An-Najah National University

Faculty of Engineering

Industrial Engineering Department

Experimental study of orthogonal cutting Using Lathe Tool Dynamometer (PE1)

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Submitted as a graduation project for fulfillment of the requirements of the B.Sc. degree in Industrial Engineering

May 2010

الاهداء

إلى من جرع الكأس فارغاً ليسقيني قطرة حب
إلى من كلّت أنامله ليقدم لنا لحظة سعادة
إلى من حصد الأشواك عن دربي ليمهد لي طريق العلم
إلى القلب الكبير**والدي العزيز**

إلى من أرضعتني الحب والحنان
إلى رمز الحب وبلسم الشفاء
إلى القلب الناصع بالبياض **والدتي الحبيبة**

إلى سندي وقوتي وملاذي بعد الله
إلى من آثروني على انفسهم
إلى من علموني علم الحياة
إلى من أظهروا لي ما هو أجمل من الحياة **إخوتي واخواتي**

إلى من تذوقت معهم أجمل اللحظات
إلى من جعلهم الله أخوتي بالله ...... و من أحببتهم بالله **اصدقائي**

إلى من يجمع بين سعادتي وحزني
إلى من أتمنى أن أذكرهم ....إذا ذكروني
إلى من أتمنى أن تبقى صورهم ....في عيوني

ACKNOWLEDGMENTS

First of all, we would like to thank our **God** who helped us to complete our project.

Next, our gratitude and thanks go to our supervisor **Dr. Ahmad Al-Ramahi** for his Constructive idea, encouragement, Experience, follow up, and for everything.

We Are very grateful and appreciated to the following people and institutes:

1- An-Najah National university ,Faculty of engineering , for allowing us to use the devices and instrument available in engineering workshop

2- Engineering work shops, represented by the expert technician teacher

Eng Shokri Al-Ghalaienee, Eng Miniem Al-Masri

3- Industrial Engineers who always encouraged and helped us through all study period (Eng. Suliman Daiefee, Eng Nidal Dwaikat, Dr. Hussam Arman)

4- Anybody we have forgotten to acknowledge previously, for any type of criticism, help, comment and support.

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1.1 Introduction

All machining processes remove material to form shapes. As metals are still the most widely used materials in manufacturing, machining processes are usually used for metals. However, machining can also be used to shape plastics and other materials which are becoming more widespread. Basically all the different forms of machining involve removing material from a component using a rotating cutter. The differences between the various types arise from the relative motion between cutting tool and work piece and the type of cutting tool used. Typically machining will be done using a machine tool. This tool holds the work piece and the rotating cutting tool and allows relative movement between the two. Usually machine tools are dedicated to one type of machining operation, although some more flexible tools allow more than one type of machining to be performed. The machine tool can either be under manual or automatic (Computer Numeric Control - CNC) control. Automatic control is more expensive because of the need to invest in the necessary control mechanisms however it becomes more desirable as the number of components produced increases and labor costs can be reduced. The speed at which a machine tool can process individual components is a function of the cutting speed of the tool and the downtime involved in changing the work piece and maintaining the tool (this will usually involve changing the cutting edges of the tool). Some very flexible tools allow automatic changing of components and cutting tools, however they greatly add to initial purchase price of the machine tool. The cutting speed of the tool is usually dictated by the type of material being machined, in general the harder the material, the slower the machining time. Machining speed can be increased by increasing the rotational speed of the cutter; however this will be at the expense of the tool life. Hence for machining processes there is an optimum cutting speed that balances tooling costs with cutting speed.

In order to dissipate the heat generated between the work piece and the cutting tool, cutting fluids are sprayed onto the tool. The cutting fluid also acts to remove cut material away from the cutting region and lubricates the tool - work piece interface but may require that the component is cleaned afterwards.

It is important to view machining, as well as all manufacturing operations, as a system consisting of the work piece, the tool and the machine. The introduction topic in this section covers primers on topics like mechanics & shear bending in machining, and heat in machining. The traditional machining includes primers on turning, milling, drilling, and grinding.

1.2 machining process

1.2.1 Turning process

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- with the work piece rotating,
- with a single-point cutting tool, and
- With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape.

Even though a single-point tool is specified, this does not exclude multiple-tool setups, which are often employed in turning. In such setups, each tool operates independently as a single-point cutter.

Turning is used to produce rotational, typically axi-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed.

Adjustable cutting factors in turning

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

Speed, always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important figure for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference (in feet) of the work piece before the cut is started. It is expressed in surface feet per minute (sfpm), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

Feed, always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in inches (of tool advance) per revolution (of the spindle)

Depth of Cut is practically self explanatory. It is the thickness of the layer being removed from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in inches. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work

CUTTING TOOLS FOR LATHES

For cutting tools, geometry depends mainly on the properties of the tool material and the work material. The standard terminology is shown in the figure (1.1). For single point tools, the most important angles are the rake angles and the end and side relief angles.

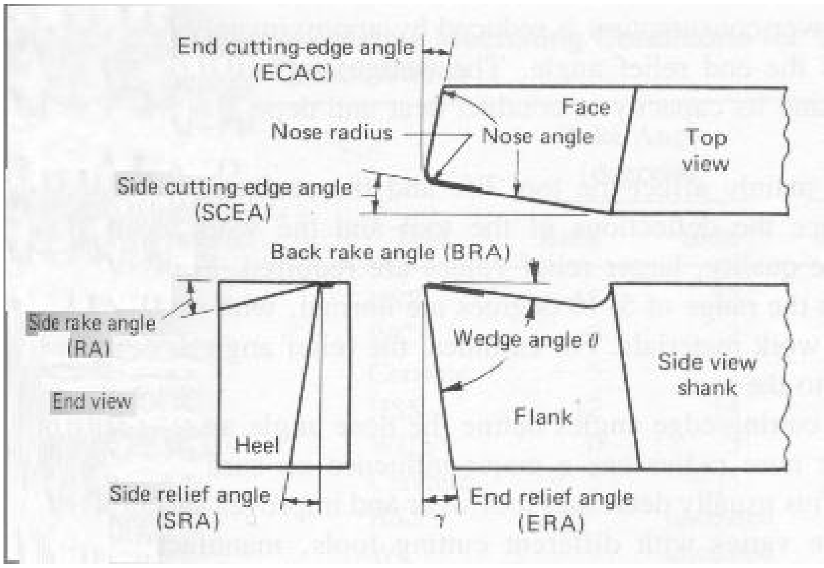


Figure: 1.1: Tool Geometry of cutting tool

The back rake angle affects the ability of the tool to shear the work material and form the chip. It can be positive or negative. Positive rake angles reduce the cutting forces resulting in smaller deflections of the work piece, tool holder, and machine. If the back rake angle is too large, the strength of the tool is reduced as well as its capacity to conduct heat. In machining hard work materials, the back rake angle must be small, even negative for carbide and diamond tools. The higher the hardness, the smaller the back rake angle for high-speed steels, back rake angle is normally chosen in the positive range.

Most lathe operations are done with relatively simple, single-point cutting tools. On right-hand and left-hand turning and facing tools, the cutting takes place on the side of the tool; therefore the side rake angle is of primary importance and deep cuts can be made. On the round-nose turning tools, cutoff tools, finishing tools, and some threading tools, cutting takes place on or near the end of the tool, and the back rake is therefore of importance. Such tools are used with relatively light depths of cut. Because tool materials are expensive, it is desirable to use as little as possible. It is essential, at the same, that the cutting tool be supported in a strong, rigid manner to minimize deflection and possible vibration. Consequently, lathe tools are supported in various types of heavy, forged steel tool holders, as shown in the figure (1.2) .

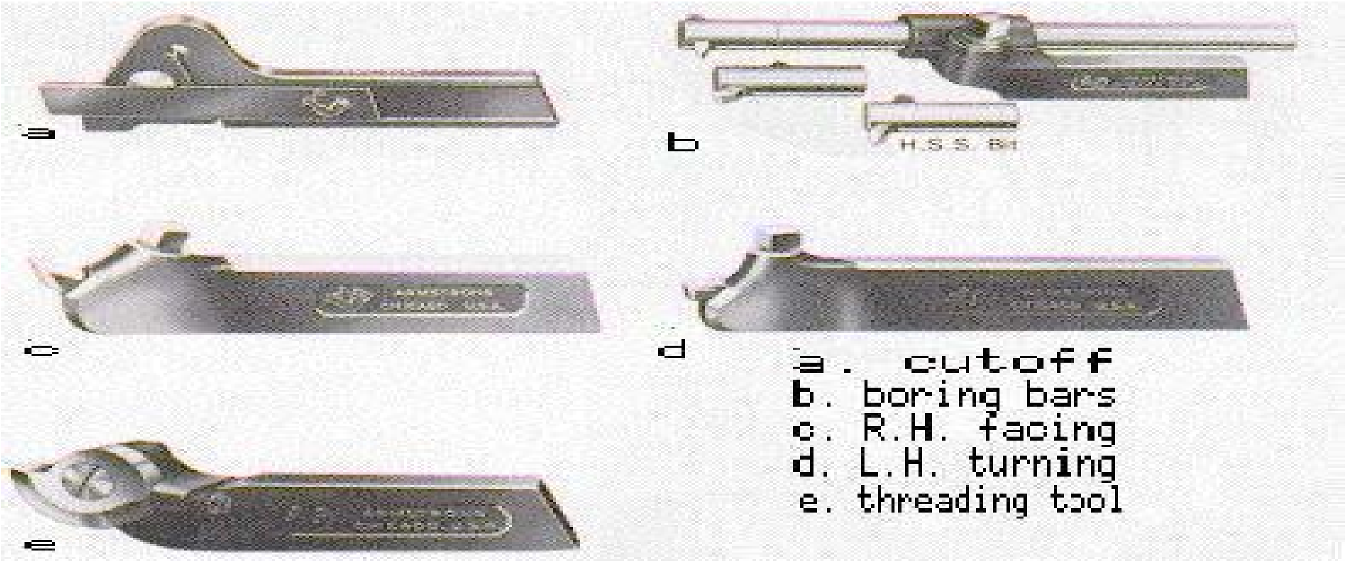


Figure1.2: supporting steel holders

TURNING MACHINES

A Turning machine is a theoretical device that manipulates symbols contained on a strip of tape. Despite its simplicity, a Turing machine can be adapted to simulate the logic of any computer algorithm, and is particularly useful in explaining the functions of a CPU inside of a computer. The "Turing" machine was described by Alan Turing in 1937, who called it an " (automatic)-machine". Turing machines are not intended as a practical computing technology, but rather as a thought experiment representing a computing machine. They help computer scientists understand the limits of mechanical computation.

A succinct definition of the thought experiment was given by Turing in his 1948 essay, "Intelligent Machinery". Referring back to his 1936 publication, Turing writes that the Turing machine, here called a Logical Computing Machine, consisted of: an infinite memory capacity obtained in the form of an infinite tape marked out into squares on each of which a symbol could be printed. At any moment there is one symbol in the machine; it is called the scanned symbol. The machine can alter the scanned symbol and its behavior is in part determined by that symbol, but the symbols on the tape elsewhere do not affect the behavior of the machine. However, the tape can be moved back and forth through the machine, this being one of the elementary operations of the machine. Any symbol on the tape may therefore eventually have an innings. A Turing machine that is able to simulate any other Turing machine is called a Universal Turing machine (UTM, or simply a universal machine). A more mathematically-oriented definition with a similar "universal" nature was introduced by Alonzo Church, whose work on lambda calculus intertwined with Turing's in a formal theory of computation known as the Church–Turing thesis. The thesis states that Turing machines indeed capture the informal notion of effective method in logic and mathematics, and provide a precise definition of an algorithm or 'mechanical procedure'.

The turning machines are, of course, every kind of lathes. Lathes used in manufacturing can be classified as engine, turret, automatics, and numerical control, major components and parts of lathe machine are shown in figure (1.3).

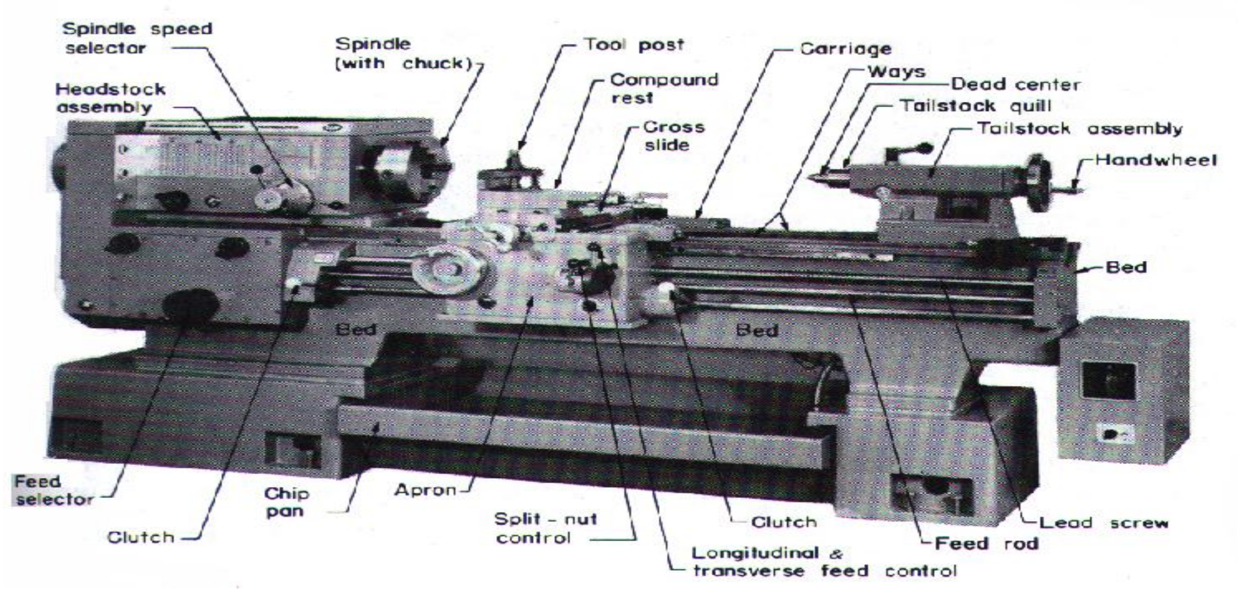


Figure 1.3: Lathe Machine

Milling Process

Milling is the process of cutting away material by feeding a work piece past a rotating multiple tooth cutter. The cutting action of the many teeth around the milling cutter provides a fast method of machining. The machined surface may be flat, angular, or curved. The surface may also be milled to any combination of shapes. The machine for holding the work piece, rotating the cutter, and feeding it is known as the Milling machine.

CLASSIFICATION OF MILLING:

Peripheral Milling:

In peripheral (or slab) milling, the milled surface is generated by teeth located on the periphery of the cutter body. The axis of cutter rotation is generally in a plane parallel to the work piece surface to be machined as shown in figure (1.4 a).

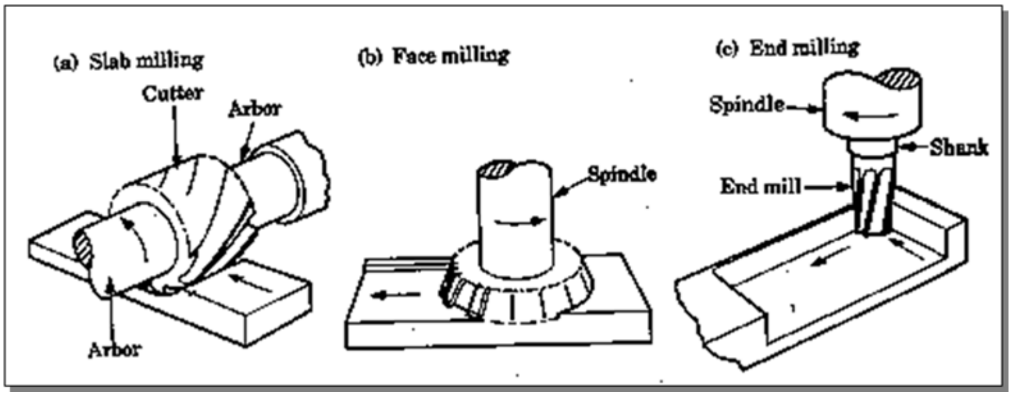


Figure 1.4: Classification of milling a: slap milling
b : face milling

c : end milling

Face Milling:

In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the work piece surface as shown in figure (1.4 b). The milled surface results from the action of cutting edges located on the periphery and face of the cutter.

End Milling:

The cutter in end milling generally rotates on an axis vertical to the work piece as shown in figure (1.4 c). It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body.

Milling machines

Milling machine can be found in a variety of sizes and designs, yet they still possess the same main components that enable the work piece to be moved in three directions relative to the tool. These components are shown on manual vertical milling machine figure (1.5) and they are :

- Base and column - The base of a milling machine is simply the platform that sits on the ground and supports the machine. A large column is attached to the base and connects to the other components.
- *Table* - The work piece that will be milled is mounted onto a platform called the table, which typically has "T" shaped slots along its surface. The work piece may be secured in a fixture called a vise, which is secured into the T-slots, or the work piece can be clamped directly into these slots. The table provides the horizontal motion of the work piece in the X-direction by sliding along a platform beneath it, called the saddle.
- Saddle - The saddle is the platform that supports the table and allows its longitudinal motion. The saddle is also able to move and provides the horizontal motion of the work piece in the Y-direction by sliding transversely along another platform called the knee.
- Knee - The knee is the platform that supports the saddle and the table. In most milling machines, sometimes called column and knee milling machines, the knee provides the vertical motion (Z direction) of the work piece. The knee can move vertically along the column, thus moving the work piece vertically while the cutter remains stationary above it. However, in a fixed bed machine, the knee is fixed while the cutter moves vertically in order to cut the work piece.

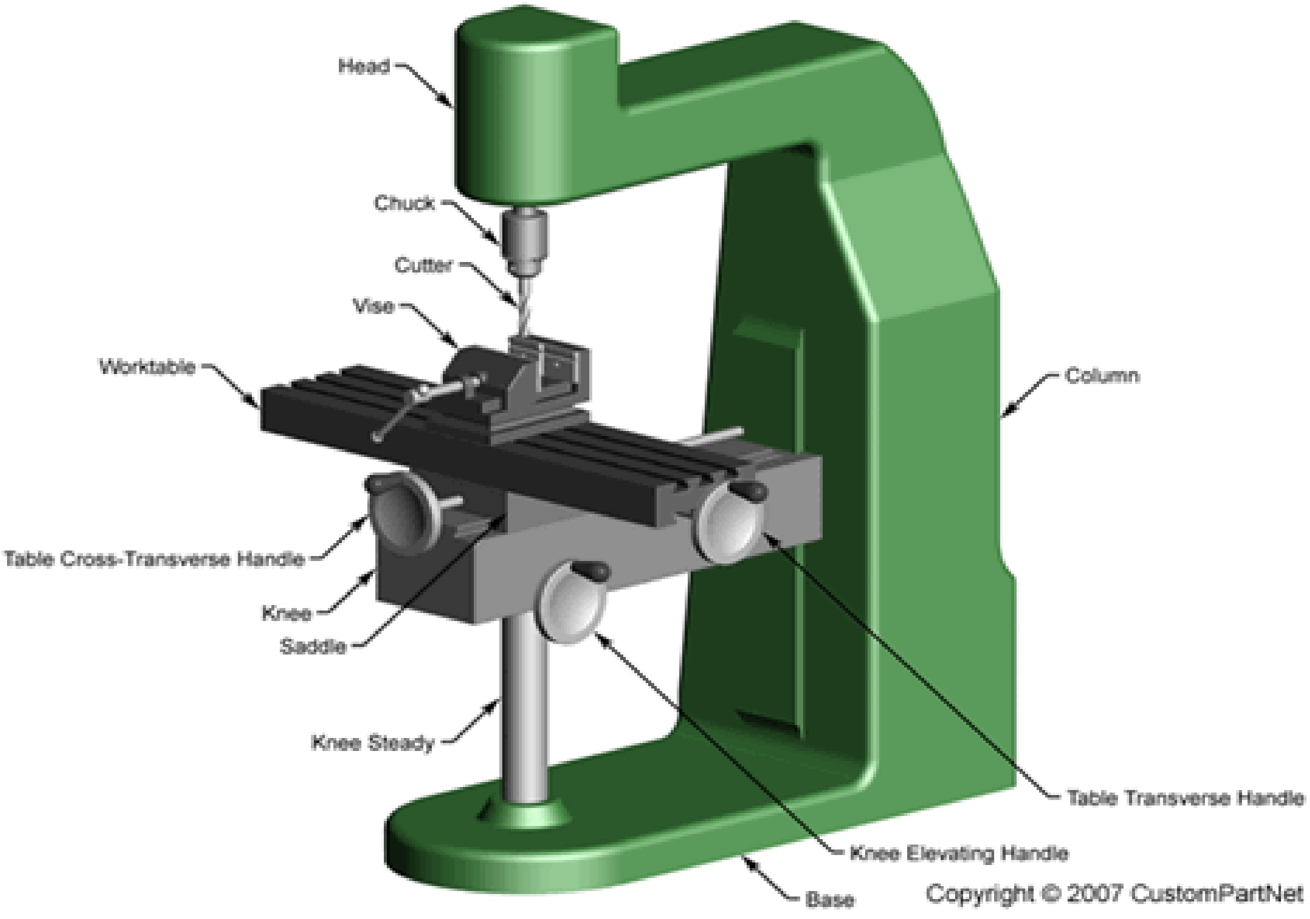


Figure 1.5**:** Manual vertical milling machine

1.2.3 Drilling process

Drilling is the manufacturing process where a round hole is created within a work piece or enlarged by rotating an end cutting tool, a drill. Reaming is a similar process where a whole feature is enlarged to a very specific or accurate size by introducing a rotating end and side cutting tool called a reamer.

Process Parameters:

Depth of cut: The depth of the hole generated by the drilling process

Feed: The rate that the drill advances into the material, generally measured in distance per flute

Speed: The cutting speed is usually measured at the periphery of the drill in surface feet or meters per minute

Thrust: The axial force required to drill

Torque: The twisting moment required to drill

Surface Finish: The roughness of the walls of the drilled hole; a measure of the hole quality

Drilling machine

The drilling machine (drill press) is a single purpose machine for the production of holes, the components of drilling machine are shown in figure (1.6). Drilling is generally the best method of producing holes. The drill is a cylindrical bar with helical flutes and radial cutting edges at one end. The drilling operation simply consists of rotating the drill and feeding it into the work piece being drilled. The process is simple and reasonably accurate and the drill is easily controlled both in cutting speed and feed rate. The drill is probably one of the original machining processes and is the most widely used.

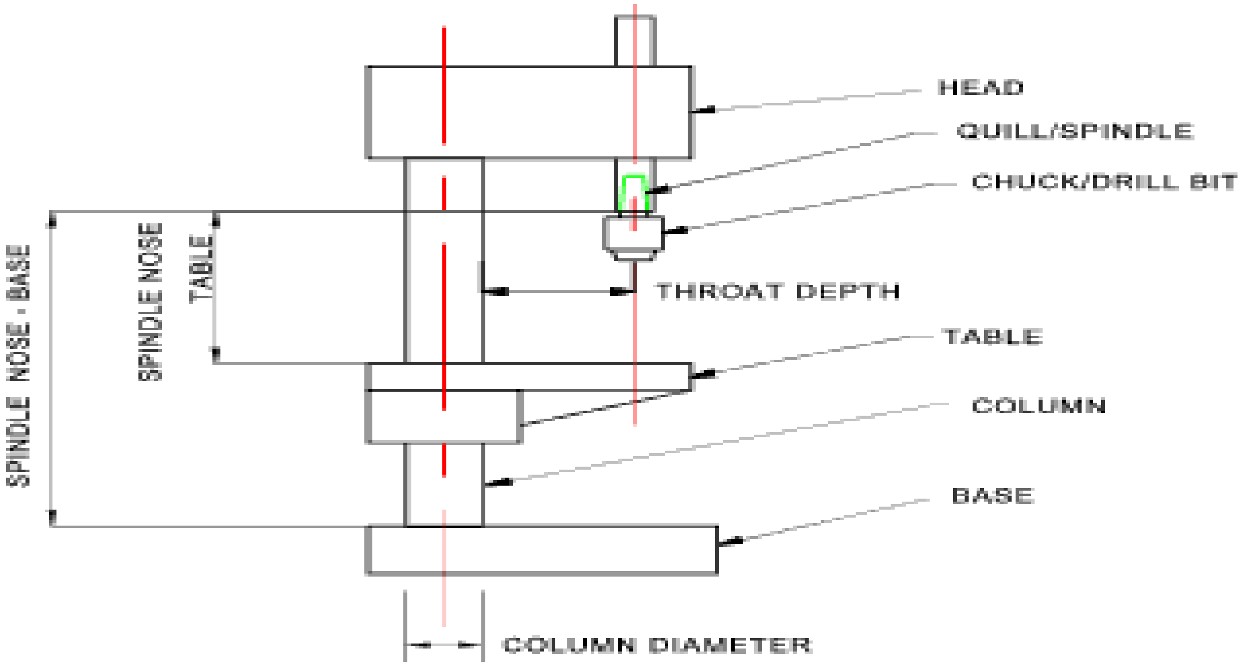


Figure 1.6: drilling machine

1.2.4 Grinding process

Grinding is a machining process that uses an abrasive wheel as the cutting tool.

A wide variety of machines are used for grinding. They include:

- hand-cranked knife-sharpening stones;
- handheld power tools such as angle grinders and die grinders;
- various kinds of expensive industrial machine tools called grinding machines; and
- The bench grinders often found in residential garages and basements.

Grinding practice is a large and diverse area of manufacturing and tool making. It can produce very fine finishes and very accurate dimensions; yet in mass production contexts it can also rough out large volumes of metal quite rapidly. It is usually better suited to the machining of very hard materials than is "regular" machining (that is, cutting larger chips with cutting tools such as tool bits or milling cutters), and until recent decades it was the only practical way to machine such materials as hardened steels. Compared to "regular" machining, it is usually better suited to taking very shallow cuts, such as reducing a shaft's diameter by half a thou. Technically, grinding is a subset of cutting, as grinding is a true metal cutting process. Each grain of abrasive functions as a microscopic single-point cutting edge (although of high negative rake angle), and shears a tiny chip that is analogous to what would conventionally be called a "cut" chip (turning, milling, drilling, tapping, etc.). However, among people who work in the machining fields, the term *cutting* is often understood to refer to the macroscopic cutting operations, and grinding is often mentally categorized as a "separate" process. This is why the terms are usually used in contradistinction in shop-floor practice, even though technically grinding is a subset of cutting.

Grinding Machine

A **grinding machine** is a machine tool used for grinding, which is a type of machining using an abrasive wheel as the cutting tool figure (1.7). Each grain of abrasive on the wheel's surface cuts a small chip from the work piece via shear deformation

The grinding machine consists of a power driven grinding wheel spinning at the required speed (which is determined by the wheel’s diameter and manufacturer’s rating, usually by a formula) and a bed with a fixture to guide and hold the work-piece. The grinding head can be controlled to travel across a fixed work piece or the work piece can be moved whilst the grind head stays in a fixed position. Very fine control of the grinding head or table’s position is possible using a venire calibrated hand wheel, or using the features of NC or CNC controls. Grinding machines remove material from the work piece by abrasion, which can generate substantial amounts of heat; they therefore incorporate a coolant to cool the work piece so that it does not overheat and go outside its tolerance. The coolant also benefits the machinist as the heat generated may cause burns in some cases. In very high-precision grinding machines (most cylindrical and surface grinders) the final grinding stages are usually set up so that they remove about 200nm (less than 1/100000 in) per pass - this generates so little heat that even with no coolant, the temperature rise is negligible.

Figure 1.7: grinding machine

1.3 Forces Analysis:

1.3.1 Orthogonal cutting

In mathematics, two vectors are **orthogonal** if they are perpendicular, i.e., they form a right angle. The word comes from the Greek *ὀρθός* (*orthos*), meaning "straight", and *γωνία* (*gonia*), meaning "angle". For example, a subway and the street above, although they do not physically intersect, are orthogonal if they cross at a right angle.

In Orthogonal Cutting assumes that the cutting edge of the tool is set in a position that is perpendicular to the direction of relative work or tool motion figure (1.8). This allows us to deal with forces that act only in one plane.

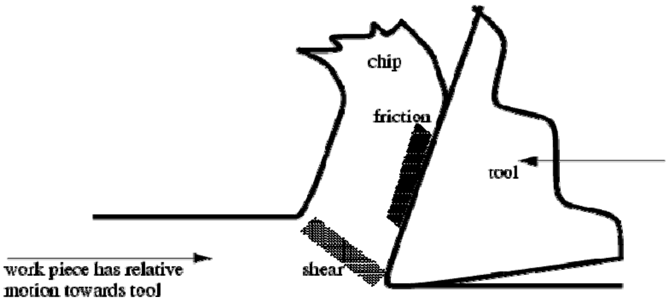
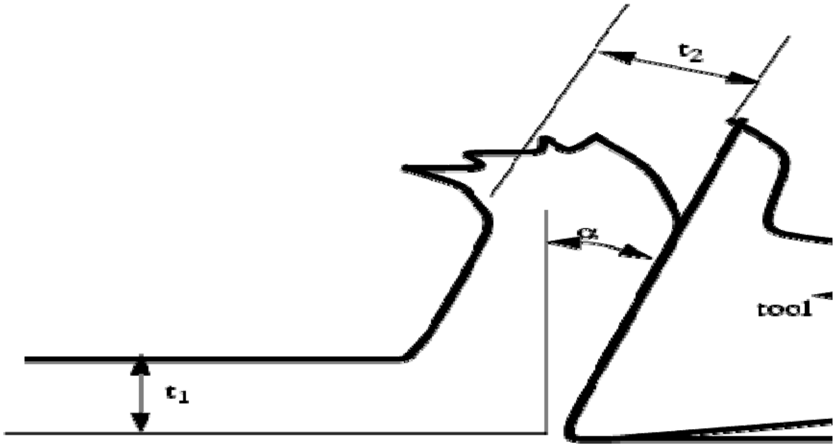


Figure 1.8: orthogonal cutting condition

We can obtain orthogonal cutting by turning a thin walled tube, and setting the lath bit cutting edge perpendicular to the tube axis.

Next, we can begin to consider cutting forces, chip thicknesses, etc. Figure (1.9) shows the physical geometry of orthogonal cutting between tool and plane.



where,

t_1 = undeformed chip thickness
t_2 = deformed chip thickness (usually $t_2 > t_1$)
α = tool rake angle

If we are using a lathe, t_1 is the feed per revolution

Figure 1.9: the physical geometry of cutting

Next, we assume that we are also measuring two perpendicular cutting forces that are horizontal, and perpendicular. This then allows us to examine specific forces involved with the cutting. The cutting forces in figure (1.10), (Fc and Ft) are measured using a tool force dynamometer mounted on the lathe.

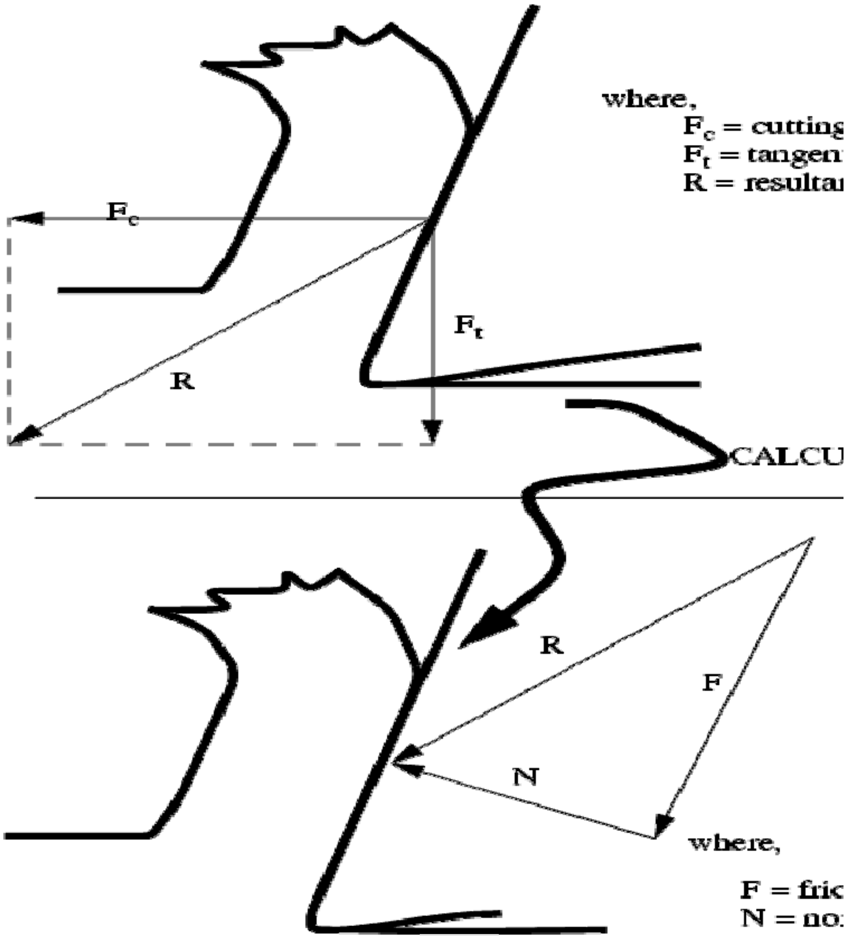


Figure 1.10: orthogonal Cutting forces

Forces and angles in orthogonal cutting:

As shown in side view of orthogonal cutting figure (1.11) below, we can note that:

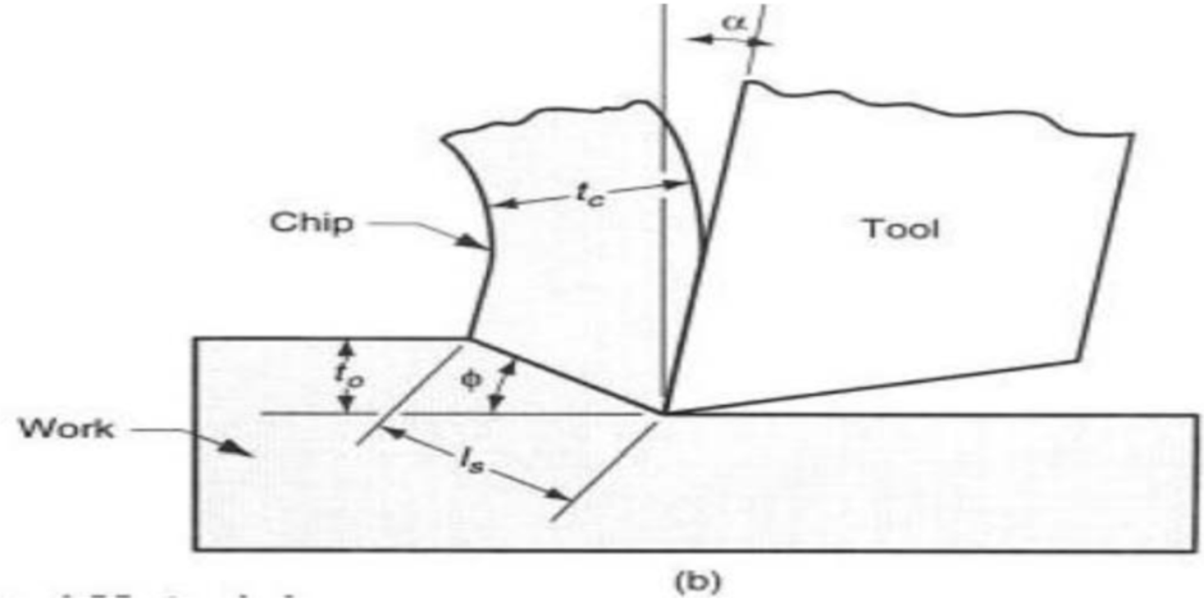


Figure 1.11 : side view of orthogonal cutting

Note that (**α**) is the rake angle and determines the direction of chip flow. Also , ϕ is the shear plane angle.

The thickness of the chip prior to chip formation is($t_\circ$),as the chip is formed it increase in thickness to(t_c) so the chip thickness ratio (r) is given by :

$$r = \frac{t_\circ}{t_c}$$

And if we make the substitutions $t_\circ = L_s \, sin\phi$, and $t_c = L_s \cos(\boldsymbol{\phi - \alpha})$ then we can write :

$$r = \frac{L_s \sin\phi}{L_s \cos(\phi - \alpha)}$$

The last equation can be rearranged to determine (**ϕ**) as :

$$\tan\phi = \frac{r \cos\alpha}{1 - r \sin\alpha}$$

Force relationships:

Consider the forces acting on the chip during orthogonal cutting figure (1.12 a), these forces can be separated into two perpendicular components:

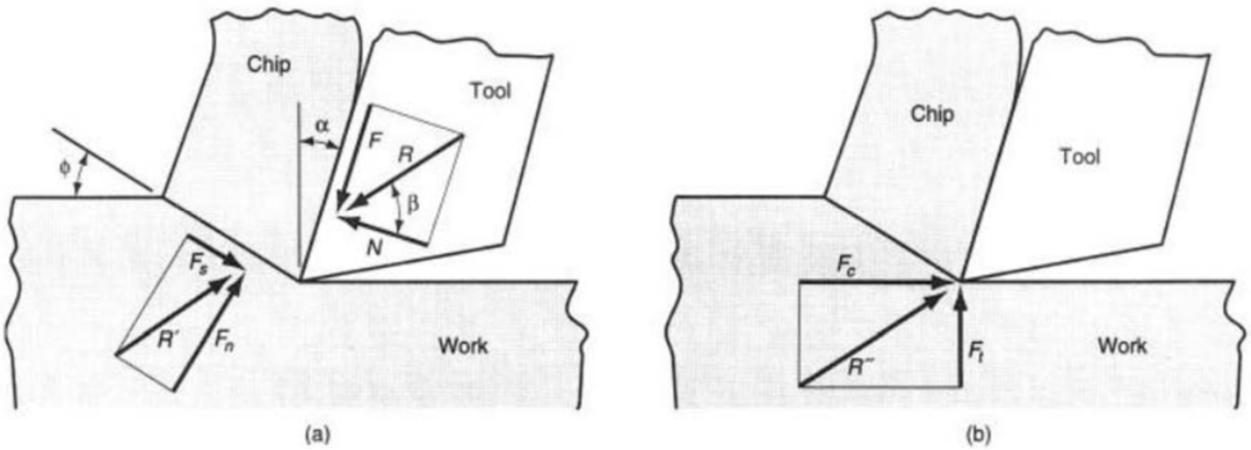


Figure 1.12 : forces in metal cutting : (a) forces acting on the chip in orthogonal cutting and (b) forces acting on the tool that can be measured.

1) Friction force (F) : between the tool and the chip
2) Normal force to friction(N) : normal to friction force

Therefore, we can write

$$\mu = \frac{F}{N} \text{ (} \mu \text{ : coefficient of friction)}$$

$$\mu = tan\beta \text{ (} \beta \text{ : friction angle)}$$

The forces imposed by the work on the chip figure (1.12 b) are :

1) Shear force (Fs) : causes shear deformation in the shear plane
2) Normal force to shear(Fn) : normal to shear force

Now ,the shear strength that acts along the shear plane is obtained from

$$S = \frac{Fs}{As}$$

Where (As) is the shear plane area and calculated from:

$$A_s = \frac{t_\circ\, w}{sin\phi} \text{ (w : width of cut)}$$

Note that none of the four force components F,N,Fs and Fn can be directly measured. However , by using a dynamometer two additional force components that act against the tool can be directly measured and they are :

1) Cutting force Fc :same direction as the cutting speed and it is the same as Ft (tangential force) in turning process
2) Thrust force Ft:perpendicular to the cutting force (in direction of $t_{\circ}$) and it is the same as Fa(axial force) in turning process

And from the force diagram of orthogonal cutting figure(1.13) we can obtain geometric relationships among Fc, F , Fn , N , Ft , and Fs as follows:

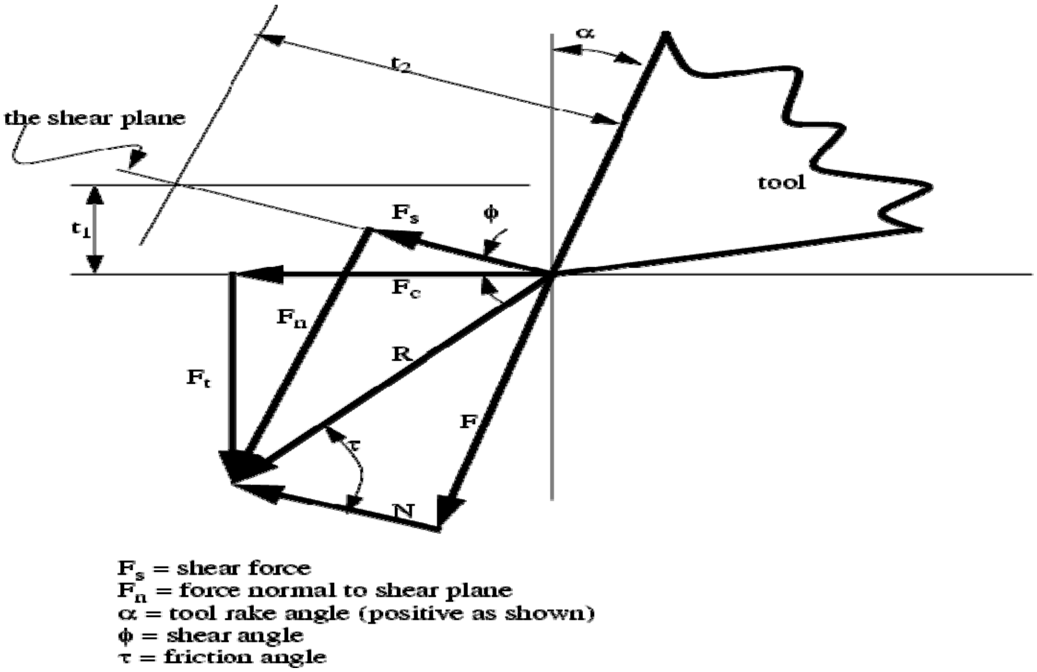


Figure 1.13 : Force diagram of orthogonal cutting

1) $F = Fc \sin\alpha + Ft \cos\alpha$
2) $N = Fc \cos\alpha - Ft \sin\alpha$
3) $Fs = Fc \cos\boldsymbol{\phi} - Ft \sin\boldsymbol{\phi}$
4) $Fn = Fc \sin\boldsymbol{\phi} + Ft \cos\boldsymbol{\phi}$

1.3.1. a Orthogonal cutting- conditions

To satisfy the condition for orthogonal cutting, the cutting tool must have:

a) a zero back rake

b) a plan approach angle of 90°, so that the cutting edge is radial to the work

c) a small nose radius

d) an overall length of 63mm to 83 mm to insure adequate clamping

And these details are shown in figure (1.14)

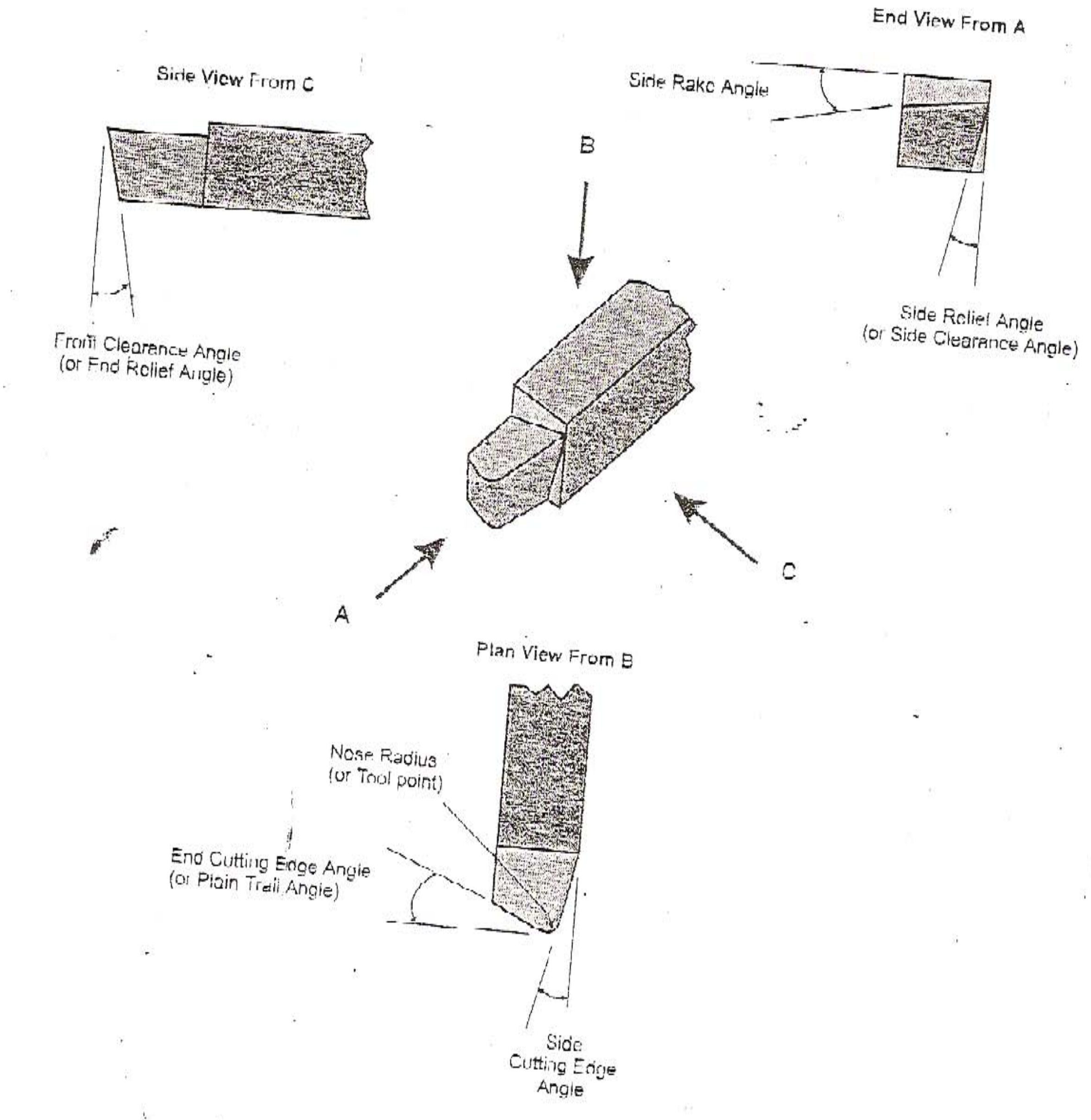


Figure1.14 main feature of cutting tool in orthogonal cutting

1.4 Safety Rules in using cutting tool

1) Keep in mind that machinery capable of cutting metal is inherently dangerous.

2) Develop and use common sense when using the equipment (think before you act).

3) Keep in mind that rotating equipment stores significant amounts of energy and represents a serious entanglement hazard. Remember if it looks unsafe it probably is. Be sure to Discuss the operation of the lathe in detail with the TA before conducting the tests.

4) Do not operate the machine until you have had detailed instruction from the TA.

5) make sure the work piece is adequately clamped in the spindle for the job being Performed. Rotating parts with a slight imbalance can generate large forces, also Metal cutting generates large forces. The clamping force must be high enough to Resist movement under these conditions. Make sure the TA checks the part clamping Before starting the machine, (Never leave the chuck key in the spindle.)

6) make sure the tool holder and cutting insert are adequately clamped for the job being Performed

7) Always wear safety glasses when around the machine.

8) Long hair should be tied back to avoid being caught in the revolving parts of the machine (Keep loose items away from rotating objects).

9) Loose clothing, rings or watches should not be worn when operating machine tools to

Avoid having them getting caught in the machine.

10) Wear long pants (preferably cotton) as metal cuttings removed from the workpiece during the machining process can reach temperatures in excess of 300ºC and can burn.

11) Watch out for sharp edges on the part, tool and on the chips. Use gloves when handling sharp objects but remove them when operating the machine to avoid them getting caught in the rotating machinery.

12) Do not use rags near the rotating machines when the spindle is running. Rags can be

Caught in the rotating spindle and the result can be serious injury. Rags may be used

For material handling and for cleaning purposes provided there are no rotating hazards

Nearby.

13) Use extreme caution with the chips produced during machining. Chips are sharp and some chips are long stringers which can easily be caught up in the spindle and thrown with great force. In general do not clear chips away from the work area when the

Machine is in motion. If it is necessary ask the how this can be best done. (If

Necessary there is a long handled tool available for pushing the chips out of the way

14) Sandals and opened toed shoes are not permitted in the lab.

15) It is mandatory to report all cases of injury to the lab .

16) Anyone using the lab equipment is expected to work safely at all times. If you do not work safely you will be asked to leave. Re-admittance to complete the lab requires

The approval of the department chair, you are responsible for your safety and the

Safety of others working around you, If you do not know how to safely operate the

Equipment it is your responsibility to seek out the proper instruction from the lab TA.

Chapter 2

PE1 Lath Tool Dynamometer

2.1 PE1 Lathe Tool Dynamometer

2.1.1 Introduction

LATHE TOOL DYNAMOMETER

To measure cutting forces at different speed and different material two component of cutting forces in orthogonal cutting the axial & vertical components. The unit is with strain gauge bridge balance with power supply & digital indicator.

A large number of factors on forces involved in cutting metals with single point cutting tools may be investigated using this dynamometer

Some of important variables which we will study include:

1. tool geometry
2. rate of tool feed
3. surface cutting speed of the work piece
4. work piece material

From measurement of tool forces other important parameters, such as the power consumed at the cutting edge and the specific cutting pressure can be calculated

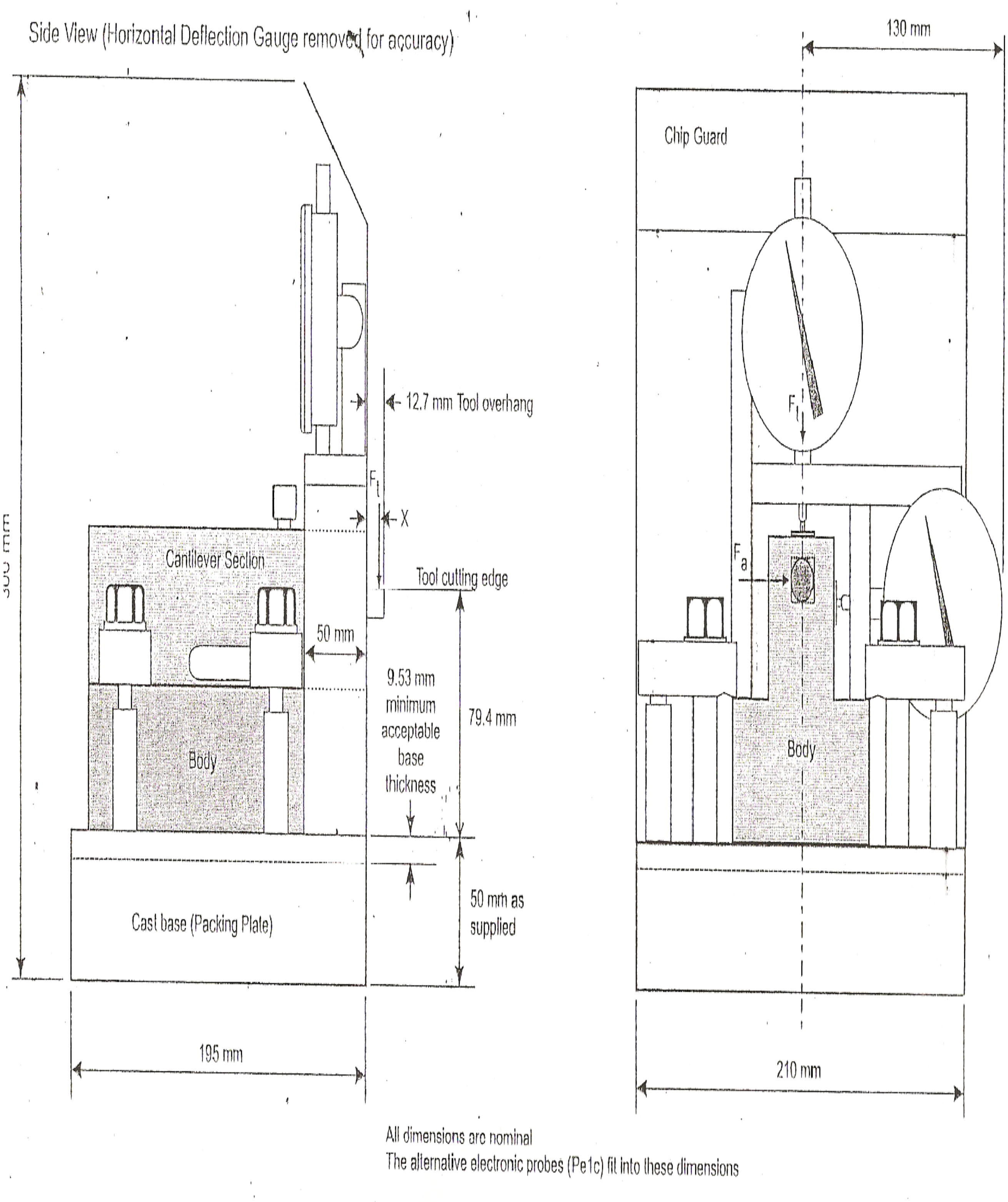


Figure 2.1: dimension of the PE1

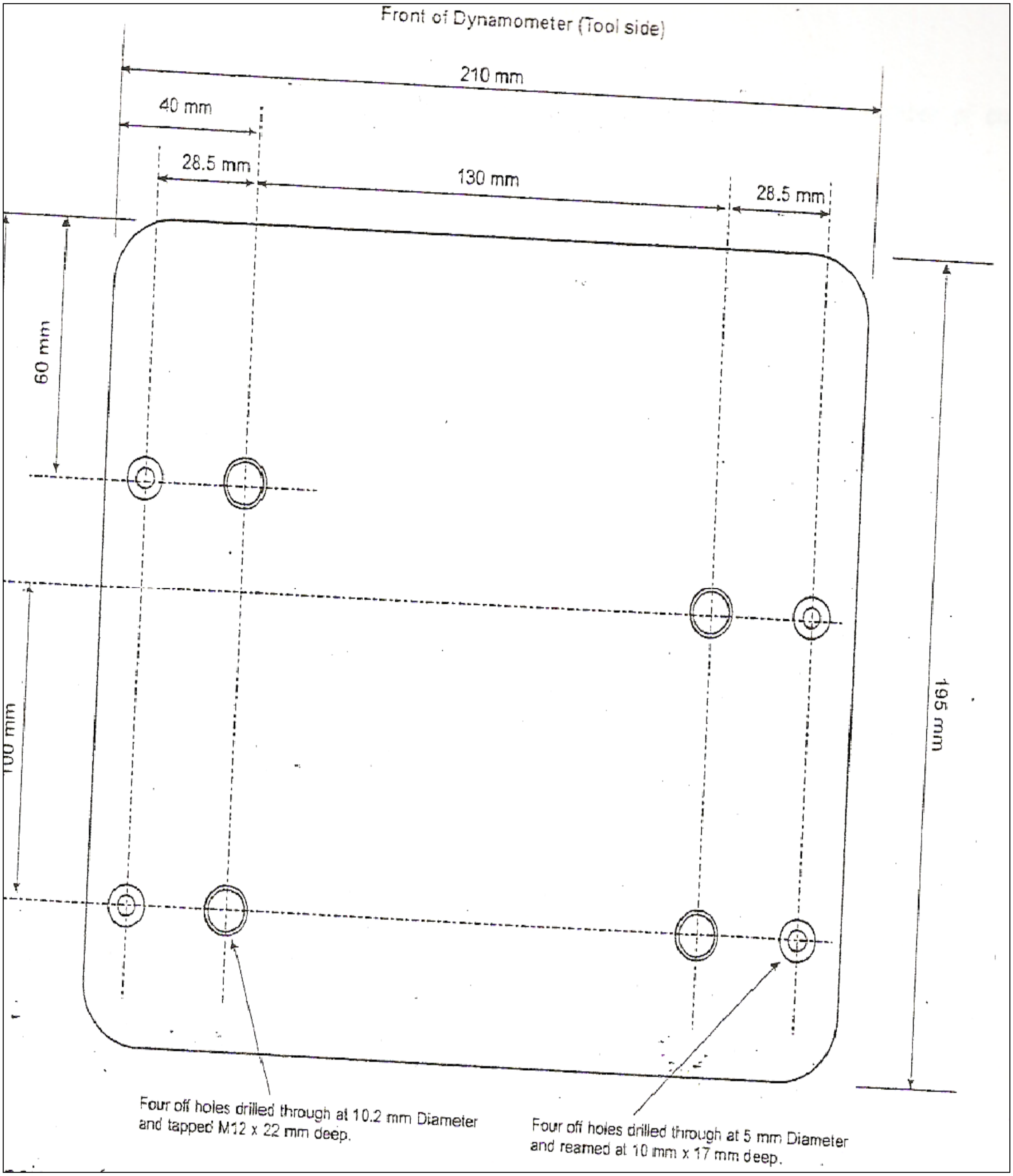


Figure 2.2: dimension of packing plate/base (plan View)

2.2 Design and Feature

The design of any lathe tool dynamometer involves a compromise, to try and satisfy a number of conflicting requirements. The instrument should have:

- high stiffness in order to insure that the dimensional accuracy of the cutting process is maintained
- high natural frequency in order to minimize the tendency for chatter vibrations to occur during cutting .however the dynamometer must give deflections which are large enough to be measured accurately

The design of PE1 has been determined by experiment. It gives the best compromise between easily readable dial gage movement and freedom from vibration, with sufficient range of application to enable the effect of the major variable in metal cutting to be demonstrated

The dynamometer accept 7.94mm square tools which are held by four clamping screws in a 15.88mm square hole on the axis of the cantilever.

The tool cutting edge must lie at the intersection of the neutral axis of the cantilever cross-section. The cutting force is applied very nearly through the cutting edge, but at some angle to it (i.e. the feed\revolution is relatively small) so the two component of the force result in bending in the cantilever without twisting. Hence the deflections in the two directions are completely independent of each other, which simplified calibration.

Dial gauge are mounted on side plates attached to the dynamometer body and contact stainless steel studs inserted in the cantilever .A stainless steel chip guard protect the dial gauges from flying metal cuttings (or chips)

It is important that the distance x (shown in 2.3) from the line of action of the forces applied to the tool to the front face of the cantilever, is the same during the calibration and metal cutting this distance is 10.16mm.so, for a standard depth of cut of 5.08mm, the tool overhang must be 12.70mm.A tool setting gauge is provided to assist rapid setting of the correct tool overhang for the standard depth of cut. This gauge maybe used without removing the chip guard.

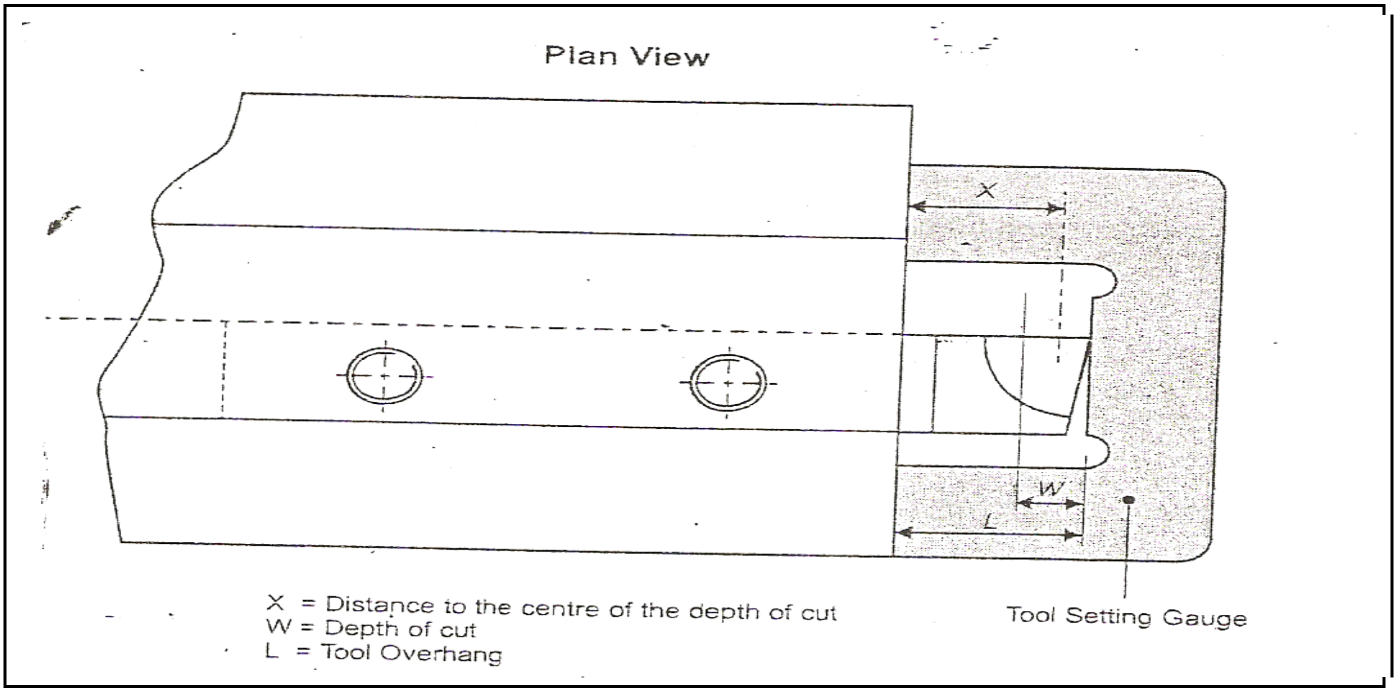


Figure 2.3: using the tool overhang setting gauge

In order that the dynamometer maybe adapted to suit a wide variety of standard lathes it is mounted on a cast iron packing plate of nominally 50mm thickness. The lower surface of this plate is left ready for the customer to machine it to correct thickness to suit the lathe on which the dynamometer is to be fitted. The dynamometer normally mounts on the lathe cross slide after removing the compound slide. The packing plate may be drilled to suit the existing compound slide fixing bolts

2.3 Setting up PE1 lathe tool dynamometer

the procedure for setting up is as follows:

1. Remove the lathe compound slide, clean all mating surfaces and fit the dynamometer packing plate to the lathe cross side
2. Position the dynamometer on the packing plate with the cantilever axis perpendicular to the work piece. Install the lower dial gauge to insure that it clears the holding down clamp .this may be done by a arranging for a dial gauge mounted from the lathe carriage to contact the side face of the cantilever .then, by traversing the cross slide , the dial gauge will indicate any misalignment. Tighten the dynamometer clamps.
3. Set the tool in appropriate bottom corner of the square hole in the cantilever, using the tool overhang setting gauge, when the standard depth of cut is to be used. Make sure that the tool is firmly clamped using all four holding screws. This is important to avoid chatter vibrations of the tool, due to inadequate clamping
4. Check that the dial gauge or electronic transducer are securely clamped in position and the deflection on the appropriate gauge occurs when applying loads by hand in the directions of Ft and Fa

   Note: Ft causes the cantilever to deflect away from the gauge reading the vertical deflection, and Fa causes the cantilever to deflect towards the gauge reading the horizontal deflection

2.4 Lathe Tool Dynamometer Calibration Unit PE1a

The calibration unit comprises the following items:

a) Dummy tool

b) Loading frame and steel ball

c) Weight hanger

d) Wieghts-10 off10 kg

To calibrate the dynamometer using the above equipment, follow these procedures:

1. Mount the dynamometer on a suitable machine bed
2. Fit the dummy tool in the square hole at the front of cantilever, using the tool setting gauge to set the correct tool overhang
3. Zero the dial gauge (or electronic gauge unit), place a steel ball in the conical recess in the dummy tool and hang the loading frame on the dummy tool. A conical recess in the loading frame locates on the steel ball.
4. Load the dynamometer using the weight hanger and weights in increments of 10 Kg and note dial gauge or probe readings after each load
5. Repeat readings for unloading
6. Plot load against deflection and determine the calibration factor for the dynamometer from the gradient of the graph

7. Repeat this procedure for the horizontal component with the dynamometer mounted on an angle bracket (not supplied) on the machine bed. Check that he cantilever axis is horizontal by placing a spirit level on the side face of the cantilever.

Chapter Three

Experimentations

3.1 Experimentations

3.1.1: Abstract

In this chapter typical experiment were performed and the result of them were analyzed and related figure were drawn to show deferent relationships between variables.

Experiments that were conducted are :

1. Effect of varying feed on cutting force (constant cutting speed and tool side rake angle)
2. Effect of varying cutting speed on cutting force (constant feed and tool side rake angle)
3. Effect of varying tool rake angle on cutting force (constant cutting speed and feed)
4. Determination of Ultimate Tensile Strength of aluminum using force dynamometr (constant feed ,tool side rake angle and cutting speed)

3.1.2 Experiment #1: Effect of varying feed on cutting force

Objectives:

1. To determine the effect on tool forces in orthogonal metal cutting when varying feed with constant speed and tool side rake angle
2. To calculate the specific cutting pressure
3. To calculate Power Consumed at the cutting edge

Apparatus:

1. Lathe machine (figure 3.1)
2. PE1 tool dynamometer(figure 3.2)
3. Aluminum work piece
4. Coolant Substance

Figure 3.1: lathe machine

Figure 3.2: lathe tool dynamometer

Abstract:

In this experiment, the effect of feed on the cutting forces is investigated using aluminum work piece material; the tests were carried out using a lathe tool dynamometer. The results suppose to show that increasing feed will increase cutting forces

Introduction

Turning process is one of the most important processes used for machine elements construction in manufacturing industries i.e. aerospace, automotive, and shipping. In turning process the work piece material is rotated and the cutting tool, travelling to the left, removes a surface layer (chip) of the workpiece material, producing three cutting forces components, i.e. the main tangential force F_t, which acts on the cutting speed direction, the feed force F_a (axial force), which acts on the feed rate direction and the radial force F_r, which acts on the direction which is normal to the cutting speed.

It was observed that the cutting forces are directly depended on the cutting parameters i.e. cutting speed, feed , depth of cut, tool material and geometry, workpiece material type and coolant type

The knowledge of the influence of cutting conditions (cutting speed, feed , cutting depth), tool characteristics (tool angles, nose radius, tool material), mechanical properties and chemical composition of workpiece material on the developed cutting forces, could help to understand the cutting mechanism i.e. the workpiece machinability, the chip formation process, the frictional and thermal properties at tool-chip interface, the crater and flank wear growing at the cutting tool.

Theory:

In here the theory of orthogonal cuts:

The feed(***f)*** is the tool advancement per revolution along its cutting path in mm/rev the feed rate (***ft)*** is the speed at which the tool advances into the part longitudinally in mm/ min and it is related to ***f*** through the spindle rpm **N**:

$$ft = fN$$

The feed influences chip thickness and how the chip breaks. The undeformed chip thickness $(t_\circ)$ in orthogonal cutting is related to(***f)*** as follows ***:***

$$t_\circ = \boldsymbol{f}$$

The depth of cut (***d)*** is the width (w) in orthogonal cutting of material removed from the workpiece surface:

$$w = d = \frac{\boldsymbol{D1-D2}}{\boldsymbol{2}}$$

Where**:** D1: original diameter of work piece

D2: new diameter of work piece

The time ***tm*** required to cut length **L** in the feed direction is:

$$tm = \frac{\boldsymbol{L}}{\boldsymbol{ft}}$$

Where **L**: length of the work piece to be turned

The material removal rate ***MRR*** of turning process is related to orthogonal cutting by the relation :

$$\boldsymbol{MRR} = t_{\circ}\, v\, w = f\, v\, d \quad \mathbf{m^3/min}$$

Where : f **:** indicates the thickness of the chip prior to chip formation **(** $t_{\circ}$ **)**

V : indicates the cutting speed between workpiece and tool

d **:** indicates the width of material removed from workpiece **(w)**

The cutting speed V it given by :

$$\mathbf{V = \boldsymbol{\pi}\, D\, N}$$

And **D**: original diameter of work piece

N: cutting speed

The specific cutting pressure **(S.C.P) =** the cutting force, F_t divided by the cross section area of the undeformed chip gives the nominal cutting stress or the specific cutting pressure and its give by:

S.C.P=Tangential force (Ft)/ Area of cut

Where area of cut =$\boldsymbol{feed\ (f) * depth\ of\ cut}$ **(d)**

The power consumed at tool point **(P) =Ft* cutting speed**

(Assuming that the power due to axial force is negligible)

The deflection of tool can determined by using vertical and horizontal dial gages on lathe tool dynamometer by applying :

Deflection = pointer reading * 5 * 0.002

Where : pointer reading: indicates the number that the pointer indicate on it

5 : indicates that there is 5 divisions between each number and another

0.002 : it is because there 0.2 mm/rev, graduated in 0.002 mm divisions

The tool over hang **(Lh) =10.16+Depth of cut /2**

Procedure:

1. Aluminum work piece with 57mm diameter was used in experiment
2. depth of cut was determined to insure adequate rigidity(d=2mm)
3. lath machine was checked to make sure that it works well and safe
4. safety rules were followed during the experiment, such as wearing glasses and lap coat
5. Gage unit was mounted on a suitable table alongside the lathe as shown in figure (3.3) to isolate it from lathe vibrations.

Figure3.3: Supported gage unit alongside lathe

6. After that the work piece was supported at tail stock by running center
7. The experiment was started by changing feed gradually using control panel on lathe machine with constant speed(N=770rpm) and depth of cut(2mm) and rake angle(5°)
8. coolant lubricant was used to decease temperature
9. the extra chip was removed continuously in order not to affect the work
10. The magnitude of any pointer vibration was noted when deflection reading was taken
11. The reading of deflections were taken from two dial gages on dynamometer and was filled in table as shown in results knowing that vertical gages use to measure tangential force and horizontal use to measure axial force (Fa)(the values of forces were taken from the related calibration graph which shows relationship between force and deflection, see appendix B)
12. The specific cutting pressure and power were also calculated.

Results:

Table 3.1: Tool angles detail

Back Rake angle	0°
Front Clearance angle	5°
Side Clearance Side	5°
Plan Approach Angle	90°
Plan trail angle	8°
nose radius	0.76mm
Side rake angle	5°

Figure (3.4) shows side, end and plan views of cutting tool used

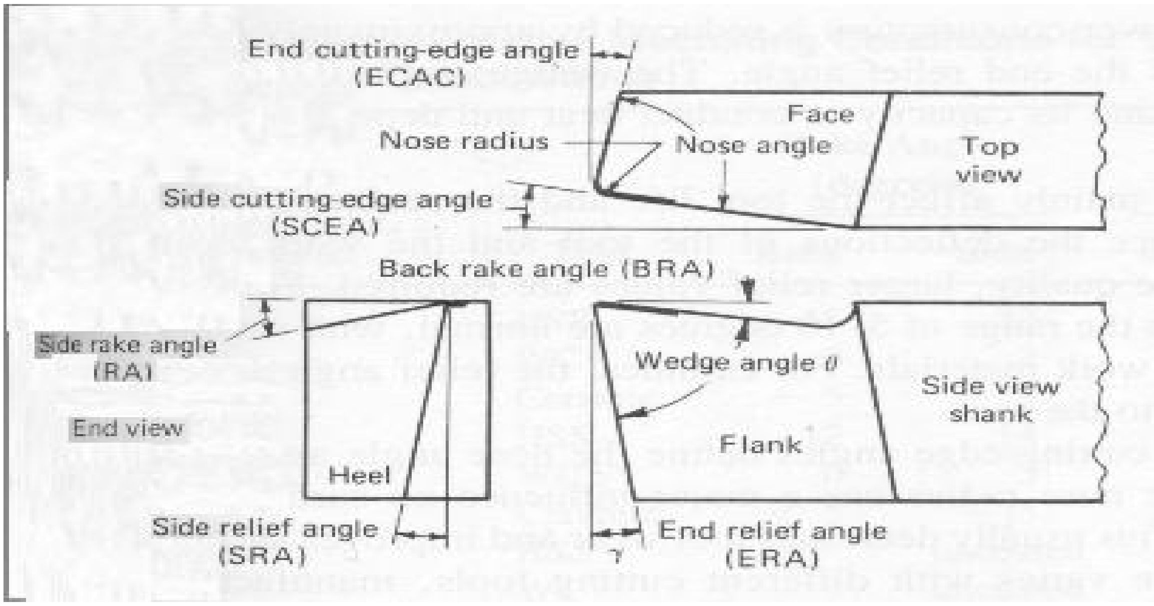


Figure (3.4): general test detail (Related Angles of tool)

Table 3.2 shows details needed in experiment

Work piece	Aluminum
Cutting Conditions	Speed(N=770rpm), feed(0.136-0.468mm/rev), depth of cut(d=2mm)
Depth of cut	2mm
Lathe Size	9x89
Cutting position	90°
Work piece original diameter	57mm
cutting speed	137.81m/min

Table 3.2: feed test detail

feed mm/rev	**cutting speed (m/min)**	**vertical component**			**Axial component**			**specific cutting pressure (N/mm²)**	**power consumed(W)**
		Deflection (mm)	**Pointer Vibration (mm)**	**Force (N)**	**Deflection (mm)**	**Pointer Vibration (mm)**	**Force (N)**		
0.136	**137.81**	**0.015**	**±1.5**	**330**	**0.005**	**±0.5**	**120**	**1213.235294**	**45477.3**
0.188	**137.81**	**0.02**	**±2**	**410**	**0.01**	**±1**	**230**	**1090.425532**	**56502.1**
0.234	**137.81**	**0.022**	**±2.2**	**460**	**0.012**	**±1.2**	**260**	**982.9059829**	**63392.6**
0.272	**137.81**	**0.025**	**±2.5**	**520**	**0.015**	**±1.5**	**330**	**955.8823529**	**71661.2**
0.376	**137.81**	**0.03**	**±3**	**650**	**0.025**	**±2-3**	**530**	**864.3617**	**89576.5**
0.468	**137.81**	**0.034**	**±3.4**	**750**	**0.026**	**±2.6**	**540**	**801.2821**	**103357.5**

Table 3.3 : table of result of variable feed

Sample Calculations:

- The specific cutting pressure **(S.C.P) = Tangential force (Ft)/ Area of cut =330/(0.136*2mm)=1213.235N/mm²**
- The power consumed at tool point **(P) =Ft* cutting speed (N) = 330*137.81=45477.3w**

Related Graphs:

The relationship between forces and deflection is appearing in figure (3.5),(3.6)

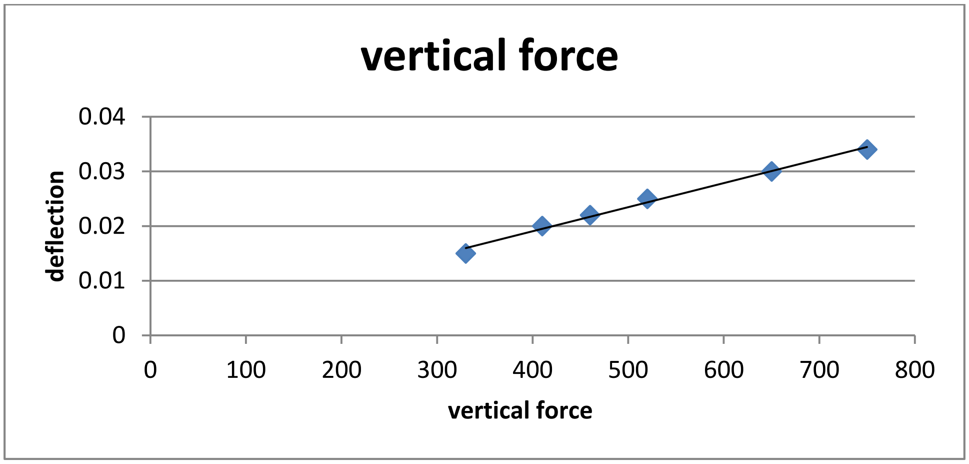


Figure3.5: Deflection versus vertical force

From figure (3.5) we conclude that vertical force increase as deflection increase

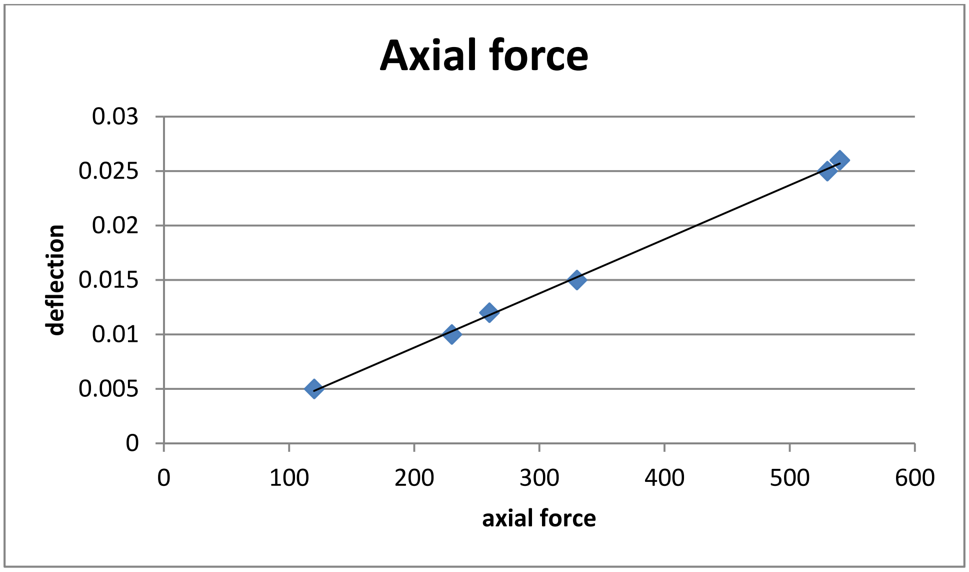


Figure 3.6: deflection versus axial load

From figure (3.6) we conclude that axial force increase as deflection increase

The relation between two forces and feed also was studied

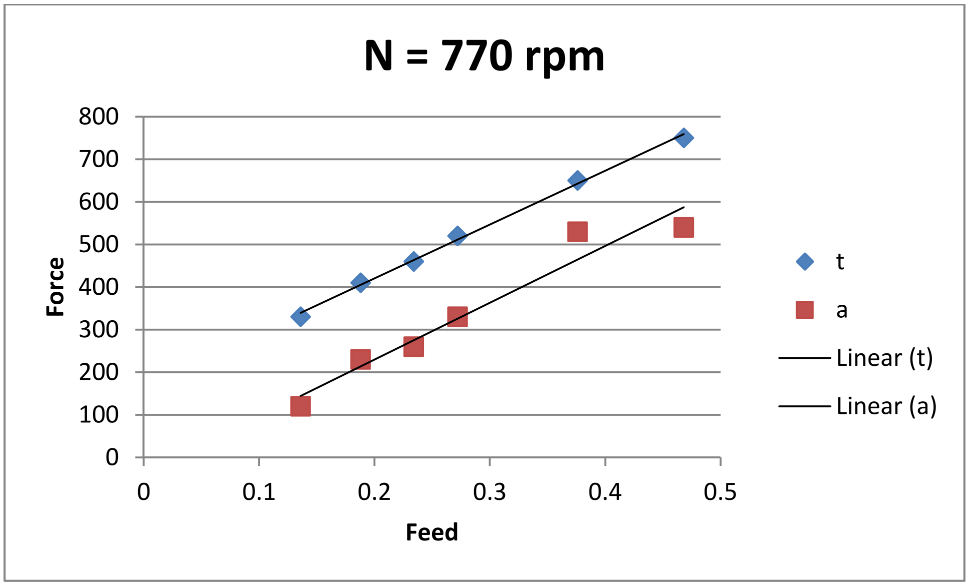


Figure3.7: forces versus feed

The data above is obtained experimentally. From the figure (3.7) we conclude that as feed increase tangential and axial loads increase

The relation between specific cutting pressure and feed was studied

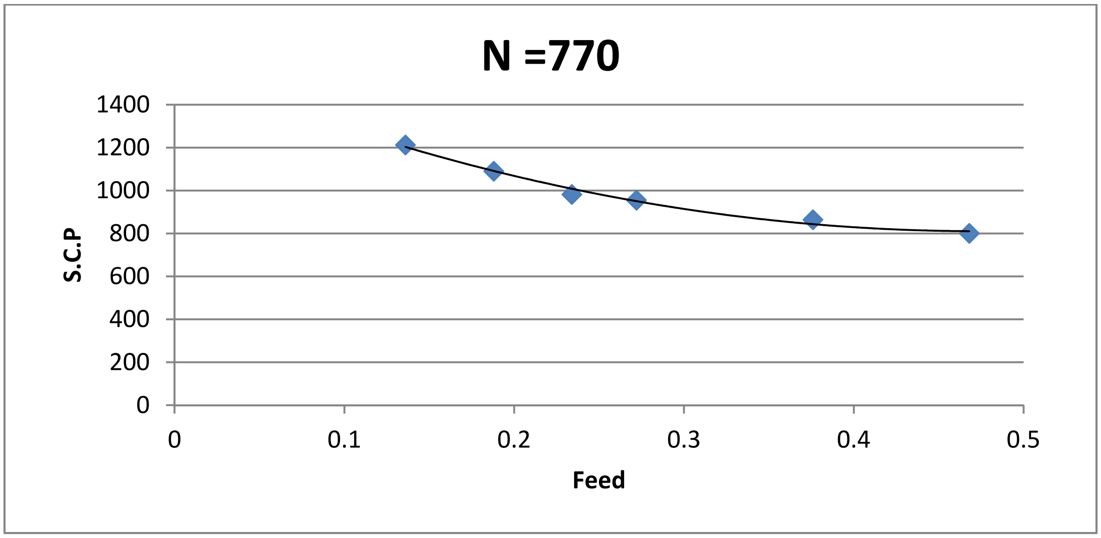
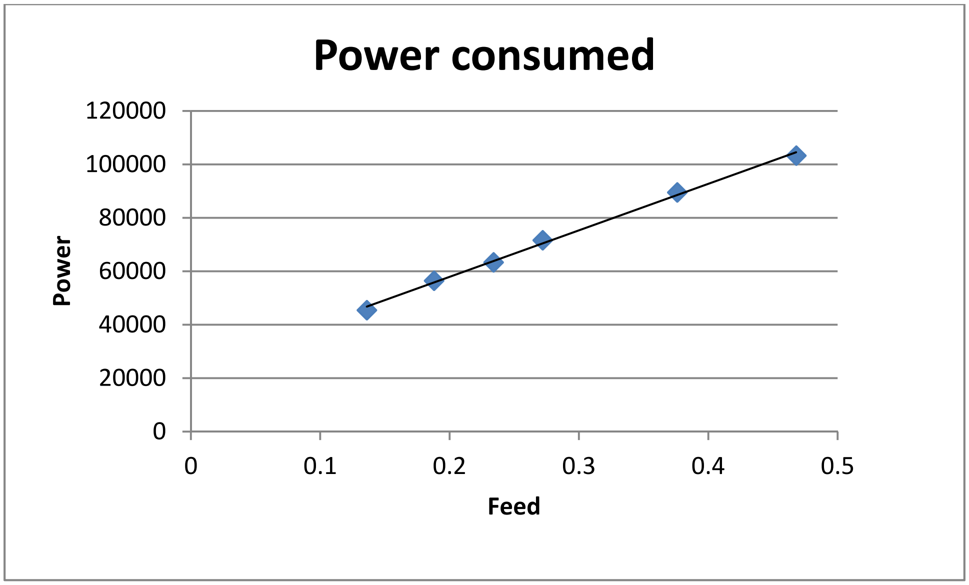


Figure3.8: S.C.P versus Feed

The data above is obtained experimentally. From the figure (3.8) we conclude that S.P.C is inversely proportional with feed

The relation between power consumed at tool point and feed were studied as shown in figure 3.9 :



As shown from figure above as feed increase power consumed at tool point also increase and the relation between them is linear.

Discussions& Conclusions:

1) In orthogonal cutting As Deflection increase tangential force and axial force will increase.
2) Increase feed per revolution will increase tangential force and axial force.
3) And Specific cutting pressure is inversely proportional with feed
4) The relation between feed and power is linear because power = F V and while cutting speed is constant during the experiment with F increasing as feed increasing this will cause to increase the power as feed increase with same rate.

3.1.2: Experiment#2:

Effect of varying cutting speed on cutting forces

Objectives:

1. To learn about machining equipment and the metal cutting process.
2. To better understand the relationship between metal cutting parameters and other process issues that affect cutting force values
3. To observe and understand the effect of speed and its effect on the process.

Apparatus:

1. Lathe machine
2. PE1 tool dynamometer
3. Aluminum work piece
4. Suitable Lubricant

Abstract

Cutting tools are subjected to extremely unfavourable conditions during machining operations. High cutting temperatures, compressive and shear stresses, chemical interactions, mechanical loads are some adverse conditions that wear these tools. Cutting force is an important phenomenon for the tool deterioration. In this experiment, the effects of increasing cutting speed on the cutting forces will be studied.

Introduction:

In mathematics, two vectors are **orthogonal** if they are perpendicular, i.e., they form a right angle. The word comes from the Greek *ὀρθός* (*orthos*), meaning "straight", and *γωνία* (*gonia*), meaning "angle". For example, a subway and the street above, although they do not physically intersect, are orthogonal if they cross at a right angle

The tool cutting edge is set at 90' to the direction of movement. The effectiveness of the tool depends greatly upon the slope of the active surface of the tool. The tool would tend to curl the chip in the form of a clock spring or a flat spiral. This is not the best form of chip for efficient metal removal. The disposal of such chips present difficulties, particularly in turning as the chip will stay on top of the tool holder and may damage the work piece's surface.

Turning process

Is machining a workpiece at various cutting depth, the feed rate is usually selected based on the maximum depth of cut. Even if this selection can avoid power saturation or tool breakage, it is very conservative compared to the capacity of machine tools and can reduce the productivity significantly. Many adaptive control techniques have been reported that can adjust the feed rate to maintain the constant cutting force. However, these controllers are not very widely used in manufacturing industry because of the limitations in measuring the cutting force signals and selecting the appropriate cutting force level. A synthesized cutting force monitor is introduced to estimate the cutting force as accurately as a dynamometer does. The reference cutting force level as well as the feed-rate is selected considering the spindle motor characteristics

Theory:

The feed(***f)*** is the tool advancement per revolution along its cutting path in mm/rev the feed rate (***ft)*** is the speed at which the tool advances into the part longitudinally in mm/ min and it is related to ***f*** through the spindle rpm **N**:

$$ft = fN$$

The feed influences chip thickness and how the chip breaks. The undeformed chip thickness $(t_\circ)$ in orthogonal cutting is related to(***f)*** as follows ***:***

$$t_\circ = \boldsymbol{f}$$

The depth of cut (***d)*** is the width (w) in orthogonal cutting of material removed from the workpiece surface:

$$w = d = \frac{\boldsymbol{D1-D2}}{\boldsymbol{2}}$$

Where**:** D1: original diameter of work piece

D2: new diameter of work piece

The time ***tm*** required to cut length **L** in the feed direction is:

$$tm = \frac{\boldsymbol{L}}{\boldsymbol{ft}}$$

Where **L**: length of the work piece to be turned

The material removal rate ***MRR*** of turning process is related to orthogonal cutting by the relation :

$$\boldsymbol{MRR} = t_\circ\, v\, w = f\ v\ d \quad \mathbf{m^3/min}$$

Where : f **:** indicates the thickness of the chip prior to chip formation **(** $t_\circ$ **)**

V : indicates the cutting speed between workpiece and tool d **:** indicates the width of material removed from workpiece **(w)**

The cutting speed V it given by :

V = π D N

And **D**: original diameter of work piece

N: cutting speed

The specific cutting pressure **(S.C.P) =** the cutting force, F_t divided by the cross section area of the undeformed chip gives the nominal cutting stress or the specific cutting pressure and its give by:

S.C.P=Tangential force (Ft)/ Area of cut

Where area of cut =$\boldsymbol{feed\ (f) * depth\ of\ cut}$ **(d)**

The power consumed at tool point **(P) =Ft* cutting speed**

(Assuming that the power due to axial force is negligible)

The deflection of tool can determined by using vertical and horizontal dial gages on lathe tool dynamometer by applying :

Deflection = pointer reading * 5 * 0.002

Where : pointer reading: indicates the number that the pointer indicate on it

5 : indicates that there is 5 divisions between each number and another

0.002 : it is because there 0.2 mm/rev, graduated in 0.002 mm divisions

Procedure:

1. The work piece diameter and length was determined
2. Standard depth of cut and feed was used
3. Test information was followed in table shown below:

Table3.4: variable speed test information

Lathe Size	=	9x89
Cutting Position	=	90°
work piece original diameter	=	57mm
feed per revolution	=	0.272
depth of cut	=	2.5mm

4. Six setting from (15m/min to 250m/min) were used
5. The reading of gages was taken and filled in the table shown 3.5

Results:

Table3.5: Table of results for variable speed

feed mm/rev	cutting speed (m/min)	vertical component			Axial component			specific cutting pressure (N/mm²)	power consumed(W)
		Deflection (mm)	Pointer Vibration (mm)	Force (N)	Deflection (mm)	Pointer Vibration (mm)	Force (N)		
0.272	14.67	0.05	± 4.5-5.5	1078	0.05	± 5	1029	1585.294118	15814
0.272	29.53	0.045	± 4.5	980	0.45	± 4.5	931	1441.176471	28939
0.272	53.69	0.04	± 3.5-4.5	882	0.03	± 3	637	1297.058824	47355
0.272	71.59	0.03	± 2.5-3.5	637	0.025	± 2.8	539	936.7647059	45603
0.272	137.81	0.02	± 2	392	0.015	± 1.5	313.6	576.4705882	54022
0.272	250.57	0.02	± 2	392	0.015	± 1.5	313.6	576.4705882	98223

Sample calculations:

- V= π D N = π * 0.057 * 82 m/min
- Deflection =$\left(\frac{4.5+5.5}{2}\right)$ (5) (0.002) = 0.05 mm
- The specific cutting pressure (S.C.P) = Tangential force (Ft)/ Area of cut =1078/(0.272*2.5mm)=1585.294N/mm²
- The power consumed at tool point (P) =Ft* cutting speed = 1078*14.67=15814w

Related Graphs:

The relationship between cutting speed and tangential force shown in figure (3.9)

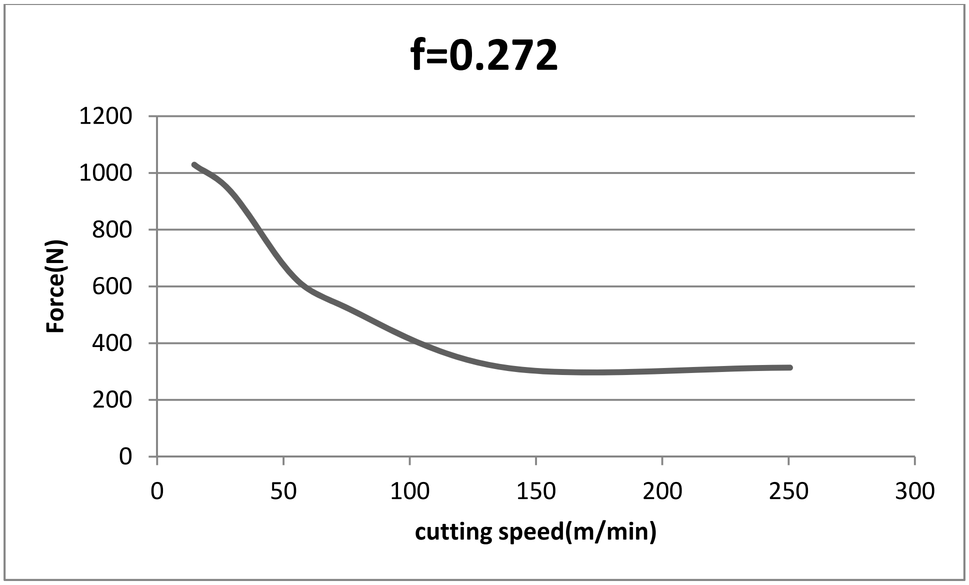


Figure 3.9:Tangential force versus speed

The data above is obtained experimentally. From the figure (3.9) we conclude that Force is inversely proportional with cutting speed

Discussions& conclusions:

- Effect of Cutting Speed on the Cutting Process

A change in the cutting speed also impacts the cutting process. This is due to the fact that

The temperature in the secondary deformation zone (close to the rake face of the tool)

Continuously increases with cutting speed and therefore the deformation process in this zone Changes as a whole.

- The cutting force slightly affected by cutting speed, whilst it increases when the feed or depth of cut is increased.
- The effect of feed rate on cutting force is much more evident than the effect of speed. The magnitude of the feed constant is found to be greater than the velocity constant.
- Selecting of cutting parameters from the cutting force versus cutting speed and feed rate alone will not give a right selection without taking in account other factors like chatter or burr formation.
- Increasing feed cause Chatter

3.1.3: Experiment#3:

Effect on the tool force in orthogonal cutting and chip formation When varying tool Rake Angle

Objectives:

1. To determine the effect of tool rake angle variation on cutting performance
2. To study the relation between tools side rake angle and power consumed at tool point
3. To get the greater accuracy of measurement in turning operation.
4. To better understand the mechanism of chip formation

Apparatus:

1. Lathe machine
2. PE1 tool dynamometer
3. Aluminum work piece
4. Tools with side rake angle(5°,10°,15°,20°,25°)

Figure3.10: Tools with side rake angle (5°, 10°, 15°, 20°, 25°)

Abstract

Accuracy of machined component is one of the most critical considerations for any manufacturer. Many key factors like cutting tool and its setting angle, machining conditions, resolution of the machine tool and the type of workplace etc., play an important role.

Introduction:

We know that cutting tool angle plays a vital role in surface finish and also to get most desirable finish. We should match the centre of work piece with respect to the tool

To make concentric. As far as matching of centre is concerned, we should have correct data/datum that can provide information's that for what variation, the center alignment shall be done.

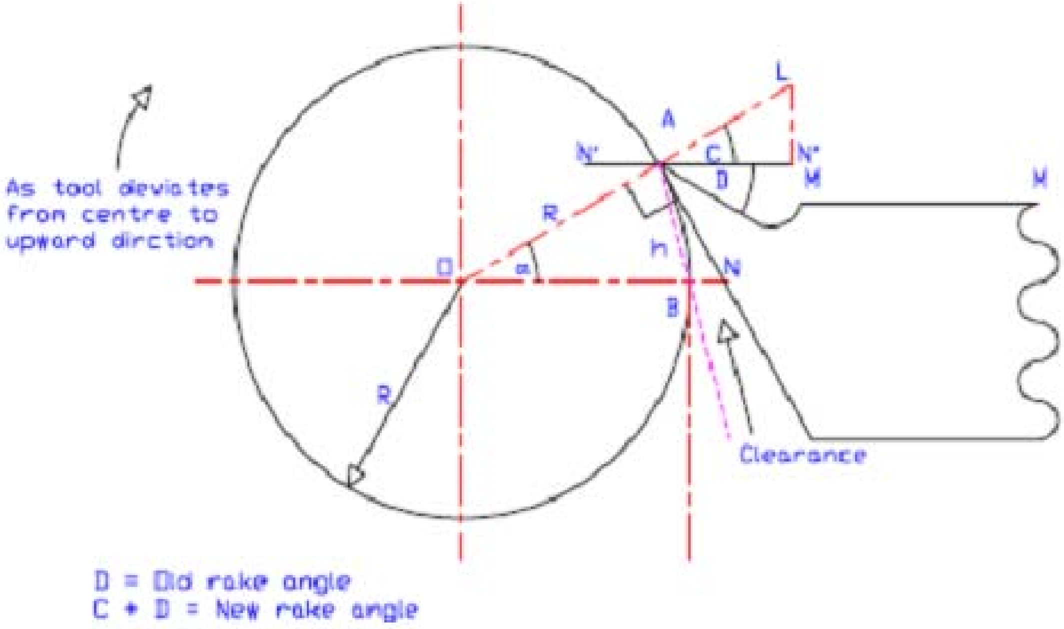


Figure 3.11: Machining while tool is at an angle α to the center

Theory:

Let h = height of deviation from centre

α = angle of deviation

Then from Δ OAB, we get,

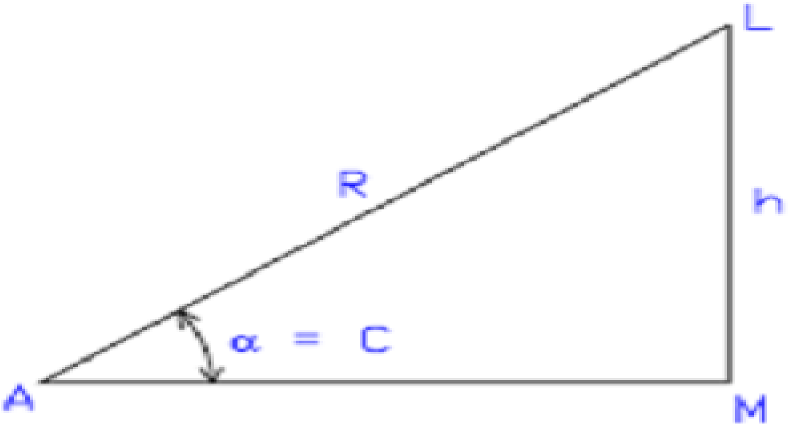
$\text{Sin}\,\alpha = h / r$

$\therefore \alpha = \sin^{-1} (h / r)$

It is obvious that change in clearance

= previous clearance – α [given, $\alpha = \sin^{-1} (h / r)$

& new rake= previous rake + $\sin^{-1} (h / r)$



Procedure:

1. The work piece diameter and length was determined
2. Standard depth of cut and feed and speed was used
3. Test information was followed in table shown below:

Table3.6: variable tool rake angle test information

Lathe Size	=	9x89
Cutting Position	=	90°
work piece outside diameter	=	57mm
feed per revolution	=	0.55
depth of cut	=	2mm
speed	=	71.59 m/min

4. five setting from (5° to 25°) were used

5. The reading of gages was taken and filled in table 3.7

Results:

Table3.7: Result table of variable tool rake angle

feed mm/rev	cutting speed (m/min)	vertical component			Axial component			specific cutting pressure (N/mm^2)	power consumed(W)	Un deformed chip thickness	Tool side rake angle
		Deflection (mm)	Pointer Vibration (mm)	Force (N)	Deflection (mm)	Pointer Vibration (mm)	Force (N)				
0.376	**71.59**	**0.05**	**± 5**	**1100**	**0.03**	**±3**	**640**	**1462.765957**	**78749**	**0.376**	**5°**
0.376	**71.59**	**0.045**	**± 4.5**	**1000**	**0.025**	**± 2.5**	**540**	**1329.787234**	**71590**	**0.376**	**10°**
0.376	**71.59**	**0.04**	**± 4**	**880**	**0.02**	**± 2**	**430**	**1170.212766**	**62999.2**	**0.376**	**15°**
0.376	**71.59**	**0.035**	**± 3.5**	**770**	**0.015**	**± 1.5**	**330**	**1023.93617**	**55124.3**	**0.376**	**20°**
0.376	**71.59**	**0.02**	**± 2**	**430**	**0.005**	**± 0.5**	**110**	**571.8085106**	**30783.7**	**0.376**	**25°**

Sample calculations:

- The specific cutting pressure **(S.C.P) = Tangential force (Ft)/ Area of cut =1100/(0.376*2mm)=1462.765N/mm²**
- The power consumed at tool point **(P) =Ft* cutting speed = 1100 * 71.59=78749 w**
- Un deformed Chip Thickness **($t_\circ$)= f =0.376 mm**

Related Graphs:

The graph below shows relationship between axial and tangential forces with varying tool side rake angle

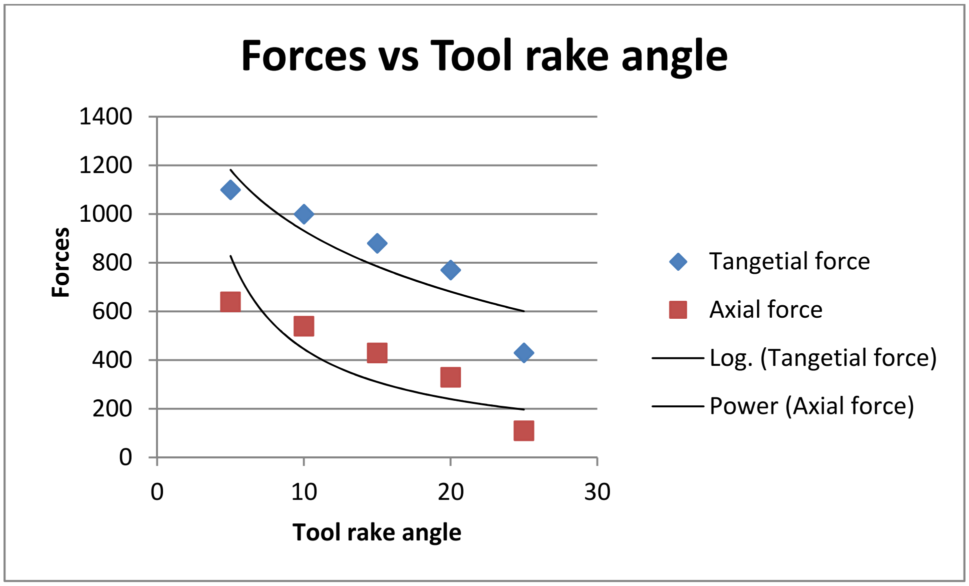


Figure3.12: tool side rake angle versus two forces

The data above is obtained experimentally. From the figure (3.12) we conclude that forces are inversely proportional with tool side rake angle

Figure 3.13 shows the relation between tool side rake angle and power consumed at tool point

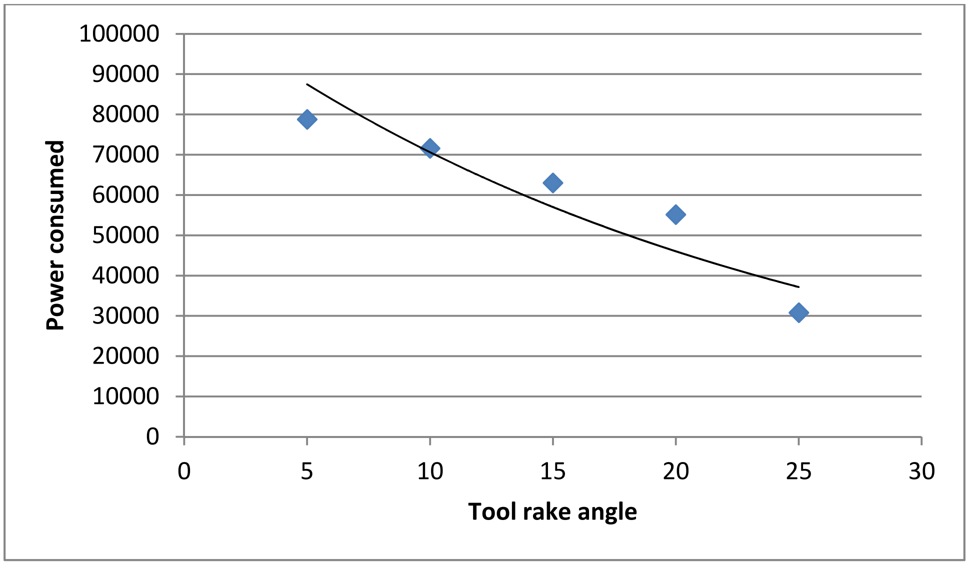


Figure3.13: Tool side rake angle versus power consumed at tool point

From figure 3.13 it is clear that when the side rake angle of tool increases the power consumed at tool point will decrease.

Discussions& conclusions:

1) An increase in the tool side rake angle causes the shear plane angle to increase
2) A decrease in the coefficient of friction causes the shear plane angle to increase
3) The tangential and axial forces decreases with increasing tool side rake angle because increasing tool side rake angle will increase shear plane angle and this leads to lower shear plane area
4) Increasing tool side rake angle will lower shear plane area and this mean lowering power and energy needed for deformation

3.1.4: Experiment#4:

Determination of Ultimate Tensile Strength of aluminum using force dynamometr

Abstract:

In this experiment we want to know the ultimate tensile strength of work piece (Aluminum) by using Dynamometer so it is required to determine the thickness of deformed chip during the experiment by using the caliber.

By fixing the cutting speed, feed and tool rake angle while maintain the depth of cut on certain value we can calculate the ultimate tensile strength of aluminum

Objectives:

1. To Find the ultimate tensile strength of aluminum
2. To find the error in our calculation

Apparatus:

1. Lathe machine
2. Aluminum work piece
3. Cutting Tool with rake angle (20°)
4. Suitable Lubricant
5. Caliper

Introduction:

Tensile strength (σ_{UTS}) is indicated by the maxima of a stress-strain curve and, in general, indicates when necking will occur. As it is an intensive property, its value does not depend on the size of the test specimen. It is, however, dependent on the preparation of the specimen and the temperature of the test environment and material. The standard way to measure tensile strength is to use a small bar with uniform width (apart from at the edges where the thickness increases) and to 'pull' at each end until the bar fails. In the process, other mechanical properties may be obtained. Other testing methods also exist, such as the test. However, in here we shall show how the ultimate tensile strength can be obtained for a work material using lathe tool dynamometer.

Theory:

As shown in side view of orthogonal cutting figure (3.14) below, we can note that:

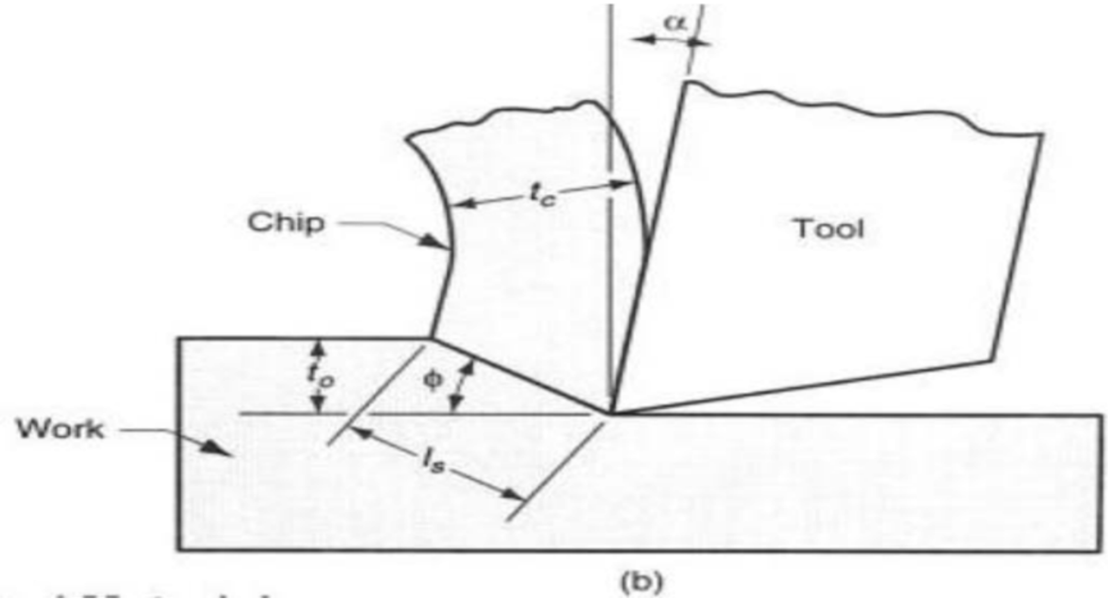


Figure 3.14: side view of orthogonal cutting

Note that (α) is the rake angle and determines the direction of chip flow. Also , ϕ is the shear plane angle.

The thickness of the chip prior to chip formation is($t_\circ$),as the chip is formed it increase in thickness to(t_c) so the chip thickness ratio (r) is given by :

$$r = \frac{t_\circ}{t_c}$$

And if we make the substitutions $t_\circ = L_s \, sin\phi$, and $t_c = L_s \cos(\boldsymbol{\phi} - \boldsymbol{\alpha})$ then we can write :

$$r = \frac{L_s \sin \phi}{L_s \cos(\phi - \alpha)}$$

The last equation can be rearranged to determine ($\boldsymbol{\phi}$) as :

$$\tan\phi = \frac{\mathrm{r} \cos\alpha}{1 - \mathrm{r} \sin\alpha}$$

Consider the forces acting on the chip during orthogonal cutting figure (3.15 a), these forces can be separated into two perpendicular components:

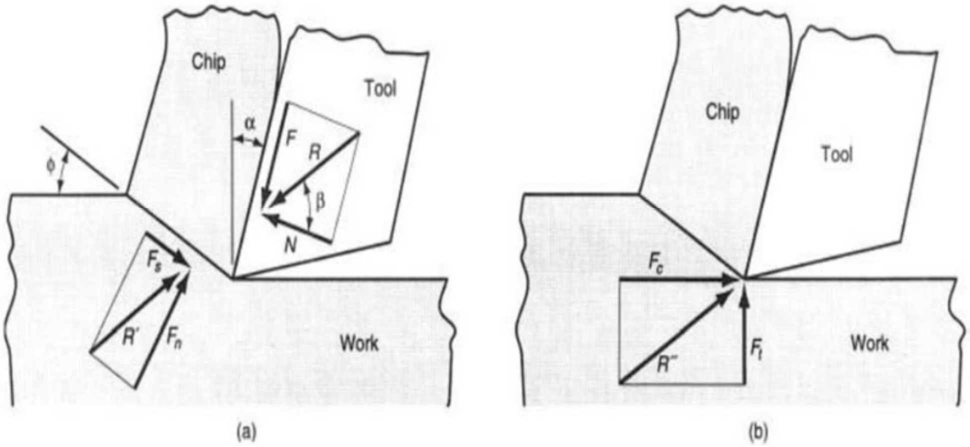


Figure 3.15: forces in metal cutting : (a) forces acting on the chip in orthogonal cutting and (b) forces acting on the tool that can be measured.

3) Friction force (F) : between the tool and the chip
4) Normal force to friction(N) : normal to friction force

Therefore, we can write

$$\mu = \frac{F}{N} \text{ (μ : coefficient of friction)}$$

$$\mu = tan\beta \ (\ \beta : \text{friction angle} \ )$$

The forces imposed by the work on the chip figure (1.12 b) are :

3) Shear force (Fs) : causes shear deformation in the shear plane

4) Normal force to shear(Fn) : normal to shear force

Now ,the shear strength that acts along the shear plane is obtained from

$$S = \frac{Fs}{As} \text{ and } S = 0.7\ \sigma_u \text{ where } \sigma_u \text{ is the ultimate tensile strength}$$

and (As) is the shear plane area and calculated from:

$$A_s = \frac{t_\circ\, w}{sin\phi} \text{ (w : width of cut)}$$

Note that none of the four force components F,N,Fs and Fn can be directly measured. However , by using a dynamometer two additional force components that act against the tool can be directly measured and they are :

3) Cutting force Fc :same direction as the cutting speed and it is the same as Ft (tangential force) in turning process

4) Thrust force Ft:perpendicular to the cutting force (in direction of $t_\circ$) and it is the same as Fa(axial force) in turning process

Note force diagram shown in figure 3.16, we can conclude that :

$$F_c = \frac{\boldsymbol{F_S} \cos(\boldsymbol{\beta} - \boldsymbol{\alpha})}{\cos(\boldsymbol{\phi} + \boldsymbol{\beta} - \boldsymbol{\alpha})}$$

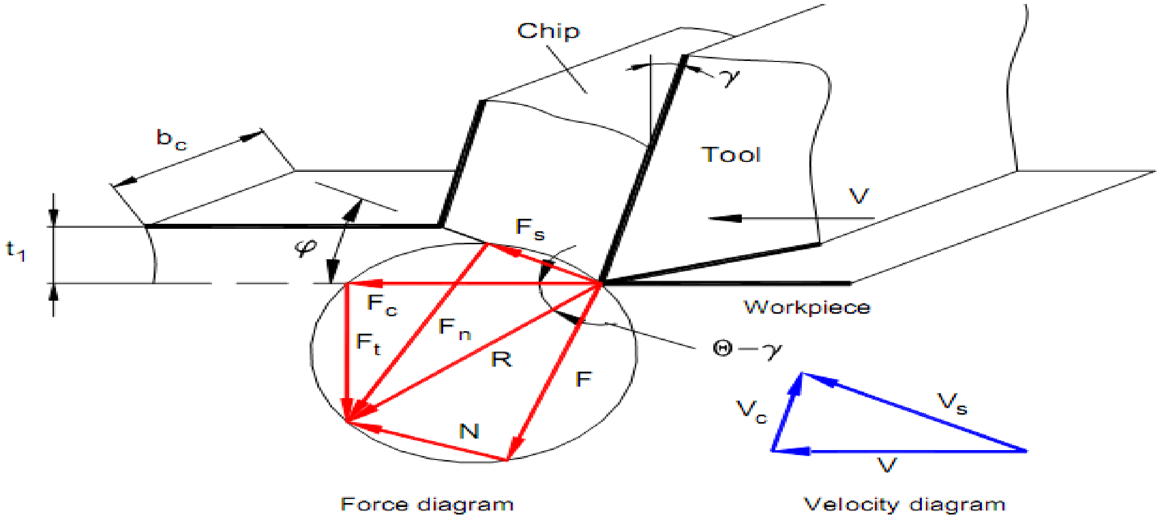


Figure3.16: Force Diagram of orthogonal cutting

Procedure:

1. the cutting speed was fixed on (v)= 770 rpm
2. feed was fixed on (f)= 0.468 mm/rev
3. the cutting tool with rake angle $(\alpha) = 20$ was used
4. the depth of cut was (d)= 3 mm
5. the lathe was turned on and the pointer reading was determined , and the thickness of deformed chip (t_c) was measured by using the caliber which they are respectively 2.5 mm , 1 mm

Results and Discussions:

Chip thickness ratio $r = \frac{f}{t_c} = \frac{0.468}{1} = 0.468$ where (f) indicates the thickness of the chip prior to chip formation in turning process

From orthogonal cutting we know that $tan\boldsymbol{\phi} = \frac{\boldsymbol{r\ cos\alpha}}{\boldsymbol{1-r\ sin\alpha}} = \frac{\mathbf{(0.468)(\,}\boldsymbol{cos}\mathbf{20)}}{\mathbf{1-(0.468)(}\boldsymbol{sin}\mathbf{20)}}$

Which mean $\boldsymbol{\phi} = 27.64$

From merchant equation we have $\beta = 2(45 + \alpha/2 - \boldsymbol{\phi})$

$$= 2\,(45 + 20/2 - 27.64)$$

$$= 54.72$$

We know from force diagram that $F_C = \frac{\boldsymbol{F_S \cos(\beta - \alpha)}}{\boldsymbol{\cos(\phi + \beta - \alpha)}}$ where F_s is the shear force

With pointer reading = 2.5 mm, the deflection is 2.5*5*0.002 = 0.025 mm which mean that F_c = 550 N (from the curve of vertical force see appendix B), so

$$F_S = \frac{\boldsymbol{F_c \cos(\phi + \beta - \alpha)}}{\boldsymbol{\cos(\beta - \alpha)}} = \frac{\boldsymbol{550 \cos(27.64 + 54.72 - 20)}}{\boldsymbol{\cos(54.72 - 20)}} = 310.43 \text{ N}$$

But we know that $F_S = S\,A_s$ where (S), (A_s) are the shear strength and shear plane area respectively

Shear plane area is given by $\boldsymbol{A_s = \frac{f * d}{sin\phi}}$ so:

$$S = \frac{\boldsymbol{F_S}}{\boldsymbol{A_s}} = \frac{\boldsymbol{F_S * sin\phi}}{\boldsymbol{f * d}} = \frac{\boldsymbol{(310.43)(sin27.64)}}{\boldsymbol{(0.468 * 10^{-3})(3 * 10^{-3})}} = 102573370.4 \text{ Pa}$$

But $S = 0.7\,\sigma_u$ where σ_u is the ultimate tensile strength of aluminum

$$\text{So } \boldsymbol{\sigma_u = \frac{S}{0.7} = \frac{102573370.4}{0.7}} = 146533386.3 \text{ Pa}$$

The theoretical value of σ_u is 150000000 Pa and the practical value is 146533386.3 Pa so the error is

$$\text{Error} = \frac{|Practical - theoretical|}{theoretical} \times 100\ \%$$

$$= \frac{|146533386.3 - 150000000|}{150000000} \times 100\ \% = 2.31\ \%$$

Chapter Four

Recommindations

5.1 **Recommendations:**

1. Add four experiments discussed in this project to manufacturing process lab
2. Follow safety rules when execute any of the experiments
3. Read experiment hand out before doing it
4. Insure that lathe machine work well before do any experiment
5. Make experiments with more workpiece material than aluminum such as steel, brass, copper
6. When removing chip be sure that you are in good distant from lathe
7. Do more experiment on lathe tool dynamometer than it discuss in the project

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Manual of PE Lathe Tool Dynamometer

Appendix A

Experiments Hand Out

A1: Effect of varying feed on cutting force

A2: Effect of varying cutting speed on cutting force

A3: Effect of varying tool rake angle on cutting force

A4: Determination of Ultimate Tensile Strength of aluminum using force dynamometr

A1: Effect of varying feed on cutting force

An-Najah National University
Faculty of Engineering
Industrial Engineering Department
Manufacturing process Lab

Experiment "1"
Effect of varying feed on cutting force

Prepared by:

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Husam Abu Radi

2010

Objectives:

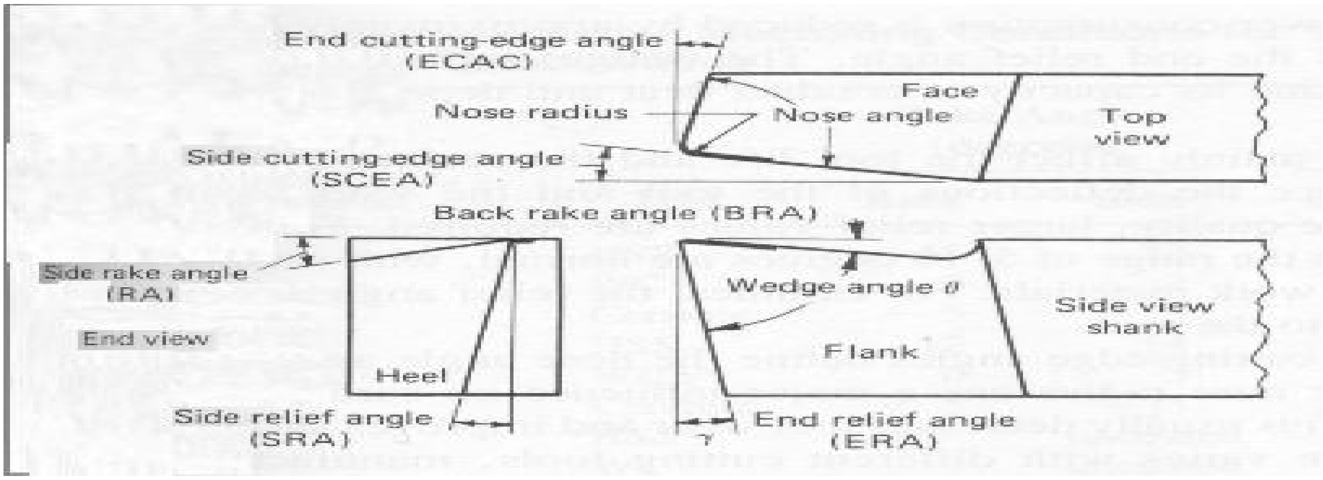
1. To determine the effect of feed on tool forces while keeping constant speed and tool side rake angle
2. To calculate the specific cutting pressure
3. To calculate Power Consumed at the cutting edge

Apparatus:

1. Lathe machine
2. PE1 tool dynamometer
3. Aluminum Or Steel work piece

CUTTING TOOLS FOR LATHES

For cutting tools, geometry depends mainly on the properties of the tool material and the work material. The standard terminology is shown in the following figure. For single point tools, the most important angles are the rake angles



and the end and side relief angles.

The back rake angle affects the ability of the tool to shear the work material and form the chip. It can be positive or negative. Positive rake angles reduce the cutting forces resulting in smaller deflections of the work piece, tool holder, and machine. If the back rake angle is too large, the strength of the tool is reduced as well as its capacity to conduct heat. In machining hard work materials, the back rake angle must be small, even negative for carbide and diamond tools. The higher the hardness, the smaller the back rake angle. For high-speed steels, back rake angle is normally chosen in the positive range.

Procedure:

1. Determine the work piece diameter and length and needed data of this experiment and fill it in a table as shown bellow

tools	=	
tool material	=	
Back rake angle	=	
front clearance angle	=	
plan approach angle	=	
plan trail angle	=	
Nose radius	=	
work piece	=	
cutting condition	=	
depth of cut	=	

2. Support the work piece at tail stock by running center
3. Use the tool setting gage to set the tool over hang

4. Insure that you have suitable distance from lathe and work in safety way such wearing glasses ,lab coat, gloves, etc
5. set speed and depth of cut as constant and variable feed

   Six setting from (o.136 to 0.468 suggested)

6. Fill the following table with required data

Lathe type	=	
Lathe Size	=	
Cutting Position	=	
work piece original diameter	=	
cutting speed	=	

7. Remove continuously extra chip formed during experiment
8. Set out the result in table as shown in the table below (get the reading of forces from graphs which shows relation between deflection and forces)
9. Be sure that you use good coolant substances when you do experiment

Results

- Set out the result in the table shown below:

feed mm/rev	cutting speed (m/min)	**vertical component**			**Axial component**			specific cutting pressure (N/mm²)	power consumed(W)
		Deflection (mm)	Pointer Vibration (mm)	Force (N)	Deflection (mm)	Pointer Vibration (mm)	Force (N)		

Calculations:

Material removal rate $\boldsymbol{MRR} = t_{\circ}\, v\, w = f\ v\ d$ **m³/min**

Deflection = pointer reading * 5 * 0.002

The specific cutting pressure **(S.C.P) = Tangential force (Ft)/ Area of cut (N/mm²)**

Where area of cut =$\boldsymbol{feed\ (f) * depth\ of\ cut}$

The power consumed at tool point **(P) =Ft* cutting speed (N)**

Discussion and questions:

Q1) Plot Load in Kg Versus feed per revolution

Q2) Plot S.C.P versus feed per revolution

Q3) Discuss The relationship between deflection and applied load what do you notice?

Q4) Comment on your results

A2: Effect of varying cutting speed on cutting force

An-Najah National University
Faculty of Engineering
Industrial Engineering Department
Manufacturing process Lab

Experiment “2”
Effect of varying cutting speed on cutting force

Prepared by:

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Husam Abu Radi

2010

Objectives:

1) To learn about machining equipment and the metal cutting process
2) To better understand the relationship between metal cutting parameters and other process issues that affect cutting force values
3) To observe and understand the effect of speed and its effect on the process.

Apparatus:

1. Lathe machine
2. PE1 tool dynamometer
3. Aluminum work piece
4. Lubricant

Introduction:

In mathematics, two vectors are **orthogonal** if they are perpendicular, i.e., they form a right angle. The word comes from the Greek *ὀρθός* (*orthos*), meaning "straight", and *γωνία* (*gonia*), meaning "angle". For example, a subway and the street above, although they do not physically intersect, are orthogonal if they cross at a right angle

The tool cutting edge is set at 90' to the direction of movement. The effectiveness of the tool depends greatly upon the slope of the active surface of the tool. The tool would tend to curl the chip in the form of a clock spring or a flat spiral. This is not the best form of chip for efficient metal removal.

Theory:

The feed(***f)*** is the tool advancement per revolution along its cutting path in mm/rev the feed rate (***ft)*** is the speed at which the tool advances into the part longitudinally in mm/ min and it is related to ***f*** through the spindle rpm **N**:

$$ft = fN$$

The feed influences chip thickness and how the chip breaks. The undeformed chip thickness $(t_\circ)$ in orthogonal cutting is related to(***f)*** as follows ***:***

$$t_\circ = \boldsymbol{f}$$

The depth of cut (***d)*** is the width (w) in orthogonal cutting of material removed from the workpiece surface:

$$w = d = \frac{\boldsymbol{D1-D2}}{\boldsymbol{2}}$$

Where**:** D1: original diameter of work piece

D2: new diameter of work piece

The time ***tm*** required to cut length **L** in the feed direction is:

$$tm = \frac{\boldsymbol{L}}{\boldsymbol{ft}}$$

Where **L**: length of the work piece to be turned

The material removal rate ***MRR*** of turning process is related to orthogonal cutting by the relation :

$\boldsymbol{MRR} = t_{\circ}\, v\, w = f\; v\; d$ **m³/min**

Where : f **:** indicates the thickness of the chip prior to chip formation **($t_{\circ}$)**

V : indicates the cutting speed between workpiece and tool

d **:** indicates the width of material removed from workpiece **(w)**

The cutting speed V it given by :

V = $\boldsymbol{\pi}$ D N

And **D**: original diameter of work piece

N: cutting speed

The specific cutting pressure **(S.C.P) =** the cutting force, F_t divided by the cross section area of the undeformed chip gives the nominal cutting stress or the specific cutting pressure and its give by:

S.C.P=Tangential force (Ft)/ Area of cut

Where area of cut $=\boldsymbol{feed\ (f) * depth\ of\ cut}$ **(d)**

The power consumed at tool point **(P) =Ft* cutting speed**

(Assuming that the power due to axial force is negligible)

The deflection of tool can determined by using vertical and horizontal dial gages on lathe tool dynamometer by applying :

Deflection = pointer reading * 5 * 0.002

Where : pointer reading: indicates the number that the pointer indicate on it

5 : indicates that there is 5 divisions between each number and another

0.002 : it is because there 0.2 mm/rev, graduated in 0.002 mm divisions

Procedure:

1. Determine the work piece diameter and length and needed data of this experiment and fill it in a table as shown below

tools	=	
tool material	=	
Back rake angle	=	
front clearance angle	=	
plan approach angle	=	
plan trail angle	=	
Nose radius	=	
work piece	=	
cutting condition	=	
depth of cut	=	

2. Support the work piece at tail stock by running center
3. Use the tool setting gage to set the tool over hang
4. Insure that you have suitable distance from lathe and work in safety way such wearing glasses ,lab coat, gloves, etc
5. Six setting from (15to 250m/min suggested)
6. Fill the following table with required data

Lathe type	=	
Lathe Size	=	
Cutting Position	=	
work piece outside diameter	=	
tool side rake angle	=	

7. Remove continuously an extra chip formed during experiment
8. Be sure that you use good coolant substances when you doing experiment

Results:

Set out the result in the table shown below:

feed mm/rev	cutting speed (m/min)	**vertical component**			**Axial component**			specific cutting pressure (N/mm²)	power consumed(KW)
		Deflection (mm)	Pointer Vibration (mm)	Force (N)	Deflection (mm)	Pointer Vibration (mm)	Force (N)		

Calculations:

The cutting speed V it given by :

$$V = \pi D N$$

Where **D**: original diameter of work piece

N: cutting speed

The specific cutting pressure the cutting force, F_t divided by the cross section area of the undeformed chip gives the nominal cutting stress or the specific cutting pressure

(S.C.P) = Tangential force (Ft)/ Area of cut (N/mm²)

Where area of cut $= \boldsymbol{feed\ (f) * depth\ of\ cut}$

The power consumed at tool point **(P) =Ft* cutting speed (N)**

Discussion and Questions:

Q1) Plot force versus speed comment on your results

Q2) Calculate undeformed chip thickness and mention kinds of chip

Q3) mention Three sources of error in this experiment

Q4) calculate material removal rate

Q5) for orthogonal cutting of Aluminum rod, the following data are obtained: depth of cut = 0.125″ feed = 0.007″ per rev. $\alpha = 15°$, $\beta = 30°$. The dynamic shear strength of the work material = 80000 1b/in^2. Calculate Fc and Ft.

Q6) a steel tube 42 mm outside diameter is turned on a lathe. The following data was obtained:

Rake angle = 32°

Cutting speed = 18 m/min.

Feed = 0.12 mm/rev.

Length of continuous chip in one revolution = 52 mm.

Cutting force = 180 kg

Feed force = 60 Kg.

Determine:

(a) Chip thickness ratio

(b) Chip thickness after cut

(c) Shear plane angle

(d) Coefficient of friction.

A3: Effect of varying tool rake angle on cutting force

An-Najah National University

Faculty of Engineering

Industrial Engineering Department

Manufacturing process Lab

Experiment "3"

Effect of varying tool rake angle on cutting force

Prepared by:

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Husam Abu Radi

2010

Objectives:

1. To determine the effect of tool rake angle variation on cutting performance
2. To study the relation between tools side rake angle and power consumed at tool point
3. To get the greater accuracy of measurement in turning operation.
4. To better understand the mechanism of chip formation

Apparatus:

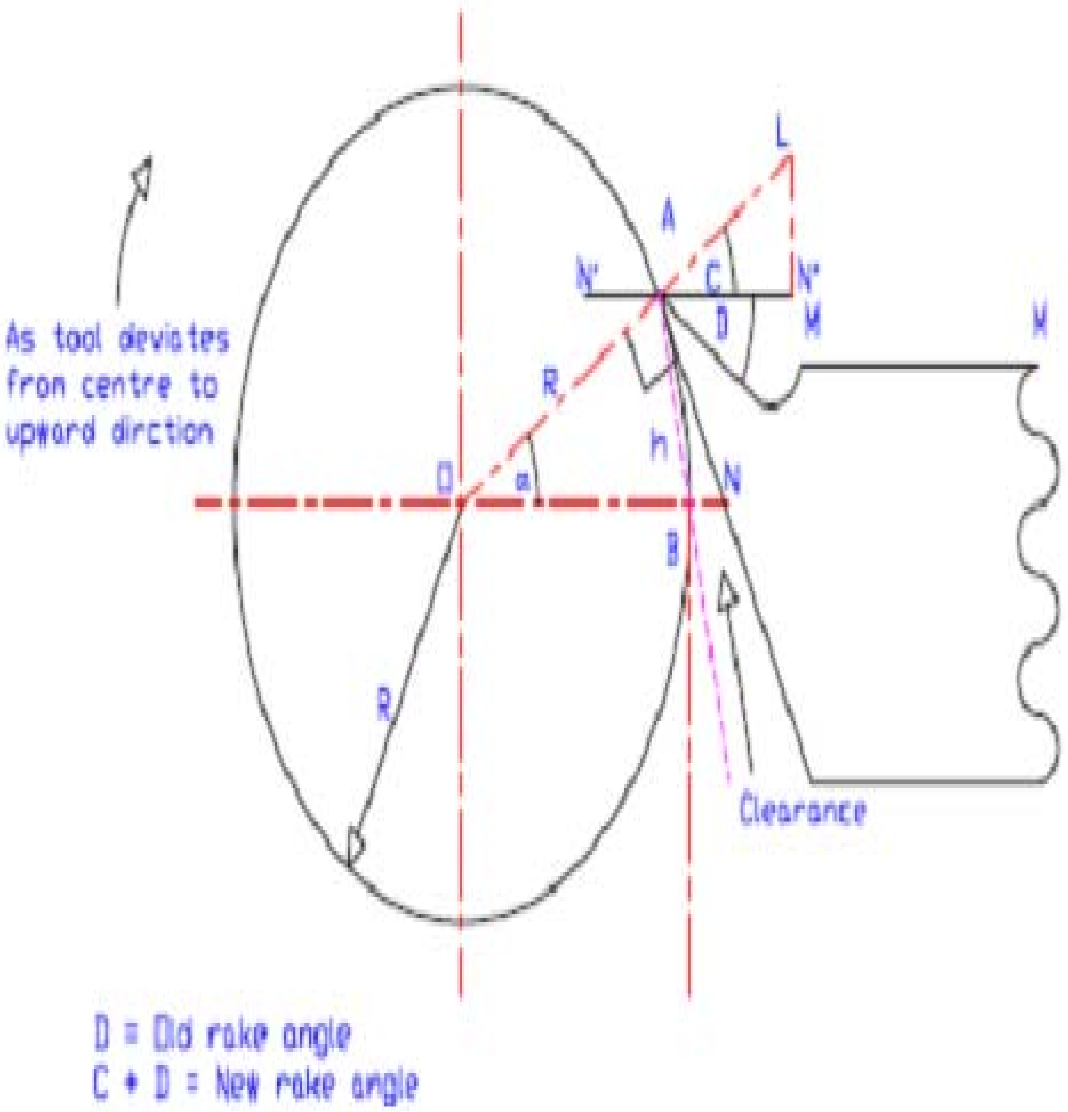
1. Lathe machine
2. PE1 tool dynamometer
3. Aluminum work piece
4. Tools with side rake angle(5°,10°,15°,20°,25°)

Abstract

Accuracy of machined component is one of the most critical considerations for any manufacturer. Many key factors like cutting tool and its setting angle, machining conditions, resolution of the machine tool and the type of workplace etc., play an important role.

Introduction:

We know that cutting tool angle plays a vital role in surface finish and also to get most desirable finish. We should match the centre of work piece with respect to the tool To make concentric. As far as matching of centre is concerned, we should have correct data/datum that can provide information’s that for what variation, the center alignment shall be done.



Theory:

Let h = height of deviation from centre

α = angle of deviation

Then from Δ OAB, we get,

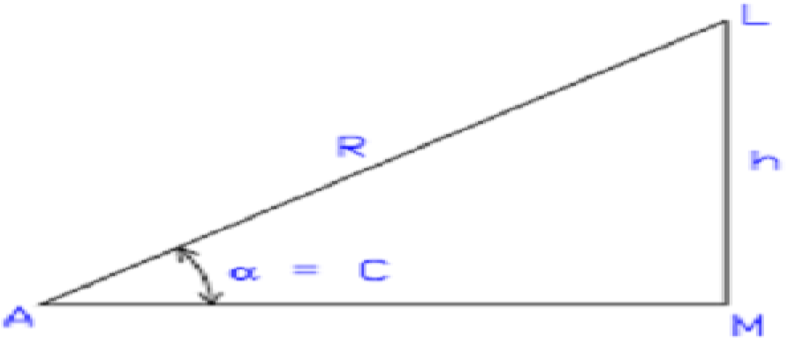
$\sin \alpha = h / r$

$\therefore \alpha = \sin^{-1} (h / r)$

It is obvious that change in clearance

= previous clearance – α [given, $\alpha = \sin^{-1} (h / r)$

& new rake= previous rake + $\sin^{-1} (h / r)$



Procedure:

1. determine The work piece diameter after setting dynamometer on lathe
2. fill the information needed for experiment in the table shown below

Lathe Size	=	
Cutting Position	=	
work piece outside diameter	=	
feed per revolution	=	
depth of cut	=	
speed	=	

1. change the tool side rake angle from (5° to 25°)
2. take the reading of gages and fill it in the table of result below
3. go to graphs and get the reading of forces

Results:

Set out the results in the table shown below:

feed mm/rev	cutting speed (m/min)	vertical component			Axial component			specific cutting pressure (N/mm²)	power consumed(W)	Tool side rake angle
		Deflection (mm)	**Pointer Vibration (mm)**	**Force (N)**	**Deflection (mm)**	**Pointer Vibration (mm)**	**Force (N)**			

Calculations:

The specific cutting pressure **(S.C.P) = Tangential force (Ft)/ Area of cut (N/mm²)** Where area of cut $= \boldsymbol{feed\ (f) * depth\ of\ cut}$

- Deflection = **Pointer reading * 5 * 0.002**

- The power consumed at tool point **(P) =Ft* cutting speed**

Discussion and Questions:

1. Plot tool side rake angle versus forces and comment on your results

2. Plot tool side rake angle versus power consumed, Is the relation increasing or decreasing ? Why?
3. What source of error in this experiment

A4: Determination of Ultimate Tensile Strength of aluminum using force dynamometr

An-Najah National University

Faculty of Engineering

Industrial Engineering Department

Manufacturing process Lab

Experiment “4”

Determination of Ultimate Tensile Strength of aluminum using force dynamometr

Prepared by:

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Eman Jondob
Fadi Zorba
Mahdi Awad
Husam Abu Radi

2010

Objectives:

1. To Find the effect Ultimate tensile strength of aluminum
2. To find the error in our calculation

Apparatus:

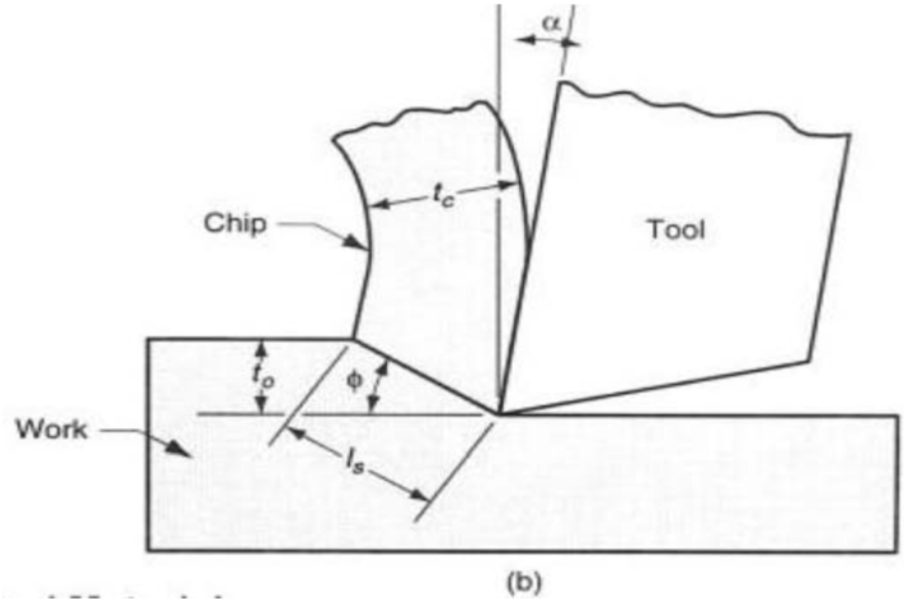
1. Lathe machine
2. Aluminum work piece
3. Cutting Tool with rake angle (20°)
4. Suitable Lubricant
5. Caliper

Introduction:

Tensile strength (σ_{UTS}) is indicated by the maxima of a stress-strain curve and, in general, indicates when necking will occur. As it is an intensive property, its value does not depend on the size of the test specimen. It is, however, dependent on the preparation of the specimen and the temperature of the test environment and material. The standard way to measure tensile strength is to use a small bar with uniform width (apart from at the edges where the thickness increases) and to 'pull' at each end until the bar fails. In the process, other mechanical properties may be obtained. Other testing methods also exist, such as the plane strain compression test. However, in here we shall show how the ultimate tensile strength can be obtained for a work material using lathe tool dynamometer.

Theory:

As shown in side view of orthogonal cutting figure below, we can note that:



Note that ($\boldsymbol{\alpha}$) is the rake angle and determines the direction of chip flow. Also , ϕ is the shear plane angle.

The thickness of the chip prior to chip formation is($t_\circ$),as the chip is formed it increase in thickness to(t_c) so the chip thickness ratio (r) is given by :

$$r = \frac{t_\circ}{t_c}$$

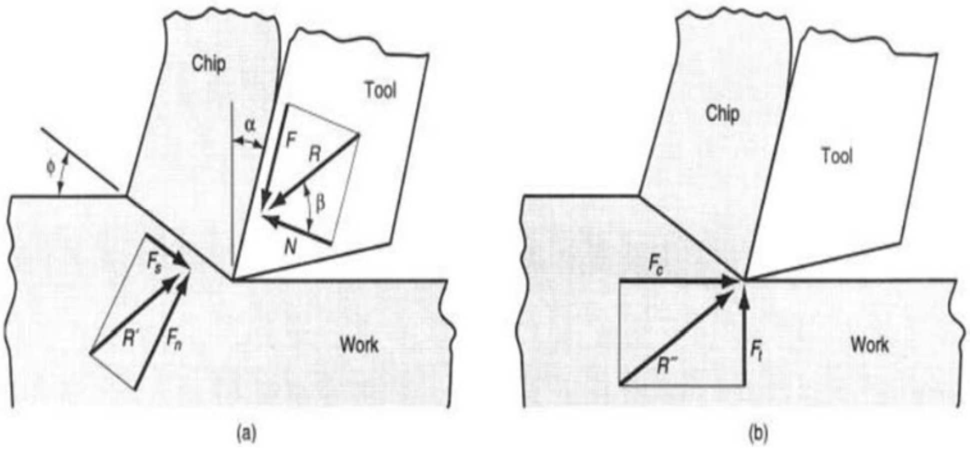
And if we make the substitutions $t_\circ = L_s \, sin\phi$, and $t_c = L_s \cos(\boldsymbol{\phi} - \boldsymbol{\alpha})$ then we can write :

$$r = \frac{L_s \sin \phi}{L_s \cos(\phi - \alpha)}$$

The last equation can be rearranged to determine ($\boldsymbol{\phi}$) as :

$$\tan\phi = \frac{\mathrm{r} \cos\alpha}{1 - \mathrm{r} \sin\alpha}$$

Consider the forces acting on the chip during orthogonal cutting figure (1.12 a), these forces can be separated into two perpendicular components:



forces in metal cutting : (a) forces acting on the chip in orthogonal cutting and (b) forces acting on the tool that can be measured.

5) Friction force (F) : between the tool and the chip
6) Normal force to friction(N) : normal to friction force

Therefore, we can write

$$\mu = \frac{F}{N} \text{ (} \mu \text{ : coefficient of friction)}$$

$$\mu = tan\beta \text{ (} \beta \text{ : friction angle)}$$

The forces imposed by the work on the chip figure (1.12 b) are :

5) Shear force (Fs) : causes shear deformation in the shear plane
6) Normal force to shear(Fn) : normal to shear force

Now ,the shear strength that acts along the shear plane is obtained from

$$S = \frac{Fs}{As} \text{ and } S = 0.7\ \sigma_u \text{ where } \sigma_u \text{ is the ultimate tensile strength}$$

and (As) is the shear plane area and calculated from:

$$A_s = \frac{t_\circ\, w}{sin\phi} \text{ (w : width of cut)}$$

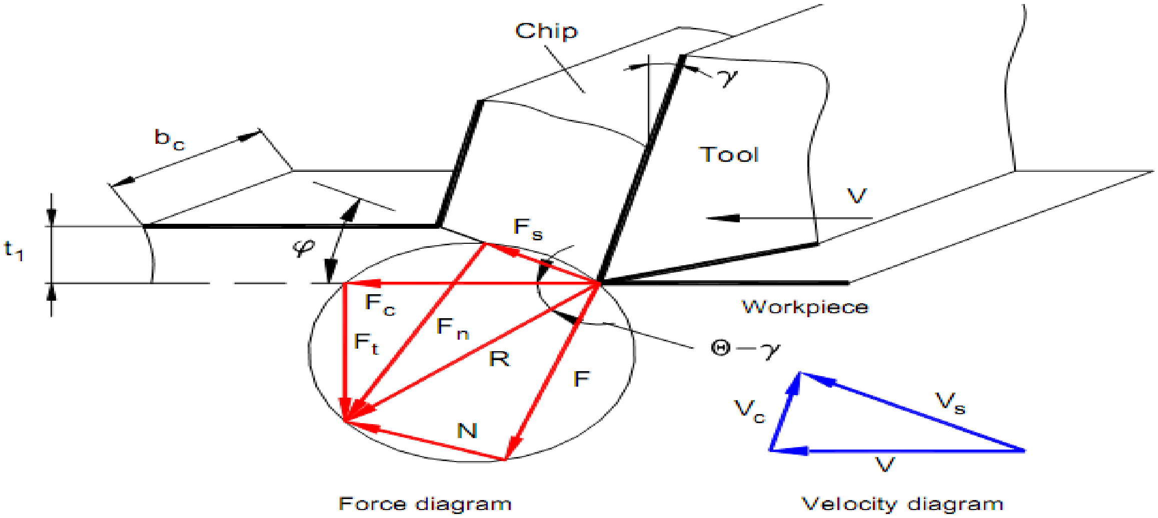
Note that none of the four force components F,N,Fs and Fn can be directly measured. However , by using a dynamometer two additional force components that act against the tool can be directly measured and they are :

5) Cutting force Fc :same direction as the cutting speed and it is the same as Ft (tangential force) in turning process

6) Thrust force Ft:perpendicular to the cutting force (in direction of $t_{\circ}$) and it is the same as Fa(axial force) in turning process

Note force diagram shown in figure, we can conclude that :

$$F_c = \frac{F_S \cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$



: Force Diagram of orthogonal cutting

Procedure:

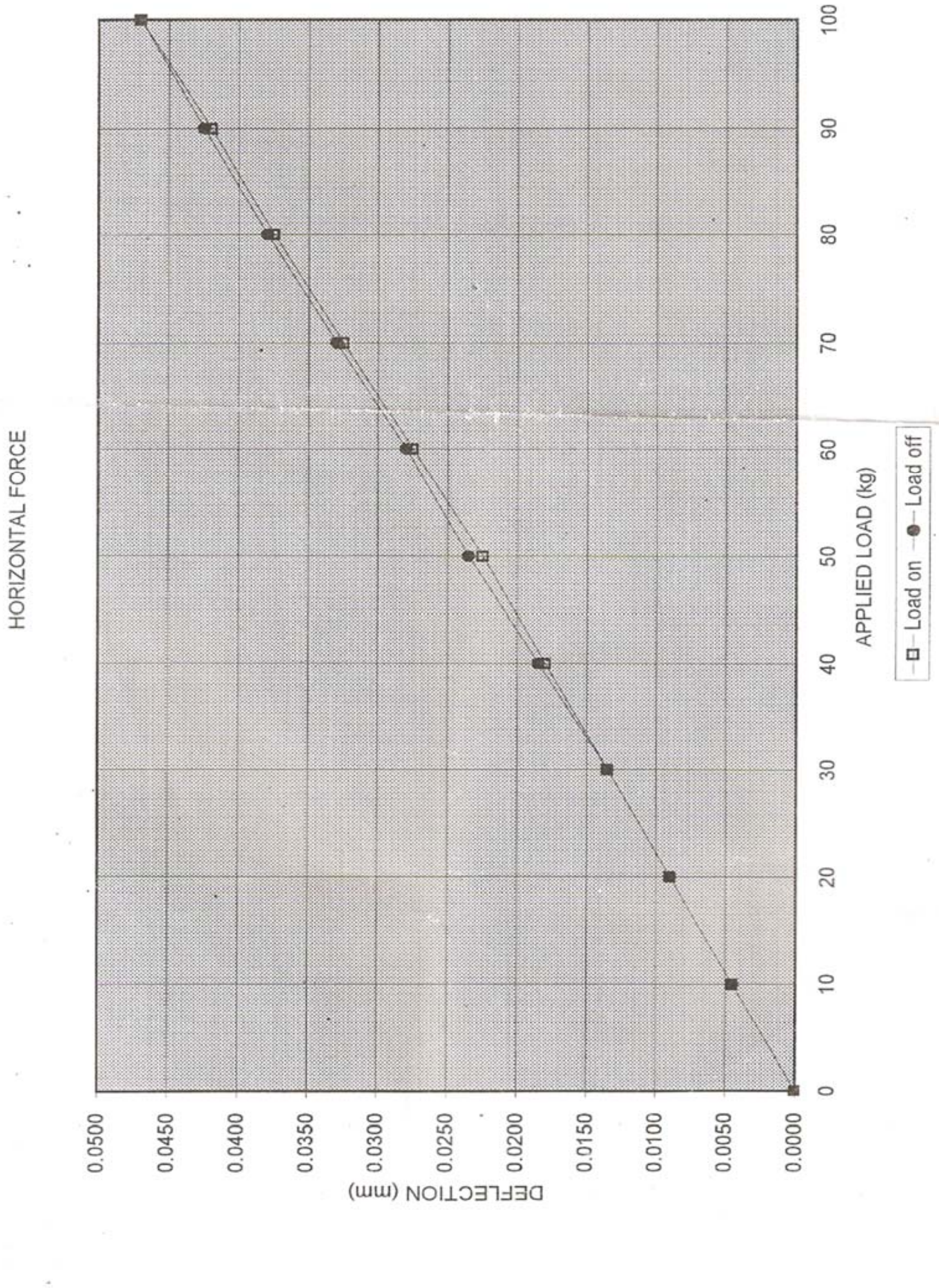
1. Fix the cutting speed on known value
2. Fix the feed on known value using control panel on the lathe
3. Use the cutting tool with known rake angle
4. Use known depth of cut
5. turned on the lathe and take the pointer reading, determine the deflection as it equal pointer reading *5*0.002 and from calibration graph determine tangential force
6. measure by using the caliber the thickness of deformed chip (t_c)
7. Use orthogonal cutting equations, merchant equation and force diagram to find the ultimate tensile strength of workpiece

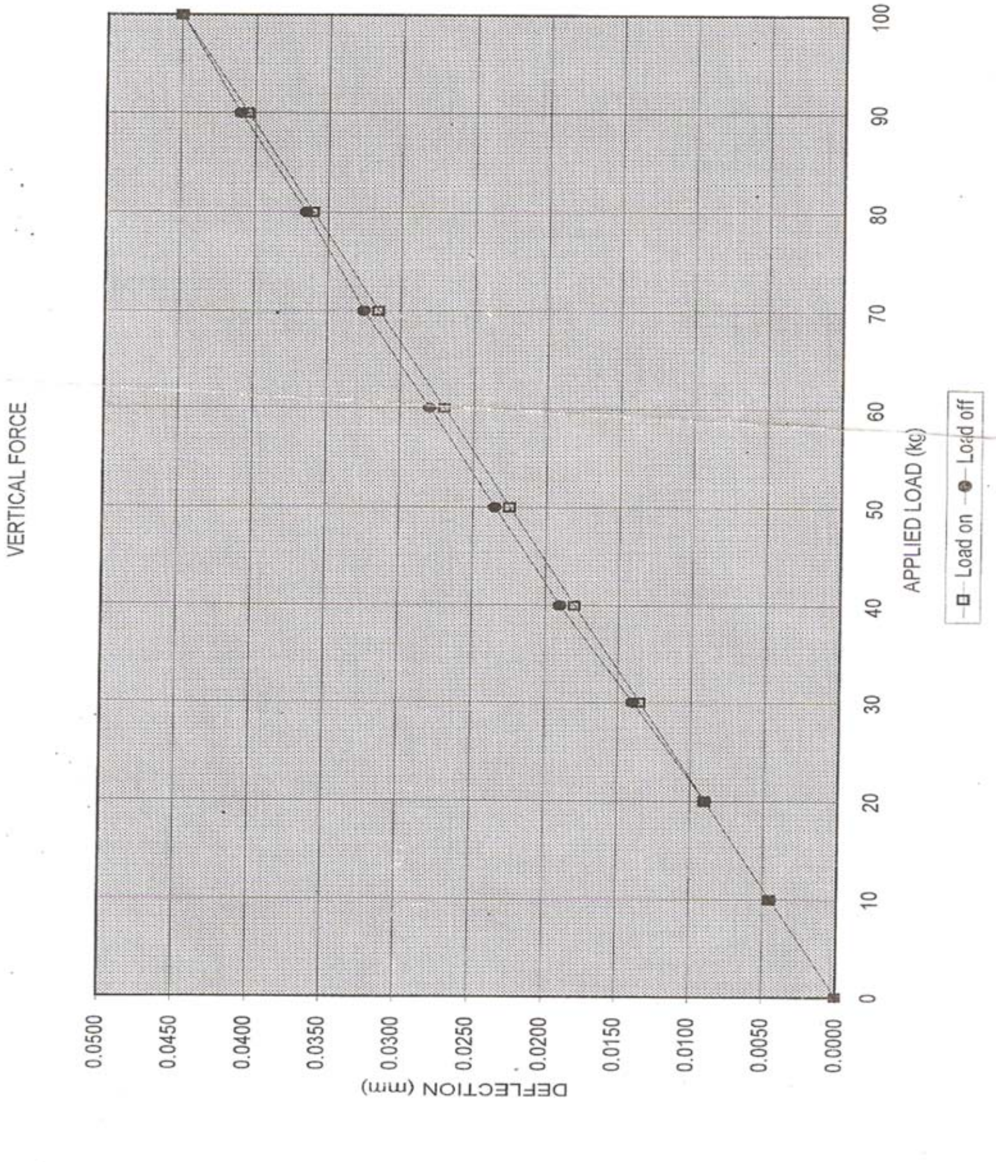
Discussions:

1. Calculate the ultimate tensile strength of material
2. Compare it with theoretical value ,which equal for aluminum 150 Mpa
3. Find the percentage error in calculation
4. Calculate yield strength of material
5. Mention three source of error in this experiment

Appendix B

Calibration graphs shows relationship between load and deflection


HORIZONTAL FORCE
DEFLECTION (mm)
0.0500
0.0450
0.0400
0.0350
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
0
10
20
30
40
50
60
70
80
90
100
APPLIED LOAD (kg)
□ Load on
● Load off


VERTICAL FORCE
DEFLECTION (mm)
0.0500
0.0450
0.0400
0.0350
0.0300
0.0250
0.0200
0.0150
0.0100
0.0050
0.0000
0
10
20
30
40
50
60
70
80
90
100
APPLIED LOAD (kg)
□ Load on
● Load off