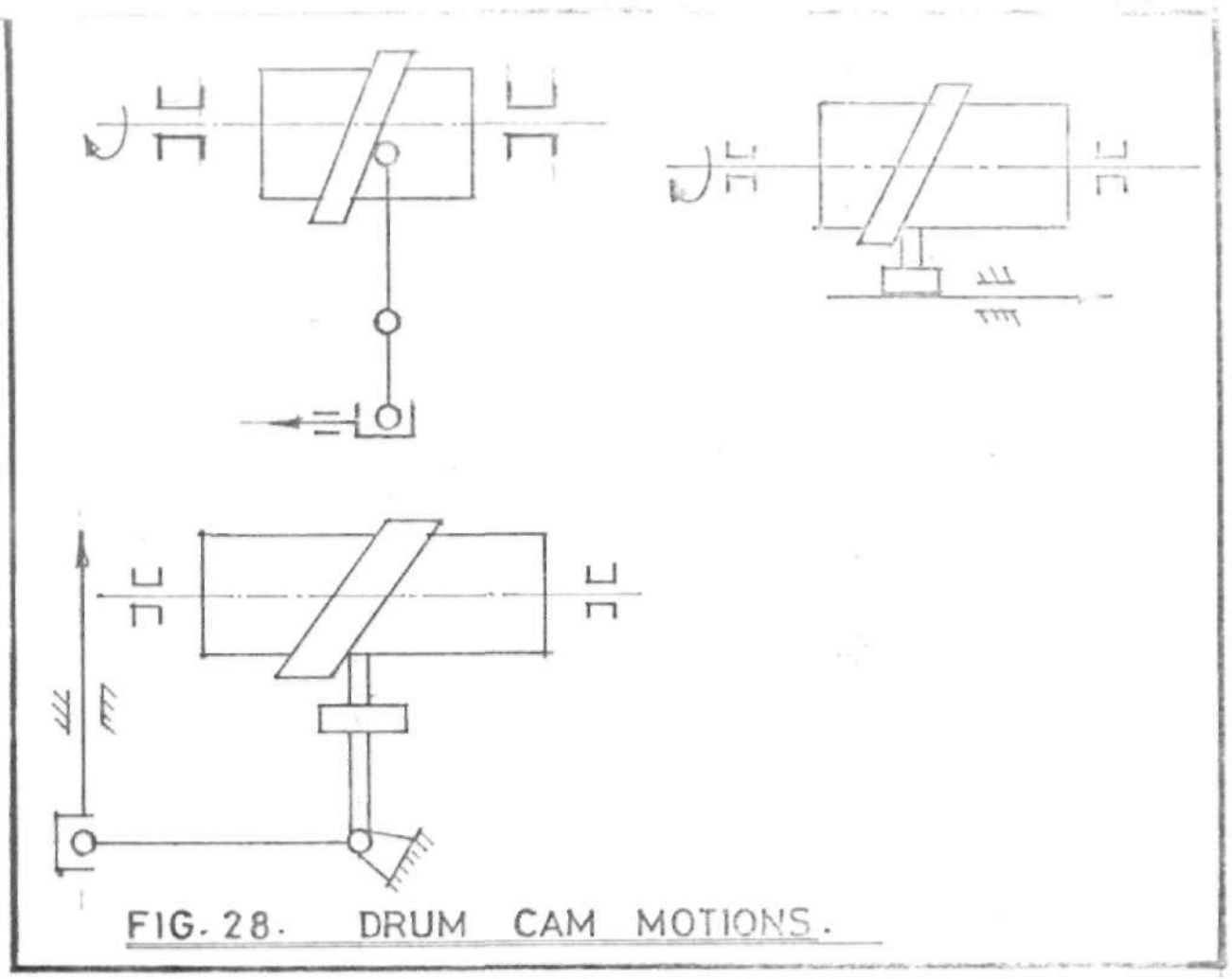


FIG. 28. DRUM CAM MOTIONS.

the axis of rotation of the cam as shown in Figure 27. Cylindrical or drum cams are used to transmit motions with longer strokes in planes parallel to or passing through the axis of rotation as in Figure 28. The edge cams (Figure 29) are used to transmit motions like drum cams but with short strokes.

Cams can be solid or removable straps fastened to a cam body. We can have cam tracks made of two straps bolted to the cam body (usually drum) to give a positive path for the follower. Edge type cams are used where the follower is pressurized against the cam. Cams have productive and non-productive movements. Since a cycle of cam rotation produces one component, the cam therefore divides into 360°, for working sequence. Automatic machine tools usually have quick idle movements and slow feed motions. This is usually accomplished in many ways. A method is for the lathe to have a single camshaft which can rotate with two speeds with the slower for all the cutting feeds and the faster for all idle motions. This method is limited in use since, owing to inertia of cams, camshafts cannot be run within a wide range of speeds without creating damaging impact loads on the change-over mechanism. Another method is to have a high speed auxiliary camshaft which is engaged during idle motions. There are some simple lathes where idle motions are few in which idle motion and feed motion are done at the same speed. These have one camshaft with one speed and have no complicated links.

2.12.13.4. Single Spindle Automatics

Apart from the automatic turret and capstan lathes (Chapter 3), the most common of these are the automatic cutting off machines and Swiss type screw machines. In the cutting off machine, the work-piece is clamped in the collet chuck of a rotating spindle while the cross slides (2 to 4 in number) having form tools and parting off tools are automatically fed. Some have swing stops for lengths control where automatic bar feeds are used. Both working and idle motions are at the same speed and some models have end working tool slides for end drillings, reaming, etc.

2.12.13.5. Screw Cutting Automatic Lathes

Swiss type screw machines are bar machines originated from Switzerland where they are used for small watch and clock parts machining. They are also used for mass production in precision industries for the manufacture of radio parts, instruments, etc. The machines are designed to close tolerances. They can take up to 1½" bars. The machine has a sliding headstock which houses the spindle through which the bar is passed and gripped by a collet. The headstock moves in slide-ways, on the bed (unlike in other lathes where the head-stock is fixed). The tool bracket is fixed and can have up to six tool slides which are fed radially towards the revolving bar. A camshaft carries the cams which control bar feed, chucking, headstock feed, tool slides and auxi-liary attachments (for drilling, tapping, cross drilling, slotting, etc.). The headstock feed gives longitudinal

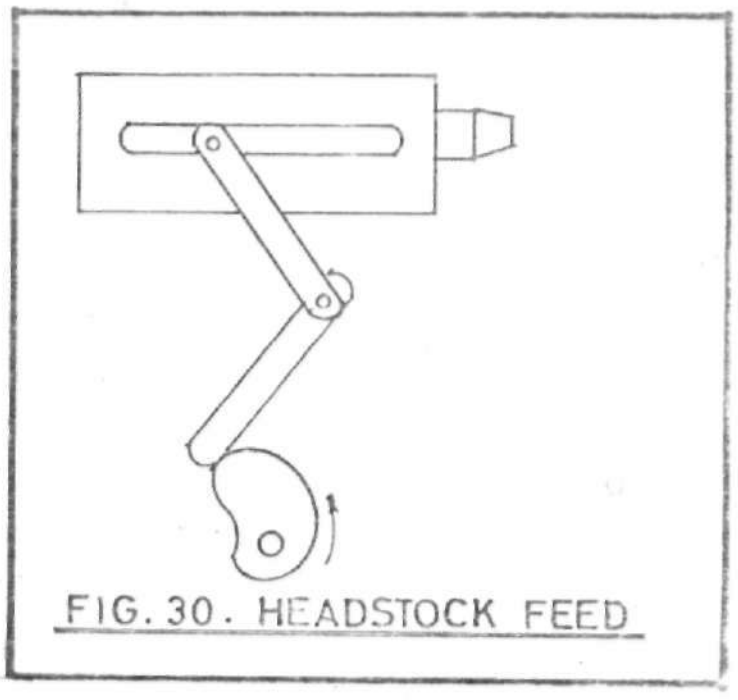


FIG. 30. HEADSTOCK FEED

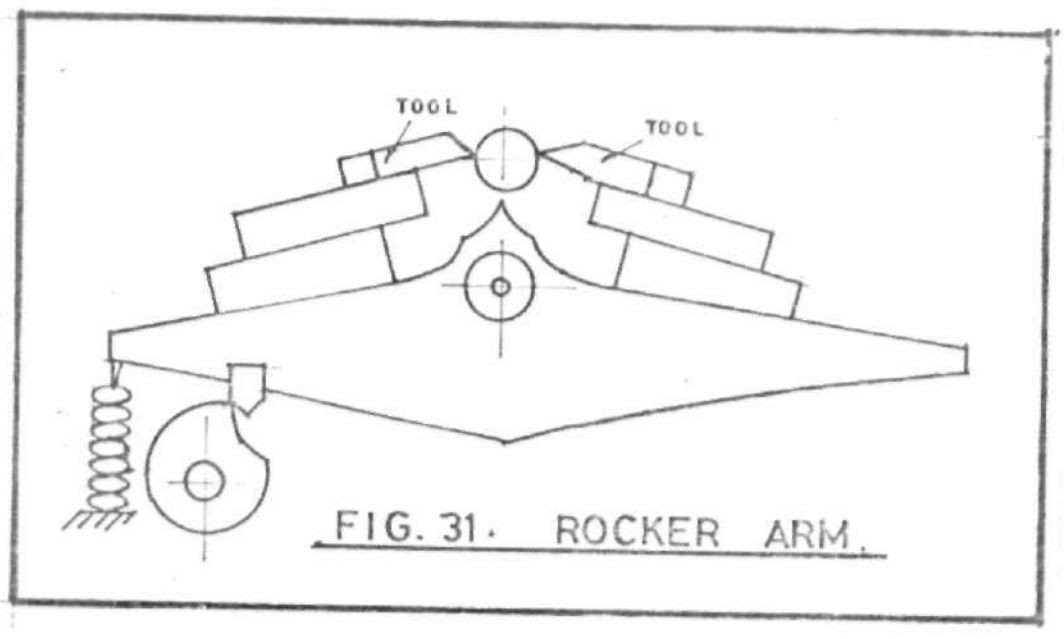


FIG. 31. ROCKER ARM.

feed to workpiece. While this feed is on the cam for the tool slides is usually in 'dwell' position so that tool is in fixed position for longitudinal machining. When the workpiece is parted off, the collet grip is released and the headstock returns sliding over the bar to the starting position, leaving a length in the front of the collet which grips the bar ready for machining. The headstock forward feed is through cam while return is by spring. A disc cam is used to operate a bell crank, one end of which bears on the pusher attached to the headstock through a tee slot for stroke adjustment (Figure 30).

The tool bracket is a casting standing vertically fixed to the machine bed. It carries the tool slide and has a mounting for auxiliary attachments. The tool is clamped to the slide and they can only be fed in and out. The two lower slides are actuated by a rocker which rocks about a pin through the action of a cam on the camshaft, and a return spring (Figure 31). Screws are used to adjust the lateral position of tools. The tools can form, turn, cut off, chamfer, undercut, knurl, etc. For cutting purposes, the cutting tools on the rocker slides are placed in inverted positions. The vertical tool slides are actuated by cams on the camshaft through connecting rods and levers (Figure 32). Special attachments mounted on the bed are used for end works. These attachments usually have independent feed and speed. The tool bracket has steady bushes which allow slender parts to be machined. The bush supports

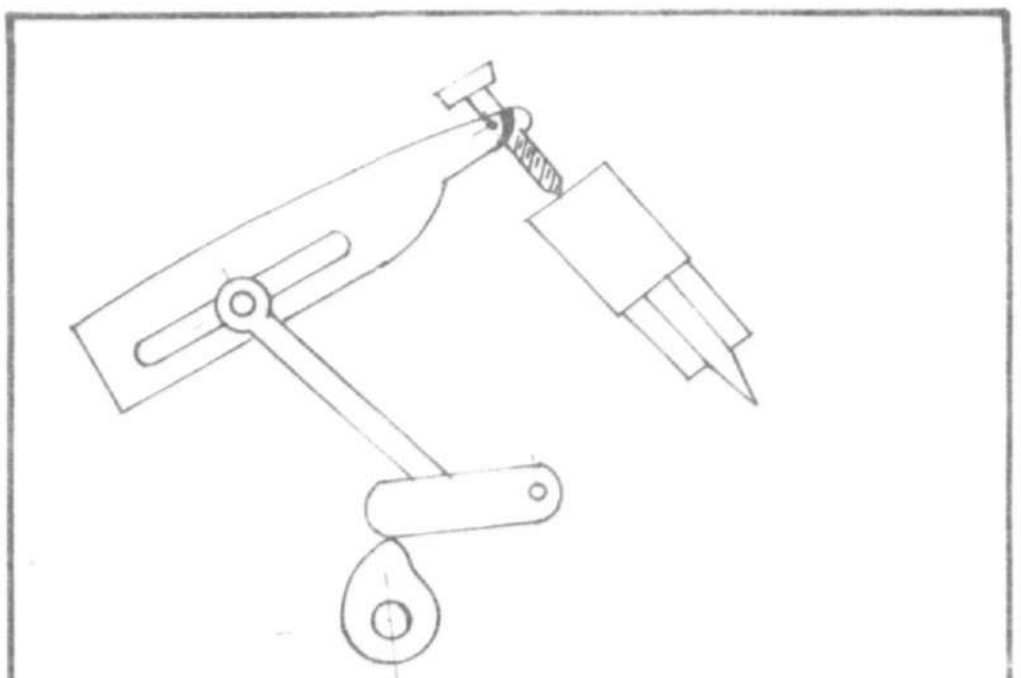


FIG. 32. VERTICAL SLIDE MOTION.

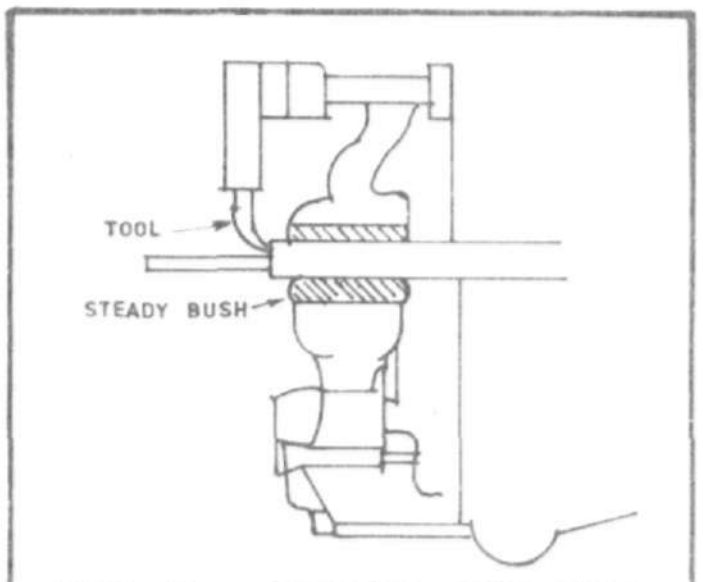


FIG. 33. STEADY SUPPORT

the workpiece very closely behind the cutting tool for minimum vibration and deflection from action of cutting forces (Figure 33). The steady bush can be removed for short pieces. The camshaft incorporates safety pin that shears to protect cams and their shaft. Like other bar automatic machines, it has trip switches in bar feed mechanism to stop machine when bar stock is exhausted.

The bars used are usually of close tolerance (centre-less ground bars are usually used). Where end working attachments are used the algebraic sum of the feed of the attachment and the headstock is the feed of cut, whereas for cross slide feed, the feed of cut is the geometric sum of the feed of cross slide and that of the headstock.

The other automatic lathes are the capstan, turret and multi-spindle lathes which are treated in the next chapters.

2.12.14. Multi-Tool Lathes

These, like the capstan and turret lathes, ar for mass production. They have one workpiece spindle with several tools working on the workpiece at the same time. They are also referred to as multi cut lathes. They take works between centres and they are versatile. These are advantages over capstan and multi-spindle lath They are generally used for production of stepped shaft and long workpieces. With equally spaced tools on a bar, long workpieces can be machined with short feed (the feed

equals the distance between two adjacent tools). They have simple feeds and the gear-boxes are, therefore, not complicated. They are of very robust construction and they have rigid and well supported carriages so that forces of cuts that act in many direction and on many points are with-held. They generally produce faster than capstan/turret lathes. They are used for large variety of jobs, especially machining gear blanks, shafts, pistons, camshafts, and other jobs that can be held in fixtures, chucks, or between centres. They are economical for short run jobs, owing to the ease of setting up the tools. They are, however, rarely used for parting off and threading. Tools slide can be cam, hydraulic, pneumatic or screw and nut operated. It is possible to have a tool holding bar with facilities for individual tool in-feed. The tools on the bar move inside fixed guides and carry followers which follow the profiles of cam-plates fixed to the front of the lathe, as the saddle moves the bar along the bed.

They can be fully or semi-automatic, but it is usual to have them manually loaded. All idle movements are rapid and the machine stops immediately after withdrawal of tools. Change gears and sliding gears are used like in other lathes for speed and feed changes. The quick idle motions can be through a separate motor or through over drive gears. Some of them have two carriages with one being fed transversely and the other longitudinally. This allows for parting off, groove cutting and the use of formed tools.

The machine uses all the attachments used by other lathes, These include taper turning, facing, and centre drive attachments. The centre drive attachment supports and drives workpiece in the middle to allow for both ends of the workpieces to be machined simultaneously. This is driven through overhead transmitting shaft at the same speed as lathe spindle. The drive shaft has telescopic splined drive coupling to allow for adjustment along bed for varying length of workpieces.

CHAPTER THREE

3 - CAPSTAN AND TURRET LATHES

The centre lathes gradually become inadequate to meet the quantity of production required by their users, owing to the time required to change tools. This led to the development of turret and capstan lathes. The earliest type of turrets used were the four sided square turrets which are now standard equipment for centre lathes. Capstan, turret, multi-spindle and multi-tool lathes are only economical for mass production owing to the time required for setting up tools. Where the quantity of workpieces to be produced is less than six, it is always advisable to use centre lathes which have much easier to set tools.[10] It is now usual to have a pre-setting bay for tools to ensure that tools are set when the machines are running. This has enhanced the efficiency of these lathes. For the turret and capstan lathes, tools are indexed to meet workpiece unlike in multi-spindles where jobs index to meet the tools.

Engine lathes can be converted to turret or capstan operation by fitting suitable attachments to them. If centre lathe tailstock is replaced with a six position turret tool post which can be fed along a slide to meet the workpiece, we have a manual capstan lathe.[11] The turret will provide the end working tools while the cross slides will support the side working tools.

The capstan and turret lathes are similar in design, tooling and application, except in the indexing head that

carries the main (or end) tools. In capstan, the head is carried in a slide which is mounted on a base that is locked in a suitable position along the bed. The slide is fed to the work longitudinally (along the bed of the lathe) by the use of a spoke-like handle projecting from the slide front. Usually anti-clockwise rotation of the handle advances the head to the work while clockwise rotation retracts it. If the slide retracts to a point, it usually disengages an indexing locking pin and the turret indexes through $\frac{360^{o}}{n}$ for a turret head with n stations (for six stations $\frac{360^{o}}{n} = 60^{o}$). The capstan lathe normally has front and back cross slides mounted on a saddle that can be power driven. The cross slide feed can be power fed and in some rare cases, the turret slide is power driven. When these are power driven, it is usual to incorporate trip stops to disengage the slides feeds. Capstan lathes are generally for short components usually from bar stocks though chucking machines are available.

In turret lathes, the indexing main tool head is mounted on a saddle which slides directly over the bed and is usually power fed, though handles for manual operations are available. It is usual to refer to capstan lathes as "ram turrets" while the turret lathes are referred to as "saddle type turrets".(10) The turret lathe deals with larger and longer works and it is usually provided with quick transverse mechanism.

Because their cross slides are not on saddles, they are only fed in and out of work.

Capstan lathes are lighter and easier to operate, but since their turret heads are mounted on slides, their movements are restricted to the lengths of slides which are short, though the bases can be adjusted along the beds. Thus the head over-hangs the base and can therefore not be useful for heavy work in this position. This makes them useful for small and medium sized work only. Because it is on saddle which slides directly on bed and thus have no overhang, the turret machine's tool head is more rigid and is used for heavy jobs like castings. The slides of both types are heat treated and are much better than ordinary lathes, owing to the volume of work they produce. It is very common to find these machines automated (fully or partially).

3.1 AUTOMATIC TURRET AND CAPSTAN LATHES

The most common fully automatic types are the bar machines. In automatics all feeds are by power with stops which put the machines into another operating sequence through the use of limit switches, cams mounted on camshaft, solenoids or other means. In some machines, the spindle speeds and feed rates of each turret position can be pre-set and changed accordingly as the turret indexes through the use of electromagnetic friction clutches built into the main and feed gear-boxes that are engaged by a rotary automatic control unit linked to the turret head.

3.2 STOPS

Stops are common features in capstan and turret lathes, especially in the automatic types. The cross

slide feeds can have a number of stops depending on the type of tool post mounted. Where the stops are more than two in number, they are arranged in circular form and they index in the same manner as the tool post - thus if tool post is hand indexed they are also hand indexed and where the tool post indexes automatically, the stop carrier is linked to this mechanism and it is indexed in similar manner. The saddle for the cross slides in capstan lathe may also have stops corresponding to the number of tool stations of the slide. Where there are 4 slides in front and 2 at the back and the stations operate independently, the saddle stops are six, and they index to correspond with the operating tool station. In this case, indexing of the saddle stops is usually manually through handwheel. The capstan slide and turret saddles have stops corresponding to the number of tool stations available. Their indexings are geared to those of the turrets. These stops can be in form of screw heads carried on a stop bar head (the carrier) which can be threaded for adjustment of screw protrutions. They can also be in form of rods that are held in grooved holes in the bar or cams fastened to the bar. They are numbered to correspond with the station they operate with. In manual machines, the stops trip out feeds and it is usual to set them slightly short of the required distance while the rest is done by hand. In automatic machine tools, however, because it is possible to maintain controls over the pressure applied against the stops through strain gauges, the stops are

set to precise positions. Manual feedings can also be done to dead stops but the accuracy of jobs depends on the experience of the turner.

3.3 CONSTRUCTIONS

They consist of bed, headstock, feed gear-box, apron, the turret saddle or the capstan slide, and the cross slide. Except for the turret and capstan features, their designs are basically the same as other lathes. The bed is usually box-shaped grey iron casting with a system of well developed internal stiffening ribs. The headstock houses the feed gear-box, but permits narrower speed range and smaller steps. The small precision types also have step pulley for speed changes. Some of the larger types (especially the precision types) have reducing gearbox with electromagnetic clutch-change system coupled to an induction motor mounted at the base and connected to the spindle through pulleys. A general feature of the headstock is the elaborate provision for rapid stopping, starting and speed changing. A recent design features the use of multi-speed motors directly coupled to the spindle.(12) The use of D.C. motors is also gaining ground . This allows for infinite speed change between a range. In many recent designs constantly meshing gears are used with speed changes done through clutches, thus eliminating sliding gears. These clutches allow for high acceleration and are designed for high torque load.(12) They are small in diameter to allow for close shafts spacings, thus reducing the peripherial speed of gears and producing balanced high rotational speeds.

3.3.1. Preoptive Machines

In some machines, (e.g. Alfred Herbert Limited) the next spindle speed can be chosen while the spindle is running by setting a pointer on an indicator dial.(13) This speed can be automatically switched on to, as soon as the operation with previous speed is completed or by depressing a push button when it is necessary to change to the next speed. These machines are called pre-optive machines and they use friction or jaw clutches, built into the headstock controlled by hydraulic cylinders which come into play when the pre-selecting button is depressed. In some cases, sliding cluster gears are directly shifted by hydraulic cylinders when the button is depressed.(4) These save machining time and are useful for mass production.

3.3.2. Spindle Support

As in other lathes, where the cutting tool tends to force the work and spindle backwards, the thrust is taken by thrust bearings, thrust washers, and tapered roller bearings. It is usual to have the spindle supported by roller bearing at one end and thrust taking bearing at the other end.

3.3.3. The Carriage

The feed gear trains are simpler than those of other lathes, since they have narrower speed range and no lead screws - so threads are died, tapped, or rolled. The cross slide carriage of a capstan lathe can be either the "reach over" type where the rear and front tool posts are mounted on a single carriage unit or they

can be the 'side-hung' type where the two are mounted on two separate carriages that do not span the width of the bed. The reach over type is more rigid, but limits the diameter of workpiece that can be swung, since the carriage passes under the work. The side-hung type, owing to its lower rigidity, disallows heavy cuts.

3.3.4. The Tool Posts

It is usual to have the square turret tool post in front and simple single tool or double tool posts at the rear. The revolving main turret can be circular or polygonal with each side carrying a face with circular holes, flange or chucks for tool mountings. The circular hole permits the use of shanked tool holder. The turret is fitted on a vertical stem which is screwed at its upper end to take a simple clamping lever that prevents lift when tools are cutting. When the turret is an indexing circular table upon which tool holders are mounted using tee slots, we have flat turret lathes.

3.3.5. Turret Indexing Mechanisms

The turret is indexed automatically at the end of each return stroke of the slide by various methods, one of which is as shown in Figure 35. It has an indexing plate and a modified Geneval secured to the base of the turret. When the slide is retracted, the pivoted spring loaded lever contacts a ramp or projection on the base. As the turret slide, to which the lever is pivoted continues its return stroke, the other end of the lever moves the locking bar out of the slot (against the lever spring pressure). When the bar is clear and the turret slide

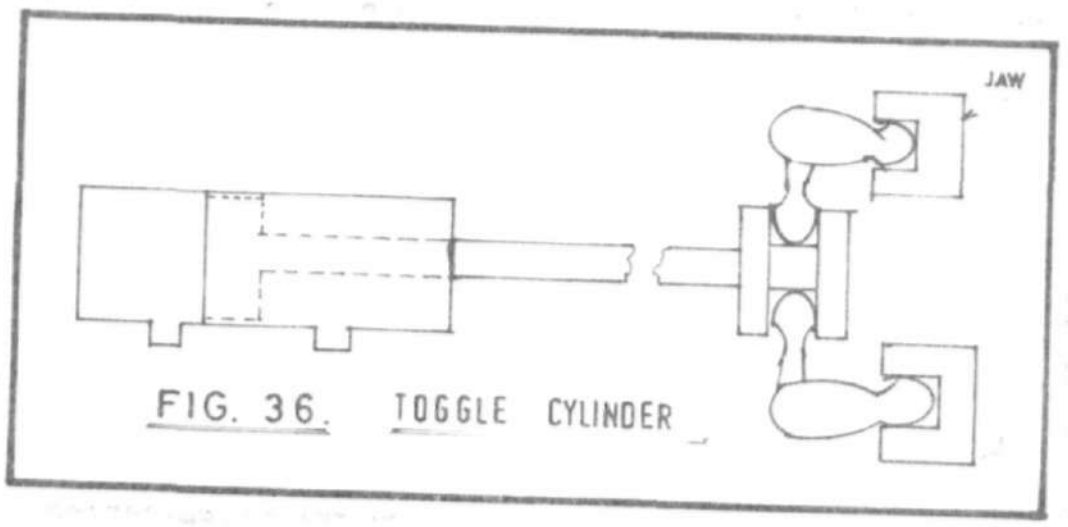


FIG. 36. TOGGLE CYLINDER

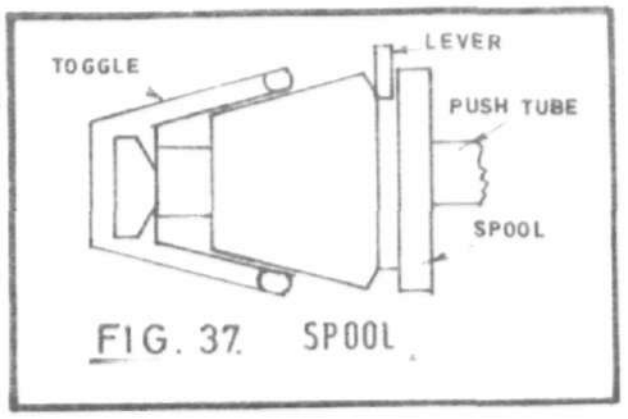


FIG. 37. SPOOL

3.3.6.1. Pneumatic Chucks

In principle, they consist of a double acting cylinder with very small stroke, which has its piston rod attached to a pull rod that passes through the spindle bore to operate a toggle lever, connected to the chuck jaws (Figure 36). The toggle ensures that the chuck is not opened unless a positive load is applied The spindles' noses carry flanges (not threaded) for better chuck fixings.

3.3.6.2. Collet Operating Mechanism

When the machines are designed for bar works they accommodate collets. These collets are generally operated (pushed or pulled) through toggle which is operated by a spool with inclined surface that is actuated by a lever (Figure 37). The mechanism is usually fixed to the back of the lathe spindle. For manual machine, the lever can be hand operated, while for automatic machine it can be operated by a cylinder, or through a solenoid coil.

3.3.7. Automatic Loading

In turret and capstan lathes as well as in other automatic machines, loading and unloading of workpieces can be done while spindles are still rotating by the use of loading and unloading magazines, which, for chucking machines can be in the form of clamping fingers. The finger can rotate with the workpieces and can be opened and closed while rotating. Air chucks can also be opened or closed while the spindles are rotating while the use of collet opening spools allows for its opening and clos-

with spindle rotating. Loading magazine can be fixed into a face of the turret or can be fixed to an attachment which swings in and out when necessary.

3.4 BAR FEED

The bar machines usually have a bar support that is fixed to the back of the spindle. The support feeds the bar forward automatically to a length stop when the collet grip is released. In its simplest form, the feed mechanism consists of a tube attached to the headstock casting at one end and on a stand at the other. Sliding in this tube is a gripping finger attached to a wire which is attached at its other end to heavy weights. The wire passes over a pulley and the action of the weights tends to pull the finger towards the machine. Through the upper part of the finger is a hole designed to take bushes to suit bars of various shapes and diameters. The bar is inserted through the grip and the spindle to the collet, and the finger is tightened on the bar with a bolt. The weight then forces the bar against the collet so that once the collet is opened the bar is pushed forward to a pre-set stop. The collet closes and holds the bar in position, the stop is swung away and machining starts. Because bar rotates inside the tube, to avoid noise, the tube is lined with treated wood. In recent bar machines, tube loading is done at the front end of the tube thus saving space. In this case, the tube is stood on a pivot so that the front end can swing in and out.

3.5. TOOLS AND TOOLING

Their tools are the same as those used in multi-spindle lathes. Some of these tools are identical to those used on simple lathes while the rest, like forming tools, knee furning tools (or combination boring and turning tools holders) and thread rolling dies, are designed for mass production. Turret lathes' tools are more robust than capstan lathes, to allow their heavy cuts. To increase production, more than one tool are made to work on the workpiece. It is usual to have one tool from the turret (end working tool) one from the front slide and one from the back, working simultaneously on the work. Where a knee turning tool is used, two tools can be fed in from the turret. To avoid any vibration due to overhang of tools, and to act like guides, some turrets have steady bars protruding from the top of their headstocks. These engage guiding holes in the turrets, tools or travelling workpiece steadies fixed to the slide.

As in multi-spindle lathes, box turning, drilling, boring, reaming, chamfering, thread tapping and dieing are done from the turret head while the cross slides are used for forming, large facing, short diameter turning, grooving, recessing, and parting off. Parting off, recessing and necking tools are usually held in the rear tool post. Where tools are held in rear tool post, they are mounted upside down because of work-piece approach except where it is possible to reverse spindle speed when these tools operate.

3.5.1. Turret Tool Holding

The turret faces usually carry tapped holes for fixing tool holders. They also have holes coaxial with the spindles for carrying shanked tools. Shanked tools are gripped in tool holders of various forms bolted to the turret faces. Some of the holders have adjusting screws used to adjust the height of tools so that packing pieces are not required for setting tool coaxial with the work spindles.

Small turret tool holders are sometimes made to fix into the turret holes. For accurate location, especially where tools are pre-set, large tool holders with rectangular bases have circular spigots which locate in recesses in the turret faces. Tools with tapered shanks are mounted on tapered socket (or adaptor) with parallel outside diameter for fitting into holes.

3.5.2. Tool Pre-Setting

To enhance production, tools are pre-set and it is usual to have an identical turret already pre-set with all the tools and attachment ready for mounting up immediately the tools on the working unit become dull and out of gauge. This is set while the machine is working in the tool room or setting bay. This reduces lost time considerably.

For setting turret tools on the machine, it is usual to use a finished workpiece as standard setting gauge. Where finished piece is not available one is made by turning as in centre lathe. Roller turners are however, not set this way, but by turning with the cross

slide to diameter close to the diameter of the finished product and then using the box turner to finish the job by trial cuttings. Once set, the tools are ready for repetitive jobs until they produce jobs that are out of tolerance. They are then set as described above after sharpening or set against setting gauges in the tool room. A typical setting gauge used for a multi-tool boring bar is as shown in Figure 38. The gauging plate is profiled in such a way that once the tool is set to the profile, it gives the right cutting characteristics.

Once the tools and stops are set, the operation of turrets and capstan lathes can be manned by semi-skilled operator whose duty is only to select and engage the right spindle speed and stopping the machine when it malfunctions. Setting up takes a lot of time, so that the machines are only economical for large quantities.

3.6. OPERATIONS PERFORMED WITH TURRETS

In batch production, it is usually better to break work into stages which are carried out as each turret face is presented. For instance, accurate holes are generally produced in four stages: centring, rough drilling, boring and reaming. Centring is to produce a true running start for larger and more flexible drills. In bar works, dual purpose length stop can be mounted on one of the turret faces. This has an arrangement where, after the bar has been presented against the stop, a lever on the stop is operated to push out the centring tool which works on the workpiece. Rough drilling is

less accurate than boring, but boring cannot be done on blank holes so it requires the pilot operation, while reamers produce the most accurate hole though its depth of cut is very small.

3.6.1. Box Turner

Box turners are generally made to have roller followers which follow the tool about 0.75 to 1 millimetre behind, thus resisting the action of the cutting force on the workpiece, especially where the workpiece is slender. In some cases, they are made to have guide vee made of hardened steel instead of rollers for the same purpose. Some box rollers have adjustable tool holders while some have mechanism for tools withdrawal after cut. The tools are then brought back to a dead stop for another cutting operation after the tool holder is fully withdrawn. This avoids withdrawal marks on workpiece. Though box tools are ideal for mass production, some of the problems encountered in their applications are ribbing, cutting tool withdrawal marks, rough finish, non circularity and chip disposal problems. Ribbing is caused by unsuitable roller pressure which leads to deflection of the work resulting in cutting tool digging in, formihg ribs. Apart from tools withdrawing mechanism, cutting tool withdrawal marks are avoided by setting the upper roller light, and the tool a bit off centre so that when cut starts, the work lifts to bring tool to centre line. When cut ends, the work falls and the tool is higher than the work axis and therefore withdraws without marks. Tool radius is usually contri-

buting to finish work roughness especially during light cuts. Big radii and inadequate roller pressure produce very rough works. Pitting of work usually occurs when metal particles go between rollers or when the tool edge is damaged. Long jobs that are not supported before the tool deflect and whip. These affect roller pressure and tool performance, resulting in non-circular turning. It is, however, usual to support long slender works either from the turret or from auxiliary steadies fixed to the slide.

3.6.2. Tool Steady

Long tools, especially boring tools are usually supported. Boring tools carry support bushes at their free ends. These slide inside the chuck. For counter boring or chamfering tools, the tool is supported by a bush which slides in the previous hole (Fig. 39).

3.6.3. Other Tools

Apart from centring tools which can be flat pieces of hardened steel with edges ground to appropriate angles and box tools, other tools used on capstan and turret lathes are:

(a) Drills - Twist drills are held either in a morse tapered socket or in a tool holder bolted to the turret face. For deep holes, drills with straight flutes are used to allow easy passage of swarf. They are made with bores for coolant passage to the cutting points. The coolant helps to wash out the swarf. Drills are used from the main turrets.

(b) Boring tools - These are also generally used from the main turrets. They provide more accurate holes than drills ,but cannot cut unless there is a starting hole, so it is usual to drill with a drill and finish up with a boring tool. Boring tools can carry many tools for stepped diameter or in order to cut long diameter with short strokes.

(c) Reamers - These produce accurate holes but have very small depths of cut. They are also used from the main turrets.

(d) Facing tools - are held in cross slide though special facing tools with tool slides that can be held on the turret head are available.

(e) Knurling tools - are usually used from capstan head in conjunction with box tools. The Knurler is used to replace the rollers. If the knurling tools cannot be set at the end of works or there is a disturbing flange, the cross slide is used (especially in the capstan and combination turret lathes where the cross slides are held on saddles). In this case, the knurling tools are held in front tool post.

3.6.4. Form Tools

Drills, boring tools, reamers, facing tools, and knurling tools, are tools used in all types of lathes (centre, capstan, turret or multi-spindle). Formed tools are, however, rarely used on simple engine lathes, but they form a major set of tools for multi-spindles and turret lathes. The tools have the shapes of the required contour. They are held in rear cross slides

in inverted position. Because large cutting surface areas are involved, cutting forces are heavy; if they are not held in inverted position, digging into work or pulling down of work will occur. Since they are inverted, they have to be held in the rear tool post. In this position, the cutting forces act upwards and take any slackness out of the slides. (For these same reasons, parting tools are usually held in the rear post). Form tools are flat, or circular. Circular tools are disc with faces turned to the required profiles.

3.6.5. Threading On Turret/Capstan Lathes

External threadings are done in 2 ways:

(i) using dieheads held in turret heads. This is quicker and more accurate, and are therefore more readily employed where possible. One of the limiting factors is the diameter that die heads can accommodate.

(ii) Using single point tool held in cross slide to generate threads. This has no size limitation, but is less accurate.

Dieheads are usually self opening. When the required length of thread is formed, a stop exerts resistance to any further feed of the head, causing the die blades to open clear of thread for withdrawal without stopping or reversing spindles speeds. Single point threadings are only done in capstan lathes or combination turret lathes with lead screws. In this case, a means in which the nut is disengaged from lead screw and the cross slide is backed out slightly before tool withdrawal is usually incorporated. When the nut is re-engaged, the cross slide advances automatically to the workpiece.

Another feature of the capstan and combination turret lathes (with lead screws) is the use of thread chasers instead of single point tools. Because diameter of thread that can be cut by dieheads is limited, chasing was developed to cater for large work diameters. Turret lathes (without lead screws) can be fitted with chasing attachments which comprise a leader or master screw shaft driven by a shaft from the feed box. Half or full nuts engage the lead screw through a lever so that the tool is fed at the right speed to match the pitch of thread being cut. The attachment is provided with many lead screws that are easily changed to allow for a wide range of thread pitches, especially when used in conjunction with many feed gear-box speeds. Chasers are like collections of single point tools and are therefore to be withdrawn from work after cut. Since the withdrawal point must be accurate, the withdrawal mechanism is always incorporated.

Internal threads are produced by single point tools (as for external threadings) or by collapsible taps. Small holes are tapped by insertion of ordinary taps with the correct threads. They have tapered ends for easy entry into holes and longitudinal grooves along cutting edges for swarf removal. Collapsible taps are used for mass production and they produce better jobs. Some taps have tap holders that are capable of revolving and sliding in their bodies. When the holder is pushed into the body, it is locked and will not revolve, thus holding the tap stationary for cutting. When the depth of

tap is reached, the holder is drawn forward relative to the body and this disengages the driving peg and allows the tap and holder to revolve with workpiece. To withdraw the tap the machine spindle is reversed. A collapsible tap usually incorporates a dog that collapses the tap before withdrawal. Taps are usually allowed to float slightly in their holder so that they can find exact hole centres.

3.7 ATTACHMENTS

3.7.1. Taper Turning: In the turret lathes, tapers can be formed or produced, using shell cutters and tapered reamers, but it is easier to use taper turning attachments which are the same as those used with the centre lathes, and they work where cross slides are mounted on saddles.

3.7.2. Copying Attachment: Because of large force, form tools are used only for small surfaces. Larger profiles are produced using copying attachments like in centre lathes.

Other attachments used with ordinary lathes are used here. Chasing attachment and auxiliary drives are other types used with these types of lathes

3.8 OTHER TYPES OF TURRET LATHES

Capstan lathes range from the simple bar machines to the powerful ram type. Most bar works require simple operations, but in large quantities. Simple machines are designed for these works. The spindle drives in these machines are through pedal operated counter shafts equipped with high, low and reverse speeds. It is the most basic of

these types of machines.

3.6.1. Horizontal Axis Turret

Some turret lathes like the German built Pitler lathes, have horizontal axes of turret operations, so that turret moves in vertical plane.(10) This type is produced mainly in Russia. The turrets are fed in or out on the bed ways by means of rack and pinions. It is usually arranged so that the tool is at its upmost position before it is brought in line with workpiece axis. This makes it more rigid, since overhang is reduced. In this position, tool thrust is parallel to the turret slide.

3.6.2. Vertical Turret

There are vertical turret lathes used for blanks of large diameters and weights, but short heights. All their features are like boring machines or vertical lathes but the turrets are mounted on the main tool heads. The chuck is a rotating table since the spindle axis is vertical. Milling, grinding, and centre drilling can be done with attachments. The table rotates in horizontal plane. The main feed is vertical though there can be some horizontal auxiliary feeds. The turrets index about horizontal axes. The gear-boxes are usually simple as the steps of speeds are very few. It is usual for them to be pre-optive with speed changing automatically as turrets index. A lot of workpiece clamping accessories are necessary as range of sizes of work is very high.

3.8.3. Combination Turret Lathes

The combination turret lathes, combine the functions of capstan and turret lathes as they have turret saddles and cross slide saddles which can carry rear and front tool posts. They are not usually used for bar work and they are usually subjected to heavy workings. The two saddles travel along the bed and are usually power fed. The beds are flame hardened and provided with covers for the protection of the slide surfaces. The bed structures are designed for easy swarf and coolant disposal. They have wide ranges of speeds and the speed change levers are usually connected to the declutching and braking lever which actuates before the speed is changed and engages after the gears have meshed, thus allowing for rapid speed changes. They are mostly supplied with pneumatic operated chucks with two jaws (for irregular workpiece holdings). The saddles can be arranged to have common feed shaft but with different change gears. The cross slide is also usually power fed. They have lead screws (unlike other turret lathes) and therefore cut threads. Tools for bar work comprise of adjustable turret stop, roller or vee bar turning steady, drills both twist and straight flutes- drill chucks, tool holders, dead centres, self opening die-heads and collapsible taps. For chucking works, there are, in addition, extension arms, floating reamer holders, knee turning tool holders, and boring bars with split bushes for holding the tools in the turret holes.

CHAPTER FOUR

4 - MULTI-SPINDLE LATHES

To increase the efficiency of production when large quantities are required, multiple head machine tools are often necessary.(14) Even in case of drilling heads where jigs and fixtures are used to increase output, multi-heads drills are far better since many operations are combined and production sped up if more than one workpiece is worked on at the same time. Multi-spindle machines have a principal advantage over single spindle type in the saving of time per workpiece. In the turret machines, only one turret face works on a workpiece at a time whereas in the multi-spindle lathes all turret faces (end tools) work at the same time on all the spindles. So while in turret machines, time for a workpiece is the sum of all the time required for all turret operations in multi-spindles, machining time per workpiece is that of the longest single cut (or operation). It is thus usual to divide operation required on a workpiece in such a way that it is done in sequences of approximately equal time. Thus if an operation is very long (like parting off), it is divided up into stages and done in two or more operating stations.

4.1 FEATURES OF MULTI-SPINDLE LATHES

The first main feature is that they have many spindles, driven at the same speed and holding work at some stages of machining. They retain the essential features of the turret lathes. The end tool slide

replaces the turret. This slide does not index but moves along a cylindrical stem while the spindles (in most cases) index to meet the tools. The slide has a number of sides (depending on the number of spindles) upon which usual turret tool holders are clamped. A spindle carrier carries the spindles and rotates (or indexes) about the stem. The machines also have a number of cross slides which hold side working tools allowing for multi-tool operations at any working station. Their scope and accuracy are equal to those of single spindle machines but they require long set-up time. This makes them uneconomical for short runs of work. They have facilities for special attachments which perform operations outside the scope of ordinary lathes. As the number of spindles goes up, the costs of the machines increase. This, coupled with the high cost of toolings, makes them uneconomical to be operated for runs that are less than three days.(15) The automatic machines usually run for weeks on a job and are only stopped for sharpening of tools and inserting new bar stocks or loading up of the feed magazine.

Multiple position of operations in indexing multi-spindles has an advantage of separating roughing jobs and finishing jobs which are done at different stations. The number of working stations is dictated by the number of spindles (which is equal to the number of faces of the end working slide). The working stations are indicated by numbers. At the end of the cutting stroke of the last tool slide, the spindle carrier indexes to the next position (or station).

Because large number of cutting tools operate at the same time in a multi-spindle set-up, efforts must be made, to:

(i) balance the cutting forces;

(ii) overlap working and idle movements;

(iii) apply pre-set tooling;

(iv) use standard tools.

4.2 CLASSIFICATIONS OF MULTI-SPINDLE LATHES

Classification of multi-spindle lathes depends on method of work holding, capacity, arrangement of spindles, number of spindles, method of indexing, and principle of operations. Thus they can be fully automatic or semi-automatic, bar or chucking, horizontal or vertical, step indexing or continuous indexing (this applies to vertical lathes only) and parallel action or progressive action types. The bar types work on bar stock, and are usually fully automatic. The chucking types work on blank or pieces of items from castings, forging, etc., and are usually semi-automatic except where arrangements are made for automatic hopper/magazine feeding. Bar machines are sized according to the size of bars that can pass through the spindle hole, while chucking machines are sized according to the maximum diameter of workpiece that each spindle can swing.

The number of spindles are usually 3, 4, 5, 6 and 8. It is possible to have 10 or 12 spindles.

In the parallel action types, the same operation is performed simultaneously in all the spindles and workpieces do not index but have all the operations required to turn them to finished products performed in one station. These are like collections of ordinary lathes driven through the same gear-box. They are used for short parts of simple operations. They are usually referred to as multiple flow lathes,(16) because all the workpieces are loaded and ejected at the same time. They have very high rate of production and are usually used for bar works. In the progressive action (or indexing types) each spindle with a workpiece clamped on is indexed consecutively to the working stations which are arranged around a pitch circle diameter with the angular distance between two adjacent stations being $\frac{2\pi}{n}$ where n is the number of spindles. At each station one or more operations are performed according to the sequence of machining operation in the set-up.

Because chucking machine deals with metals that are cast, cold or hot worked, so having rough skin for machining the chucking machines are usually more robust and rigid, and take more powerful drive motors. It is possible to have double indexing or arrangement in which the spindles are grouped into two for double production of simplier workpieces; here we have parallel progressive machines.

4.3. OPERATING SEQUENCE

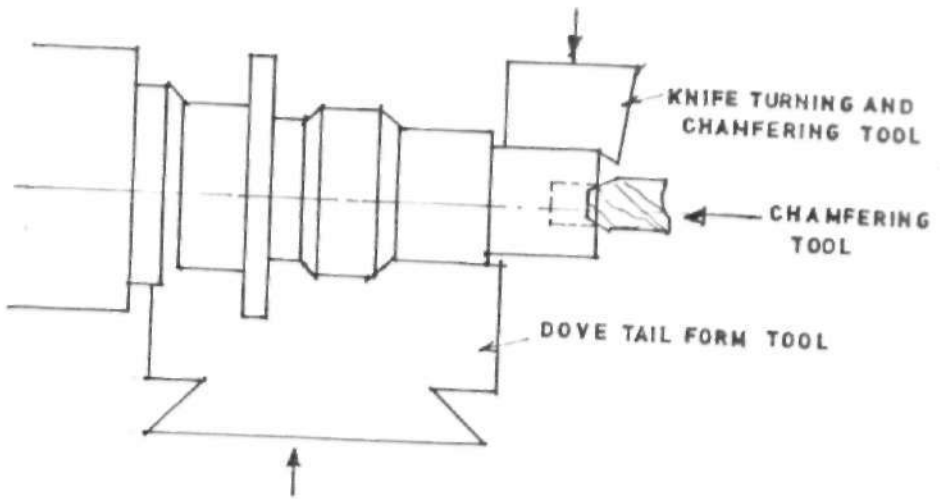
4.3.1. Parallel Action: In parallel action multi-spindles (or multi-flow lathes), there are no mechanisms for indexing

and the spindles are stacked in line, in a vertical plane. A typical type is the four-spindle automatic parting off lathe. Here, arrangements are made for feeding the bar stock into the collet against a stop which also acts like a support (or tailstock) while the parting off tools from the cross slides operate. Arrangements for end drilling and simple end working can be done, but they generally have no end working tools. They have no particular sequence of operations as all the jobs are fed in at the same time, the machining on them done at the same time and parted off at the same time. It is possible to machine between centres on them. They usually have two sets of spindles with one set rotating in opposite direction to the other. So it is usual to have one set of tools fed from the front and the other fed from the rear for correct tool approach.

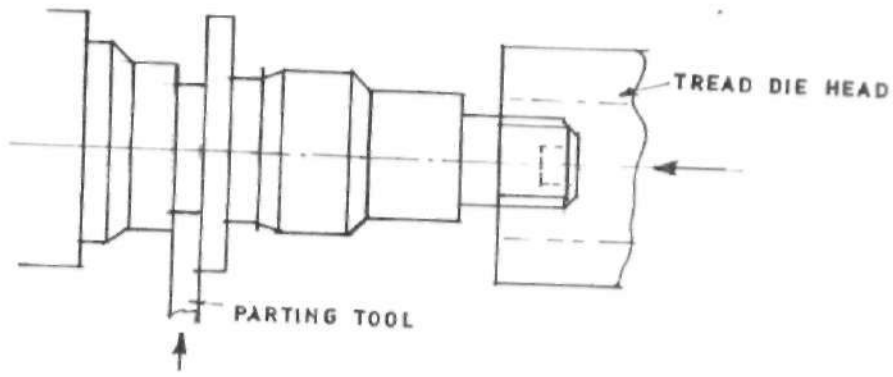
4.3.2. Indexing (Progressive) Multi-Spindles - In the indexing multi-spindles, the workpiece is machined progressively from one station to the other until it is dropped in the unloading station which can be the loading station (in some chucking machines where these operations are too long, the unloading and loading are done in stations adjacent to each other). The spindle speed at every station is the same and this leads to the use of rotating gadgets for tools that require different operating speeds, so that the effective speed of machining is the differential of the spindle speed and tool speed. In cases where tools are fed to eccentric positions, the work spindle can be declutched and held stationary while

the tools rotate, or the tool carrier is rotated at the same speed as spindle (i.e. tool carrier speed is synchronized with spindle speed). This means that relative displacement is zero. The tools have to be rotated to produce speed of cut. This is highly complicated since it is not easy to have synchronism. These types of jobs are usually done in attachments like those used by the Wickman Machine tools in converting six spindle machines to ten. Two additional operations are done at two stationary spindles (with rotating tools) where the third station is for loading into the attachment while the fourth is for unloading.(3) The attachment was made to fix into a housing provided on the machine and it has automatic transfer finger which takes workpieces from the unloading station of the main spindle to the loading station of the auxiliary spindle. The auxiliary spindles index but are not rotating. In multi-spindle lathes, the main tool slide feed is the same for all the stations, arrangements are therefore made to have independent tool slides where there is need for different feed rate or strokes.

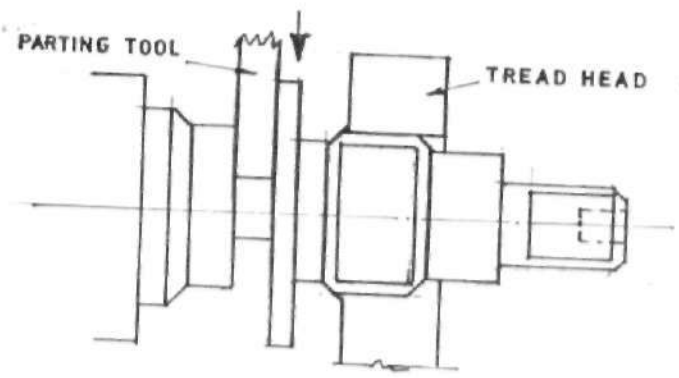
Spindle indexing is usually anti-clockwise. The spindles are mounted round a PCD (dictated by the size of drive gears) in a cylindrical carrier. Opposite each station is its end working tool mounted on the end (main) slide that runs on a stem from the centre of spindle carrier. Some stations have cross feed tools mounted on slides that move in and out radially. When the longest operation on the workpiece is finished, the tool is fully withdrawn, the spindle indexes to the next station of



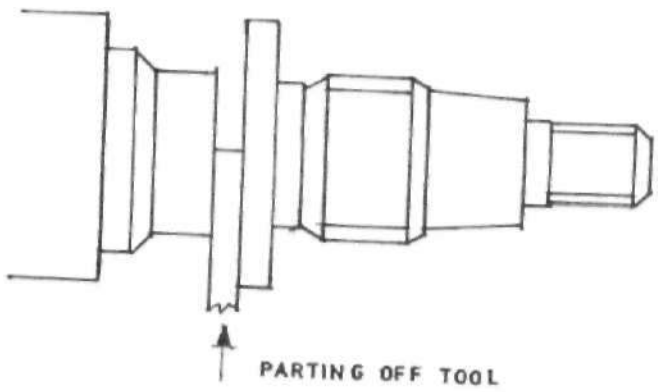
STATION III



STATION IV



STATION V



STATION. VI

FIG. 41. OPERATING SEQUENCE IN A 6 SPINDLE LATHE

tools for further operations. (Thus in a six-spindle machine, spindle in station 1 goes to 2, 2 goes to 3, etc., and 6 comes to 1), so each spindle is presented to new sets of tools. A six-spindle lathe has sixe sets of tools or stations of tools. Different operations are performed on the work at each station and at every indexing, a completed work is dropped. The longest operation plus the idle times give the overall macnining time. Idle periods are made as short as possible and operations are usually divided up to give approximately equal operation time. A typical operating sequence is as described in Figure 41 for a six-spindle bar lathe.(15)

At station 1, the bar is fed through the spindle against a stop which is set to give the required length. The stop swings away and the first end tool (the twist drill) comes in from the main tool slide (end tool slide) which is fed forward. A circular form tool is fed from the cross slide. When the tools reach their depts of cut the main tool slide and the cross slide are withdrawn. At this time, the action in other stations are completed and the bar is indexed forward to station 2. (The bar in 2 goes to 3, etc.). Station 2 is 60^{o} away from station 1. At station 2, the bottom of the hole is squared through the squaring drill fed from the main slide and another form tool is fed from cross slide for further profiling of the slides. (A new bar piece is fed into 1 and undergoing the station's cutting action simultaneously). After the operation, the workpiece is indexed to station 3 where form tool and kneel turning and chamfering tools are fed from two cross slides.

The chamfering of the holes is done through a chamfering tool fed from the main slide. When the operation is completed and tools are withdrawn, the workpiece is indexed to station 4 where die-head mounted on the main tool slide cuts the end thread. This is independently fed at a feed corresponding to the lead of the thread. The start of the parting off operation is begun with parting tool fed from the cross slide.

Three tools are used for parting off. They are fed at stations 4, 5 and 6. This is part of the operation broken into three stages because of its length, in order to avoid slowing down the machining processes, This improves output. At station 5, where the second parting off tool is fed from the cross slide, the larger die-head cuts the thread on large diameter. At station 6, the parting off is completed and the unloading finger is fed from the end slide (or can be swung into the station) to take the workpiece and drop it into the collecting station. If there are no threads that can be damaged, or, if the workpiece is very light, it is usual to drop the finished product down a shute into a compartment in the bed. This sequence of operation is repeated for all workpieces and the cycle goes on continuously. As a work is indexed out of one station, another is indexed into it (and new bar is fed into station 1 while completed piece is dropped at station 6).

.3.3. OPERATING SEQUENCE OF MULTI-SPINDLE CHUCKING LATHES

Separate blanks (forging, casting, and other pieces)

are machined on multi-spindle chucking automatic lathes equipped with loading hopper and magazine loader (for automatic loading) or semi-automatic lathes with manual loading and unloading. Two types of work are usually done on chucking machines - work previously machined in another machine tools (second operation works) and blanks like forgings & castings. The set-up and sequence for magazine feed chucking machines are almost the same as bar machines except that the processing capacity for chucking is less. This capacity is, however, usually sufficient since blanks have forms close to finished workpieces. Blanks that cannot be machined in magazine fed automatic lathes are done in manual loading (semi-automatic) chucking machines. For efficient blank machining, the following are necessary:

(i) The form of the blank should be near the form of the finished product so that less stock is removed than when workpiece is made from bars.

(ii) Blanks should be machined in two settings, since the surface used for clamping in the first setting is subsequently machined.

(iii) Larger torque than that required for corresponding bar machines are necessary, since skin surfaces of blanks are very rough.

Blanks are usually larger than bar stocks and this means that chucking machines are more rigid and more powerful.

A typical set-up is that used on 3-spindle chucking machines for machining bearing rings from cast. This is done in two stages. In the first stage, station 1 is used

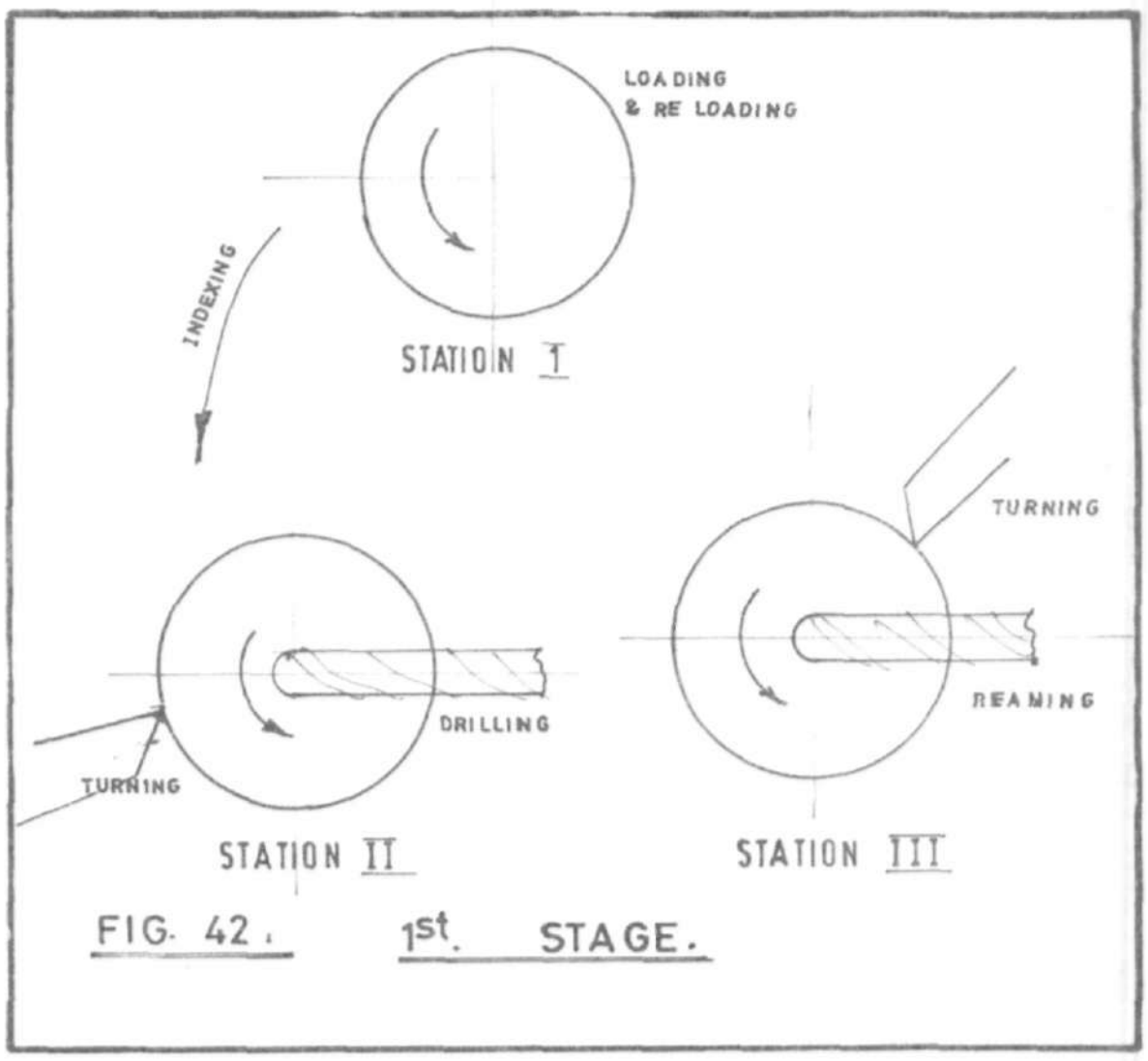


FIG. 42. 1st. STAGE.

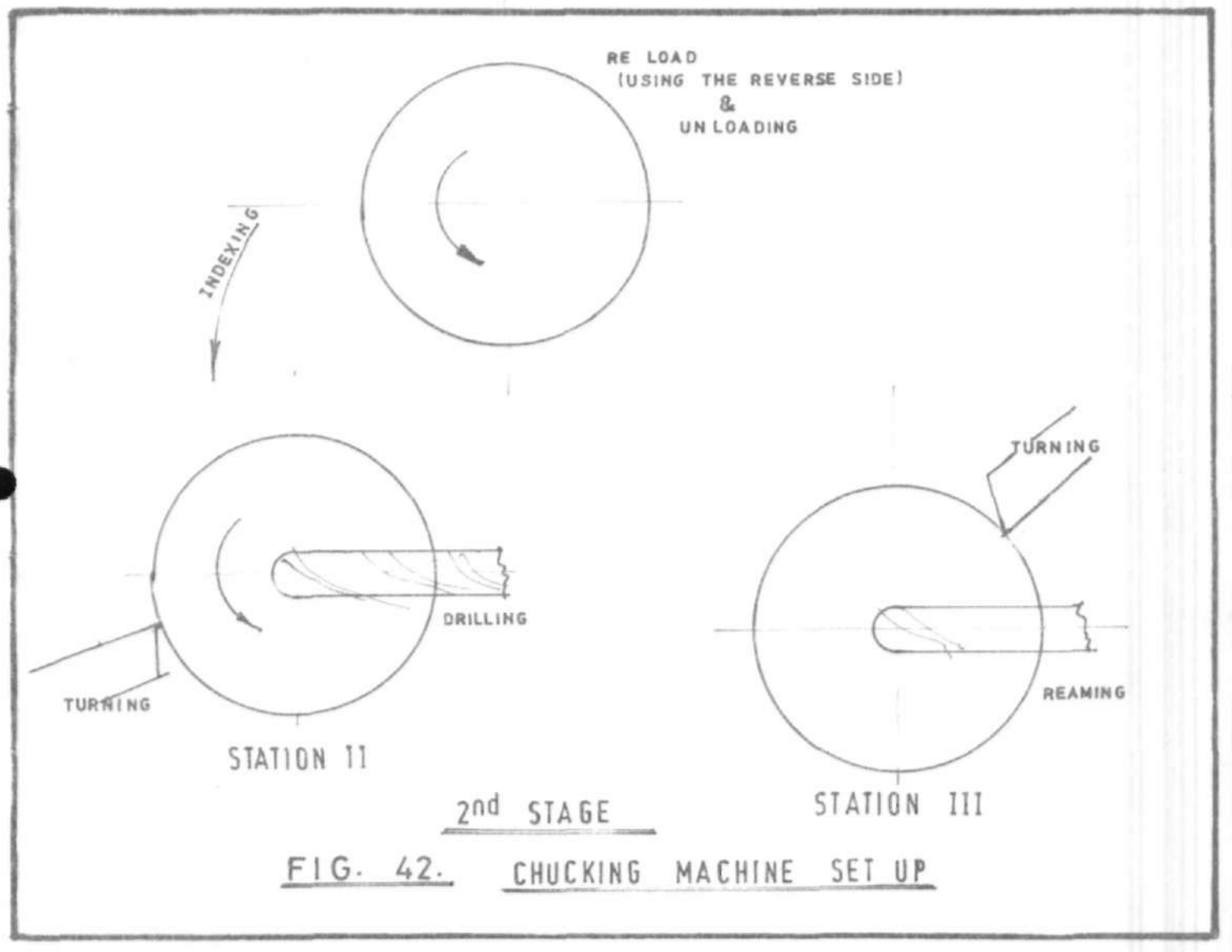


FIG. 42. CHUCKING MACHINE SET UP

for loading; station 2 for turning and drilling of first half; station 3 for turning and reaming of this half. In the second stage the work is reversed and reloaded in station one. Station 2 is for turning and drilling of the reverse side and station 3 for final turning and reaming. The work then goes back to station 1 for final unloading. (See Figure 42). If a six-spindle machine is used, station 4 is used for reloading, leaving station 1 for loading and unloading.

The choice between number of spindles to employ depends on the simplicity of the work. If the operation is simple, a six-spindle machine can be used as 2 3-spindle machines or even 3, 2-spindle machines. In the latter case, workpieces are fed in stations 1, 3 and 5 and unloaded in stations 2, 4 and 6. In the first case, it is possible to load in stations 1 and 4 and unload in stations 3 and 6. But where the loading station should be as close as possible, loading is done in stations 1 and 2 and double indexing are done so that the workpiece loaded in 1 is indexed to 3 and unloaded at 5 while the other piece is unloaded at 6. This is called parallel/ progressive machining.

In a six-spindle machine, where the work is properly divided, the time to machine one piece is about 1/6th of the time taken on turret lathes.

4.3.4. MACHINING OF DIFFERENT WORKPIECES

It is possible to produce two different workpieces using double indexing, provided the following conditions are present.

(i) The total machining time for the two must be equal (or nearly equal).

(ii) Cutting speeds and feeds must not differ considerably or else it will require the use of gadgets and attachments.

(iii) The heaviest machining operation must be performed by the most rigid tool slides.

4.3.5 MACHINING CONVENTIONS

Because of need to improve production (which has been helped by the use of cemented carbide tip tools on multi-spindle lathes allowing for high cutting speeds and feed) some conventions have been found necessary in the practice of multi-spindle lathe machines. These are:

1. External surfaces are turned with form tools when the length of formed surface is not too long and accurate length diameters and good surface finish are required. Obviously where it is impossible to machine the surface by tools on end tool slide, form tools must be used.

2. Holes are drilled, bored or reamed (depending on accuracy required) from tools held in end tool slide. Drilling of deep accurate holes are done in two or three stations with the subsequent machining to full depth done with a core drill and a reamer. Stepped holes are better done when the largest diameter is first done so that the effective length of travel of the drills are reduced. In drilling large diameter through holes on bars, the tool is over-travelled so that the next piece is spot drilled ready.

3. Both the end and side tools can be used for facing

and chamfering, but it is usual to use the side tools.

4. Long external surfaces are turned by tools held in the end tool slides and are divided between stations.

5. Finishing operations are done by end working tools or forming tools.

Roller back rests are used for turning accurate surfaces or when workpieces overhang a long distance from the chuck. Shaving tools are used to have high precision surface. They are essentially a floating finish-form tools with roller support. The roller and tool have a set distance between them. They move together and pass over the work which comes between them. Accuracy of cut is between 0.02 mm and 0.03 mm. These are held in end tool slides.

The more the number of spindles employed in an operation, the simplier the tools required, since work can be distributed into more stations. This surely increases rate of production.

Setting up of multi-spindle automatics to manufacture a workpiece is done carefully after designing the tool layout and pre-setting the tools. Usually a sample piece is made before the setting up is accepted for automation. To set up inching motor can be provided for the camshaft or provision for turning the shaft through crank is provided. In fully automatic machines production continues until the tool wear affects the size of the workpiece - giving an over-sized piece. The tools are then changed with another pre-set set while the removed sets are sharpened, reprofiled and

pre-set, while the machine is running. Continuous samplings and random samplings are done for quality control. The machine is stopped immediately persistent out of gauge workpieces are produced.

4.4. GENERAL CONSTRUCTION FEATURES OF HORIZONTAL MULTI-SPINDLE LATHES

4.4.1. Parallel Action Multi-Spindle Lathes

The machine generally consists of a frame with headstock positioned at the left end. The headstock which houses the horizontal work spindles arranged in line one above the other is mounted on a cast base. Each spindle has stock feed and chuck operating mechanism, which can be hydraulic, pneumatic or mechanical. The stock is supported by a bracket, which is free standing with bushes to hold each of the bars. The camshaft is housed in the top brace which joins the headstock with an up-right at the right for rigidity. The cams on the camshaft operate the collet clamping mechanism, the cross slide feeds and (where end workings are done) the tailstock feed. The right column holds the tailstock which can support the centres, or adjustable stops for feed bar length control. It is usual to have two cross slides per spindle. One can take parting off tool, while the other takes form tool The cross slides move in slots provided on the headstock. Because the number of cams carried by the camshaft are small, the camshaft can be made to operate on two speeds - one for feed motion and the higher speed for idle motions.

4.4.2. INDEXING (PROGRESSIVE ACTION) MULTI-SPINDLE LATHES

The chucking and bar machines are basically of the same design except that one is designed for blank holdings while the other is designed for bar holdings. The chucking machines are usually semi-automatic. This introduces a problem of making the spindles stationary in the station used for loading and unloading. The machines have switches that trip off the machines when the last stock is machined.

The designs are usually the box types with the headstock and gear-box being mounted separately on the base and linked together rigidly by a top brace. This provides for rigid and convenient arrangements of the the principal parts. The gear-box is usually at the right-hand side, while the headstock is at the left of the heavy base which also serves as reservoir for the cutting fluid and sump for the lubrication oil. The top brace in some designs houses the main camshaft while in others it houses the auxiliary camshaft with the main camshaft running below the central shaft. The central shaft transmits motion from the gear-box to the spindles at the headstock (Figure 44). The camshaft runs in ball bearings and is made to carry drum and discs on which cams are profiled or fastened.

Most modern multi-spindles are designed to make full use of cemented carbide tipped tools and are therefore driven by relatively high horse power motors (a 1" bar machine uses 15 H.P. mptor[11]). It is usual to have the motor driving a constant speed shaft through a matched

set of vee-belts. From this shaft a second shaft is driven through slide gears to provide a range of speeds (usually 2). This shaft also transmits motion to another shaft through another set of slide gears, depending on the range of speeds required. The number of shafts and the number of slide gears depend on the number of step speeds required. The constant speed shaft usually drives the high speed or over-run clutch which is engaged during non-productive periods of the machining cycle. A simple transmission train is shown in Figure 45.

Here the drive from the motor is transferred through match set of belts into constant speed input shaft B. The shaft drives through spur gears, the speed and feed gears for machining and through the bevel gears for the high speed non-machining return of tool slide (being a simple machine, the cams are few and camshaft can have two speeds). The spindle drive shaft attached to the speed gears goes through the stem and carries a gear at the spindle carrier that meshes with each of the spindle gears arranged around the gear. The feed of the tool slide is from the feed gear-box which drives the tool slide cam through shaft D worm pair G, gears T, H and worm J.

The high speed return is through shaft E, gear F, which is secured to the roll ratchet S. The function of S is to allow for over-running motion. G is attached to the inner shell of S while F is attached to the outer shell. When G is driven, the inner shell is hooked to the outer and S drives F. At this point clutch X_1 is disengaged.

But as soon as X_1 is engaged, it drives F at a higher speed and this ratchets over the inner shell of S and therefore bye-passes the worm G. This then drives the camshaft through H and J. At the end of the quick motion, clutch X_1 is disengaged and the inner member S takes over the forward drive. The main cam-shaft A is below the drive dhaft and runs the full length of the machine, and is driven by worm pair J. The shaft A also carries the cams for other operations and attachments like collet operating, bar feed, high speed clutches, stock stop, cross slides feed, brake, as well as the arm for the Geneval indexing mechanism (Figure 46) and locking cam.

4.4.2.1. Other Drives

Generally, the gear trains are based on centralized drive principle. Only the inching rotation of camshaft (where this is available) for setting up, the chip conveyor, and in some cases, the lubrication and cooling pumps, have separate motors. The cooling and lubrication pump drives are otherwise taken through chain drives from the constant speed shaft. All multi-spindles have flow switches that knockoff the machines when lubricating pumps are not delivering lubricants. The chip conveyor runs through the central opening of the base.

4.4.2.2. Headstock

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The headstock has a central bore for spindle carrier with work spindles. It also carries the carrier locking device and levers, tie rods for actuating the tool slides. Four bronze shoes on the rear wall of the headstock prevent axial movement of the carrier. In bar machines, mounted

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behind the headstock is a rear support housing for stock feeding and collet operating mechanism. Carrier lifting (vertical lathes) and indexing machanism are also housed in the headstock. The bar stock tubes and reels usually lie further left of the rear support. The cross tool slides travel in ways attached to the front end wall of the headstock.

4.4.2.3. Main Tool Slide

The main or end tool slide travels horizontally on a hollow stem press fitted into the spindle carrier. Inside the stem is the shaft driven from the gear-box transmitting motion to work spindles. In some designs, the end tool slide is held rigid by a guide arm (or shoe) which travels in a way under the top brace. The shape of the slide is a polygon with the number of sides corresponding to the number of spindles. On the surface of the polygon are fastened tools (turret types of tools) and different types of fastening provisions like dovetail slots, bolt holes, are provided. Tools move in and out at set strokes and for pre-set periods & they can be driven from camshaft that is attached to the gear-box or separately driven to allow for the selection of proper relative speeds of spindle and tools for various operations. The main and cross slides provide multi tooling positions for each spindle.

4.4.2.4. Spindles

Adequate provision is essential for supporting multi cut thrust on spindles, while each spindle thrust is taken

care of by thrust bearings, the overall thrust is catered for by rigidity. The main drive shaft and the meshing gears in the carrier are usually made of 4% Nickel Chrome Steel that is case hardened while the spindles are made of case hardened, ground mild steel.(14) The spindles run in two supports. In some designs, the front supports are double row roller bearings with tapered bore while rear are angular contact ball bearings. In other designs, the front are tapered roller bearings while the rear are sin-gle row roller bearings or tapered roller bearings, depending on the axial thrust expected. The bearings are preloaded in precision machines. For chucking unit it is usual to have the front support to be two tapered roller bearings mounted backing each other, while the back is a double row roller bearing. These support the heavy thrust generated by blank machinings. The work spindles contain collets tubes for bar works and chucks for chucking works. The collet tubes contain the spring collets at one end, the operating mechanism at the other end. The chuck can have automatic chuck operating mechanism, feeding fingers, and hoppers/magazine for automatic loading and unloading. At loading and unloading stations, there are disengaging clutches that bring the spindles to rest immediately they are indexed to the stations. The clutch can be electromagnetic, hydraulic, pneumatic or manual operated. It is usual to use the same type as that used for chuck operations. When the blanks in the magazine or the bar stock is finished, the machines are always equipped with proximity switch, photocell, toggle

switch or any other sensing device that stops the machine. The same device sends signals to a warning lamp.

4.4.2.5. Bar Feeds

There are many ways of bar feeds. Most of them are the same as those used in turret lathes. Some use cams mounted on camshaft. The cam operates lever that pushes forward the bar clamping finger. After the workpiece is chucked, the machine can be programmed for one or more operations before indexing into the next station. If the loading operation is long enough, the machine is indexed into the next station immediately the operation is completed.

4.4.2.6. Indexing

Indexing can be through Geneval mechanism, geared motor or maltese cross mechanism. For some machines, accurate and positive location is ensured by allowing the drum to move a little past its correct position and then drawn back into contact with hardened locator. Most of the machines use locating pins and clamping pads to ensure positive location and firm grips of the drum in each position. Before indexing, the clamping lever is released and the locating pin withdrawn. The Geneval indexing principle is as shown in Figure 47.

Arm N on the main camshaft engages in the Geneval cross slots formed on a plate bolted to the indexing gear which meshes with the gear Q of the spindle carrier. Lever L rocks freely on the indexing gear shaft and carries a roller follower at the two ends. One roller engages a slot in the locking pin D. As the arm N approaches

a slot in the geneval plate, the cam contacts the other follower of L causing the plunger to be withdrawn from one of the locating holes in the carrier disc. The roller of arm N then engages the geneval slot and rotates the indexing gear which in turn rotates the spindles carrier through one spindle position. The cam is then free from the roller and the plunger spings back to locate.

4.4.2.7. Cross Slide Feed

Except for the loading and unloading stations, every station has at least one cross slide, mounted in the front end of the headstock carrying form tools, parting off tools and other tools requiring only radial feeds. They, as well as end tool slides, always have rapid approach, slow cutting feed and quick return. The tool slides are independent unlike the end slides. Their motions are generally controlled from the main camshaft through lever system. In some designs the cams for the cross slides are fastened to a gear in mesh with another gear mounted on the camshaft. Because of the cost of cams and time wasted in cam calculation and set-up, the lever mechanisms in many machines are designed to allow for stroke variations (Figure 48).

This ensures that only few cams are stocked for many cutting operations and variation in strokes are only done by adjusting a link. It is usually provided with a micrometer scale to help in measuring this feed. It is usual to design them with constant rapid approach, which is affected by a different cam that tilts the link rapidly allowing for rapid approach while the feed cam takes over

after. Some Wickman multi-spindle lathes have a special feature of not using change cams at all(10) They have infinitely variable working strokes with constant idle approach. Changes in feed length are completely accomplished by sliding adjustments to lever arms. This is an improvement on the other sets that require some change cams.

4.4.2.8: End Slide Feed

Operations like straight turning hole drilling or boring, internal and external threadings are performed on the end (main) tool slide. The end tool slide generally moves as a block and all the end tools move together except the Alfred Schutte model which has a patent method of controlling the tool slides strokes independently trhough a simple sliding adjustment of connecting rods (or quills) along graduated scales.(17) This allows alteration to the tool feed strokes without affecting the fast approach and return of the slides. In some modern tools, the stems for the end tool slides are made stationary and each tool is moved in a groove cut in the stem through cam operations or hydraulic pushers. This allows for independent settings of the end tools. The hydraulic pusher is usually preferred as it allows easy automation and simplifies setting up thus reducing the setting up time. The end tool slides move along nitrogen hardened stems(the centre guide) and usually have wipers for prevention of the entry of swarf into the sliding faces. Each tool is mounted on the slides through dovetails or tee bolts.

They include shank type tools like reamers, roller boxes and knee tools. Except where the tools are supplied by machine tools manufacturer, the mounting for shank tools is often bored in position by mounting a drill in the spindle to ensure correct alignment between tools and spindle.

Generally the motion of the slide is effected from the camshaft. Like the cross slides, they usually have provision for rapid approach, slow cutting feed and quick returns. Most models have the approach stroke and work feed stroke adjustable through the use of stops and adjustable links. A typical example is as shown in Figure 49.

Here the rapid approach and withdrawal of end tool slide is effected by the motion of the carriage block actuated through a roller follower B by a cam on the camshaft. During this period, the feed lever is held stationary and the pinion attached to the block starts rotating as it moves along with it. This gear meshes with both the rack of the tie rod (RI) and that of the tool slide (R2). Since tie rod rack (R1) is stationary, rack R2 as well as the end tool slide travel a distance twice that of the carriage block. The rapid approach continues until the block runs against a stop screw (which is adjusted to give the stroke of the rapid approach Immediately the block is stationary, another cam on the camshaft actuates the feed lever which turns slowly. This movement pulls rack R1 which turns the pinion. Since the block is now stationary, the motion of the

pinion is transferred to rack R2 for end tool slide cutting feed. The feed stroke is set by adjusting the position of the rod in the slot of the lever and this is usually graduated. During rapid withdrawal, the lever and block return simultaneously to the initial positions.

Because the amount of adjustment on the feed lever is limited, stroke adjustment is limited and this requires the use of change cams for longer strokes. To avoid this, the Wickman machine uses a quadrant lever[5] (Figure 50). The stroke of the feed is adjusted by the position of the tie rod on the quadrant. The method of quick approach is as for other methods. The toration of the quadrant is controlled by edge cam A while the motion of the carriage block is controlled by cam path B.

When the follower F1 is at its dwell position (this position corresponds to the concentric path of A), the carriage block is pushed rapidly through its cam B and follower F2, moving the tool slide rack R2 and the slide with it at a motion twice the speed of cam push for rapid approach. At the end of the approach, the block is held stationary against a stop and cam A moves the quadrant through the follower F1. This pushes the tie rod and rotates the pinion in the block through the rack R1. The pinion pushes the rack R2 and moves the slide through its cutting feed slowly. The return is also rapid and both the block and the quadrant return simultaneously.

4.5 CAMMING IN MULTI-SPINDLE AUTOMATICS

As in other automatics, control of cam movements is

either directly or indirectly by the main camshaft. Cams for various machining positions are generally selected from a range of standard cams according to rise and feed required. The availability of standard cams has greatly enhanced the use of the automatic machines since the cost of producing one - off cam is usually highly prohibitive. In drum cams, cams are detachable so that different rise and feed can be obtained by screwing cam plates on to the cam drums which are fixed to the camshaft. A workpiece is produced per revolution of main tool slide cam, so all other cam calculations are related to this tool slide cam drum.

Operation for multi-spindles automatic machines revolves a lot on selection of cams having the right rise for the tool operating slides. This requires a lot of time during set-up and generally requires the use of inching motor or manual manipulation during set-up. This problem as well as the problems associated with tool set-up make the multi-spindles automatic very uneconomical for short runs. In the Wickman and Alfred Shutte patented models, this camming problem is greatly reduced by the use of adjustable stroke mechanisms.

Cams for loading and unloading are rarely changed since these operations are usually the same in most machining procedures.

4.6. ATTACHMENTS FOR MULTI-SPINDLE LATHES

All the work spindles of multi-spindle indexing lathes rotate at constant speed and are not reversed. (There is no provision for independent spindle drives). Because of this, special attachments are used on the

machines to give among other things, the correct relative speed and feed. Some of these attachments are: independent feed attachment, high speed drilling attachment, threading attachment, recessing attachment, and flat generating attachment.

4.6.1. Independent Feed Attachments: These are end working attachments used when the feed of any cutting tool is different from that of the main tool slide travelling on the central stem. The tool holder movement can be controlled through a lever system from constant work feed and return cam attached to a drum on the camshaft. The strokes are adjusted through adjustable levers. It is also possible to cam it independently of the main tool cam since the main aim is to change the length of travel of the tool so that the feed rate is different from others on the main tool slides. A typical method of achieving this is shown in Figure 51.

Sector S swivels through action of a cam about a fixed pin. The motion is transmitted through adjustable link L1 to lever L2 which is linked by tie rod L3 to the tool holder. L1 can be varied in the slot of S to vary the travel. L3 can also be extended forward or backward and the feed is spring loaded to give positive movements.

4.6.2. High Speed Drilling Attachments: Here the tools are driven in opposite direction to the spindle speed either through separate motor (air or electric) or gearing from the central shaft, using spinned shaft. The sum of the speed of the tool and that of the spindle (the relative speed of the two) gives the speed of cut. The speed ratio

can be changed using changed gears. Withdrawal of tool is done at the same time with withdrawal of other main tool slides. For reaming and low speed drilling of axial holes, the tool is held stationary. The drilling and reaming attachments are usually mounted on end tool slides or independent slide and are generally not used in the first working station. The use of independent slides for the attachment is common to allow for different feed rates.

4.6.3. Threading Attachment: Threads can be cut with self opening die-heads and self collapsing taps or with solid taps and dies. If solid taps and dies are used, method called the over-running method is used. The two methods require the rotation of the tool at the same direction as that of the work spindle but the over-running method employs two speeds of tool rotation. The motion is often got through gearings from the central shaft. It is usual also to use them with independent feed to allow for the different feed rates required. For self opening dies or self collapsing taps, the tool spindles are fed against a stop which trips the tool for opening or collapsing before quick return to initial position like other tools. The spindle speed is usually more than the tool speed and the relative speed is usually the difference between the two speeds (being in the same direction).

In over-running method, provisions are made for advancing the tool at the threading spindle speed and changing of speed at end of cut for backing out purposes. It is usual to have a starting cam which advances the work

rapidly. The lead of the tool then draws the tool to follow the thread so that the tap screws into or the die screws unto work at the correct speed of cut and feed. When the thread length is reached, a clutch is automatically engaged to increase the tool speed to more than that of spindle speed so that the tool withdraws from the work.

4.6.3.1. Kinematic For Threading Attachment

A typical kinematic for this is as shown in Figure 52.

The spindle and attachment rotate in the same direction. For the collapsible taps/self opening dies method, only clutch A is used throughout. But in over-running method, clutches A and B are employed. Clutch A is used to provide the cutting speed.

Thus if main shaft speed is 100 r.p.m., the attachment speed using the gearing indicated is $100 \times \frac{32}{44} = 73$ r.p.m.

The drum spindle speed is $\frac{100 \times 56}{40} = 140$ r.p.m.
The relative speed = speed of cut is 140 - 73 = 67 r.p.m.

In over-running method, when the withdrawal of thread is required, the clutch B is chosen. The spindle speed is still 140 r.p.m.

But the attachment speed is $\frac{100 \times 60}{31} = 193$ r.p.m.
The relative speed is 140 - 193 = 53 r.p.m. and this withdraws the threading tool.

Arrangements for change gears are also made so that different types of thread can be cut.

This kinematic also can be used to explain high speed

drilling arrangement except that the speed is opposite that of spindle. Since drills can be withdrawn without damaging the hole, they are withdrawn like other tools with no need for clutches.

4.6.4. Recessing Attachments: These are used to chamfer or groove the back end of a workpiece. The tool is secured to a block which can slide at any angle to the horizontal on a base block secured to the end tool slide. The sliding block is arrested by a stop on the upper cross slide of the machine so that as the end tool slide continues to feed forward, the cutting tool is plunged radially into the work.

4.6.5. Flat Generating Attachment: In the attachment the cutter head which is held on a cross slide rotates at twice the spindle speed in the same direction (Figure 53).

When a cutter with two diametrically placed tools is used, a square is generated. With three equally spaced tools a hexagon and with n equally spaced tools, we have 2n polygon. The surfaces are not very flat, but slightly convex, corresponding to an arc of an allipse.

4.7 TOOLS AND TOOLINGS

The operations performed on the multi-spindles are vircually the same as those on turret lathes. These operations include:

(a) Turning - external, cylindrical, tapered, formed surfaces and facing,

(b) Drilling - core drilling, off centred drilling, reaming, cylindrical and tapered boring.

(c) Turning - annuler grooves, fillets and corner radii, recessing and chamfering.

(d) Cutting - external and internal threads.

(e) Thread rolling and knurling.

(f) Parting off.

External surfaces are generally turned from end slides. Central holes are drilled or bored by end tools which are also used for knee turning, reaming, and counter boring. Threads are generally cut by tools mounted on end tool slides (like solid taps and dies, self opening dies and collapsing taps), but on some occasions threads are cut by tools on cross slides like threading rolls, chasers and single point threading tools. For single point thread cutting, the machine must have provision for lead screw which is usually provided as a form of attachment. Cross slides are used for parting off, chamfering, form turnings and shaving.

4.7.1. End Working Tools

The cutting tools are similar to those used on turret and capstan lathes. They are secured in holders mounted on end tool slides or clamped in cross slides. The end tool slides are in every respect similar to turrets except that they do not index. For end working tools, to provide accurate alignment, the holders are sometimes bored in position. Drills are held in simple holders clamped rigidly to the slide since they do not rotate (except in high speed drilling) and are fed forward with the holder. To allow for floats when reaming and tapping, self aligning holders are sometimes used.

4.7.2. Turning

Turning tool may be of the box type with roller

follower support fed from end tool but most turning is done through form tools fed from the cross slide. Roller steady turning tools are used for machining bars or slender work and are either base mounted or shank mounted. There are some roller steadies without turning tool used as support for forming operations.

4.7.3. Tool Holder Mounting

End tools holders are sometimes bolted on Tee slots or through flanges to the faces of the polygon shaped end tool slides which slide on hardened stem. Cross slides holders include form tool holders that are either tee slot bolted or dovetail holders and other standard tool holders. The tools for cross slides are mounted almost as they are done on lathes.

4.7.4. Form Tools

Form tools are either flat or circular. Flat form tools are easy to make and are generally used for machining deep grooves as they can be given side clearance but circular form tools maintain form for longer period.

4.8 OTHER GROUPS OF MULTI-SPINDLE LATHES

4.8.1. The Multi-Spindle - Vertical Lathes - These are for mass production of large parts and are generally semi-automatic (loading always done manually). The setting up is also time consuming so their applications are only effective for mass production. They are chuckings and work is rarely done between centres. They are used mainly in automobile and tractors industries as well as in other heavy mass production shops.

They are basically the same as horizontal types but

they are designed to operate in a vertical position so that the end tools are arranged about a vertical column (corresponding to bed). They are heavier, more rigid and more powerful than the horizontal types and are designed for machining larger diameter blanks of relatively short lengths. These machines have a number of vertical work spindles arranged about a P.C.D. in a drum which is rotatable about a vertical axis. Generally, one station is for loading and unloading. This station has no end tools but has facilities for cranes, forklifts, and other heavy machinery handling equipment. They generally have some horizontal slides that act like cross slides arranged radially about the spindles. Some spindles can have more than one of such slides.

4.8.1.1. Types of Vertical Multi-Spindle Lathes

They could be multi-station progressive action type like the indexing horizontal multi-spindles, or continuous action. The continuous action types are the equivalent of the parallel action horizontal types. Because of the need to have only one loading and unloading bay, the continuous action type is designed in such a way that the tooling column indexes or rotates continuously as the spindle turn-table moves, so that a tool station starts and finishes all the work necessary on a blank. They usually have two columns - a stationary inner column and the rotating outer column which is made integral with the turn-table carrying the spindles. Vertical multi-spindle lathes are classified according to their number of spindles and they are sized according to the max. dia. of work that can be machined on them.

4.6.1.2. Advantages Of Vertical Multi-Spindles

The major advantages of vertical multi-spindles over the horizontal types include:

(a) easy accessibility of loading - they are more convenient to load and unload;

(b) they have horizontal turn tables so that weight reaction can be better supported through thrust bearings, washer or roller contacts - allowing them to support heavy weight and the spindles are not under any bending loads from the weights of the workpieces;

(c) the spindle carrier can be made very large to allow for larger PCD of spindles so that heavy end working slides can be fitted and also to increase space for special tooling arrangements;

(d) they occupy very much less floor space than horizontal types of the same capacity, though they require higher work bays;

(e) loading tackles like cranes, forklifts can be easily used;

(f) the operator has easier access to the spindles and a better view; this facilitates loading, unloading, resetting and supervision of operations;

(g) any heat generated in swarf will only affect the front face of headstock and cannot cause thermal deformation of machine as when hot swarf drops on bed of horizontal lathes;

(h) swarf removal is easier without need for designing special shaped column.

4.8.1.3. General Features

As in horizontal multi-spindle lathes, all end working tools can operate at the same time. Slides can be transversed by cams or by individual electric motors. The rapid idle motions can be through electric motors or by linkages and gearings with over-running clutch arrangements. Safety interlocks are provided to ensure that conflicting motions cannot be engaged simultaneously. On rare occasions, the machines are made fully automatic so that the operations that need be done by an operator are emptying of finished good hopper and loading of the load magazine. Owing to the sizes of workpieces, however, the loading and unloading are rarely automated. At the loading and unloading stations of both types the spindles are stationary and it is usual to have a safety limit switch attached to a guard which must be closed before operating cycles can be started. In progressive types, this guard must be closed before the machine can index. This ensures the safety of the operator and the proper positioning of the workpiece, when loading. Some progressive machines (with even number of spindles) can have double loading stations. Here, controls are placed in the two stations and work does not commence until the guards of these stations are closed. Double loading is necessary when two workpieces per cycle are needed or when a work requires being reversed for back side operation. The tools are like those for the horizontal types but broad forming tools are rarely used. Guiding attachments and other attachments are frequently used as well as various types of tool holders, including those incorporating

automatic relief of the cutting tools when tool mark on tool withdrawal is to be avoided.

4.6.1.4. Operations

The operations generally performed on them are straigh" turning, facing, boring, recessing, reaming, core drilling, and spot facing. Threading is rarely done. As for the horizontal indexing type, in progressive vertical lathes, time required to machine a piece is the sum of machining time of the most time consuming (limiting) operation and the time required for idle motions (indexing, locking tool withdrawal, etc.); and if an operation is too long, it is also divided up and performed in more than one station . Loading and unloading are done while other operations are on and these are usually the most time consuming operations. In the continuous action, just like in the parallel action horizontal multi-spindle, the operation is like that of a collection of vertical lathes arranged around a rotating base so that each lathe comes in succession to the loading/unloading bay.

4.6.1.5. Basic Constructions

The progressive and continuous types have the same basic construction, except that in the progressive type only one stationary column is used, while in the continuous type, two columns are used - one inside the other. The outer one indexes as the work indexes (or moves continuously as the spindle carrier), " while the inner one is stationary. To turn continuous action machine to progressive type, all that would be done is to hold the outer column stationary and index the spindle carrier. The two types

consist mainly of a base, carrier with spindles, columns and tool slides, feed mechanism with speed and feed gear-boxes, main drive, reducing gears and cam drums. Cams are fastened to the drum by screws and the drum is driven by a shaft from either speed or feed gear trains. The columns and the carriers are mounted on the base. The hydraulic, coolant, lubrication pumps, chuck control pedals, and other auxiliaries are usually mounted on external pads around the base with spindle brake, carrier clamping and lifting cylinder, inside the base. The mechanism for indexing and locking the spindle carrier can be mounted on the base. In some designs, where the motor is mounted on top of the column, the speed gear-box and feed mechanisms are also mounted on the top. Where motors are mounted at the base, the gear-box and feed mechanisms are arranged below the carrier at the base of the machine.

For very heavy machines, controls are electro-hydraulic with chucks being operated by hydraulic. Indexing is generally through Geneval mechanism but can be through cranked mechanism, and it is done after the last tool is withdrawn. Tool slides of heavy machines can be hydraulic operated or driven through powered screw and nut. Tool slides are rigid and they travel on hardened ways. They also have rapid approach, slow work stroke and rapid return and these are generally achieved through cams and linkages. Trip dogs are used as position indicators.

The base has a sump for coolant. The tools column is a truncated cone at its lower part and a polygon at the upper. The inner column of the continuous type is cylindrical at the upper part. The number of sides of polygons of

the tool column corresponds to the number of stations. Slide ways are fastened by screws to these faces, except at the loading stations of the progressive types. The feeds of the column slides are vertical but arrangements can be made to feed them cross-wise or both (compound).

4.8.2. PROGRESSIVE ACTION VERTICAL MULTI-SPINDLES

The general block diagram of a progressive action vertical multi-spindles are as shown in Figure 54. Here as the work spindles index from one station to another, some machining operations are performed in accordance with the set-up of tools in that station. The tools are on slides that slide along a fixed column providing the vertical end workings. Some machines have horizontal cross slides arranged around the turn-table. As for most vertical multi-spindles, one station is used for loading and unloading. This station has no tool slide but has material handling equipment for these operations. At the loading bay the spindle is made stationary, in many ways: some machines incorporate a clutch which is disengaged at the loading station and engaged at other stations, through the action of a cam, trip dog and limit switches (for electro-magnetic clutches).

In other machines, the spindles are driven through rotating disc, attached to the spindle that drives through engaging catchments of another disc - the drive disc. The drive disc is always rotating and the spindles are either slightly raised or the drive discs slightly lowered to disengage spindle drives. This is always done before indexing, so that at the loading station,

all that is done is to keep these discs disengaged. The drive discs are lowered in machines designed for heavy workpieces.

Automation is generally through mechanical means though electro-pneumatic, electro-hydraulic, and numerical controls have recently been introduced. Where the drive motor is mounted on top of the column, transmission is done through a drive shaft which passes through the centre of the column to the spindles. Feed can be through cams attached to the central shafts or nuts and screws driven by separate motors. Change gears are used to set spindle speed and tool feed.

4.8.3. CONTINUOUS ACTION MULTI-SPINDLE LATHES

For the continuous action type (Figure 55), the design is to allow for simultaneous rotation of the spindle carrier and the column, so that the same tool head starts and finishes work on the workpiece.

The continuous rotation introduces a loading problem as loading is done in a zone while the carrier is gently revolving. Machining of a workpiece is finished when the spindle carrier rotates a full revolution, so that as the spindle enters the loading zone, machining is completed and the tool withdraws. The spindle rotation stops, the clamp on the workpiece is released and the job is removed while a new blank is loaded. The clamping is done automatically and the spindle starts rotating immediately the guard is closed. The tool is advanced as soon as the machine leaves the loading zone.

The inner column is mounted on the base and it serves as a pivot about which the spindle carrier along with the outer column rotates. The motor is usually mounted besides the base. Change gears are also used to set spindle speeds and tool feeds.

In the continuously moving type the carrier and outer column are rotated together by a motor different from the main drive. They have gear trains and change gears for speed changes. This speed dictates the cycle time. The main tool heads are operated from the cams of a stationary drum through follower rollers and linkages(Fig.56)The drum is stationary since the column rotates thus carrying the follower along. The tool head travels on guides in the outer column. In the indexing type, the carrier and column are indexed through Geneval mechanism. Feed can be through camshaft from the main gear train or by separate motor.

4.8.4.

Many end working attachments used in horizontal multi-spindles are used. One attachment that is specifically used on the vertical multi-spindles is that which converts vertical feed (longitudinal) of the tool slide to horizontal (cross) or compound (horizontal and vertical) feed. The horizontal feed is got through linkages from the vertical travel of a bracket fastened to the tool head (Figure 57).

The bracket B with an adjustable tie rod T is actuated by the feed drum cam, for vertical movement. This moves plate P which has inclined slot for a follower F

secured to the tool slide S so that when the plate moves down or up, the slide travels right or left. The tool slide is in a guide for pure horizontal movement. If this guide is not fixed then the motion will be horizontal and vertical (compound). This attachment is used where there are no facilities for independent cross slides

It is possible to have multi-tool set-up as in the other types, and tracer controlled copying attachments can be used on these machines.

4.9 GENERAL

It has been seen that the economical advantages of multi-spindles lathes have been increased by the use of attachments and mechanisms for making non-machining time short. Machining time has also been greatly reduced by the use of ceramic tools that permit high work speed, deep cut and high feed.

A maginal problem in production of machined parts is that of chip disposal and its solution is necessary for production under high cutting rates. Chips have to be removed from the cutting site as rapidly as possible to prevent excessive workpiece temperature. Even where chip configuration is unfavourable, free fall of chips has to be ensured. This leads to the use of mechanical aids like vibration belt or screw conveyors and other mechanisms to prevent dangerous accumulation of chip in front of the cutting site.

Because of the quickness of indexing and clamping of spindle carrier, this time is often negligible. It

can then be said that a multi-spindle of n spindles will speed production up by (n-1) times that of a single spindle equivalent. This is allowing for a station to be used for loading and unloading, where automation is full, it is possible to increase the ratio to n.

CHAPTER FIVE

5 - DESIGN CONSIDERATIONS

The first major consideration for this project is to increase the productivity of a universal lathe machine. Attachments are always in use to effect this increase. In addition to the attachments described earlier, some attachments have been made to convert them to "CAPSTAN" and "TURRET" lathes, but none has been designed to make them have multi-spindle output. An initial decision was made to look into the possibility of making such attachments and to confirm if the attachments would be useful.

Through visits to the machine shops of some industries in Lagos, Port-Harcourt and Ibadan as well as some production workshops, it was found that none of them had multi-spindle lathes and only very few of them had capstan or turret lathes. Most of them have a few lathes, a milling machine, one or two drilling machines, a shaper and a power saw. The most common lathes in these shops are the medium sized lathes that swing about 400 mm diameter of work above the beds. In many cases these lathes are made to handle small jobs that are usually required in some quantities. Though the machine has the capacity to take many of these jobs simultaneously, because they have only one spindle, they can only be used for one at a time. This is a waste of power, time and money. Unfortunately, the machines are used most of the time in this fashion. It

is not possible to justify the purchase of multi-spindle lathes for such jobs as it will be uneconomical to buy such expensive machines (which is about five to ten times the cost of a lathe of the same capacity) unless they will be used all the time. Multi-spindle lathes are not used for short run jobs.

5.1 PERSONAL EXPERIENCE

My personal experience at Dunlop Nigeria Industries Limited, Ikeja, where I work, shows that there are times one wishes the company has multi-spindle lathes. Such times are not many, so one cannot justify the wish. A good example of such a time is during the annual maintenance shut-down of the company. In this period, many repetitive machining jobs are done. One of these is the making of "floating roller" bush for a cooling conveyor. This conveyor is immersed in water and the floating rollers are to support it in water. The rollers are supported by plain bushes 20 mm bore, 40 mm outside diameter and 20 mm long, made from bronze. There are over 300 pieces to change. With the pressure of work on the machine shop, only one lathe is usually available for this job. This means 24 hours per day machining. This experience will be common to many industries, confirming a need for an attachment that can turn the Universal lathe to multi-spindle lathe. If the attachment is not costly, it will have a very big market in the country.

Though this country has been used for feasibility

study, the attachment will have markets in other countries, even in developed countries, since not all their industries have multi-spindle lathes.

5.2 CONDITION FOR MARKETABILITY

Having decided that a multi-spindle attachment to lathe machine is to be designed, to appeal to the market in view (e.g. Dunlop Nigerian Industries Limited and many other production workshops), the attachment must be:

(a) simple to operate - it should be manual

(b) reliable and rigid - machine tools are usually designed for abuse and mis-use - the attachment must be designed with a very large factor of safety (2 and above); this will make it reliable and durable; the more rigid it is, the less the chances of vibration. care must be taken, however, not to make it too heavy;

(c) inexpensive - the avoidance of complicated parts will make the attachments inexpensive; if it is costly, it will not appeal to small workshops, which are many in industrial areas; if the cost is below ₦500.00, it will have a good market;

(d) standard - it should meet the standard required of machine tools; that is, its spindle must run true in precision bearings and it must be rigid; the work clamping device must be standard; it must not produce chatter;

(e) easy to mount, so that little time is lost in

mounting and dismantling it; provision for quick mounting on various types of universal lathes must be made.

5.3 TYPE OF ATTACHMENT CHOSEN FOR DESIGN

(a) Although tooling efficiency is high in Capstan lathes and these lathes have considerable higher productivity than the Universal lathes, attachments to convert centre-lathes to these types of lathes were not considered becasue they have a disadvantage in that the time for setting workpiece as well as unloading it is additional to machining time. This is the basic advantage a multi-spindle lathe has over the Capstan or Turret lathes. Furthermore, these types of attachments are already available.

(b) In the parallel action multi-spindle lathes, the workpiece stays in a station and all the machining operations are performed in it. It has many spindles with idential operations. If a parallel action multi-spindle attachment is designed, it will be as if the lathe is turned to a number (depending on the number of spindles) of lathes performing the same job simultaneously. It is even possible to have indexing tool holders working on the workpieces to make it a collection of Capstan Lathes. The design of this attachment would be very simple since there would be no need for indexing. It, however, suffers again from the limitation of having loading time being additional to machining time.

Owing to the limitations given, the parallel action type was not accepted for design.

The need to load and unload workpiece into one spindle while work is on at the other spindles, means that a multi-spindle attachment with indexing facilities is to be designed. The spindle at the loading and unloading stations must be stationary.

5.4 NUMBER OF SPINDLES

The number of spindles considered for this proposed attachment were six, five, four, and three; with one idle station, the working stations were therefore five, four, three and two respectively. Owing to the similarity of the design of six and three spindles, these were chosen for the design. While the six-spindle attachment provides better productivity, the complications involved in the manufacturing and tooling arrangements made the three-spindle attachment to be chosen as first trial for the proposed prototype.

5.5 THE DRIVE FOR THE PROPOSED ATTACHMENT

In multi-spindle lathes, the drive is taken from the gear-box through a central shaft to the spindles. The central shaft carries a gear that meshes with the spindle gear (see Fig. 44). This method is to be used in our proposed design. The lathe spindle is to be connected to a drive shaft. The drive shaft will carry a gear that will transmit power to the spindles. If all the spindles are to rotate, then the gear of the drive shaft would mesh directly with the spindle gears. This is possible also if all the spindles are to have clutches so that at the loading station the clutch would be disengaged. This will make the design costly. The

method used in some vertical multi-spindle lathes is to lift a catching plate of the spindle from the constant rotating drive disc. Arrangement for this method will make the design cumbersome.

To have the desired stationary loading station, the idea of non-indexing intermediate gears is brought into use (see Drawings 001 and 005). These intermediate gears will transmit drive from the drive shaft gears to the spin-dle gears. All that is done is to ensure that the intermediate shaft is not fixed in the loading station (see Fig. 58).

It would, however, become necessary to stop the lathe while indexing so as to allow for meshing of gears. The lathe brake will provide effective brake for the spindles. This arrangement makes the attachment spindles' rotation to be the same as lathe spindle. The drive shaft is to be rigidly secured to the spindle nose. Since no spindle nose is in mind, a connecting adaptor is brought into play. This adaptor is to be made to suit the drive shaft and the lathe spindle nose. This is to be made by the user (who has the knowledge of the spindle nose thread or flange).

For the prototype testing, one of Ahmadu Bello University Production Laboratory lathe was chosen. The adaptor was therefore to be made to suit this lathe spindle flange. The lathe is made by ANDRYCHOWSKA FABUYKA MASZYN METAL export WARSZAWA of Poland, Type TUE 40 NR FABR 9063. This swings 400 mm above its bed and has detachable bed to provide gap. (See Plate No.2).



PLATE 2 A.B.U. PRODUCTION LAB. LATHE

5.6 INDEXING

To index, the spindle is fixed into a carrier which indexes in a housing (the support). This indexing is to be made by hand. Since the spindle is to be stopped before indexing, the spindle can be used for the manual indexing. This will become more difficult to do as the number of spindles increases, especially if heavy work holding devices are used. There will be a need to incorporate a crank arrangement or a pinion and wheel arrangement. The wheel will be attached to the carrier while the pinion will be held in the support. The carrier must be positively located so that the spindles are presented to the tools accurately. The locating method to be used is the one used in most of the square turrets i.e. spring loaded ball and hole arrangement.

When the indexing is done, the carrier is to be clamped. This is to be done through grub screw fixed into the support. Since the intermediate gear is not to index, this should be rigidly held in the support.

5.7 MOUNTING ON THE BED

The support is to be mounted on the lathe bed. This is to be done through a rod screwed to the housing. This can then be clamped through a clamping plate to the bed. The rod is to have thread for nuts that will be used to clamp the plate to the bed. The clamping plate can be made of standard size, though this can be modified by the user.

5.8 WORK HOLDINGS

The choice of work holding devices is to be guided by consideration of the type of market/users that attachment is designed for. The simplicity of chucks and their adaptability to a wide range of workpieces make them better than collets. Though collets have positive grips and need no complicated setting up, the design of collect opening devices will make the attachment costly. Furthermore, if collects are used there is need for large members to be kept for a small range of sizes of workpieces. This will be more costly than chucks. Tapers are, however, to be provided in the spindle bore to accommodate collets and centres. If this is not done, collets can be accommodated through the use of collets adaptors which can be screwed to spindle nose or bolted to spindle flange.

Having decided to use chucks, let us consider the four main types of chucks - Pneumatic, Hydraulic, Magnetic and Manual Chucks.

5.8.1. PNEUMATIC CHUCKS

These have lots of advantages like energy and time saving over manual chucks, but are generally very costly. Furthermore, they require the use of air compressor, the cost of which will make the attachment very costly. They need valves and other accessories. These types of chucks are very bulky, and will make the attachment cumbersome.

5.8.2 HYDRAULIC CHUCKS

These are even bigger than pneumatic chucks

and they require, apart from many valves (directional and interlocked), a hydraulic pump complete with motor and tank. This will also make the design very costly.

5.8.3. MAGNETIC CHUCKS

Magnetic chucks can be of permanent magnets or electro-magnets. Because works are rotated, magnetic chucks are rarely used in lathes.

5.8.4. MANUAL CHUCKS

These are the familiar types of chucks and they have either independent or self-centring jaws. They require manual operation and are therefore not quick at clamping. However, since the loading and unloading are to be done when other works are being machined, this will not be an inhibiting factor.

For ease of setting up, the independent jaw types are out of consideration, leaving us with the 3-jaw or 4-jaw self-centring chucks. These are not expensive and are available locally. For instance, a 3-jaw 100 mm chuck can be obtained in Nigeria for less than ₦100.00. With the high cost of articles in the country, the prices should be much less in other countries.

5.9 DESCRIPTION OF THE PROPOSED ATTACHMENT

With all the above considerations, the attachments designed are as shown in our drawings numbers 004 and 001 for three-spindle attachment and 005 for the six-spindle attachment. The design is based on the attachment being used on medium sized lathes that swing up to 400 mm workpieces above their beds. These are the most

common lathes in this country. For it to be used on bigger lathes, the mounting screw is threaded for its full length. It can also be used for smaller lathes with gap arrangements.

With reference to drawing No. 001, adaptor part number 1 connects the drive shaft (item No. 2) to the lathe spindle. The drive shaft is supported by two bearings, one in the support (the housing item No. 3) and the other in the spindle carrier (item No. 4). This ensures that the carrier indexes true to the drive shaft. The drive shaft carries gear that meshes with intermediate gears (item No. 6). These gears transmit power to the attachment spindle gears.

The spindle gears are of the same size with that of the drive shaft, so that the speed of the attachment spindle (item No. 5) is the same as the lathe spindle. The spindles are supported by two bearings, one a roller bearing and the other a tapered roller bearing (to cater for axial thrust) inside the spindle carrier which indexes in the support. The spindle noses are tapered to morse 6 to allow for the use of collets and centres. The carrier is located by spring loaded ball arrangement and clamped by a grub screw (item No. 11). The support is mounted through screw (item No. 19) clamping plates (items Nos. 21 and 22) and nuts (item No. 20), to the lathe bed. When the attachment is mounted on the lathe, care must be taken to support the weight and not to create any strain on the lathe spindle. This is important when a smaller lathe is to be used.

All exposed bearing holes were covered with cover plates which are also used as retainer for the bearing outer shell.

5.10 MAXIMUM DIAMETER OF WORK THAT CAN BE SWUNG

To allow for chuck indexing, the pitch circle diameter of the attachment chuck centre cannot be more than 300 mm about the lathe centre if a 100 mm chuck is to be used. This was, however designed to be 200 mm.

For 3-spindle attachment, the angular distance between two adjacent chucks is 120°. The chuck centre is 100 mm from the lathe centre. From Fig. 59, it follows that the maximum diameter of workpiece that can be swung is 2x.

$$x = 100 \sin 60$$

$$= 86.6 \text{ mm}$$

$$2x = 173.2 \text{ mm} \quad \text{Say } 170 \text{ mm.}$$

Since only two spindles are operating at the same time, the overall effect on the spindle is less than that of machining a 400 mm workpiece of equivalent material at the same speed by the lathe. If the attachment is used on larger lathes, there is no problem. Where it is used on smaller lathes (gap types or those with removeable bed to create gap), procautional care must be taken to ensure that maximum diameter of workpiece that would be swung by each chuck is not more than half the maximum swing diameter recommended for the lathe.

In a six-spindle attachment, included angle is 60°.

Therefore $x = 100 \sin 30$

$$= 50$$

$$2x = 100 \text{ mm.}$$

5.11 SWARF REMOVAL

This is not a problem in the 3-spindle attachment since the two working stations are in the same horizontal plane and there is no possibility of swarfs falling on another cutting tool. The disposal is therefore the same as used in the universal lathe itself. The amount of chips is relatively small as the size of workpiece is small. The lathe brushes can handle these chips effectively. For six-spindle attachment, swarf disposal becomes a problem as arrangement has to be made to prevent swarfs from falling on the cutting station directly below another cutting station. A simple method is by making trays out of galvanized sheet, and attaching these trays to the tool holders in such a way that they inclined downwards away and are directly under the tools. This will reduce slightly the diameter of workpieces that can be machined. The swarf is made to fall outside the machine and can be collected by the machine operator.

5.12 LUBRICATION

The design does not incorporate any oil or grease nipples as the attachment is expected to be pre-packed with grease. Though it can be treated as a gear-box and filled with oil, this will require the use of mechanical seals on the shaft, since there will be excessive leakages otherwise. Seals will increase the cost of the attachment. When grease is used, the covers will need to be stuffed with felt to disallow escape of grease. The moving surfaces for indexing will need grease supply; this can be applied by unscrewing the clamping grub screw

and packing in grease through the holes, or through grease nipple.

Though the grease required for the gears is the open gear type, grease like Mobilac mm or National Cadium compound D, the grease required for the bearings should be soft type, National Darina grease that can withstand some increase in temperature. A comprimise grease that can be used is the Mobilplex 48 which is readily available locally.

5.13 COOLANT SUPPLY

The supply of coolant can be made by installing an adaptor to the nozzle of the existing coolant pipe. This adaptor can have two heads for the 3-spindle attachment or five heads for the six. The adaptor is best made by the machine user since a knowledge of the type of coolant pipe supplied on the machine is necessary. It may require disconnecting the single head pipe and replacing it with the appropriate multi-head type.

5.14 TOOLING

For the 3-spindle attachment, the simple four-station tool holder usually supplied with the lathe can be used (a two-station holder can also be used). This can be clamped in the middle and tools held to cut in the two stations. It will be necessary to educate on the fact that in this case the tool cutting on the front spindle has to be inverted (Figure 60).

If the lathe has front and back tool holders, then front can be used for front spindle while the back is

used for back spindle. In this case the back tool has to be inverted (Fig. 61) as most machinists should have known. Arrangement for end working can also be done. The centre heights of the spindles are lower than that of the lathe.

For the six-spindle attachment, the situation is not as simple. This will require replacing the existing tool station with one designed in line with those used in multi-spindle lathes and the tool carrier attached by a rigid support to main slide which will be held in the centre (Figure 62). This arrangement will, however, limit the amount of cutting forces that can be exerted on the workpieces. Both end working tools and side working tools can be used.

CHAPTER SIX

6 - DESIGN CALCULATIONS

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	NOTE:- (1) The standard hand-books available are in imperial units, so all calculations were done in imperial units, while the solutions were converted to metric. (2) All Part Numbers are as shown in Drawings Nos. 001. 002 and 003.	
	ITEM NO. 1: CONNECTING ADAPTOR The connecting adaptor was made to connect to the back plate of the lathe chuck of one of the production laborator lathes at the Ahmadu Bello University. This has six tapped holes M10 at 175 mm PCD for the existing flange of the lathe. The lathe chosen is a TUE 40 Centre Lathe of Andychowska Fabryka Maszyn Metal Export of Poland Fabr. No. 9063. This lathe swings 400 mm of work above its bed. (See Plate 2). Since the design has no particular lathe in mind, the adaptor should be provided by the user to	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	match the lathe that the attachment is to be used on.	

ITEM NO.12: DRIVE SHAFT BOLTS

The drive shaft connects rigidly to the adaptor by four bolts at 50 mm PCD. They connect through abutment which provides frictional force to help in providing additional drive torques to those provided by the drive bolts.

The bolts' resistance to shear force and their frictional forces provide the main drive torque.

Ratio of torque transmitted by friction (T_f) to those transmitted by shear (T_s) is given by

$$\frac{T_f}{T_s} = \frac{N\, d^2 S_t\, f}{N\, d^2 S_s} \qquad (18)$$

where

N = No. of bolts

d = Diameter of bolts

S_t = Tensile stress

S_s = Shear stress

f = Coefficient of friction

Take $S_t = S_s$

Take $S_t = S_s$

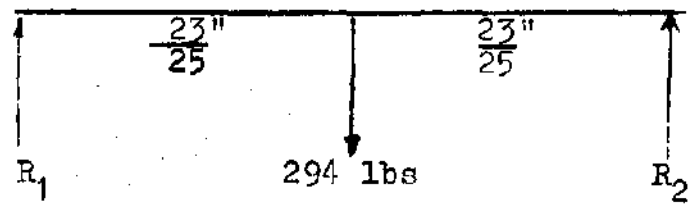
Note S_t is greater than S_s and this improves the value of $\frac{T_f}{T_s}$

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	Then $\frac{T_f}{T_s}$ = f between f ∠ steel is approximately 0.15 (18) $\frac{T_f}{T_s} = 0.15$	
	Total torque transmitted by bolts T_B $T_B = T_f + T_s = 1.15\ T_s$.	
	All frictional torques are neglected and attributed to the margin of safety.	
	Than $T = T_s$	
PCD of bolts = 50 mm	Shear force $F_s = T_s \div \frac{PCD}{2}$	
H.P.= 10 η = 70%	Take design horse power to be 10. (This is about the H.P. of medium sized lathes that swing 400 mm over beds). Take efficiency at spindle nose to be 70% of the main drive.	
	. . H.P. at spindle nose is 7 h.p. Torque is give by $T = \frac{6300\ h.p.}{r.p.m.}$ (19)	
r.p.m. = 1000	where r.p.m. is spindles revolution per minute. Take r.p.m. = 1000 rpm (optimum speed) $T = \frac{63000\ h.p.}{1000} = 441$ lb-in.	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	$\frac{PCD}{2} = \frac{50}{2}$ mm = 25 mm = 1 inch.	
	$F_s = \frac{T}{1} = 441$ lbs	
	$F_s = \frac{\pi d^2 S_s N}{8}$ (18)	
	$\therefore\ d^2 = \frac{8 F_s}{\pi S_s N}$	
N = 4	Screws are made from SAE 1035 (20)	
S_u for	with ultimate tensile stress (S_u) of	
SAE 1035	30 tons/in^2 = 67200 lb/in^2 (13)	
= 67200	Allowable shear stress $S_w = \frac{S_u}{2n}$ (19)	
lb/in^2	n = factor of safety	
n = 2	Take n = 2	
	$S_w = \frac{67200}{4}$ lb/in^2 = 16800 lb/in^2	
	Take S_w = 15000 lb/in^2	
	$d^2 = \frac{8(441)}{4\pi(15000)} = 0.0187$ in^2	
	d = 0.137 in = 3.42 mm	d=10 mm
	Use M10 allen cap screws.	Screw = M10
	ITEM NO. 7: DRIVE GEAR	
	For simplicity of manufacture, and because shaft/spindles in the attachments have parallel axes, spur gears are chosen.	
	Lewis formula can be used to get the pitch. From standard tables, however, the maximum diametral pitch	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
PCD of gear = 75 mm	to transmit 7 h.p. is 10. (19) If PCD = 75 mm = 3 in No. of teeth, $N_t = 3 \times 10 = 30$ With $N_t = 30$ PCD = 75 mm Module is $\frac{75}{30} = 2.5$ mm Minimum width is 4 x module (19) $\simeq 10$ mm Width of gear, w = 20 mm	$N_t = 30$ Module = 2.5 mm Gear width w = 20 mm
Density of steel = 0.284 lb/cu-in	<u>ITEM NO. 2: DRIVE SHAFT</u> The drive shaft is to be supported by two bearings 46 mm apart and it carries the drive gears midway between the supports. Density of steel is 0.284 lb/cu-in. The gears are 75 mm PCD; 20 mm thick Assume bore of the gear to be 25 mm = 1" Volume of gear is $\frac{\pi}{4}\left[(\frac{75}{25})^2 - 1^2\right] \times \frac{20}{25}$ $= \frac{\pi}{4}(9 - 1)\frac{20}{25} = \frac{8}{5}\pi$ = 5.03 cu ins. Weight of the gear is 5.03 x 0.284 lbs = 1.43 lbs. Take maximum diameter of drive shaft to be 50 mm = 2".	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	The shaft length between supports = 46 mm $\doteq$ 2"	
	Volume of shaft between supports $= \pi(\frac{2}{2})^2 \times 2$	
	Weight of shaft between supports $= 2\pi(0.284)$ lbs = 1.781 lbs.	
	The weights of shaft and gear are therefore negligible.	
T = 441 lb-in.	Torque on gear, T = 441 lb-in	
PCD of gear = 75 mm $r = \frac{75}{2}$mm	Force on gear, $F_g = \frac{T}{r}$ where r = radius of gear. $r = \frac{75}{2}$ mm = 1.5 ins $F_g = \frac{441}{1.5}$ = 294 lbf	
	The total concentrated load acting on the gear is 294 lbf.	



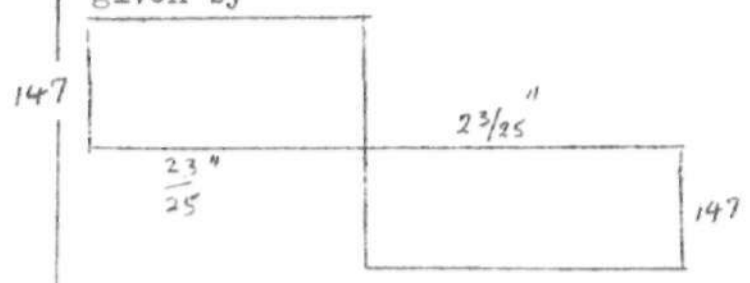
FORCE DIAGRAM ON DRIVE SHAFT

R_1 is reaction of first bearing

R_2 is reaction of second bearing

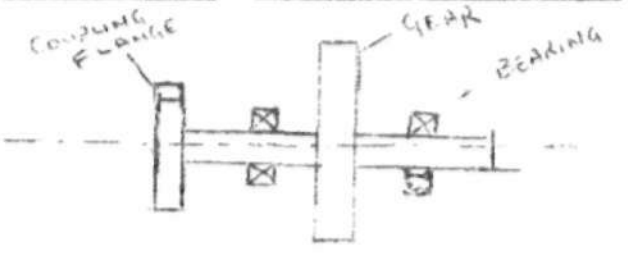
Since the gear is midway between supports, $R_1 = R_2 = \frac{294}{2}$

= 147 lbs.

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	The Bending Moment diagram given by	
	 BENDING MOMENT DIAGRAM OF DRIVE SHAFT.	
	Maximum Bending Moment, M $= 147 \times \frac{23}{25}$ lbf-in $= 135.24$ lbf-in	
T = 441 lb-in	Using Maximum Shear Theory Equivalent Torsion, $Te = (M^2 + T^2)^{\frac{1}{2}}$ (19) $= \left[(135.24)^2 + (441)^2\right]^{\frac{1}{2}}$ $= 461.27$ lb-in	
	Diameter of shaft d_s is given by $d_s = 1.72 \left(\frac{Te}{s}\right)^{\frac{1}{3}}$ $= 1.72 \left(\frac{Te}{s}\right)^{\frac{1}{3}}$ (19)	
	where s = allowable stress.	
$S_u = 30$ tons/in^2	The shaft is to be made from BS en 8 alloy steel with ultimate stress, $S_u = 30$ tons/in^2 (13) $= 67200$ lbf/in^2.	
n = 2	Allowable shear stress, $S = \frac{S_u}{2n}$ (19) n = factor of safety	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	Take $n = 2$ $S = \frac{67200}{4}$ lb/in^2 $= 16800$ lbf/in^2 Take $S = 15000$ lb/in^2 $d_s = 1.72 \left[\frac{461.27}{1500}\right]^{\frac{1}{3}} = 0.54$ in $= 13.47$ mm Take another factor of safety $d_s = 26.94$ mm Take $d_s = 30$ mm. There is no need to calculate the effect of key on the strength of shaft, since the shaft is solid and it is over-designed.	Diameter of shaft $d_s = 30$ mm

ITEM NO. 27: DRIVE SHAFT BEARING



BEARING REACTION

Though a part of the overall reaction is taken by the flanged coupling, this is taken as part of the margin for safety. It is therefore neglected.

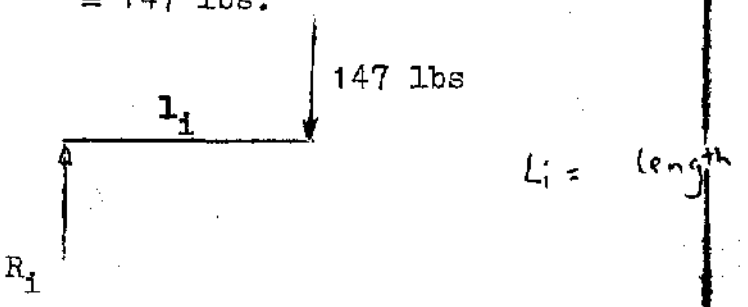
The tangential force on the

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
$r = \frac{75}{2}$mm $= 1\frac{1}{2}$"	gear is given by $F_t = \frac{T}{r}$ $F_t = \frac{441}{1.5} = 294$ lbs This force is tangential to the pitch circle diameter.	
$\alpha = 20^0$	Acting perpendicular to this force is the separating force F_s = $F_t \tan \alpha$ (19) where α is the pressure angle of the gear $\alpha = 20^0$ $F_s = F_t \tan 20$ lbs $= 294 \tan 20$ lbs $= 107$ lbs.	
	The resultant force F_R on the bearing is given by $F_R = (F_t^2 + F_s^2)^{\frac{1}{2}}$ lbf $= \left[(294)^2 + (107)^2\right]^{\frac{1}{2}}$ lbf $= 312.87$ lbf. This is the load on the bearings. Machine tools usually have rolling bearings, though in some heavy duty types where speed is low and constant flood lubrication is possible, bush bearings are used.	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	The design is for rolling bearings. The equivalent force on the bearing is given by	
	$F_e = f_k f_d f_l f_s F_R$ (21)(19)	
	f_k is the gear form factor which, for normal gear, is between 1.1 and 1.3, and for precision	
f_k= 1.2	gear is between 1.05 and 1.1 (21)	
	Take f_k = 1.2	
	f_d is the operating factor which, for bearing used under light shock load, is between 1.0 and 1.2; for moderate shock, it is between 1.5 and 3.0 (21)	
f_d= 1.2	Take f_d = 1.2	
	f_l is hours factor.	
	If attachment is designed for	
f_l= 2.24	24 hours per day working for 10 years	
	f_l = 2.24 (22)	
f_s= 1	f_s is the speed factor which is taken as 1.	
	F_R = 312.87 lbf	
	F_e = 1.2 x 1.2 x 2.24 x 1	
	x 312.87 = 1009.19 lbs.	
	From SKF Bearing Catalogue Roller bearing NJ 206E has a limiting	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	speed of 9500 rpm when grease lubricated or 12000 when oil lubricated. (These speeds indicate f_s is less than 1).	
	Its static load rating is 4900 lbs and dynamic load rating is 4500 lbs.	SKF Roller bearing NJ 206E
	The bearing is suitable for the design size:-	
	30 mm Bore	30mm I.D.
	62 mm O.D.	62mm O.D.
	16 mm Wide	16mm Wide
	ITEM NO. 3: CARRIER SUPPORT and ITEM NO. 4: SPINDLE CARRIER	
	No design calculation was done. Close checks on various types of gear-boxes made by CROFT, CARTER and KOPPS, which transmit up to 20 h.p. show that the wall thicknesses of these parts are adequate for the expected duty.	
	ITEM NO. 6: INTERMEDIATE GEAR	
η = 100%	Assume 100% efficiency transmission from spindle nose to the gear;	
h.p.=3.5	the horse power transferred to each of the two intermediate gears in 3-spindle attachment is 3.5 h.p.	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
$N_{t_1} = 10$	The intermediate gear is to have 10 teeth. N_{t_1} = No. of teeth = 10 Speed ratio of the intermediate gear to the drive gear is 3:1 (30 T : 10 T). Design speed of drive gear = 1000 r.p.m. ∴ Speed of intermediate gear = 3000 r.p.m. Torque on gear $T_i = \frac{6300 \times 3.5}{3000}$ = 73.5 lb-in. Force on gear = $\frac{T_i}{r_i}$ where r_i = radius of pitch circle of intermediate gear = $\frac{25}{2}$ mm = $\frac{1}{2}$ in. Force on gear F_i = 73.5 x 2 = 147 lbs.	

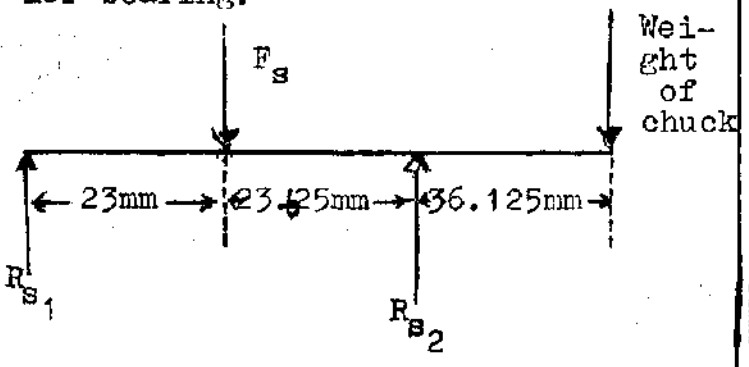


FORCE DIAGRAM OF INTERMEDIATE GEAR

The gear can only be supported at one end with a bearing. The reaction R_i at the bearing end is 147 lbs.

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
l_i = 46mm	Distance between middle of bearing and that of gear is 46 mm. i.e. l_i = 46 mm The maximum bending moment M_i is $M_i = 147 \times \frac{46}{25}$ lb-in $= 270.48$ lb-in. Using maximum shear theory $Te_i = \left[M_i^2 + T_i^2\right]^{\frac{1}{2}}$ lb-in $= \left[(270.48)^2 + (73.5)^2\right]^{\frac{1}{2}}$ lb-in $= 280.29$ lb-in. Diameter of shaft $d_i = 1.72(\frac{T_e}{S_w})^{\frac{1}{3}}$ ins S_w is allowable stress which, for BS en 8, is 15000 psi (as in previous calculation. $d_i = 1.72 \left[\frac{280.29}{15000} \right]^{\frac{1}{3}}$ ins $= 0.46$ in $= 11.41$ mm ∴ 17 mm shaft can be used.	d_i = 17mm
F_{t_i} = 147 lbs	ITEM NO. 14: INTERMEDIATE SHAFT BEARING The tangential force on the gear $F_{t_i} = 147$ lbs	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
$\alpha = 20^\circ$	The separating force $F_{s_i} = F_{t_i} \tan\alpha$ $F_{s_i} = 147 \tan 20 = 53.5$ lbs The resultant force on bearing $F_{R_i} = \left[(147)^2 + (53.5)^2\right]^{\frac{1}{2}}$ $= 156.43$ lbs.	
$f_k = 1.2$ $f_d = 1.2$ $f_s = 1$ $f_l = 2.24$	Take the same multiplying factors as those of the drive shaft bearings. The equivalent force F_{e_i} is $F_{e_i} = 1.2 \times 1.2 \times 2.24 \times 1$ $\times 156.43$ lbs $= 504.58$ lbs From SKF bearing catalogue, Roller bearing SKF NJ 203 has dynamic load rating of 2200 lbs, static load rating of 11600, limiting speed in grease of 17000 rpm and in oil of 20000 rpm. The bearing is chosen for the design size: 17 mm Bore 40 mm O.D. 12 mm Wide	SKF Roller bearing NJ 203 17mm x 40mm x 12mm.

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
S_{u_s} = 45 tons/in^2 n = 2	ITEM NO. 5: SPINDLE The spindle is to be made of B.S. en 16 alloy steel. This has an ultimate tensile stress S_{u_s} of 45 tons/in^2 = 100800 lb/in^2 (13) Allowable shear stress S_{w_s} = $\frac{S_{u_s}}{2\ n}$ (19) Again take n = 2 $S_{w_s} = \frac{100800}{4}$ lbf/in^2 = 25200 lb/in^2 Take S_{w_s} = 25000 lb/in^2 The design points of support are 23.625 mm from the middle of the gear width at the chuck end where it is to be supported with tapered roller bearing and 23 mm at the lathe headstock end with cylindrical roller bearing.  In the three-spindle attachment, two spindles are working spindles.	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
η = 100%	Assume 100% efficient transmission from drive gear through intermediate gear to spindle gear.	
h.p.=3.5	The power transmitted to each of the working spindle gears is 3.5 h.p.	
Gear PCD = 75 mm	The gears are also 75 mm PCD 2.5 module 30 teeth.	
	As before, neglect the weight of spindles and gears.	
rpm = 1000	Torque on gear $T_s = \frac{63000 \times 3.5}{rpm}$. rpm of spindle gear is 1000 $T_s = \frac{63000 \times 3.5}{1000}$ $= 220.5$ lb-in Gear PCD is 75 mm = 3" $\therefore$ Radius of pitch circle, r_s $= 1.5"$ Force on gear, $F_s = \frac{T_s}{r_s} = \frac{220.5}{1.5}$ The spindle supports 110 mm chuck. The weight of the chuck was physically measured to be 6 lbs. This weight is assumed to act at the middle of the chuck. This is 36.125 mm from R_{s_2}. (Reaction at the tapered roller bearing).	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS

R_{s_1} = Reaction at cylindrical roller bearing.

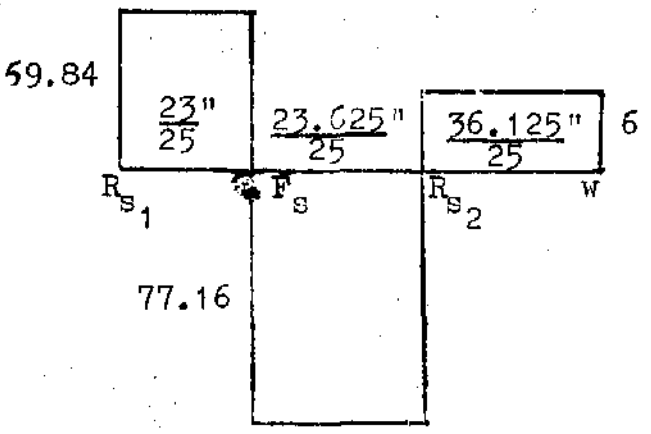
Take moment about R_1

$R_{s_2}(46.675) = (147 \times 23) + (6 \times 82.75)$ lbs

$R_{s_2} = \frac{(147 \times 23) + (6 \times 82.75)}{46.625}$ lbs

$= 83.16$ lbs.

$R_{s_1} = 147 + 6 - 83.16 = 69.84$ lbs.



BENDING MOMENT DIAGRAM OF SPINDLE

Bending moment is the sum of the positive moments which equals the negative moment,

$M_s = (147 - 69.84)(\frac{23.625}{25})$ lb-in

$= 77.16 \times \frac{23.625}{25}$ lb-in

$= 72.91$ lb-in.

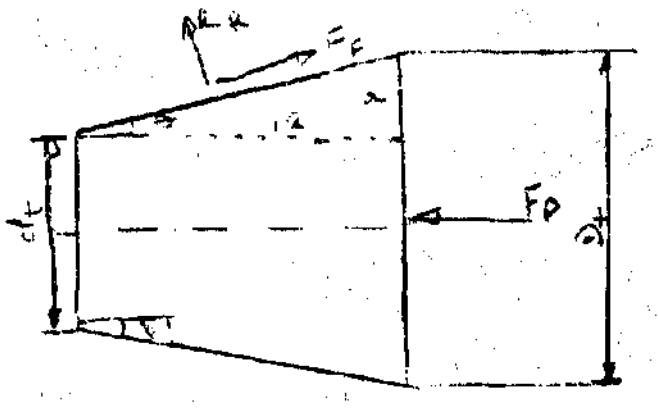
Using maximum shear theory equivalent

Torsion, $T_{e_s} = (M_s^2 + T_s^2)^{\frac{1}{2}}$ lb-in

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	$= \left[(72.91)^2 + (147)^2\right]^{\frac{1}{2}}$ lb-in $= 164.09$ lb-in. The spindle is a hollow shaft. Internal stress S_s is given by $S_s = \frac{5.1\ T_{e_s}}{d^3(1-q^4)}$ (19) $d^3 = \frac{5.1\ T_{e_s}}{S_{w_s}(1-q^4)}$ $d = \left[\frac{5.1\ T_{e_s}}{S_{w_s}(1-q^4)}\right]^{1/3}$ T_{e_s} = 164.09 lb-in S_{w_s} = allowable shear = 25000 lb/in^2 q = ratio of bore diameter to external diameter $q = \frac{d_{ip}}{d_p}$ d_{ip} = bore diameter of spindle d_p = O.D of spindle. In practice, $d_p = 3\ d_{ip}$ or $d_p = 2\ d_{ip}$	
$d_p = 2\ d_{ip}$	Take $d_p = 2\ d_{ip}$ Then $q = \frac{1}{2}$ $d_p = \left[\frac{5.1 \times 164.09}{25000(1 - \frac{1}{16})}\right]^{\frac{1}{3}}$ ins	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	$= \left[\frac{5.1 \times 164.09}{25000 \times 0.9375}\right]^{\frac{1}{3}}$ $= 0.329$ ins $= 8.23$ mm. NOTE:- A calculation neglecting the effect of chuck's weight gives d = 8.2 mm. The effect of chuck's weight is therefore negligible. Take diameter to be 30 mm If d_p = 30 mm d_{ip} = 15 mm Though the key-way weakens the spindle and produces stress concentration, the effect is not taken into consideration because ratio $\frac{d_{ip}}{d_p}$ = ½ is less than 0.6 when the effect becomes critical. (19) Also the designed shaft diameter is more than three times the calculated shaft diameters.	d_p=30mm d_{ip}=15mm
	SPINDLE NOSE TAPER Frictional taper is to be used as in tools holders. Forces on the taper are given by	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS



FORCES ON NOSE TAPER (18)

d_t is diameter of taper at smallest end.

D_t = diameter of taper at big end

F_P = Retaining force.

F_F = Frictional force.

R_R = Normal reaction

$\therefore \quad F_F = \mu R_R$

where μ = coefficient of friction

At equilibrium

$$F_P = F_F \cos\theta + R_R \sin\theta$$

where $\theta = \frac{1}{2}$ the angle of taper

$$F_P = \mu R_R \cos\theta + R_R \sin\theta$$

$$= R_R(\mu \cos\theta + \sin\theta).$$

In a self holding taper (used in machine tools), torque is transmitted by friction and calculation is based on the mean diameter. $\frac{D+d_t}{2}$

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	Mean diameter = $\frac{D_t + d_t}{2}$	
	Maximum Torque that can be transmitted by the taper T_{max}	
	= F_F x mean radius	
	= $\mu R_R(\frac{D_t + d_t}{4})$	
	= $\frac{\mu F_P}{\mu \text{Cos } \theta + \text{Sin } \theta} (\frac{D_t + d_t}{4})$	
	For the spindle	
	$d_t = \frac{15}{25}$"	
μ = 0.15	μ = 0.15 for steel to steel (18)	
	In a taper, taper per foot is $t = 2(12 \tan \theta)$	
	Morse 6 taper was chosen as this corresponds to the taper on most of the available shanks.	
Morse 6 Taper = 0.6256"/ foot.	Morse 6 taper = 0.6256" per foot. (20)	
	$t = 24 \tan \theta = 0.6256$	
	$\theta = \tan^{-1} \frac{0.6256}{24}$	
	= 1.493°	
	$d_t = \frac{15}{25}$" = 0.6"	
l_t=60mm	Length of taper, l_t is taken to be 60 mm = $\frac{60}{25}$ ins.	
	$\therefore D_t = \frac{15}{25} + (\frac{0.6256}{12} \times \frac{60}{25})$ ins	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	$= 0.6 + 0.125$ in $= 0.725$ in $\frac{D_t + d_t}{2} = \frac{0.725 + 0.6}{2}$ in $= 0.6625"$ $T_{max} = \frac{F_P}{\pi(\text{Cos } \Theta + \text{Sin } \Theta}\ (\frac{D_t + d_t}{4})$ To get the value of F_p, (the thrust force), assume that a $\frac{1}{4}$" drill drill is held in the chuck with a feed of 0.02" per revolution into mild steel. Thrust for feed of 0.02" per revolution is 1500 lbf (20) $T_{max} = \frac{0.15(1500)}{0.15\text{Cos } 1.493^{\circ} + \text{Sin } 1.493^{\circ}} \times (\frac{0.6625}{2})$ $= \frac{0.15(1500)}{0.15 - 0.026} \times \frac{0.6625}{2}$ $= \frac{(0.15)(1500)(0.6625)}{(0.124)(2)}$ $= 601$ lb-in. The design torque of the spindle is 220.5 lb-in, which is much less than the maximum torque to be transmitted by the taper. Morse 6 taper is suitable for the nose.	Nose taper is Morse 6

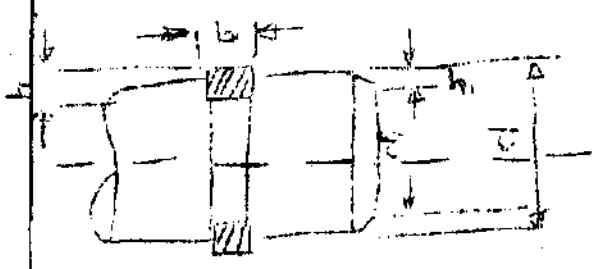
INITIAL DATE	CALCULATIONS AND SKETCHES	RESULTS
	ITEMS NOS. 27 and 13: SPINDLE BEARINGS	
	For each spindle, one taper roller bearing (Item 13) and one cylindrical roller bearing (Item 27) are to be used. This is because axial loads are expected on the spindles.	
	The tangential force on the spindle gear F_{t_s} is given by	
T_s= 220.5 lb-in r_s= 1.5"	$F_{t_s} = \frac{T_s}{r_s} = \frac{220.5}{1.5}$ lbs = 147 lbs.	
	Separating force on the gear	
α = 20°	$F_{ss} = F_{t_s} \tan \alpha$ = 147 tan 20 = 53.5 lbs	
	Resultant force, F_{RS}	
	$= \left[(147)^2 + (53.2)^2\right]^{\frac{1}{2}}$	
	= 156.43 lbs.	
	For the cylindrical roller bearings, use the same factors as were used before.	
	Equivalent force, F_{es}	
	= 1.2 x 1.2 x 2.24 x 1.x 156.43	
	= 504.58	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	SKF NJ 206E roller bearings that were used for the drive shaft are suitable for the spindle.	SKF NJ 206E size 30 mm x 62 mm x 16 mm
	For the thrust bearing, equivalent load R_e is given by $R_e = F_a + 1.2\ F_e$ (21) where F_a = axial load (equivalent) F_e must not be more than 55% of F_a (21) Take F_e = 55% of F_a and use the same factor for F_e as in cylindrical bearing.	
	Then F_e = 1.2 x 1.2 x 2.24 x 1 x 156.43 lb = 504.58 lbs. $F_a = \frac{F_e}{55\%}$ = 917. 42 lbs $R_e = \left[917.42 + 1.2(504.58)\right]$ lbs = (917.42 + 605.5)lbs = 1522.92 lbs.	
	Tapered roller bearing SKF 30206 has a dynamic load of 7800 lbs, static load of 5700 lbs and limiting speed of 6700 rpm in grease, 9000 rpm in oil. It is therefore suitable for the design dimension:	SKF Bearing 30206 30mm Bore 62mm O.D. 17.25 mm Wide

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	30 mm Bore 62 mm O.D. 17.25 Wide.	
	ITEM NO. 15: KEYS From handbooks, square keys are preferred for shaft of 30 mm (1.2 ins) (20) From table, key for shaft diameter of 1.2" is ¼" square (20) ¼ = 6.25 mm Key seat is 3.125 mm. The drive shaft key is subjected to the maximum shear stress and it is therefore used for design calculations. Diameter of drive shaft 30 mm = 1.2 ins Radius of shaft = 0.6 ins Equivalent torsion on shaft = 461.27 lbs Shear force, $F_K = \frac{461.27}{0.6}$ = 768.78 lbs. The minimum length of key is given by $l = \frac{F_K}{W\ S_{WK}}$ (19) where W = width of key	$W_1 = W_2$ = 6.25mm

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
Take S_{WK} = 15000 psi	S_{WK} = allowable shear stress of key which is taken as 15000 psi $l = \frac{768.78}{\frac{1}{4} \times 15000}$ = 0.205" = 5.13 *mm* 10 mm key is used. Woodruff keys are used for light torque transmission and could have been used for the design if not for the difficulty expected in its production. $\frac{1}{4}$" x $\frac{1}{4}$" key steels are readily available in stock.	l = 10mm

ITEMS NOS. 16 and 17: CIRCLIPS



CIRCLIP DIMENSIONS

From the above sketch,

d = diameter of shaft

d_i = groove diameter

h_i = groove depth

h = circlip thickness

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	b = circlip width.	
	h is between 0.08d and 0.15d (23)	
	The groove depth h_i is between	
	0.25h and 0.3h (23)	
	$d_i = d - 2h$;	
	$\therefore$ d_i is between d -(0.3)2h and	
	d -(0.25)2h	
	Using upper limit of h (= 0.15d)	
	and lower limit (0.08d).	
	Then d_i is between 0.91d	
	and 0.96d.	
	The lower limit is used for	
	small shafts (23)	
	$\therefore$ $d_i = 0.91d$	
d_a=30mm	The groove diameter for 30 mm	
d_b=17mm	shaft	
	$d_{ia} = 0.91 \times 30$	d_{ia} =
	= 27.3 mm	27.3 mm
	The groove diameter for 17 mm	
	shaft	
	$d_{ib} = 0.91 \times 17$	d_{ib} =
	= 15.47 mm	15.47 mm
	Width of ring b is given by	
	0.03d and 0.06d (23)	
d_a=30mm	Take the upper limit for shafts	
d_b=17mm	For 30 mm shaft. b_a = 0.06 x 30 mm	
	= 1.8 mm = 2 mm	b_a= 2mm

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	For 17 mm shaft, b_b = 0.06 x 17 = 1.03 mm = 1 mm	b_b= 1 mm
P = 10 lbf d_h= 7mm	ITEM NO. 24: LOCATING SPRING During indexing, location is by spring and ball arrangements. The load P on the spring is assumed to be 10 lbf. A helical compression spring with round section is to be used. The holes bore, d_h = 7 mm = 0.28 in. A spring from gauge 18 wire that is $\frac{7"}{32}$ pitch diameter can be used. Diameter of wire = 0.0475" (20) Pitch diameter = $\frac{7"}{32}$ = 0.21875" (20) Overall diameter = 0.0475 + 0.21875 in = 0.266 in This has a maximum load of 19.21 lbf and deflection per coil of 0.028" (20)	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	The ball is to lift 2mm = 0.08 in $\therefore$ Minimum number of coils N_c is $\frac{0.08}{0.028}$ = 3 coils Six coils were used.	N_c = 6
Use M16 screw d =16mm S_u = 6722 lb/in^2 n = 2	ITEM NO. 11: CLAMPING GRUB SCREW Use M16 grub screw to clamp the carrier after indexing. The maximum compressive load P_c exerted on the carrier is given by $P_c = S_c (0.55d^2 - 0.25d)$ (20) S_c = allowable compressive stress $= \frac{S_u}{n}$ where S_u = ultimate tensile strength = 67200 lb/in^2 (as before) $S_c = \frac{S_u}{n}$ (19) Take n = 2 (as before) $S_c = \frac{67200}{2}$ lb/in^2 = 33600 lb/in^2 d = nominal outside diameter of screw = 16 mm = 0.64" $W = 33600 \left[0.55(0.64)^2 - 0.25(0.64)\right]$ = 2193.41 lbs. The load that can be exerted by the screw is 2193 lbs which is more than the working forces in the system	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	The screw can be used for clamping.	d = 16mm
W_a= 160 lbs.	ITEM NO. 19: SUPPORT MOUNTING SCREW The support is hanged by a 30 mm screw. The screw supports the weight of the system and helps in taking care of the thrust on the system. The attachment was weighed and its weight W_a was 160 lbs. The weight that can be supported by the screw is also given by $W_g = S_c(0.55d_g^2 - 0.25d_g)$ (20) where d_g = nominal diameter of screw = 30 mm = 1.2 ins	
d_g=30mm		
S_c = 33600 psi	S_c = 33600 psi (as for grup screw) $W_g = 33600\left[0.55(1.2)^2 - 0.25(1.2)\right]$ = 16531 lbs. When nuts are tightened, there is initial stress in the screw. There is no need to calculate this as W_g = 16531 lbs can take care of it. THRUST To consider the thrust that can be withheld by the screw, neglect	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	the effect of weight of the attachment.	
	Shear force of screw, F_g is given by	
	$F_g = \frac{\pi d^2 S_s}{8}$ (For one screw) (18)	
S_u=67200	S_c = allowable shear stress $= \frac{S_u}{2n}$ lb/in^2	
	$S_s = \frac{67200}{4}$ lbs/in^2	
n = 2	= 16800 lb/in^2	
	$F_g = \frac{\pi(1.2)^2(16800)}{8}$	
	= 9500.18 lbs.	
	This is more than the thrust expected on the system. (Total thrust on two bearings = 2 x 917.42 = 1834.84) So screw is suitable for use.	
	d_g = 30 mm	d_g = 30mm
	ITEMS NOS 21 and 22: CLAMPING PLATES	
	The maximum shearing force that can be sustained by the clamping plates is given by	
	$F_{sp} = .2t_p d_p S_s$ (20)	
	where t_p x d_p represents the projected area.	

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
S_s= 15000 psi d_p= 31mm F_{sp} = 1834.84 lbs	S_s = allowable shear stress = 15000 psi diameter of hole, d_p for 30 mm screw = 31 mm = $\frac{31}{25}$" Thrust on the system is the same as the shear force on the plate. F_{sp} = 1834.84 lbs $t_p = \frac{F_{sp}}{2\, d_p S_s}$ $= \frac{1834.84}{2 \times \frac{31}{25} \times 15000}$ $= \frac{1834.84 \times 25}{64 \times 15000}$ in = 0.05" = 1.25 mm. Use 5 mm plate.	t_p= 5mm

TOLERANCING

All the bearings used are by SKF. The tolerances used on shafts which go into bearings and housings into which bearings go are given by the SKF recommendations in their general catalogue No. 2800/GB 600 April 1970 edition.

There may be need to change these tolerances if the bearings used are from different manufacturers.

INITIAL DATA	CALCULATIONS AND SKETCHES	RESULTS
	With the standardization going on in bearing manufacturing, it is expected that the tolerances will hold for other bearings. The tolerances are j5 for shafts and K6 for housings. (21).	
	With the tolerance of the shaft diameters fixed according to bearing requirements, the 30 mm shaft has a limit corresponding to j5. To have a running fit on the gear, the gear bore was chosen as G7 (see shaft basis fits). (20)(21)	
	The spindle carrier indexes in the support. This is therefore made of loose clearance with carrier outside diameter on e8 and support inner diameter on H8.	
	Where specific tolerances are not given in drawings 002 and 003, the usual machine shop tolerances of 0.001" per inch can be used.	

CHAPTER SEVEN

7 - PRODUCTION OF PROTOTYPE

The prototype was produced and assembled in the machine shop of Dunlop Nigerian Industries Limited, Ikeja.

Care was taken to produce the parts to the tolerances given in the Drawings Nos. 002 and 003. The most important part to be accurately located are the holes of the spindle and intermediate gear bearings in the spindle carrier (Part No. 4 Drawing No. 001) and the carrier support (Part No. 3 Drawing No. 001). These were located by using the tool makers' butoon. The buttons were 12 mm diameter and 12 mm high.

These holes were first located roughly with scriber, scale and divider. The centres were pick-punched. This method located the holes centres accurately to about 0.25 mm. The holes were then drilled on the drilling machine and tapped to take 4 BA screws. The buttons were fastened in places with the screws and washers and they were tightenedhard enough to allow buttons to be tapped lightly with hammer into final positions (there was enough clearance in the button to allow for relocation). Using internal micrometers (for setting distances between buttons), the axis of the buttons were set accurately to correspond to the required axis of the holes and the buttons were securely tightened. The distances between the buttons were again checked to ensure that they did not shift. The workpiece was mounted on the face

plate such that axis of one button at a timewas concentric with lathe axis. (This was done by setting them with the centre of the tailstock). The button was removed and the hole was drilled and bored. This was repeated for the other buttons. It is expected that the accuracy of the location is within 0.0125 mm. This method wasted a lot of time. The use of drilling jigs will help a lot in the production. Drills, squaring drills and reamers will then be used.

The major source of inaccuracy is the bearings used. These bearings are normal machine bearings and are therefore not precise enough for machine tools. It is necessary to use precision bearings when making the attachment for commercial purposes. These can be purchased directly from bearing manufacturers.

Production of each part is described below. Reference drawings are Drawings Nos. 001, 002 and 003.

ITEM NO. 1: CONNECTING ADAPTOR

This was made from 200 mm mild steel rod cut to 35 mm length and faced at both ends to a length of 30 mm. All the holes' centres were located with scriber, scale and divider. They were drilled on the drilling machine.

ITEM NO. 2: DRIVE SHAFT

The drive shaft was machined from 100 mm diameter BS en 8 alloy steel rod cut to 125 mm length. The holes were located as for Item 1 before they were drilled and tapped. The key seat was milled and hand pressed. Because there was no facilities for flame hardening in the workshop, this was not done. Since the production is

not for commercial purpose, flame hardening is not essential.

ITEM NO. 3: CARRIER SUPPORT

The support was turned out of a 100 mm thick mild steel plate flamed out to a 400 mm diameter before it was turned to the outside diameter of 335 mm. This eliminated the area affected by the heat of the flame. The inner part was bored out. The central hole was drilled and reamed on the lathe while the two holes for intermediate shaft bearings were drilled using the tool makers' button earlier described. All other holes were located in the normal machine shop methods and drilled on the drilling machine. Those requiring tapping were tapped.

The drawings indicated the material to be cast iron which is cheaper than steel, but the casting that was produced was porous and not accurate. Though there were foundary shops that could do better bobs, a second attempt to cast was not done, since we are only producing the prototype to prove the design.

Cast has some advantages over steel. Some of these are its high compressive strength and high capacity for damping vibrations. This made it ideal for this part as well as the spindle carrier. For better strength, however, cast steel can be used, though this is costly and has greater tendency for resonance.

ITEM NO. 4: SPINDLE CARRIER

Though the drawings also indicate that this part should be made from cast iron, for the same reasons as

for Item 3, it was fabricated from mild steel plates.

Two pieces of 350 mm diameter plates were flame cut from 40 mm mild steel plates. These plates were turned close to the required outside diameter of the item. They were faced to give half the overall thickness of the carrier. Each plate was turned to produce half the internal recess required. A 45° chamfer was machined on the joining lips of the plates. The two plates were joined together by a 90° full weld. The outside diameter was then turned to the required size (305 mm). The 132.5 mm hole was bored and the central hole, 62 mm, diameter was also bored on the lathe. The other six bearing holes (three on each face) were bored using the tool makers' button (as earlier described).

The cover holes were located in the usual machine shop method. They were drilled and tapped. At clamping positions, squaring drills were used to make flat surfaces (milling cutter can be used). The locating dimples were made with a drill.

ITEM NO. 5: SPINDLE

Though the drawing asks that the spindle noses be threaded for mounting chucks, the chucks available had flange mounting arrangements and the spindle noses were made to have flanges (see Fig. 63).

The spindles were machined from 100 mm mild steel rod because there was no BS en 16 rod available. For each spindle the rod was cut to a length of 125 mm and machined to the required diameters. The nose flange was made to suit the available chucks. (It is also possible

to make the nose as specified and make flange mounting adaptors screwed unto the nose). The spindle bore was drilled and reamed on the lathe while the morse taper was cut using a slender boring bar. The key seat was milled and hand dressed. The centres of the flange holes were located and drilled on the drilling machine.

For better spindle performances, there will be need to change the material from BS en 16 which is manganese-molybdenum steel to hardened Nitra alloy steel which has more strength.

ITEM NO. 4: INTERMEDIATE GEARS

The blanks for the gears were machined from 30 mm diameter BS en 8 alloyed steel rod cut to a length of 65 mm. The gear was then cut on the Universal milling machine.

17 mm external circlip (Item 17) was not found in the country. Even if it is found, the journal length may have to be increased to give enough backing wall for the circlip. This will make it protrude out of its cover (Item 8). To avoid the use of circlip, bearing retaining plate was used (see Fig. 64). The intermediate gear journal was faced to the width of the bearing (12 mm). It was drilled and tapped M8 by 7 mm length.

The retainer was made from 25 mm diameter rod. It was made to have a head 25 mm diameter 2 mm thick. Two flats for M8 spanners were cut on the head. It was made to have a M8 thread 6 mm long. This is screwed into the intermediate gear and tightened into the journal.

This is a better method for retaining the bearings than using circlip.

ITEM NO. 7: GEARS

80 mm diameter was turned from 100 mm mild steel rod cut to 100 mm length. 30 mm hole was bored from this rod on the lathe before it was parted to give four gear blanks 20 mm thick. The blanks were clamped together and the key way was broached.

They were later held together in a mandrel and the gear cut on the universal milling machine.

ITEM NO. 8: INTERMEDIATE GEAR COVER

This was machined from a 6.25 mm thick mild steel plate cut to 75 mm diameter. This was turned to the required outside diameter (60 mm) and faced to 5.5 mm thickness before other turnings were done. The holes centres were picked and the holes drilled on a small drilling machine.

ITEM NO. 9: MAIN DRIVE COVER

This was also machined from a 6.25 mm thick mild steel plate cut to 100 mm diameter. It was turned to the outside diameter and faced to 5.5 mm thickness before other machinings were done. The holes centres were picked and the holes drilled on a small drilling machine.

ITEM NO. 10: SPACER

50 mm diameter mild steel rod was cut to 50 mm length. This was faced and the outside diameter turned to the required dimension before it was bored to size. 8 pieces of 5 mm thickness were parted from the piece.

ITEM NO. 15: KEY

6.25 mm x 6.25 mm key steel was cut to the correct

length (10 mm) and hand dressed.

ITEM NO. 19: CLAMPING SCREW

This was machined from 30 mm mild steel rod, cut to 280 mm length. The ends were faced and centre drilled. Then 20 mm diameter was turned to the required length. The small diameter was held in the chuck and the other end supported by a centre before the 30 mm thread was cut. The other end was held in the chuck and care was taken that the chuck did not grip beyond the part to be parted off. The free end was supportedby a centre before the 20 mm thread was cut. The 30 mm end was cut to length.

ITEM NO. 21: CLAMPING PLATE

The required length was cut from flat bar 70 mm x 6mm (70 mm x 5 mm bar was not available). The hole was drilled and the plate milled to 5 mm thickness. The cutting was done with a band saw.

ITEM NO. 22: CLAMPING PLATE

This was as for Item 21.

ITEM NO. 25: SPRING SEAT PLATE

This was made by cutting 6.25 mm carbon steel rod to a length of 5 mm. This was turned to 6 mm diameter and faced to about 3 mm. The plate was then held in a magnetic holder and ground to 1 mm thickness.

ITEM NO. 28: SPINDLE COVERS

These were the same as Item 9, except that 31 mm hole for spindle protrusion was drilled.

OTHER ITEMS:

Other items were bought as they are standard items.

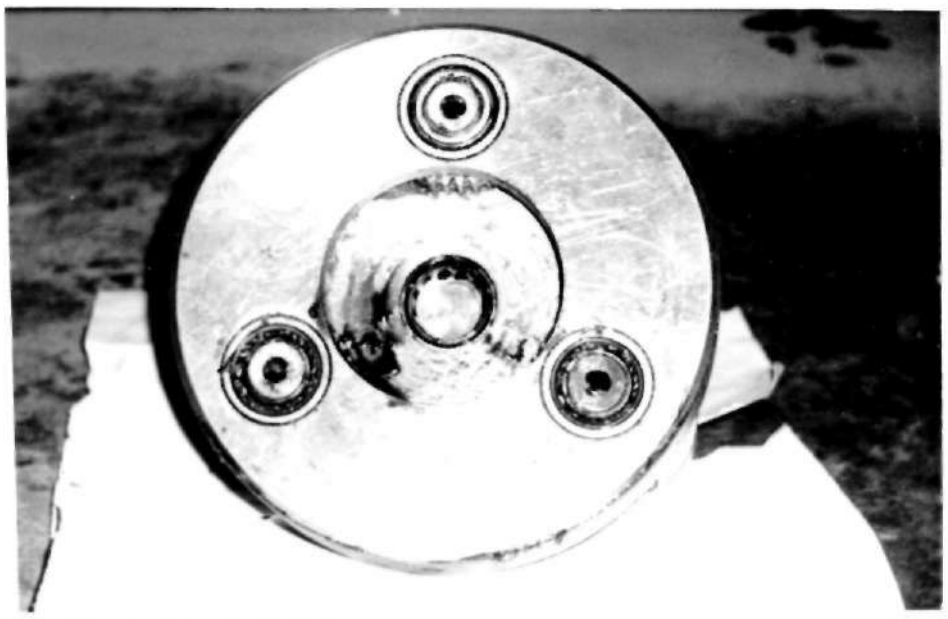


PLATE 3 SPINDLE CARRIER ASSEMBLY

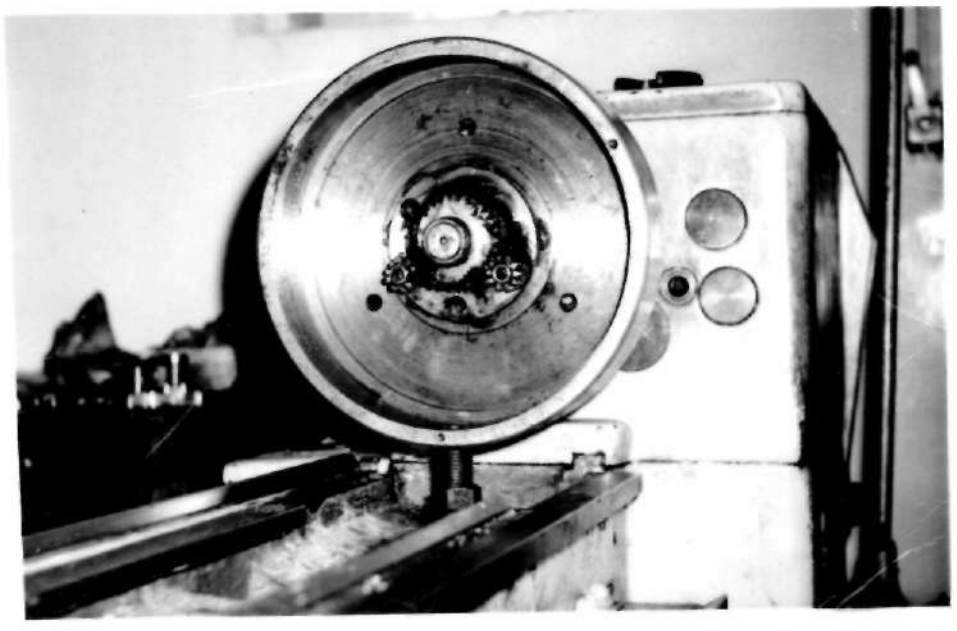


PLATE 4 CARRIER SUPPORT ASSEMBLY



PLATE 5 ATTACHMENT COMPLETE

7.0.1. Assembling

The assembling was done in two main units. The first unit was the spindle carrier assembly which houses the spindles with their gears and chucks (see Plate 3). The second was the carrier support assembly which houses the drive shaft, the intermediate gears and the mounting unit for the attachment. It also has the index location and clamping units (see Plate 4).

The carrier slides into the support assembly and it is prevented from sliding out by the clamping grub screw.

The whole unit is as shown in Plate No. 5

7.1 THE COST OF MANUFACTURING PROTOTYPE

The cost is computed for the prototype. The method used is to cost each part separately. The total cost is thus the addition of these and the cost of assembling.

ITEM NO. 1: CONNECTING ADAPTOR

This was made from 200 mm standard mild steel rod cut to 35 mm length.

1 metre of 200 mm mild steel rod costs - ₦690.00

∴ 35 mm costs - ₦ 24.15

It took machinist earning ₦58 per 40 hours (₦3,000.00 per annum of 2080 hours) 9 hours to complete the item.

Cost = $\frac{58}{40} \times 9$ = ₦13.05.

The overall labour cost will include the total fringe benefits enjoyed by the Machinist, a factor of the overhead cost of the company and the machine depreciation allowance.

So the above cost is multiplied by a factor of 2 to give the cost.

∴ Labour and overhead costs = ₦13.05 x 2 = ₦26.10

Material cost = ₦24.15

Total cost = ₦50.25

ITEM NO. 2: DRIVE SHAFT

This was machined from an 8 alloy steel rod 100 mm diameter, 125 mm long.

1 metre of rod costs ₦656.64

∴ 125 mm costs ₦ 82.08

This part was machined in 8 hours; using the previous standard,

Labour and overhead costs are $\frac{58}{40}$ x 8 x 2 = ₦23.20

Material cost = ₦82.08

Total cost. =₦105.28

ITEM NO. 3: CARRIER SUPPORT

This was fabricated from 100 mm plate cut to 400 mm diameter.

Price of 100 mm plate = ₦1,461.00

Area of standard plate = (8 ft x 4 ft) = 2.4 metres x 1.2 metres) = 2.88 sq. metres.

Area of part cut = $\pi r^2 = \frac{\pi}{4}(0.4)(0.4)$

= 0.1257 sq. metres.

Cost of material = $\frac{0.1257}{2.88}$ x ₦1461 = ₦63.75

Assuming that the welder and the machinist were on equal wages, the total hours spent on flame cutting and machining was 28 hours.

∴ Labour and overhead cost is $\frac{58}{40}$ x 28 x 2 = ₦81.20

(Note cost of gas for cutting has been taken off by the factor)

Labour and overhead costs = ₦ 81.20

Material cost = ₦ 63.75

Total cost = ₦144.95

ITEM NO. 4: SPINDLE CARRIER

This was fabricated from 2 off 40 mm plates flamed cut to 350 mm diameter.

Price of 40 mm plate = ₦548.00

Area of standard plate = (8' x 4') = (2.4 x 1.2) sq. metres = 2.88 sq. metres.

Area of part cut = $2(\pi)(\frac{0.35}{2})^2$ = 0.1925 sq. metres.

Cost of material = ₦ $\frac{548 \times 0.1925}{2.88}$

= ₦36.61

Total hour spent on flame cutting and machining was 20 hours.

Labour and overhead cost was $\frac{58}{40}$ x 20 x 2

= ₦58.00

Material cost = ₦36.61

Total cost = ₦94.61

ITEM NO. 5: SPINDLES

The spindles with the flange for chuck mounting was machined from 100 mm mild steel rod cut to 125 mm lengths.

Cost per spindle is as follows:-

Cost of 1 metre of 100 mm mild steel rod = ₦117.30

Cost of 125 mm = ₦ $\frac{117.30}{1000}$ x 125 = ₦14.66

Total hours spent on machining was 6 hours

∴ Labour and overhead costs = $\frac{58}{40}$ x 6 x 2

= ₦17.40

Cost per spindle = ₦(17.40 + 14.66)

= ₦32.06

Cost of 3 spindles ₦96.18

(Note: When en 16 alloy steel is used and the spindle nose is threaded the price is expected to be less than the above price). (40 mm rod would be used).

ITEM NO. 6: IDLER GEARS

These were machine from 30 mm en 8 alloy steel cut to 65 mm length. The retainer was cut from 25 mm mild steel rod cut 15 mm long.

1 metre of 30 mm en 8 rod cost ₦223.00

65 mm cost ₦($\frac{223 \times 65}{1000}$)

= ₦14.50

1 metre of 25 mm mild steel rod costs ₦6.60

15 mm cost ₦($\frac{6.60}{1000}$ x 15

= ₦0.10

Total cost of material per gear = ₦14.5 + 0.1

= ₦14.60

The machining was done in 6 hours.

∴ Cost of labour and overhead = $\frac{58}{40}$ x 6 x 2

= ₦17.40

Cost per gear = ₦14.60 + ₦17.40

= ₦32.00

Cost of 2 gears= ₦64.00.

ITEMNO. 7: GEARS

Gears were machined from 100 mm mild steel rod cut 25 mm long. The four gears' blanks were held together in a mandrel and the gears cut together, thus reducing the machining time.

1 metre of 100 mm mild steel rod costs ₦117.30

25 mm cost $\frac{117.30}{1000}$ x 25 = ₦2,93

Material cost for the four gears = ₦11.72

Machining was done for the four gears in 12 hours.

Cost of labour + overhead = $\frac{58}{40}$ x 12 x 2

= ₦34.80

Total cost of the gears = ₦11.72 + ₦34.80

= ₦46.52.

ITEM NO. 8: IDLER SHAFT COVER

This was machined from 6.25 mm mild steel plate rough cut to 75 mm diameter.

Price of 6.25 mm plate = ₦93.25

Area of standard plate = (8 x 4) sq. ft.

= (2.4 x 1.2) sq. metres = 2.88 sq. metres.

Area of part used = $\frac{0.075 \times 0.075}{4}\pi$ sq metres

= 0.0044 sq. metre.

Cost of material (for 1 cover) = $\frac{93.25 \times 0.0044}{2.88}$

= ₦0.14

Total time spent on machining one piece is 2 hours.

Overhead + Labour cost = $\frac{58}{40}$ x 2 x 2 = ₦5.80

Total cost per piece = ₦5.80 + ₦0.14

= ₦5.94

Cost of 2 pieces = ₦(5.94 x 2) = ₦11.88.

ITEM NO. 9: MAIN SHAFT COVER

This was also machined from 6.25 mm mild steel plate roughly cut to 100 mm diameter.

Area of part used = 0.0078 sq. metre.

Price of 2.88 sq. metres = ₦93.27

∴ Cost of material = ₦ $\frac{93.27}{2.88}$ x 0.0078

= ₦0.25

Time spent on machining was 2 hours.

∴ Labour and overhead cost = ₦ $\frac{58}{40}$ x 2 x 2

= ₦5.8

∴ Cost of cover = ₦5.8 + ₦0.25

= ₦6.05.

ITEM NO. 10: SPACERS

These were made by boring to size 50 mm length of 50 mm diameter mild steel rod and turning the outside diameter to size before parting off 8 pieces each 5mm wide.

1 metre of 50 mm mild steel rod costs ₦22,20

50 mm costs ₦ $\frac{22.20}{1000}$ x 50 = ₦1.11

Time spent in machining was 4 hours.

∴ Labour and overhead cost. = ₦ $\frac{58}{40}$ x 4 x 2

= ₦11.60

Total cost of spacers = ₦11.60 + ₦1.11

= ₦12.71

ITEM NO. 11: M16 GRUB SCREW

The price for 100 was ₦30.00.

∴ Price of one = ₦0.30.

ITEM NO. 12: M10 ALLEN CAP SCREWS

These cost ₦20.00 for 100.

∴ Price of 10 was ₦2.00.

ITEM NO. 13: TAPER ROLLER BEARING SKF 30206

The bearing costs ₦25.00 each

∴ Price of 3 bearings = ₦75.00

ITEM NO. 14: SINGLE ROW ROLLER BEARING SKF NJ203

One bearing costs ₦10.00

∴ Cost of 2 = ₦20.00

ITEM NO. 15: KEY

6.25 x 6.25 key steel was cut and dressed to suit.

Total length cut = 60 mm

Price of 1 metre of key steel = ₦1.25

Cost of 60 mm = ₦0.08

To cut, file and dress 4 keys took about 1 hour.

Labour + overhead cost = ₦ $\frac{58}{40}$ x 1 x 2

= ₦ 2.90

Total cost of keys = ₦2.90 + ₦0.08

= ₦2.98.

ITEM NO. 16: 30 mm EXTERNAL CIRCLIP

Price is ₦22.00 per 100

∴ Cost of 7 pieces = $\frac{22}{100}$ x 7 = ₦1.54.

ITEM NO.17: 17 mm EXTERNAL CIRCLIP

This item was not used.

ITEM NO. 18: BOLTS M4 x 6 mm

The bolts cost ₦7.00 for 100

Cost of 24 = $\frac{7}{100}$ x 24 = ₦1.68.

ITEM NO. 19: CLAMPING SCREW

This was machined from 30 mm mild steel rod cut to 280 mm length.

1 metre of 30 mm mild steel rod costs ₦10.92

280 mm cost ₦10.92 x 0.280

= ₦3.06

The machining took 3½ hours

∴ Labour + overhead cost = $\frac{58}{40} \times \frac{7}{2} \times 2$ = ₦10.15

Cost of screw = ₦(10.15 + 3.06) = ₦13.21.

ITEM NO. 20: M30 NUT

The nuts cost ₦85.00 per 100

∴ The cost of 2 nuts = ₦1.70.

ITEM NO. 21: CLAMPING PLATE

This was cut from flat bars 70 mm x 6 mm. This was milled to 5 mm after hole was drilled.

1 metre of bar costs ₦11.50

∴ 220 mm cost ₦11.50 x 0.22 = ₦2.53

It took 1½ hours to drill and mill

∴ Labour and overhead costs = ₦ $\frac{58}{40} \times \frac{3}{2} \times 2$ = ₦4.35.

Cost of plate = ₦4.35 + ₦2.53=₦6.88.

ITEM NO. 22: CLAMPING PLATE

This was from the same material as Item (21).

Price of 160 mm flat bar = ₦11.50 x 0.16 = ₦1.84

The labour and overhead costs are approximately the same as for Item (21) = ₦4.35.

Cost of plate = ₦4.35 + ₦1.84 = ₦6.19.

ITEM NO. 23: PLUG M8 x 4 mm (GRUB SCREW)

The price was ₦12.00 per 100

Price of one = ₦0.12.

ITEM NO. 24: SPRING

This was not bought. The cost of 6 mm O.D. helical compressive spring about 8 mm uncompressed length is estimated to be ₦0.20.

ITEM NO. 25: PLATE

This was made by cutting from 6.25 mm carbon steel round bar, a length of 5mm. The bar was turned to 6 mm diameter. The piece was held in magnetic holder and ground to 1 mm thickness.

1 metre of 6.25 mm carbon steel rod costs ₦2.75

∴ 5 mm cost ₦0.01

The machining took about 1 hour.

∴ Labour and overhead cost = ₦ $\frac{58}{40}$ x 1 x 2 = ₦2.09

Cost of plate = ₦2.09 + ₦0.01 = ₦2.91.

ITEM NO. 26: 6 mm DIAMETER BALL

1 kg of this ball costs ₦1.50

The price of one piece is insignificant.

ITEM NO. 27: SINGLE ROW ROLLER BEARING SKF NJ206E

Price of one bearing = ₦20.00

∴ Cost of 5 bearings = ₦100.00.

ITEM NO. 28: SPINDLE COVERS

This was machined from 6.25 mm mild steel plate rough cut to 100 mm diameter.

Area of part used = 0.0078 sq. metre

Price of 2.88 sq. metres of material = ₦93.27

Cost = ₦ $\frac{93.27}{2.88}$ x 0.0078 = ₦0.25

Time spent in machining was $2\frac{1}{2}$ hours

Labour and overhead costs = $\frac{58}{40}$ x $\frac{5}{2}$ x 2 = ₦7.25

Total cost per piece = ₦7.25 + ₦0.25 = ₦7.50

Cost for 3 covers = ₦7.50 x 3 = ₦ ₦22.50.

ITEM NO. 29: UNIVERSAL CHUCKS

On chuck costs ₦165.00

∴ 3 chucks cost ₦495.00.

The prototype was produced in approximately 150 man hours (133 for machining and 17 hours for assembling). With proper casting and assembly fixtures, the time will be well reduced.

7.2 COST SUMMARY

ITEM NO.	OVERALL COST (₦)
1.	50.25
2.	105.28
3.	144.95
4.	94.61
5.	96.18
6.	64.00
7.	46.52
8.	11.88
9.	6.05
10.	12.71
11.	0.30
12.	2.00
13.	75.00
14.	20.00
15.	2.98
16.	1.54
17.	-
C/F	734.25

COST SUMMARY (contd.)

ITEM NO.		OVERALL COST (₦)
	B/F	734.25
18.		1.68
19.		13.21
20.		1.70
21.		6.88
22.		6.19
23.		0.12
24.		0.20
25.		2.91
26.		-
27.		100.00
28.		22.50
29.		495.00
	TOTAL	₦1,384.64

Take 7½% of this cost as assembling cost

∴ Cost of assembling = ₦ 103.84

Overall cost of prototype=₦1488.48.

It should be noted that the most expensive parts of the prototype are the chucks. The prototype without the chuck was produced at ₦993.00. The cost of labour and materials in this country is very high. It is expected that when this attachment is produced by qualified machine makers, the price would be less than one quarter of the above price. This will make it commercially profitable.

CHAPTER EIGHT

8 - TESTING OF THE PROTOTYPE

The centre of the two working spindles of the attachment is 50 mm below the centre of the lathe. This requires the use of a tool post different from that of the lathe or alternatively, making special tools (cranked tools) for the attachment.

When the prototype was being tested, it was easier to use tool posts clamped directly on the cross slide. The tools were then packed to the required heights.

The prototype was tested in two places. The first place was Dunlop Nigerian Industries Limited Workshop where it was made and the second was at the Production Laboratory of Mechanical Engineering Department of Ahmadu Bello University, Zaria.

8.1 TESTING AT DUNLOP WORKSHOP

At this workshop, the lathe used was the Colchester Lathe that has 200 mm centre height. Two operations were performed; one was turning while the other was drilling. To use the drill, two flats were ground at the shank so that it can be held at the tool post. (It will be proper to have the correct tool holders used in multi-spindles). The drilling was done in the front station. The tool post holding the drill was clamped behind the tool post with the turning tool, so that they could have equal amount of feed. The drill used was 5 mm drill and the workpiece was aluminium bar. The slowest speed was used

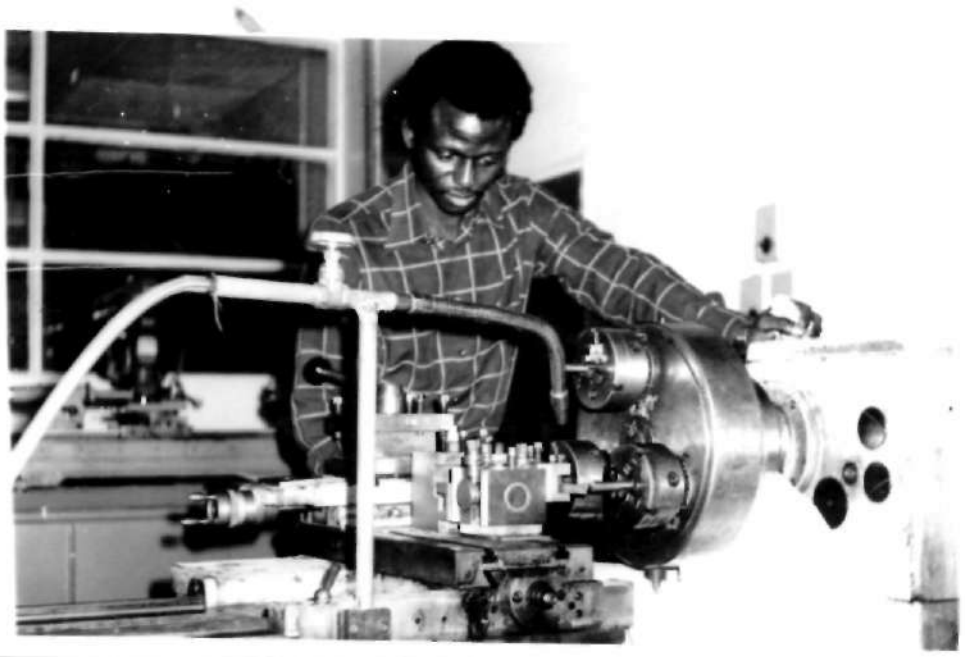


PLATE 6 TESTING ON PRODUCTION LATHE

initially, but later a higher speed was used. Six test pieces were produced in the manner.

8.2 PROBLEMS ENCOUNTERED

The only problem was that the lathe tool post could not be used. Two other tool posts were taken from smaller lathes and fastened directly to the cross slide. The compound rest could not be used.

8.3 TESTING AT AHMADU BELLO UNIVERSITY PRODUCTION LABORATORY

The attachment was mounted and tested on the prescribed centre lathe (Plate 6). Two tool posts were mounted directly to the cross slide as for the previous test.

Stepped turning was made on bright mild steel rod. This was done by advancing one tool ahead of the other. Owing to the inaccuracy expected in the production of the prototype, very light cut was taken.

Three pieces were produced. The time taken to produce these pieces was found to be less than half the time that they could have been produced on single spindle lathe.

These tests showed that the design is viable.

CHAPTER NINE

9 - COMMENTS AND CONCLUSION

Before concluding, let us compare Single spindle and Multi-Spindle Lathes.

If t_t is the total time for machining a workpiece on a single spindle lathe, t_m is the actual machining time. t_d is the time for work change, tool approach and withdrawal and other non-machining time.

$$t_t = t_m + t_d \qquad (26)$$

Rate of production, Q is given by

$$Q = \frac{1}{t_t} = \frac{1}{t_m + t_d} \qquad (26)$$

The above equation defines optimum production, first on the ideal machine tool whose down time is infinitely short and whose productivity is determined by machine time and secondly the technological ideal production cycle where the minimum machine time results in maximum output.

The above concept is important for practical applications. With the employment of n + 1 spindles of multi-spindle lathes, with n work station and one loading station, the time for machining a piece on the multi-spindle t_{ms} is $\frac{1}{nth}$ of the time for a single spindle, i.e.

$$t_{ms} = \frac{t_m}{n}.$$

If loading is done at a station while others are working, then the down time t_{ds} is only used for indexing which is about 3 to 5 seconds in multi-spindles. This is much less than the down time t_d of a single spindle.

$$t_{ms} = \frac{t_m}{n} \quad \text{i.e. } t_{ms} \ll t_m$$

$$t_{ds} \ll t_{ms} \ll t_m.$$

Comparing the total machining time per piece of multi-spindle (t_{st}) and the same time per piece of single spindle (t_t), time saving using multi-spindles, is given by Δt, where

$$\Delta t = t_t - t_{st} = t_m + t_d - (t_{ms} + t_{ds})$$

This, as a fraction of the original machining time on single spindle, E, gives

$$E = \frac{\Delta t}{t_t} = \frac{t_m + t_d - t_{ms} - t_{ds}}{t_m + t_d}$$

with t_{ds} being negligible.

$$E = \frac{t_m + t_d - t_{ms}}{t_m + t_d}$$

$$t_{ms} = \frac{t_m}{n}$$

$$\therefore E = \frac{t_m + t_d - \frac{t_m}{n}}{t_m + t_d}$$

Divide all through by t_m and make $\frac{t_d}{t_m} = K$

$$E = \frac{1 + K - \frac{1}{n}}{1 + K}$$

$$E\% = \frac{(1 - \frac{1}{n}) + K(100)}{1 + K} = \frac{(1 - \frac{1}{n}) + K}{1 + K} (100)$$

From this equation, it is sure that even when a single spindle has zero or negligible idle time, so that K = 0

$$E\% = (1 - \frac{1}{n}) \times 100$$

for n = 1

$$E\% = 0\%$$

for $n = 2$

$$E\% = 50\%$$

Where K is very large, say K = 1

$$E\% = \frac{(2 - \frac{1}{n}) \times 100\%}{2}$$

for $n = 1$, $E\% = 50\%$

for $n = 2$, $E\% = 75\%$

Since K lies between 0 and 1, then the saving on a double spindle machine is between 0 and 50% and that saved on a 3-spindle machine is between 50% and 75%.

The time saving increases as n increases, but the rate of increase drops with increase in n. For instance take K = 1 and n = 3,

$$E = \frac{2 - \frac{1}{3}}{2} \times 100 = \frac{5}{6} \times \frac{100}{1} = 83\%$$

and for K = 1 and n = 4

$$E = \frac{2 - \frac{1}{4}}{2} \times 100 = \frac{7}{8} \times 100 = 87.5\%.$$

The above equations are for ideal cases where multi-spindle lathes have no idle time and are 100% efficient. In actual practice, the time savings are less than shown. However, this shows that a tremendous time saving per workpiece is expected in a three-spindle attachment over a single spindle lathe.

The actual time saving of the attachment over a single spindle lathe is much lower than stated above since tool approach and withdrawal as well as indexing are done manually. When turning, the depth of cut on each of the workpieces cannot be more than 2 mm diameter;and this is providedthe tools are nicely sharp and correctly positioned.

The tests conducted on the prototype showed that in spite of the inaccuracy of its production, it gave about twice the productivity of the lathe on which it was tested. When made by a proper machine tool manufacturer and with the correct materials, the productivity of the attachment will be increased.

The tests conducted on the prototype proved the workability of the design and confirm that the project is technically sound. There is no doubt that it will be commercially viable.

6.1 RECOMMENDATION FOR FURTHER STUDIES IN THE SAME FIELD

The following are recommended for further studies:

(i) Methods of batch producing 3-spindle attachments including design of production and assembly fixtures.

(ii) Production and testing of the prototype of six-spindle attachment with design of efficient tooling system.

(iii) Design and production of automatic collet opening and closing device for the 3-spindle attachment.

(iv) Design and production of automatic indexing and clamping devices for the spindle carrier.

(v) Study of stress concentrations on the lathe bed and spindle during mounting of the attachment and when cuts are taken on the spindles.

(vi) Design and production of other types of attachments to improve the productivity of the 3-spindle attachment.

(vii) Pre-set toolings for the attachments.

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