LITERATURE REVIEW ON LATHE MACHINE

Shodhganga

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Abstract

In this study, the review of this published literature pertaining to the present research topic has been carried out to gain knowledge and to become familiar with the established techniques and methodology.

1. INTRODUCTION TO MACHINING PROCESSES

Machining [1] is a term that covers a large collection of manufacturing processes designed to remove unwanted material, usually in the form of chips, from a work-piece. Machining is used to convert castings, forgings, or preformed blocks of metal into desired shapes, with size and finish specified to fulfill design requirements. Almost every manufactured product has components that require machining, often to great precision[1]. The majority of industrial applications of machining are in metals. Although the metal cutting process has resisted theoretical analysis because of its complexity, the application of these processes in the industrial world is widespread. Metal cutting processes can be viewed as consisting of independent input variables, dependent variables, and independent – dependent interactions or relationships. The engineer or machine tool operator has direct control over the input variables and can specify or select them when setting up the machining process. Several input variables are described below.

1.1 Independent Input Variables

The metallurgy and chemistry of the work piece[1] can either be specified or is already known. Quite often, a material is selected for a particular application chiefly because it machines well. Cast iron and aluminium, for example, are known to machine easily. Other metals, such as stainless steel or titanium, are difficult to machine. They often have large cutting forces or poor surface finishes, which can result in short cutting tool life, yet these metals are selected to meet other functional design criteria. The size and shape of the work piece may be dictated by preceding processes casting, forging, forming, and so forth or may be selected from standard machining stock for example, bar stock for screw machines. Usually this variable directly influences the machining process or processes that are selected, as well as the depth of cut. The selection of machining processes required to convert the raw material into a finished product must be based on the geometry of the part size and shape, rotational or non-rotational, the required finishes and tolerances, and the quantity of the product to be made.

The three most common cutting tool materials currently in use for production machining operations are High-Speed Steel, both in wrought and powder metallurgy form, carbides and coated tools. Cubic Boron Nitride, ceramics, and diamonds are also being widely employed. Selection of a tool material that provides reliable service while fulfilling the functional requirements is still an art. The harder the tool material, the better it can resist wear at faster cutting speeds. The faster the cutting speed, higher the cutting temperature and the shorter the tool life. Retention of hardness at elevated temperatures as well as long tool life is desirable characteristics in cutting tools.

For every machining operation, it is necessary to select a cutting speed, a feed, and a depth of cut. Many factors impinge on these decisions because all of the dependent variables are influenced by them. Proper selection of variables also depends on the other input variables that have been elected, that is, the total amount of material to be removed, the work piece and tool materials, and the machining process or processes. These need to be selected before preliminary choices for speed, feed, and depth of cut can be made.

Cutting tools are usually designed to accomplish specific operations, and thus the tool geometry is selected to accomplish specific machining functions. Generally speaking, large rake and clearance angles are preferred, but they are possible only on High Speed Steel tools. Tools made from carbides, ceramics, and other very hard materials must be given small tool angles, which keep the tool material in compression during machining and thereby avoid tensile failure and brittle fractures of the tool. The greater the precision required of the process, the better the geometry of the cutting edge itself must be.

The selection of the right cutting fluid for a particular combination of work material and tool material can mean the difference between success and failure in almost every production machining process. Cutting fluids serve to cool the work piece, tool, and chips, to reduce friction by means of lubrication, to carry the chips away from the cutting region, to help improve the surface finish and to provide surface protection to the work piece.

1.2 Dependent Variables

Dependent variables[1] are determined by the process based on the prior selection of the input or independent variables. Thus, the manufacturing engineer's control over these is usually indirect. The important dependent variables are cutting force and power, size and properties of the finished product, surface finish, and tool wear and tool failure. To machine metal at a specified speed, feed, and depth of cut, with a specified lubricant, cutting tool material, and geometry, generates cutting forces and consumes power. A change in any of the variables alters the forces, but the change is indirect in that the engineer does not specify the forces, only the parameters that generate those forces. Forces are important in that they influence the deflections in the tools, the work pieces, and the work holders, which in turn affect the final part size. Forces also play a role in chatter and vibration phenomena common in machining.

Ultimately, the objective of machining is to obtain a machined surface of desired size and geometry with the desired mechanical properties. Because machining is a localized, plastic deformation process, every machined surface will have some residual deformation i.e. stresses left in it. These residual stresses are usually tensile in nature and can interact with surface flaws to produce part failure from fatigue or to cause corrosion. In addition, every process has some inherent process variability that changes with almost all of the input variables. Thus, the manufacturing engineer must try to select the proper levels of input variables to produce a product that is within the tolerance specified by the designer and has satisfactory surface properties.

The final finish on a machined surface is a function of tool geometry, tool material, work piece material, machining process, speed, feed, depth of cut, and cutting fluid. Surface finish is also related to the process variability. Rough surfaces have more variability than smooth surfaces. Often it is necessary to specify multiple cuts, that is, roughing and finish cuts, to achieve the desired surface finish, or it may be necessary to specify multiple processes, such as following turning with cylindrical grinding, in order to obtain the desired finish.

The plastic deformation and friction inherent in machining generate considerable heat, which raises the temperature of the tool and lowers its wear resistance. The problem is subtle, but significant. As the tool wears, it changes in both geometry and size. A dull cutting edge and change in geometry can result in increased cutting forces that in turn increase deflections in the work piece and may create a chatter condition. The increased power consumption causes increased heat generation in the operation, which accelerates the wear rate. The change in the size of the tool changes the size of the work piece. Again, the engineer has only indirect control over these variables. He can select slow speeds, which produce less heat and lower wear rates, but which decrease the production rates because the metal removal rate is decreased. Alternatively, the feed or depth of cut can be increased to maintain the metal removal rate while reducing the speed. Increasing either the feed or depth of cut directly increases the cutting forces. Therefore, while tool life may be gained, some precision may be lost due to increased deflection and chatter.

1.3 Relations between Input Variables and Process Behaviour

Machining is a unique plastic deformation process[1] in that it is constrained only by the cutting tool and operates at very large strains and very high strain rates. The tremendous variety in the input variables results in an almost infinite number of different machining combinations. Basically, there are three ways to deal with such a complex situation. Experience requires long-term exposure, because knowledge is basically gained by trial and error, with successful combinations transferred to other, "similar" situations. This activity goes on in manufacturing every time a new material is introduced into the production facility. It took years for industry to learn how to machine titanium. Unfortunately, the knowledge gained through one process may not transfer well to another even though their input variables appear very similar.

Machining experiments are expensive, time consuming, and difficult to carry out. Tool life experiments, for example, are quite commonly done, yet tool life data for most work piece/tool material combinations are not available. Even when laboratory data have been published, the results are not necessarily transferable to the particular machine tools and cutting tools on the shop floor. Tool life equations are empirically developed from turning experiments in which all input variables except cutting speed are kept constant. The experimental arrangement may limit the mode of tool failure to wear. Such results are of little value on the shop floor, where tools can and do fail from causes other than wear.

There have been many attempts to build mathematical models of the metal cutting process. Most of the theories try to predict the direction of the shearing process of metal cutting. These models range from crude, first order approximation to complex, computer based models using finite-element analysis. However, the theory of plastic deformation of metals has not yet been able to predict values for shear stresses and tool-chip interface from the metallurgy and deformation history of the material.

2. TURNING

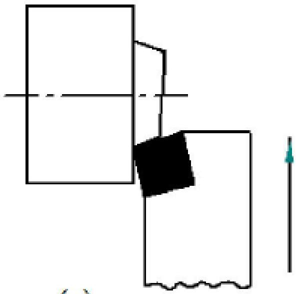
Turning[1] is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters. Turning is the machining operation that produces cylindrical parts. Turning is a machining process for generating external surfaces of revolution by the action of a cutting tool on a rotating work piece, usually in a lathe.

2.1 Process Capabilities

Often other machining operations [1] are performed in conjunction with turning. These include facing, longitudinal drilling, boring, reaming, tapping, threading, chamfering, and knurling. Common cutting tool modes used on turning equipment are shown in Fig. 1. Turning operations may be divided into two classes: those in which the work-piece is situated between centers, and those in which the work-piece is chucked or gripped at one end with or without support at the other end. Also, accessories can be obtained for milling, grinding, and cross drilling, although these operations are less frequently combined with turning. When more than two or three different operations are performed on identical parts, it is usually more practical to employ processes that use a single tool with the capability of performing two or more operations simultaneously or consecutively.

2.2 Size and Shape of Work-piece

Availability of equipment [1] that can hold and rotate the work-piece is the major restriction on the size of the work-piece that can be turned. Turning is done on parts ranging in size from those used in watches to steel propeller shafts more than 25 m long. Aluminium parts over 3.0 m in diameter have been successfully turned. In actuality, the weight of the work metal per unit of volume may restrict the size of the work-piece that is practical to turn. Problems in holding and handling increase, as weight and size increase. Some large parts are turned in vertical boring mills, some of which are capable of machining up to a 60 ton work-piece. Sometimes the entire work-piece is so unwieldy that rotating is virtually impossible. A notable example is in the turning of crankpin diameters on large crankshafts. This condition, however, usually can be overcome, and an acceptable degree of dynamic balance obtained, by counter-weighting. Counterweights may be attached either to the spindle of the machine or to the work.



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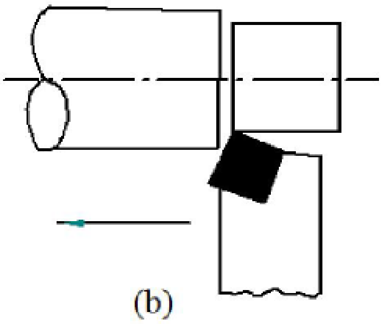

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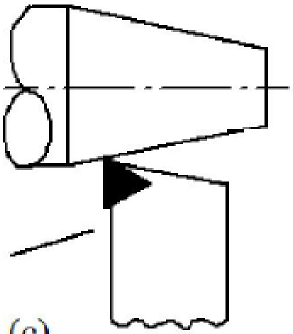

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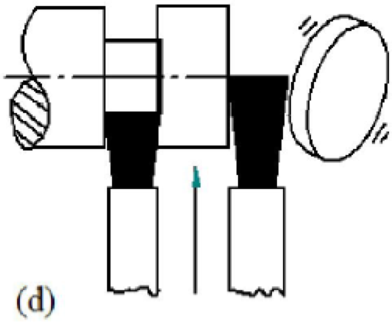

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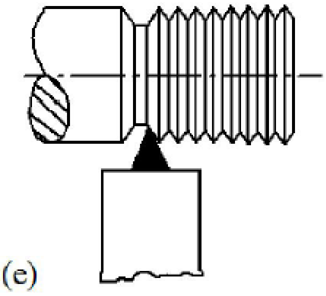

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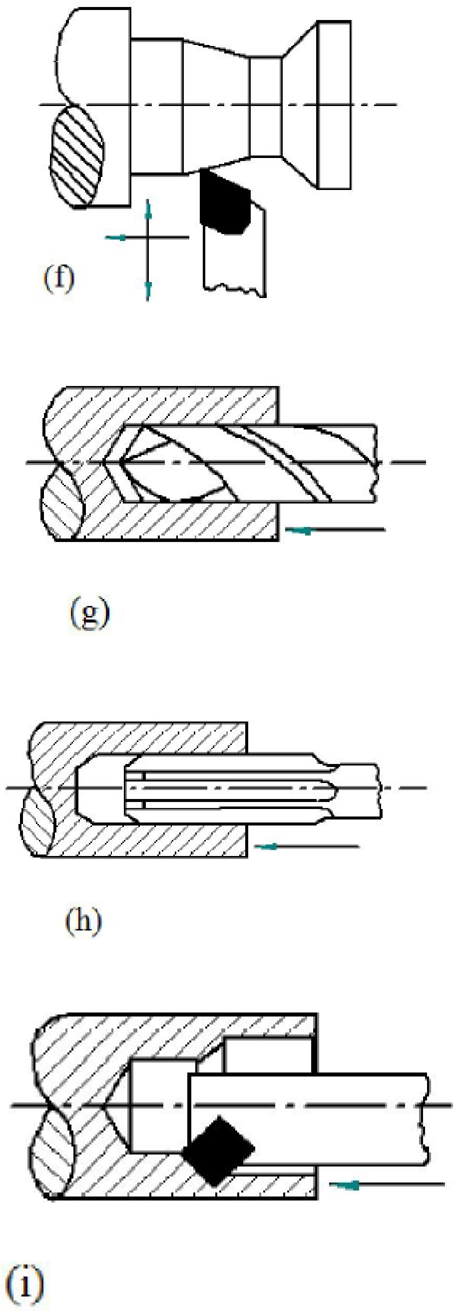


Fig. 1 Basic operations performed on turning equipment. (a) Facing. (b) Straight turning. (c) Taper turning. (d) Grooving and cutoff. (e) Threading. (f) Tracer turning. (g) Drilling. (h) Reaming. (i) Boring

2.3 Torque and Horsepower Requirements

Engagement of the cutting tool[1] with the rotating work results in a tangential force that, for a specific work metal, tool shape, and feed rate, generally is independent of the cutting speed and directly proportional to the depth of cut. That force, multiplied by the surface speed of the work-piece, serves as a basis for calculating the net horsepower required to remove metal from the piece being turned. Power required to move the tool longitudinally is usually negligible, with the exception of spade-drilling operations.

The effects of composition and hardness of the work metal on power requirements for turning are illustrated in Fig. 2 for a tool setup which uses the identical feed and depth of cut on each work metal. As shown in Fig. 2, the power values increase with increasing hardness within each family of alloys, the rate of change of power being greatest for cast irons and steels harder than 350 HB.

Besides having significance for the design of lathes, these data on power requirements provide an indication of the relative ease and cost of turning various metals.

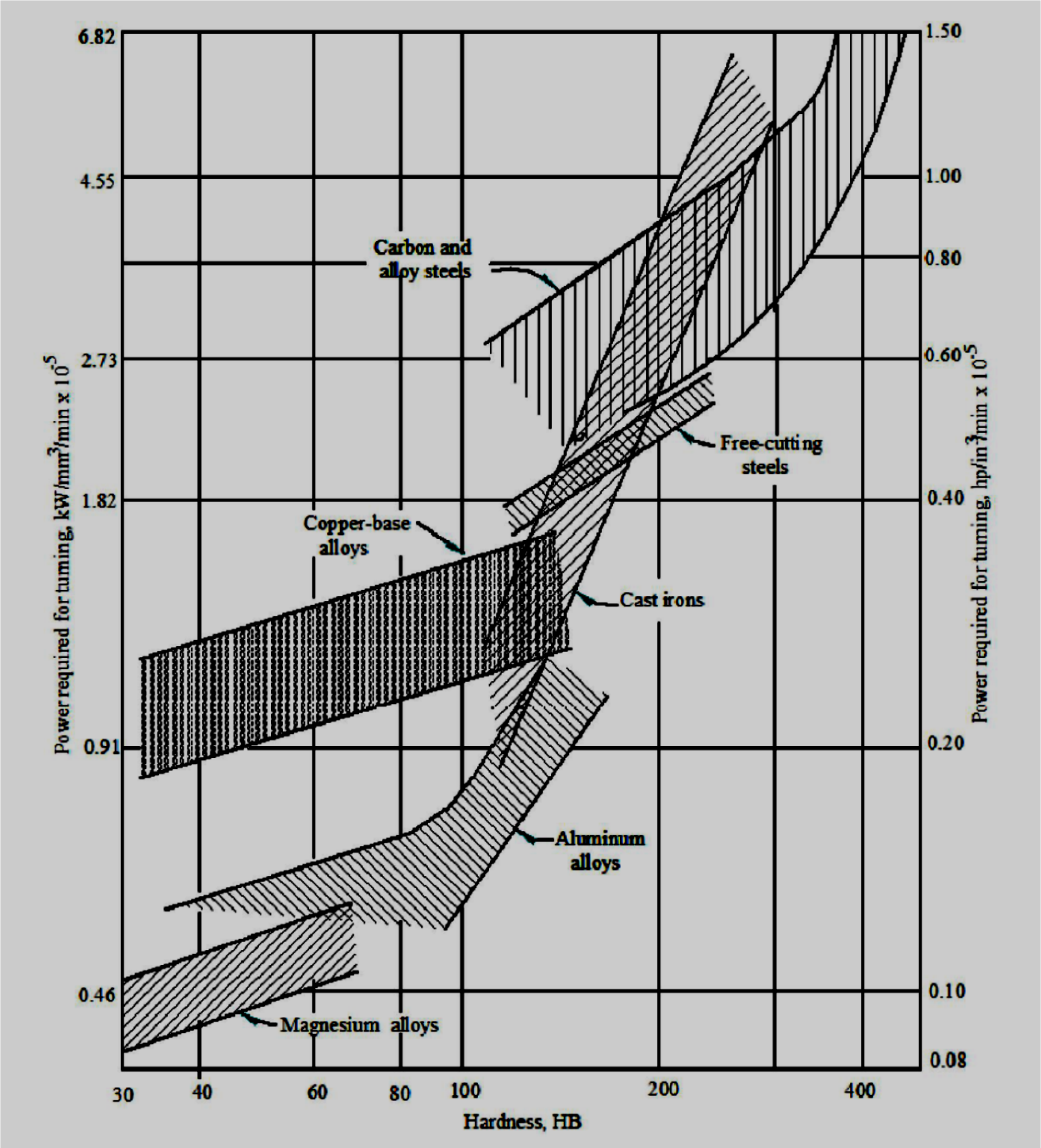


Fig. 2 Effect of composition and hardness of work metal on horsepower requirements

2.4 Work Piece Capacity

Turret lathes of the ram type[1] are built in a wide range of sizes, and saddle-type machines are built in still larger sizes. Generally, ram-type turret lathes will produce bar parts up to 76 mm in diameter and chucking work up to approximately 508 mm in diameter; ram slide stroke lengths range from 102 to 330 mm. Standard saddle-type turret lathes can handle bar work up to 305 mm diameter and chucking work up to approximately 915 mm in diameter. The new machines are made more rigid and powerful, they embody more automatic features. Some have speed and feed calculators, rapid traverse on longitudinal and cross feed, higher turning speeds, and automatic pressure lubrication.

3. LATHE

A lathe is a machine tool which rotates the work-piece on its axis to perform various operations such as cutting, knurling, drilling, Thread cutting etc. with tools that are applied to the work-piece to create an object which has symmetry about an axis of rotation. Lathes are used in woodturning, metalworking, metal spinning, Thermal spraying, parts reclamation, and glass-working.

A suitable classification of these machines is difficult because there are so many variations in the size, design, method of drive, and application. Most lathes are designated according to some outstanding design characteristic: speed lathes, engine lathes, bench lathes, tool room lathes, special-purpose lathes, turret lathes, automatic-turning machines, and modifications of these types.

3.1 Speed Lathes

The speed lathe, the simplest of all lathes, consists of a bed, a headstock, a tailstock, and an adjustable slide for supporting the tool. Usually it is driven by a variable-speed motor built into the headstock, although the drive may be a belt to a step cone pulley. Because hand tools are used and the cuts are small, the lathe is driven at high speeds up to 4000 rev/min, with the work either held between centers on a chuck or attached to a face plate on the headstock. The speed lathe is principally used for turning wood for small cabinet work or for patterns, and for centering metal cylindrical parts prior to further work on the engine lathe. In the latter operation, the center drill is held in a small chuck fastened to the headstock, and the work is guided to the center drill either by a fixed center rest or by a movable center in the tailstock. Metal spinning is done on lathes of this type by rapidly revolving a stamped or deep-drawn piece of thin, ductile metal and pressing it against a form by means of blunt hand tools or rollers.

3.2 Engine Lathes

The engine lathe derives its name from the early lathes, which were powered by engines. It differs from a speed lathe in that it has additional features for controlling the spindle speed and for supporting and controlling the feed of the fixed cutting tool. There are several variations in the design of the headstock through which the power is supplied to the machine.

3.2.1 Step-Cone Pulley Drive

Light- or medium-duty lathes receive their power through a short belt from the motor or from a small cone-pulley countershaft driven by the motor. The headstock is equipped with a four-step-cone pulley, which provides four different spindle speeds when connected directly from the motor countershaft. In addition, these lathes are equipped with back gears which, when connected with the cone pulley, provide four additional speeds.

3.2.2 Geared-Head Drive

The spindle speeds of this lathe are varied by a gear transmission, the different speeds being obtained by changing the gear trains through the positioning of levers on the headstock. Such lathes are usually driven by a constant-speed motor mounted on the lathe, but in a few cases variable-speed motors are used. A geared-head lathe has the advantage of a positive drive and has a greater number of spindle speeds available and found on a step cone driven lathe. Heavy-duty models range in size from 305 mm to 610 mm swing and from 610 mm to 1220 mm center distances, with swings up to 1270 mm and center distances up to 3.7 m being common.

3.3 Bench Lathes

The name bench lathe is given to a small engine lathe that is mounted on a work bench. In design it has the same features as speed or engine lathes and differs from these lathes only in size and mounting. It is adapted to small work, having a maximum swing capacity of 255 mm at the face plate. Many lathes of this type are used for precision work on small parts.

3.4 Tool Room Lathes

This lathe, the most modern engine lathe, is equipped with all the accessories necessary for accurate tool work, being an individually driven geared-head lathe with a considerable range in spindle speeds. It is often equipped with center steady rest, quick change gears, lead screw, feed rod, taper attachment, thread dial, chuck, indicator, draw-in collet attachment, and a pump for a coolant. All tool room lathes are carefully tested for accuracy and, as the name implies, are especially adapted for making small tools, test gages, dies, and other precision parts. Their beds frequently are shorter than ordinary engine lathes having comparable swing dimensions because they are usually used for machining relatively small parts.

3.5 Special-Purpose Lathes

Several types of special-purpose lathes are made to accommodate specific types of work. These include wheel lathes, hollow-spindle lathes, and gap-frame lathes. Wheel lathes permit the turning of journals and wheel treads of railroad car wheel and axle assemblies. A special headstock drives the assembly at a point between the two wheels.

Hollow-spindle lathes permit the loading of tubular or shaft-like work-pieces through a hollow spindle in the rear of the headstock. Work-pieces may then be extended as required through the headstock into the work area, gripped by jaw-type holders. With this type of lathe, the ends of long members can be turned without the need for a lathe long enough to accommodate the entire length of the work-piece between centers. The distance that the work-piece may extend from the rear of the headstock is virtually unlimited. However, for safety reasons, the work-piece must be supported or contained because as the unsupported length becomes unwieldy and dangerous, steady rests must be provided. Hollow-spindle lathes often are referred to as oil-country lathes, because of their extensive use for turning sections of long members such as drill pipes and sucker rods.

Gap-frame lathes, sometimes called gap-bed lathes, have been modified to provide greater diametric clearance adjacent to the headstock. With a gap-frame lathe, work-pieces that require off-center mounting or that have irregular protrusions can be turned by using this additional clearance. Otherwise, a larger lathe would be required to rotate the same work-piece. However, this does not mean that the gap-frame lathe can turn the extremes of any work-piece that can be accommodated by the larger clearance. Travel of the compound slide is restricted to the length of the ways. Therefore, as the slide approaches the headstock, it is stopped at the gap, which may not be as far as desired. This disadvantage can be partly overcome by the use of accessories that permit further travel of the tool from the compound slide. However, this involves tool overhang and decreases rigidity.

3.6 Duplicating lathes

They include copying, tracer, profiling, numerical-control, and continuous-path turning lathes. All are versatile production machines, and all are adaptable to the turning of external and internal contours. Tracer and numerical-control lathes are the most commonly used types of duplicating lathes. Each employs a different actuating system to guide the single-point cutting tool that generates the desired profile as the work-piece is rotated. Specially designed lathes known as T lathes are used to turn large diameters. These lathes have their carriage ways running parallel to the face of the chuck or at right angles to the headstock spindle centerline.

3.7 Tracer Lathes

With tracer equipment, the tool slide is controlled by means of a sensitive stylus, usually servo-actuated hydraulically, which follows an accurate template. The two- or three-dimensional template may be a finish turned work-piece or a profile cut from a flat, thin steel plate. Tracer equipment is available either as units to be attached to standard lathes or as complete, specially engineered machine tools. The combinations of feeds, speeds, and number of cuts that can be accomplished automatically are almost unlimited. For instance, some tracer lathes can be set up to make six or more passes to permit roughing, semi finishing, and finishing. These cuts may be coordinated with three or more automatic changes of speed or feed, or both, during one machining cycle. Tracer lathes can be equipped with two tracer units to operate from either ends or both sides of a work-piece, for completely turning the part on one machine. Often, however, limitations caused by the physical angle of approach of the tool do not allow one tool or tracer unit to completely machine the work-piece. A fully equipped tracer lathe incorporates one or more cross slides for use in rough or finish facing, back chamfering, grooving, or undercutting. Optional equipment includes automatic-positioning steady rests and an automatic-indexing tool head that contains both roughing and finishing tools.

3.8 Vertical Turret Lathes

With these lathes, the work is mounted on a rotating table, and the tools are mounted on vertical rams or turrets. Vertical turret lathes are used primarily for short, heavy, large diameter work-pieces. They are also ideal for light-weight but bulky parts. Controls are usually automatic (plug board or cam) but can also be manual or numerical control. Vertical turret lathes are more convenient for short, heavy pieces over about 457 mm in diameter because the work can be laid upon the table and fastened more easily than hung on the end of the spindle of a horizontal turret lathe. A turret on a vertical turret lathe is carried on a ram on a cross rail above the worktable and can be fed up or down or crosswise. There is also a side head, essentially a carriage and cross slide, alongside the table with a square turret that can be fed radially and parallel to the axis of the table. The line of machines of one leading manufacturer is typical; indexing turrets are available with table capacities to 3.7 m diameter. Larger sizes, and smaller sizes, too, if desired, have single-tool rams; there are normally two rams on the cross rail. These larger machines are called vertical boring mills and are available in sizes up to 18 m diameter. They perform turning, facing, boring, and grooving operations of huge, fairly round, and symmetrical pieces such as reduction gear housings and turbine casings. A typical vertical turret lathe has a 1.4 m diameter swing and a 65 kW drive. Typical vertical boring mill specifications include 2.3 m diameter capacity, 1.7 m maximum work height, 15 Mg maximum work-piece weight, and a 90 Kw power rating.

3.9 Automatic Turning Machines

A machine that moves the work and tools at the proper rates and sequences through a cycle without the attention of an operator to perform an operation on one piece is commonly called an automatic. Strictly speaking, the machine is a semiautomatic if an operator is required to load and unload the machine and start each cycle. Often an operator can do this for several machines in a group. Work-pieces may come to a fully automatic machine on a conveyor or an operator may load a magazine or hopper at intervals. Automatic machines are widely used for drilling, boring, milling, broaching, grinding, and other operations. Automatic turning machines are made massive, rigid, and powerful to drive cutting tools at their highest speed and get the most from gangs of tools and multiple and combined tooling. Automatic machines intended for large lots of pieces and infrequent changeover are not usually designed for quick setup. For instance, speeds and feeds are not changed by sliding levers or turning dials, as on an engine lathe, but by removing and replacing pick-off gears. The multiplicity of tools must be set with respect to each other as well as to the machine. In some cases, common practice is to preset the tools in blocks off the machine. The blocks then go into position quickly on the machine at setup time, and machine downtime is saved. Setup time may be less than an hour in favorable cases in which few changes are needed between jobs, but normally changeover takes several hours, and not infrequently up to a day or more, compared to a few minutes on an engine lathe.

Careful scheduling to run similar jobs in succession can save changeover time. Although setup time is long, an automatic machine has the advantage when cutting because it is fast and often able to make up the time lost in setup in less than 100 pieces. A basic mechanical device for driving tool slides and other units is the cam. Some machines require a set of cams for each job. The shape of each cam programs one or more movements. Because the operation is costly, only large production runs are warranted. However, each set of cams can be made to do the job in the shortest time (other machines that do not require cam changes for each job are called camless automatics). One kind has a permanent set of cams that act through adjustable linkages. Without cams, activities are carried out through adjustable electro- and hydro- mechanical devices. A different kind of automatic operation is numerical control (NC), in which the program is expressed in numbers that are fed into the controller to make the machine go through the steps of a desired operation. Leading kinds of automatic turning machines are presented here under the classifications of automatic lathes, and single-spindle and multiple-spindle automatic bar and chucking machines.

3.9.1 Automatic lathes

Automatic lathes have the basic units of simple lathes: bed, headstock, tool slides, and sometimes a tailstock. In addition, an automatic lathe drives the tools through all the steps of a cycle without operator attention once the machine has been set up. The workpiece is rotated between centers. The tools are carried on blocks on the front and rear slides. The front slide is traversed along the bed, and the tools in this case make straight cuts along the work-piece, retract at the end of the cut, and are withdrawn to the starting position. The rear tool slide typically feeds the tools toward the center of the work-piece for facing, necking, grooving, and forming, but can be given a sideways movement to relieve the tools at the end of a cut. All automatic lathes perform basically similar functions, but they appear in a variety of forms. Many have no tailstock. Some models have one slide, and others have two or three. Some slides move in one direction only; others move in two directions. Some machines have level tool slide ways; others have sloping ways, and some have overhead slides for additional tools. Some slides are fed by screws, others by hydraulic or air hydraulic means, and still others entirely by cams and templates. There are horizontal and vertical models according to spindle position.

Some automatic lathes have two or three work spindles so that two or three sets of tools can perform the same cuts on two or three work-pieces at once. Automatic lathes, particularly vertical machines, without tailstocks are commonly called chucking machines, or checkers. The distinguishing feature of this automatic lathe type is that all the tools cut the work-piece substantially at the same time. On the other types also called chucking machines, a series of groups of tools or single tools are applied to each work-piece. On the other hand, a type called precision production boring machines, like automatic lathes, makes a number of cuts at one time. The distinction is generally that its movements are in one direction, while the movements on automatic lathes are in two or more directions.

3.9.2 Automatic Bar and Chucking Machines

Automatic machines for internal and external operations on bar stock have been called automatic screw machines for years, but the term automatic bar machines is now preferred because screws are seldom made on them anymore. Their counterparts for individual pieces are called automatic chucking machines. They can be further categorized as single-spindle, Swiss-type screw machine, or multiple-spindle automatics.

3.9.3 Single-spindle automatics

Single-spindle automatics are often referred to as single-spindle automatic bar and chucking machines. In essence, they are small cam-operated turret lathes. The distinguishing features of these machines are the positions of the turret and tool mountings. The automatic screw machine has front, top, and rear slides that are fed at predetermined rates by means of disk cams. These are designed to handle work ranging from watch staffs to bars approximately 200 mm diameter and chuck work over 305 mm diameter.

3.9.4 Swiss-type automatic screw machines

Swiss-type automatic screw machines have five radially mounted tools that are cam controlled. The stock can be fed as it is being cut, making any desired cylindrical shape possible to generate. This type of lathe is especially good for turning out small-diameter instrument parts. The accuracy on small parts can be maintained to ± 0.013 mm.

3.9.5 Multi-spindle Automatics

Instead of having only one spindle, as on the engine lathe, four, six, or eight spindles may be used. These are high-production machines. Production quantities may range from 5000 to over 100,000 parts. Stock may be in bar or piece form up to 150 mm diameter.

3.10 CNC LT16 XI lathes

Numerical-control lathes differ from hydraulically controlled tracer lathes primarily in that their cutting tools are controlled electronically. All tool movements during cuts, as well as all tool indexing, cross-slide operations, and changes of speed and feed, are pre-engineered and programmed on a punched tape for electronic control of all machine movements. Advantages of the NC lathe include low inventory of tooling and fully controlled cutting conditions. For copying work, NC lathes have the capability of machining any cylindrical form without the need for a template. However, compared to tracer lathes, NC machines can be quite expensive.

An important advance in the philosophy of machine tool numerical control that took place in the early 1970s was the shift toward the use of computers instead of controller units in NC systems. This produced both computer numerical control (CNC) and direct numerical control (DNC). Computer numerical control is a self-contained NC system for a single machine tool including a dedicated computer controlled by stored instructions to perform some or all of the basic NC functions. With DNC, several machine tools are directly controlled by a central computer. Of the two types of computer control, CNC has become much more widely used for manufacturing systems, machine tools, welders, and laser beam cutters mainly because of its flexibility and the lower investment required. The preference of CNC over DNC is increasing as a result of the availability and declining costs of minicomputers and microcomputers.

One of the objectives of CNC systems is to replace as much of the conventional NC hardware as possible with software and to simplify the remaining hardware. There are many ways in which functions can be shared between software and hardware in such systems, but all involve some hardware in the controller dedicated to the individual machine[2]. This hardware must contain at least the servo amplifiers, the transducer circuits, and the interface components, as shown in Fig. 3

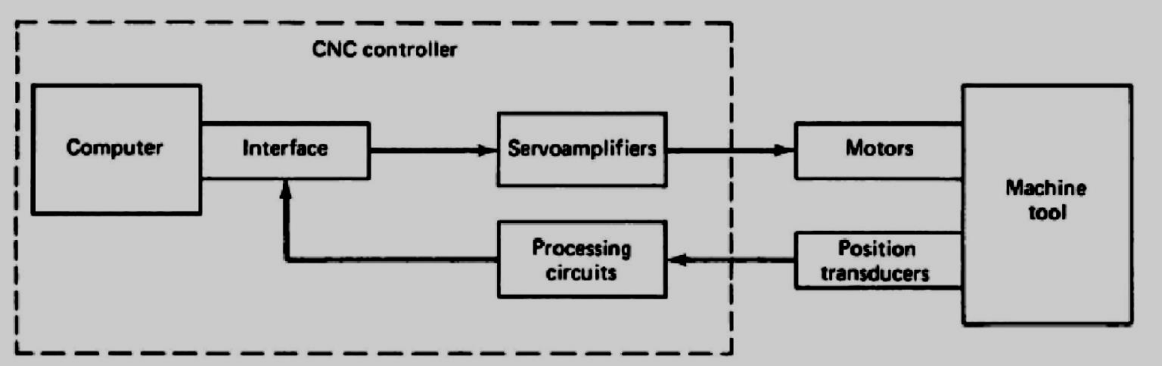


Fig. 3 Block diagram of a CNC machine

The software of a CNC system consists of at least three major programs: A part program, A service program, A control program The part program contains a description of the geometry of the part being produced and the cutting conditions, such as spindle speed and feed rate. The service program is used to check, edit, and correct the part program and to run system diagnostics. The control program accepts the part program as input data and produces signals to drive the axes of motion of the machine.

The CNC controllers of the 1980s are more powerful and more user friendly than earlier units. They incorporate troubleshooting features such as on-board diagnostics, which allow self-testing of the controller, and simulation mode, which is used to test part programs without generating axes motions. Many controllers offer high-level programming facilities, three-dimensional tool path animation with graphics, tool data base, and pre-selection of cutting parameters. The modern machine controller is a workstation [3]. It is capable of communicating with other controllers and of being integrated into a flexible manufacturing system in the future, thus permitting the gradual construction of a full flexible manufacturing system. Numerical control was introduced and developed in the metalworking industry, and the largest concentration of NC equipment remains in metalworking shops. Numerical control has been successfully implemented for turning, milling, drilling, grinding, boring, punching, and electrical discharge machines. It is interesting to note that numerical control has made possible the development of machines with basic capabilities that far surpass those of conventional machines. For example, sophisticated NC milling machines maintain control over five axes of motion and can literally sculpt complex surfaces. A new breed of NC machine tool is the machining center and the turning center, which incorporate the functions of many machines into a single device. A machining center can access multiple tools to perform such operations as milling, drilling, boring, and tapping. A turning center is a powerful lathe equipped with an automatic tool changer. Other types of NC machines include welding machines, drafting machines, tube benders, inspection machines, and wiring machines in the electronics industry.

A common feature in numerical control and robotics is that the required path of the tool is generated by the combined motion of the individual axes. In numerical control, the tool is the cutting tool, such as a milling cutter or a drill; in robotics, the tool is the instrument at the far end of the manipulator, which might be a gripper, a welding gun, or a paint spraying gun. Robot systems, however, are more complex than machine tool CNC systems for the reason discussed below.

Machine tools require control of the position of the tool cutting edge in space. In many cases, the control of three axes is adequate. Robots require the control of both the position of the tool center point and the orientation of the tool; this is achieved by controlling six axes of motion (or degrees of freedom). Some robot systems use more than six axes, and some CNC machines use more than three axes of motion. A typical example is the addition of a rotary table to a three-axis milling machine. On the other hand, many robot systems use fewer than six axes, and in such cases the wrist section contains fewer than three degrees of freedom. Similarly, there are CNC machines with only two numerically controlled axes of motion.

3.10.1 Fundamentals of Numerical Control

Numerical control equipment has been defined by the Electronic Industries Association (EIA) as a system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of these data. In a typical NC or CNC system, the numerical data required for producing a part are maintained on a disk or on a tape and called the part program. The part program is arranged in the form of blocks of information. Each block contains the numerical data required to produce one segment of the work-piece profile. The block contains, in coded form, all the information needed for processing a segment of the work-piece: the segment length, its cutting speed, feed rate, and so on. Dimensional information such as length, width, and radii of circles and the contour form such as linear, circular, or other are taken from an engineering drawing. Dimensions are given separately for each axis of motion i.e., X, Y, and so on. Cutting speed, feed rate, and auxiliary functions such as coolant on and off, spindle direction, clamp, and gear changes are programmed according to surface finish, tolerance, and machining requirements.[2,3,4,5,6 and 7].

Compared to a conventional machine tool, the NC system replaces the manual actions of the operator. In conventional machining, a part is produced by moving a cutting tool along a work-piece by means of powered slides that are engaged and disengaged by an operator. Contour cuttings are performed by an expert operator by sight. On the other hand, the operators of NC machine tools need not be skilled machinists. They only have to monitor the operations of the machine, operate the tape reader, and load and remove the work-piece. Most intellectual operations that were formerly done by the operator are now included in the part program. However, because the operator works with a sophisticated and expensive system, intelligence, clear thinking, and good judgment are essential qualifications of a good NC operator.

Preparing the part program of an NC machine tool requires a part programmer. The part programmer should possess knowledge and experience in mechanical engineering fields. Knowledge of tools, cutting fluids, fixture design techniques, machinability data, and process engineering are all of considerable importance. The part programmer must be familiar with the function of NC machine tools and machining processes and must decide on the optimum sequence of operations. The part program can be written manually, or a computer-assisted language, such as the automatically programmed tool language, can be used. In NC machines, the part dimensions are presented in part programs by integers. In CNC machines, the dimensions in part programs are sometimes expressed as numbers with a decimal point, but are always stored in the computer as integers. Each unit of these integers corresponds to the position resolution of the axes of motion and is referred to as the basic length unit (BLU). The BLU is also known as the increment size or bit weight, and in practice it corresponds approximately to the accuracy of the NC system.

In NC and CNC machine tools, each axis of motion is equipped with a separate driving device, which replaces the hand wheel of the conventional machine. The driving device may be a dc motor, a hydraulic actuator, or a stepping motor. The type selected is determined by the power requirements and the machine.

An axis of motion in numerical control means an axis in which the cutting tool moves relative to the work-piece. This movement is achieved by the motion of the machine tool slides. The main three axes of motion are referred to as the X-, Y-, and Z-axes. The Z axis is perpendicular to both X and Y in order to create a right-hand coordinate system. For example, in a vertical drilling machine (as one faces the machine), a +X command moves the worktable from left to right, a +Y command moves it from front to back, and a +Z command moves the drill up, away from the work-piece. The X-, Y-, and Z-axes are always assigned to create a right-hand Cartesian coordinate system.

Each axis of motion also has a separate control loop. The control loops of NC or CNC systems use two types of feedback devices shown in fig. 3, tachometers to monitor velocity and encoders or other position transducers (for example, resolvers) to measure position. The controller compares the actual position with the required one and generates an error. The control loop is designed in such a way as to reduce the error, that is, the loop is a negative-feedback type. A common requirement of continuous-path NC and CNC systems is the generation of coordinated movement of the separately driven axes in order to achieve the desired path of the tool. This coordination is accomplished by interpolators. Numerical control systems contain hardware interpolators, but in CNC systems interpolators are implemented by software.

3.10.2 Advantages of NC Systems

It has been clearly shown that NC manufacturing reduces the number of direct employees because fewer multipurpose NC machines are required and, in some cases, one operator can operate more than one machine. However, the ratio of indirect to direct employees might increase, and in turn, overall employment in the industry might rise despite increased automation and mechanization[6]. Output would of course also increase. Realistically, then, the advantage is not in lowering labor costs but in increasing the output per man-hour. Handling costs with NC technology have decreased, in some cases remarkably. Setup times have been substantially reduced, and actual productive time has been substantially increased. A further savings of time is achieved while passing from one operation to another during the machining of the work-piece. With a conventional machine tool, the work must be stopped at such points because the operator must go to the next step. The operator must stop the cutting process frequently and measure the part dimensions to ensure that the material is not overcut. It has been proved that the time wasted on measurements is frequently 70 to 80% of the total working time[7]. The rate of production is also decreased because of operator fatigue. In NC systems, these problems do not exist. Because the accuracy is repeatable with numerical control, inspection time is also reduced.

Numerical control produces higher-quality parts and makes possible the accurate manufacture of more complex designs without the usual loss in accuracy encountered in conventional manufacturing. Producing a part that must be cut with an accuracy of 0.01 mm or better may take a considerable amount of time using conventional methods. In numerical control using single-axis motion, obtaining such accuracies is the state-of-the-art, and they are maintained throughout the entire range of cutting speeds and feed rates. Another intangible advantage of numerical control is the production of complex parts that are not feasible in conventional manufacturing. Complex-contour cutting in three dimensions cannot be performed by manual operation. Even when it is possible, the operator must manipulate the two hand wheels of the table simultaneously while maintaining the required accuracy; thus, it becomes possible only when the part is simple and requires relatively low accuracies. It is obvious that in such work the NC machines save a considerable amount of time. Compared to conventional machining methods, the NC machine tool has the following advantages:

1. Complete flexibility; a part program is needed only for producing a new part
2. Accuracy is maintained through the full range of speeds and feeds
3. The possibility of manufacturing a part of complicated contour
4. A shorter production time
5. Higher productivity achieved by saving indirect time, such as setting up and adjusting the machine and using one operator to monitor several machining operations, or by using completely automatic operation in unmanned production.

3.10.3 NC Programming

Most NC and CNC machine tools use off-line programming methods, which can be either manual or computer assisted, such as programming with the aid of the automatically programmed tool language. During off-line programming, the machine remains in operation while a new part program is being written. Typically, when a part program is ready, it is stored on a punched tape or a floppy disk. The tape or disk is taken to the machine shop and loaded into the machine tool controller, and the part is subsequently produced. Manual part programs are written by programmers. First, the programmers must determine the machining parameters and the optimum sequence of operations to be performed. Based on this sequence, they calculate the tool path and write a manuscript. Each line of the manuscript, which is referred to as a block, contains the required data for transferring the cutting tool from one point to the next, including all machining instructions that should be executed either at the point or along the path between the points. A typical line Program according to this standard is as follows:

N102
G01
X-52000
Y9100
F315
S717
T65432
M03 (EB)

The letter and the number that follows it are referred to as a word. For example, X-52000 and M03 are words. The first letter of the word is the word address. Word addresses are denoted as follows: N, sequential number, G, preparatory function; X and Y, dimensional words; F. feed rate code; S, speed code; T, tool code; M, miscellaneous function; and EB, end-of-block character. The EB character is not printed but only punched or coded, and it is usually the carriage return code, thus permitting a new line to begin immediately afterward. The EB character indicates to the NC controller that the current reading is completed and that the axes of motion must start up. When this motion is accomplished, the next block is read.

4. CUTTING TOOLS

Cutting tool[1] is any tool that is used to remove material from the work-piece by means of shear deformation. Cutting may be accomplished by single-point or multipoint tools. Single-point tools are used in turning, shaping, planing and similar operations, and remove material by means of one cutting edge. Milling and drilling tools are often multipoint tools. Grinding tools are also multipoint tools. Each grain of abrasive functions as a microscopic single-point cutting edge, and shears a tiny chip. Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal-cutting process. Also, the tool must have a specific geometry, with clearance angles designed so that the cutting edge can contact the work-piece without the rest of the tool dragging on the work-piece surface. The angle of the cutting face is also important, as is the flute width, number of flutes or teeth, and margin size. In order to have a long working life, all of the above must be optimized, plus the speeds and feeds at which the tool is run.

Principal categories of cutting tools include single point lathe tools, multipoint milling tools, drills, reamers, and taps. All of these tools may be standard catalog items or tooling designed and custom-built for a specific manufacturing need.

The number one error when selecting tooling is calculating monetary savings based on lowest cost per tool, rather than on maximized productivity and extended tool life. To effectively select tools for machining, a machinist or engineer must have specific information about the following:

1. The starting and finished part shape
2. The work-piece hardness
3. The material's tensile strength
4. The material's abrasiveness
5. The type of chip generated
6. The work holding setup
7. The power and speed capacity of the machine tool

Changes in any of these conditions may require a thorough review of any cutting tool selection.

Different machining applications require different cutting tool materials. The ideal cutting tool material should have all of the following characteristics:

1. Harder than the work it is cutting
2. High temperature stability
3. Resists wear and thermal shock
4. Impact resistant
5. Chemically inert to the work material and cutting fluid

No single cutting tool material incorporates all these qualities. Instead, trade-offs occur among the various tool materials. For example, ceramic cutting tool material has high heat resistance, but has a low resistance to shock and impact. Every new and evolving tool development has an application where it will provide superior performance over others. Many newer cutting tool materials tend to reduce, but not eliminate the applications of older cutting tool materials.

4.1 Single Point HSS Cutting Tool

Single point cutting tools ground to specific shapes are frequently used to produce contours on work-pieces when tool travel is limited to straight-line movement, most metal removal in lathe turning is accomplished with single-point tools. Single-point tools may be produced from a solid bar of tool steel by grinding the appropriate cutting edge on one end, or they may be made of less-costly stock and provided with a tip, or insert, of carbide or other cutting material. The insert may be held in place mechanically or by brazing, soldering, or welding. Brazed, soldered, or welded inserts are resharpened after becoming dull through use; inserts held in place mechanically are usually of the disposable type.

4.2 Design of Single-Point Tools

Standard angles for single-point tools are illustrated and named in Fig. 4 which shows how back rake angle, side rake angle, end relief angle, side relief angle, end cutting edge angle, side cutting-edge angle, and nose radius are related in order to aid engineers in designing single-point cutting tools.

4.2.1 Back rake angle

It is the angle between the cutting face of the tool and the shank or holder, measured parallel to the side of the shank or holder. The angle is positive if, as shown in Fig. 4, it slopes from the cutting point downward toward the shank, and negative if it slopes upward toward the shank.

4.2.2 Side rake angle

It is the angle between the cutting face of the tool and the shank or holder, measured perpendicular to the side of the shank or holder. The angle is positive if, as shown in Fig. 4, it slopes downward away from the cutting edge to the opposite side of the shank, and negative if it slopes upward.

4.2.3 End relief angle

It is the angle between the end face of the tool and a line drawn from the cutting edge perpendicular to the base of the shank or holder and usually is measured at right angles to the end cutting edge.

4.2.4 Side relief angle

It is the angle between the side flank immediately below the side cutting edge and a line drawn through the side cutting edge perpendicular to the base of the tool or tool holder and usually is measured at right angles to the side flank.

4.2.5 End cutting-edge angle

It is the angle between the end cutting edge of the tool and a line perpendicular to the side of the shank. Side cutting-edge angle, also called lead angle, is the angle between the side cutting edge and the projected side of the shank or holder.

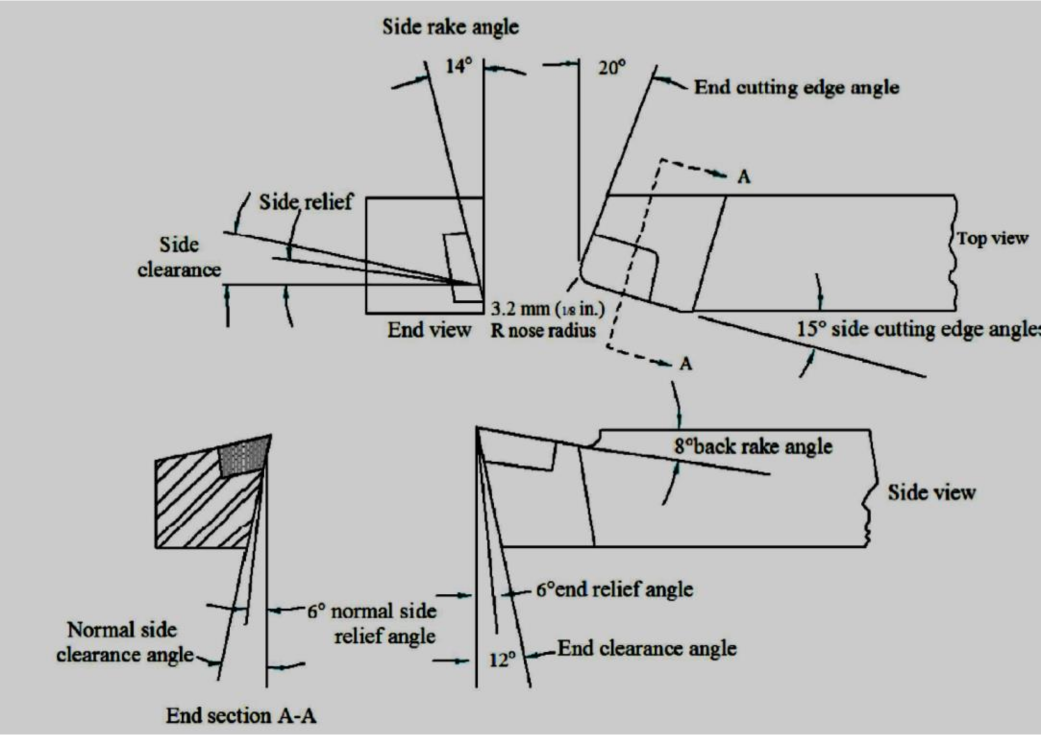


Fig. 4 Geometry of single point cutting tool

4.2.6 Nose radius

It is the radius on the tool between the end and the side cutting edges. The nose contour, normally specified as a radius, removes the fragile corner of the tool, prolongs tool life, and improves finish. The radius may be large for maximum strength or for rough cutting tools, but it may be reduced for light feeds. A radius too large may cause chatter, but the larger it is without chattering, the better the finish.

Tool design influences the power required at the tool point for turning. The side rake angle has the greatest effect. Tool design is particularly important in tracer lathe turning, for which only one tool is used to make all cuts. Because the minimum number of passes is desirable, so is the fastest rate of metal removal that is compatible with maintenance of dimensional and finish requirements. The use of only one cutting tool imposes severe restrictions on the shape of the tool. A tool often must be provided with a -3° side cutting edge angle and a 30° minimum end cutting-edge angle, resulting in a weak structure at the nose of the cutting edge. For this reason, heavy feed forces often must be avoided, if they have not already been ruled out because of required finish. Thus, surface speed becomes the criterion for determining maximum rate of metal removal, and the design of the cutting tool becomes vitally important in obtaining maximum metal removal and tool life. Increasing the surface cutting speed increases tool temperatures and results in premature tool wear.

5. Cutting parameters

The following are the different types of cutting parameters discussed.

5.1 Cutting Speed

Cutting speed for aluminium alloys is determined by the limits of the machine tool and by the work piece. Speeds as s high as 4600 m/min have been used in aerospace application. Even higher speeds have been achieved with experimental equipment. However, in most practices, mainly because of the limitations imposed by available spindle speeds, available horse power and dynamic balance of the part, machining speeds are higher than 900 m/min and they are more commonly less than 300 m/min.

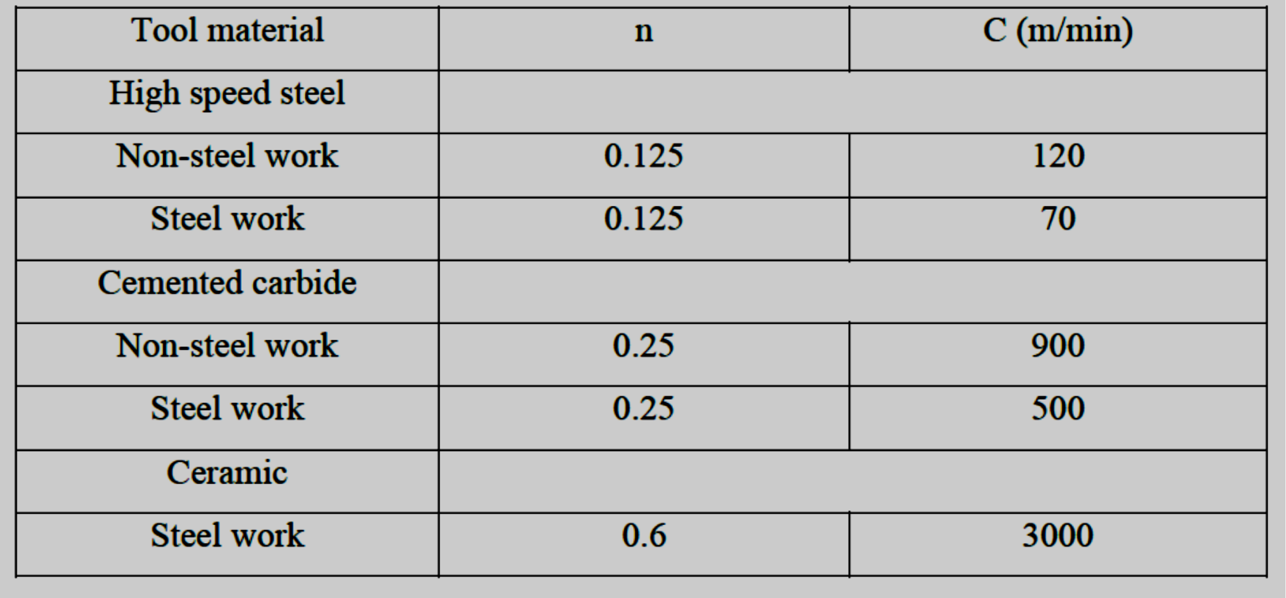
Cutting speed should be as high as is practical in order to save time and to minimize the temperature. As cutting speed is increased above 60 m/min the probability of forming built up edge on the cutter is reduced, chips breaks more readily and finishing is improved.

Cutting speed, as a variable, has a greatest influence on tool life. The relationship between cutting speed and the tool life can be expressed by Taylor's equation:

$$VT^n = C \qquad (1)$$

Where,
T = tool life in minutes, i.e. actual cutting time between resharpening or indexing.
V = cutting speed in m / min.
C = constant, whose value depends on the tool material and work material.
n = exponent, whose value depends on the tool material and work material.

Table 1 Constant values for the Taylor's equation



Tool material	n	C (m/min)
High speed steel		
Non-steel work	0.125	120
Steel work	0.125	70
Cemented carbide		
Non-steel work	0.25	900
Steel work	0.25	500
Ceramic		
Steel work	0.6	3000

As indicated earlier, under a given set of conditions, tool life is proportional to the cutting speed, and Machinability based on tool life can be expressed in terms of cutting speed. If a standard reference material permits a speed of Vs m/min for a predetermined value of the tool life T min. and a test material permits speed of Vt m/min for the same tool life, then the machinability rating of the test material can be expressed as a percentage of speeds, viz. Vt/Vs*100. This is the most common method of expressing the machinability of materials because it gives an indication of the speed to be used for a particular material and also provides an idea of the cost of machining operations. Cutting forces are fairly independent of the cutting speed, except for the fact that at higher cutting speeds, the cutting forces are slightly lower owing to the diminishing chip thickness. Normally, the surface finish improves with the cutting speed. This is mainly due to the continuous reduction of the built-up edge. After the built-up edge becomes insignificant, the surface finish is not improved with further increase in cutting speed.

5.2 Depth of cut

Depth of cut should be as great a possible within the limits of part strength, chucking equipment, power of the machine tool and the amount of stock to be removed in order to minimize the number of cuts required. As depth of cut is increased, cutting force increases. Depth of cut must be limited to a value that will not distort the work piece, cause it to slip or overload the machine. Depth of cut in roughing maybe as high as 6.35 mm for small work or up to 38.10 mm for medium work and large work. The depth of cut in finishing is often less than 0.635 mm.

The tool life at a given cutting speed is also influenced by the dimensions of cut, namely, the feed and the depth of cut. The relationship between the tool life and the depth of cut can be expressed by the following equation:

$$V_c T^n X d^x f^y = C \qquad (2)$$

Where,
Vc=cutting speed
T=tool life
d=depth of cut
f=feed rate
x and y are determined experimentally
n and C are constants found by experimentation or published data; they are properties of tool material, work-piece and feed rate.

The dimensions of cut influence the cutting forces and the material removal rate. However, the limiting factors are power, rigidity of the machine, job, fixtures, rigidity of the tool, the maximum permissible deflections of the machine and the work consistent with the requirements of accuracy, and surface finish on the job.

Surface finish is also affected to a large extent by the dimensions of cut, especially by the feed rate. With increase in feed rate, the surface finish deteriorates rapidly. Large dimensions of the cut increase the cutting force and deflection and hence deteriorate the surface finish.

5.3 Feed

Feed is the motion of the tool parallel to the axis of the work. Feed is defined in terms of the ratio of distance travelled by the time taken. Feed is generally given by the units mm/min or it is also defined by the distance travelled by the tool per revolution of the work-piece i.e. mm/rev.

Feed is the most important single factor which affects surface roughness. As the feed increases the quality of the surface roughness decreases and vice versa.

Feed will depend on the finish desired and on the strength and rigidity of the work piece and of the machine. Finishing cuts require a light feed of 0.05 mm/rev to 0.15 mm/rev, for rough cuts may use a feed of 0.15 mm/rev to 2.03 mm/rev.

5.4 Nose radius

Nose radius and feed rate have a great impact on surface finish, when establishing the feed rate for roughing operation, it is important not to over feed the nose radius of the insert. Generally, the feed rate for roughing should not be more than half the size of nose radius.

5.5 Rake angle

Rake angle is a parameter used in various cutting and machining process, describing the angle of the cutting face relative to the work.

6. CUTTING TOOL MATERIALS

As rates of metal removal have increased[8], so has the need for heat resistant cutting tools. The result has been a progression from high-speed steels to carbide, and on to ceramics and other super hard materials. Developed around the year 1900, high-speed steels cut four times faster than the carbon steels they replaced. There are over 30 grades of high speed steel, in three main categories: tungsten, molybdenum, and molybdenum-cobalt based grades. Since the 1960s the development of powdered metal high-speed steel has allowed the production of near-net shaped cutting tools, such as drills, milling cutters and form tools. The use of coatings, particularly titanium nitride, allows high-speed steel tools to cut faster and last longer. Titanium nitride provides a high surface hardness, resists corrosion, and it minimizes friction.

In industry today, carbide tools have replaced high-speed steels in most applications. These carbide and coated carbide tools cut about 3 to 5 times faster than high-speed steels. Cemented carbide is a powder metal product consisting of fine carbide particles cemented together with a binder of cobalt.

The major categories of hard carbide include tungsten carbide, titanium carbide, tantalum carbide, and niobium carbide. Each type of carbide affects the cutting tool's characteristics differently. For example, a higher tungsten content increases wear resistance, but reduces tool strength. A higher percentage of cobalt binder increases strength, but lowers the wear resistance. Carbide is used in solid round tools or in the form of replaceable inserts. Every manufacturer of carbide tools offers a variety for specific applications. The proper choice can double tool life or double the cutting speed of the same tool. Shock resistant types are used for interrupted cutting. Harder, chemically-stable types are required for high speed finishing of steel. More heat-resistant tools are needed for machining the super-alloys, like Inconel and Hastelloy.

There are no effective standards for choosing carbide grade specifications so it is necessary to rely on the carbide suppliers to recommend grades for given applications. Manufacturers do use an ANSI code to identify their proprietary carbide product line. Two thirds of all carbide tools are coated. Coated tools should be considered for most applications because of their longer life and faster machining. Coating broadens the applications of a specific carbide tool. These coatings are applied in multiple layers of under .001 of an inch thickness. The main carbide insert and cutting tool coating materials are titanium carbide, titanium nitride, aluminium oxide, and titanium carbonitride. Ceramic cutting tools are harder and more heat-resistant than carbides, but more brittle. They are well suited for machining cast iron, hard steels, and the super alloys.

Two types of ceramic cutting tools available are the alumina-based and the silicon nitride-based ceramics. The alumina-based ceramics are used for high speed semi- and final-finishing of ferrous and some non-ferrous materials. The silicon nitride-based ceramics are generally used for rougher and heavier machining of cast iron and the super alloys. Ceramic tools are produced from the materials used to coat the carbide varieties such as titanium carbides and nitrides. They are especially useful in chemically reactive machining environments, for final finishing and some turning and milling operations.

Super-hard tool materials are divided into two categories: cubic boron nitride and polycrystalline diamond. Their cost can be 30 times that of a carbide insert, so their use is limited to well-chosen, cost effective applications. Cubic boron nitride is used for machining very hard ferrous materials such as steel dies, alloy steels and hard-facing materials.

Polycrystalline diamond is used for non-ferrous machining and for machining abrasive materials such as glass and some plastics. In some high volume applications, polycrystalline diamond inserts have outlasted carbide inserts by up to 100 times. All cutting tools are “perishable,” meaning they have a finite working life. It is not a good practice to use worn, dull tools until they break. This is a safety hazard which creates scrap, impacts tool and part costs, and reduces productivity. Apart from breakage, cutting tools wear in many different ways, including:

1. Edge wear and flank wear
2. Cratering or top wear
3. Chipping
4. Built-up edge
5. Deformation
6. Thermal cracking

Edge and flank wear are both normal, slow types of tool wear. If the work material is highly abrasive, as with certain cast-irons, this type of wear will accelerate. Cratering occurs behind the cutting edge, and happens often in machining long chipping steels. If the crater grows large enough and contacts the cutting edge, the tool fails immediately. Cratering can be overcome by using titanium or tantalum carbide tools.

Chipping on a tool edge is an unpredictable form of tool failure. It is sometimes started when a high point on an edge breaks away. A stronger carbide grade, different edge preparation, or lead angle change may eliminate chipping. Built-up edge is a deposit of work-piece material adhering to the rake face of an insert.

These deposits can break off, pulling out pieces of carbide from the tool. Ductile materials, such as softer steels, aluminium, and copper cause this problem. The use of higher rake angles, faster cutting speeds, and high pressure cutting fluid all help eliminate built-up edge. Deformation of a tool or insert is due to heat build-up. Although very detrimental to the machining process, deformation is difficult to detect without the use of a microscope. Using a heat-resistant tool or reducing the cutting speed often help to prevent deformation. Thermal cracking occurs when inserts go through rapid heating and cooling cycles. Causes include interrupted cutting and poor application of cutting fluids.

7. MACHINABILITY FACTORS

7.1 Effect of Cutting Parameters On Surface Roughness

Surface finish[23] is one of the most important quality characteristics in manufacturing industries which influences the performance of mechanical parts as well as production cost. In recent times, modern industries are trying to achieve the high quality products in a very short time with less operator input. For that purpose, the computer numerically controlled machine tools with automated and flexible manufacturing systems have been implemented. In order to improve the product quality and efficiency in machining, recently, there has been intensive computation focusing on surface roughness at international level. This computation can be observed in turning processes especially in aerospace and automotive industry by increasing the alternative solution for obtaining better surface roughness. A good quality turning surface can lead to improvement in strength properties such as fatigue strength, corrosion resistance and thermal resistance. In addition, the final surface roughness also affects several function attributes of parts like friction, wearing, light reflection, heat transmission, coating and ability of distributing and holding a lubricant. Right selection of tool geometry and cutting parameters that affect surface roughness are important factors especially in providing tolerance. The desired finish surface is usually specified and the appropriate processes are selected to reach the required quality.

Surface roughness is one of the prime factors in evaluating the quality of a component as it affects all the dimensions of quality mentioned above. Since it is a very important factor of quality it has received serious attention for many years. It has formulated an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes and aesthetic requirements. Surface roughness imposes one of the most critical constraints for selection of machines and cutting parameters in process planning.

Surface Roughness is generally the vertical elevations made on the surface of the metal, for example, grooves from the tool or from each grinding granule on a grinding wheel. Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application. In some cases the surface roughness is a necessary factor, but it has to conform to certain conditions and has to be within a certain limit.

According to Kromanis, A. and Krizbergs, the quality of surface plays a very important role in functionality of produced part. Therefore, it is necessary to develop methods, which can be used for the prediction of the surface roughness according to technological parameters.

Measuring surface roughness is a crucial concern for an immense range of industries and applications, from auto component wear to medical implant efficacy, from micro electro-mechanical systems inspection to semiconductor thin-film uniformity. The performance and value of thousands of products and systems – from designer sunglass to advanced personal digital devices – is governed by characterizing and controlling micro scale surface features, including micro-inch surface roughness. Many of the major advances in science and industry over the past half century would not have been possible without accurate surface roughness metrology.

The parameter most used for general surface roughness is Ra. It measures average roughness by comparing all the peaks and valleys to the mean line, and then averaging them all over the entire cut-off length.

7.1.1 Effect of feed rate and depth of cut on surface roughness

As expected the roughness increases with feed rate. On the roughness profiles, the feed marks also become clearer and prominent. At lower feed rates the roughness becomes independent of feed rate and is a function of nose radius only [10]. This causes higher micro roughness i.e. superimposed irregularities over the grooves generated by chip removal. The plastic flow component is comparatively more. Similarly when feed rate is large and nose radius small, the surface roughness depends mainly on feed rate compared to nose radius. The plastic flow is opposite to feed direction with higher height at low feed rate which can also lead to higher roughness at low feed rate[11]. Similar difference has been reported[12] whereby lower roughness occurred at higher feed rates owing to pure cutting action and relative absence of swelling.

In the same way at low feed rate material gets ploughed rather than form chips. In this way there exists a possibility of the existence of optimum feed rate. Though the theory suggests roughness to be a function of square of feed rate, in practice it is more like directly related to feed rate. This can be due to flattening of ridges due to side flow or tool work relative vibrations. These effects are corroborated by the Fourier transforms. The generation of several harmonics at lower feed rates due to ploughing action are clearly seen which conforms to the arguments presented for the micro roughness at low feed rates. The reduction in micro roughness and pronounced periodicity is seen with the diminishing corroborates the previous argument that at high feed rate the dominant mechanism is of chip removal rather than plastic flow.

7.1.2 Effect of Cutting Speed and Nose radius on surface roughness

The surface finish decreases with cutting speed of up to 100 m/min. With increasing the cutting speed further, the surface roughness of the machined work pieces seams to increase for both the grades. This is due to the increased friction between work piece and tool interface, which eventually increases the temperature in the cutting zone. Hence the shear strength of the material reduces and the material behaves in a ductile fashion. Moreover the duplex stainless steel is sticky in nature which makes the chips to detach from the work piece with utmost difficulty, thereby increasing the surface roughness.

The decrease in surface roughness with increasing cutting speed up to 100 m/min is due to the decreasing built up edge formation tendency with increasing cutting speed. However, further increase in cutting speed causes an increase in surface roughness. This can be attributed to the increasing cutting tool nose wear at higher cutting speeds of 120, 140 and 180 m/min. It can also be observed that the minimum Ra of machined surfaces is obtained when cutting speed is at 100 /min.

7.2 Effect of cutting parameters on material removal rate

The material removal rate[21], MRR, can be defined as the volume of material removed divided by the machining time. Another way to define MRR is to imagine an "instantaneous" material removal rate as the rate at which the cross-section area of material being removed moves through the work-piece. Since the depth of cut is changing the material removal rate changes continuously during the process. In some cases this may be important. For example, if cutting forces and the resulting work-piece and tool deflections are of interest. The changing amount of material being removed along the tapered shaft means the cutting force and so the deflections will change during the process.

Machining of Aluminium is very difficult. There are a number of parameters like cutting speed, feed and depth of cut etc. which must be given consideration during the machining of Aluminium alloy. This study investigates the effects of process parameters on Material Removal Rate (MRR) in turning of Aluminium alloy. The single response optimization problems i.e. optimization of MRR is solved by using Taguchi method. The optimization of MRR is done using twenty seven experimental runs based on L27 orthogonal array of the Taguchi method are performed to derive objective functions to be optimized within the experimental domain. The optimum levels of process parameters for simultaneous optimization of MRR were identified and verified through confirmation experiments.

The Investigation presents the use of Taguchi method for optimizing the material removal rate in turning Aluminium alloy extensively used as a main engineering material in various industries such as screw products, plumbing equipment, and hose fitting etc. These materials are considered as easy to machining and possess superior machinability [13]. Taguchi’s orthogonal arrays are highly fractional designs, used to estimate main effects using only few experimental runs. These designs are not only applicable to two level factorial experiments, but also can investigate main effects when factors have more than two levels. Designs are also available to investigate main effects for certain mixed level experiments where the factors included do not have the same number of levels. For example, a four-level full factorial design with five factors requires 1024 runs while the Taguchi orthogonal array reduces the required number of runs to 16 only.

Experiments were designed using Taguchi method so that effect of all the parameters could be studied with minimum possible number of experiments. Using Taguchi method, Appropriate Orthogonal Array [16, 17] has been chosen and experiments have been performed as per the set of experiments designed in the orthogonal array. Signal to Noise ratios are also calculated to analyze the effect of parameters more accurately.

The material removal rate is the volume of material removed per unit time. Volume of material removed per unit time. Volume of material removed is a function of speed, feed and depth of cut. Higher the values of these more will be the material removal rate. It can be calculated by using the following equations[94] 3, 4, and 5.

Let, Di = initial diameter of the workpiece, mm,

d = Depth of cut, mm and

f = Feed, mm/revolution.

Then, material removed per revolution is the volume of chip whose length is and whose cross-sectional area is $d \times f$. That is,

$$\text{Volume of material removed in one revolution} = \pi D_i \times d \times f \; mm^3$$

Since the job is making N r.p.m., the MRR in mm^3/min. is given by:

$$\text{MRR} = \pi D_i \times d \times f \times N \; mm^3/\text{min} \qquad (3)$$

In terms of cutting speed V in m/min $\left(V = \frac{\pi DN}{1000} \; m/min\right)$ is given by:

$$\text{MRR} = 1000 \times V \times d \times f \; mm^3/\text{min}. \qquad (4)$$

$$MRR = 1000 \times V \times d \times f \quad \frac{mm3}{min} \qquad (5)$$

7.3 Effect of cutting parameters on machining time

The time during which a piece of equipment like machine, lathe, unit, or apparatus without direct participation of an operator, produces a change in the dimensions, shape, or state of a work-piece. The machining time depends on the characteristics of the manufacturing process; on the qualitative features of the raw material, semi-finished product, or stock; on the type of equipment and tool; and on the mechanization and automation of labor.

Standards for machining time are calculated by determining the optimum operating schedule for the equipment, which ensures maximum output, minimum prime cost of the articles being processed, and the required quality level. For example, for metal cutting machine tools the standard machining time is determined according to well-grounded conditions of cutting (depth of cut, feed, cutting speed, and number of passes). Machining time may be reduced through the introduction of high speed processing methods and by using high-performance equipment and instruments. As the level of mechanization and automation of production rises, the proportion of machining time in the standards of piece rate time for completing a unit or for completing one manufacturing operation increases. The machining time can be calculated by using the equations[94] 6, and 7.

$$L = l + l_1 + l_2 \qquad (6)$$

$l = length\ of\ surface\ tube\ machined$

l_1 = Distance required for feeding the tool cross wise to increase the depth of cut in mm

$l_2 = Over\ travel\ of\ the\ tool\ at\ the\ end\ of\ each\ cut\ in\ mm$

$L = Distance\ travelled\ by\ the\ tool\ in\ the\ direction\ of\ the\ feed\ in\ single\ cut$

$f = feed\ mm/rev$, N=rpm

$l_1 = 5mm \quad l_2 = 5mm$

$\boldsymbol{l = 35\ mm}\ L = 45\ mm$

$$\textbf{Machining time} = \frac{L}{fN}\ \textbf{min} \qquad (7)$$

7.4 Effect of cutting parameters on Machining Force

To machine metal at a specified speed, feed, and depth of cut, with a specified lubricant, cutting tool material, and geometry, generates cutting forces and consumes power. A change in any of the variables alters the forces, but the change is indirect in that the engineer does not specify the forces, only the parameters that generate those forces. Forces are important in that they influence the deflections in the tools, the work pieces, and the work holders, which in turn affect the final part size. Forces also play a role in chatter and vibration phenomena common in machining. Obviously, the manufacturing engineer would like to be able to predict forces (and power) so that he can safely specify the equipment for a manufacturing operation, including the machine tool, cutting tool, and work holding devices. The relation to calculate force[94] is given in equation 8.

$$\boldsymbol{F = k \times d \times f}\ \text{N} \qquad (8)$$

$d = depth\ of\ cut\ (mm)$

$f = feed\ per\ rotation\ (mm)$

$k = specific\ cutting\ energy\ coefficient = \mathbf{500}N\ mm^{-2}$

Because SI composition in aluminium alloy is less than 13. Therefore the standard value of *k* is 500 N/mm^2

Specific cutting force, k

Specific cutting force k (N/mm^2)
The specific cutting force is primarily a function of:
#The material being machined
#Feed
#Cutting geometry
#Tool wear (an increase of 30 to 40%)

7.5 Effect of cutting parameters on machining Power

Although one may wish to describe the energy per unit volume needed to form the chip, machine tools are typically rated in terms of power. Unit (or specific) power values can be calculated by dividing the power input to the process, *FcV*, by the volumetric rate at which material is removed and then dividing this quantity by 33,000 to convert to horsepower. The specific power, Ps, is a measure of the difficulty involved in machining a particular material and can be used to estimate the total cutting power, P.

The specific power is the power required to remove a unit volume per unit time. Therefore, the specific and total powers[1] are related as follows:

$$P = Ps \times MRR \qquad (9)$$

where MRR is the material removal rate, or volume of material removed per unit time. The material removal rate can be computed as the uncut area multiplied by the rate at which the tool is moved perpendicular to the uncut area. Thus, the cutting parameters and machine tool kinematics define the material removal rate. There are many standard sources for specific power values for a variety of materials. Unfortunately, machine tools are not completely efficient. Losses due to component wear, friction, and other sources prevent some power from reaching the tool. Therefore, the gross power[1], Pg, needed by the motor can be defined as:

$$P_g = \frac{P}{\eta} \qquad (10)$$

Where η is the efficiency of the machine

Power in Turning is the total power required in a turning operation can be calculated as $P = Ps \times MRR$. However, the material removal rate must be redefined for turning. Consider the turning operation, in which a billet of diameter D is turned with depth of cut d to diameter D1. The billet is rotated at N revolutions per minute, while the tool is fed at f r units (millimeters or inches) per revolution, which can be set directly on the machine. Recommended cutting speeds (in meters or feet per minute) are generally available from handbooks and can be converted to rotational speed where $V = DN$. Suggested feeds are also available.

Cutting power is an important parameter, especially in the case of rough operations, as it makes it possible to:

Select and invest in a machine with a power output suited to the operation being carried out.

Obtain the cutting conditions that allow the machines power to be used in the most effective way possible, so as to ensure optimal material removal rate while taking into account the capacity of the tool being used.

The required cutting power[94] P KW can be estimated using the following formula:

$$\boldsymbol{P} = \frac{F \times v}{60000}\,\mathrm{W}. \qquad (11)$$

$v = cutting\ speed\ in\ m/min$

$F = cutting\ force\ (N)$

8. ALUMINIUM ALLOY

Aluminium alloys[9] are alloys in which aluminium is the predominant metal. Typical alloying elements are copper, zinc, manganese, silicon, and magnesium. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4-13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required.

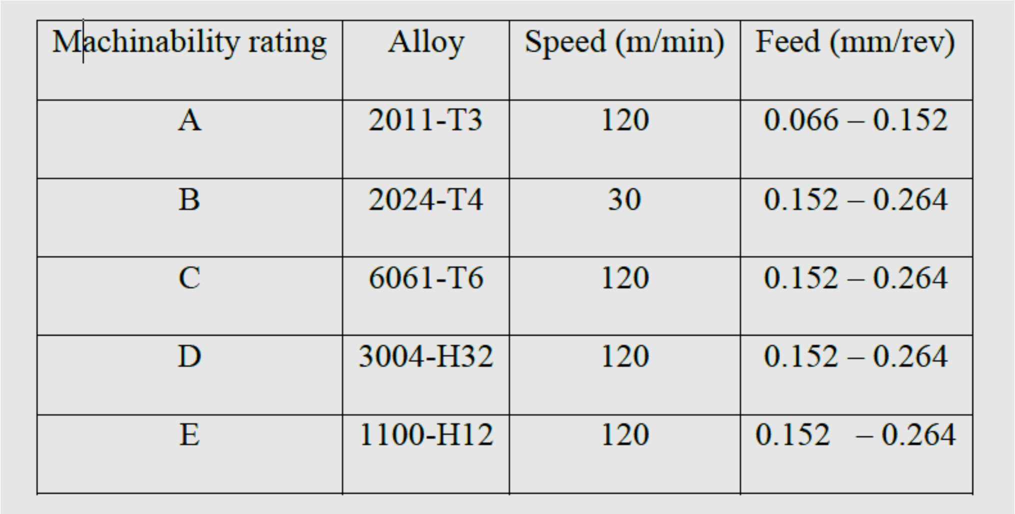
The micro-constituents[1] present in aluminium alloys have important effect of machining characteristics. Nonabrasive constituents have a beneficial effect, and insoluble abrasive constituents exert a detrimental effect on tool life and surface quality. Constituents that are insoluble but soft nonabrasive are beneficial because they assist in chip breakage; such constituents are purposely added in formulating high strength free-cutting alloys for processing in High speed automatic bar and chucking machines.

In general, the softer alloys and, to a lesser extent, some of the harder alloys are likely to form a built-up edge on the cutting lip of the tool. This edge consists of aluminium particles that have become welded to the tool edge because they were melted by the heat generated in cutting. Edge build-up can be minimized by using effective cutting fluids and by employing tools with surfaces that are free of grinding marks and scratches.

Alloys containing more than 10% Si are the most difficult to machine because hard particles of free silicon cause rapid tool wear. Alloys containing more than 5% Si will not finish to the bright machined surfaces of other high-strength aluminium alloys, but will have slightly gray surfaces with little luster. Chips are torn rather than sheared from the work, and special precautions must be taken to avoid the buildup of burrs on cutting edges.

Aluminium alloys are classified as cast, wrought, strain hardenable and heat treatable alloys. The alloys are grouped based on machinability and presented in table 2

Table 2 Aluminium alloys grouped based on the machinability rating



Machinability rating	Alloy	Speed (m/min)	Feed (mm/rev)
A	2011-T3	120	0.066 – 0.152
B	2024-T4	30	0.152 – 0.264
C	6061-T6	120	0.152 – 0.264
D	3004-H32	120	0.152 – 0.264
E	1100-H12	120	0.152 – 0.264

9. TAGUCHI TECHNIQUE

Dr. Taguchi[18, 19, 24] started to develop new methods to optimize the process of engineering experimentation. He believed that the best way to improve the quality of a design was to design and build it into the product. He developed techniques which are now known as the Taguchi Methods. His main contribution to the field is not mathematical, but rather the Philosophy. His concepts produced a unique and powerful quality improvement technique that differed from traditional practices. He developed systems that were 'robust', or insensitive to daily and seasonal variations of the environment, machine wear and other factors.

Dr. Taguchi's philosophy had far reaching consequences, yet it is founded on three very simple concepts. His techniques arise entirely out of these three ideas.

The concepts are:

1. Quality should be designed into the product and not inspected into it.
2. Quality is better achieved by minimizing the deviation from a target. The product should be so designed that it is immune to uncontrollable environmental factors.
3. The cost quality should be measured as a function of deviation from the standard and the losses should be measured system-wide.

Dr. Taguchi viewed quality improvement as an on-going effort. He continually strived to reduce the variation around the target value. The first step towards improving quality is to achieve the population distribution as close to the target value as possible.

To accomplish this, Taguchi designed experiments using especially constructed tables known as Orthogonal Arrays” (OA). The use of these tables makes the design of experiments very easy and consistent.

The Taguchi Method is applied in four steps:

1. Brainstorm the quality characteristics and design parameters important to the product/process.
2. Design and conduct the experiments.
3. Analyze the results to determine the optimum conditions.
4. Run a confirmatory test using the optimum conditions.

9.1 Design of experiment

Design of Experiment[19] is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance. All designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. Taguchi approach relies on the assignment of factors in specific orthogonal arrays to determine those test combinations. The DOE process is made up of three main phases: the planning phase, the conducting phase, and the analysis phase. A major step in the DOE process is the determination of the combination of factors and levels which will provide the desired information.

The most efficient method of experimental planning is Design of Experiments (DOE) using the Taguchi approach, which was adopted in this paper. (DOE) incorporates the orthogonal arrays, developed by Taguchi, to successfully design and conduct fractional factorial experiments that can collect all the statistically significant data with the minimum possible number of repetitions. Full factorial experiments are conducted or one factor at a time strategies are followed. The former cannot be implemented when there are too many factors under consideration because the number of repetitions required would be prohibitive, from a time and cost viewpoint. Each parameter has 5 levels which are so degree of freedom (DOF) for each parameter is 4. The total calculated (DOF) is $4 \times 4 \times 4 \times 4 \times 4 = 1024$.

After determining the number of (DOF), the next step is to choose suitable orthogonal array. In Taguchi (DOE), orthogonal array must be more than or equal to the (DOF) of design parameters. So the best orthogonal array by using Taguchi DOE is L8 & L31.

9.2. Taguchi Method for Optimization of Process Parameters

Optimization of process parameters is the key step in the Taguchi method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use [19].

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow the scope of a research project or to identify problems in a manufacturing process from data already in existence [20].

The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value. Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables. The Taguchi method has been criticized in the literature for its difficulty in accounting for interactions between parameters. Another limitation is that the Taguchi methods are offline, and therefore inappropriate for a dynamically changing process such as a simulation study. Furthermore, since the Taguchi methods deal with designing quality rather than correcting for poor quality, they are applied most effectively at early stages of process development [22]. A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way, while using a signal-to-noise ratio to analyze the experimental data could help the designers of the product or the manufacturer to easily find out the optimal parametric combinations.

A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the overall loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of the quality characteristic in the analysis of the S/N ratio, *i.e.* the lower- the- better, the larger-the-better, and the more-nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a larger S/N ratio corresponds to a better quality characteristic. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. The optimal combination of the process parameters can then be predicted.

Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the process parameter design.

9.3 Analysis of Variance

Analysis variance (ANOVA) was first introduced by Sir Ronald Fisher. It is a method of partitioning variability into identifiable sources of variation and the associated degrees of freedom in an experiment. Taguchi recommends that statistical experimental design method be employed to assist in quality improvement, particularly during parameter design and tolerance design, specifically to reduce the variability. He proposed some steps in analysis of variance, that is calculate the percent contribution and pool insignificant factors. Attribute data analysis such as the fraction defective, denoted p, can take values between 0 and 1. Frequently, p is expressed as a percentage where it can take values between 0% and 100%. With fraction defective, the best value for p is zero. Attribute accumulation is used when the experimental data can be ranked or categorized. Attribute accumulation analysis uses analysis of variance and the contribution ratio to establish significant factors.

The terminology of ANOVA is largely from the statistical design of experiments. The Experimenter adjusts factors and measures responses in an attempt to determine an effect. Factors are assigned to experimental units by a combination of randomization and blocking to ensure the validity of the result. Blinding keeps the weighing impartial. Responses show a variability that is partially the result of the effect and is partially a random error.

ANOVA is the synthesis of several ideas and it is used for multiple purposes. As a consequence, it is difficult to define concisely or precisely. Classical ANOVA for balanced data does three things at once:

1. As explanatory data analysis, an ANOVA is an organization of an additive data decomposition, and its sum of square indicates the variance of each component of the decomposition.
2. Comparison of mean square, along with F-tests that allow testing of nested sequence of models.
3. Closely related to the ANOVA is a linear model fit with co-efficient estimates and standard errors. In short, ANOVA is a statistical tool used in several ways to develop and confirm an explanation for the observed data.

Additionally:

4. It is computationally elegant and relatively robust against violations to its assumptions.
5. ANOVA provides industrial strength multiple sample comparison statistical analysis.
6. It has been adopted to analyses a variety of experimental designs.

10. STUDIES ON RESEARCH WORK OF EXPERTS

Feng Cang-Xue (Jack) [14] studied the impact of turning parameters on surface roughness. He studied the impact of Feed, Speed and Depth of Cut, Nose radius of tool and work material on the surface roughness of work material. He found that the feed have most significant impact on the observed surface roughness and also observed that there were strong interactions among different turning parameters.

Jafar Zare and Afsari Ahmad [15] the performance characteristics in turning operations of Df2 (1.2510) steel bars using TiN coated tools. Three cutting parameters namely, cutting speed, feed rate, and depth of cut, will be optimized with considerations of surface roughness. The study shows that the Taguchi method is suitable to solve the stated within minimum number of trials as compared with a full factorial design. The main objective of this study was to demonstrate a systematic procedure of using Taguchi design method in process control of turning process and to find a combination of turning parameters to achieve low material removal rate.

Prasad *et al.*[25] reported the development of an optimization model for determining the machining parameters for turning operations as a part of personal computer based generative CAPP system. The work piece material considered in their study include steel, cast iron, aluminium, copper and brass. High speed steel and uncoated carbide insert tool materials are considered in this study. The minimization of production time is taken as the basis for formulating the objective function. The constraint considered in this study include power, surface finish, tolerance, work piece rigidity, range of cutting speeds, maximum or minimum depth of cut and total depth of cut. Improved mathematical models are formulated by modifying the tolerance and work piece rigidity constraints for multi-pass turning operations. The formulated models are solved by the combination of geometric and linear programming techniques.

Feng *et al.*[26] investigated for the prediction of surface roughness in finish turning operation by developing an empirical model through considering working parameters such as workpiece hardness, feed, cutting tool point angle, depth of cut, spindle speed and cutting time. Data mining techniques, non-linear regression analysis with logarithmic data transformation were employed for developing the empirical model to predict the surface roughness.

Kirby *et al.*[27] developed the prediction model for surface roughness in turning operation. The regression model was developed by a single cutting parameter and vibrations along three axes were chosen for in-process surface roughness prediction system. By using multiple regression and analysis of variance a strong linear relationship among the parameters feed rate and vibration measured in three axes and the response surface roughness was found. The authors demonstrated that spindle speed and depth of cut might not necessarily have to be fixed for an effective surface roughness prediction model.

Pal *et al.*[28] studied on development of a back propagation neural network model for prediction of surface roughness in turning operation and used mild steel work-pieces with high speed steel as the cutting tool for performing a large number of experiments. The authors used speed, feed, depth of cut and the cutting forces as inputs to the neural network model for prediction of the surface roughness. The work resulted that predicted surface roughness was very close to the experimental value.

Singh *et al.*[29] studied on optimization of feed force through setting of optimal value of machining parameters namely speed, feed and depth of cut in turning of EN24 steel with TiC coated tungsten uncoated carbide inserts. The authors used Taguchi’s parameter design approach and concluded that the effect of depth of cut and feed in variation of feed force were affected more as compared to speed.

Ahmed[30] developed the methodology required for obtaining optimal machining parameters for prediction of surface roughness in Al turning. For development of empirical model nonlinear regression analysis with logarithmic data transformation was applied. The developed model showed small errors and satisfactory results. The study concluded that low feed rate was good to produce reduced surface roughness and also the high speed could produce high surface quality within the experimental domain.

M Y Noordin *et al.*[31] investigated the effect of feed rate, SCEA and cutting speed on the surface roughness and tangential force when turning AISI1045 steel. The ANOVA revealed that feed was the most significant factor influencing the response variable investigated. The SCEA and feed and SCEA interaction factor provided secondary contribution to the responses investigated. The cutting speed also provided secondary contribution to the tangential force. The reduced quadratic models developed using RSM were reasonably accurate.

Marinkovic Velibor *et al.*[32] studied the Taguchi method for optimization of surface roughness in dry single point turning of an alloy steel. They concluded that the surface roughness is continuously improved with increase in cutting speed, but in increase in feed rate and depth of cut causes significant deterioration of surface roughness. The results obtained using the Taguchi optimization method revealed that cutting speed should be kept at the highest level, while both feed rate and depth of cut should be kept at the lowest level.

Matthew A Kuttolamadom *et al.*[33] investigated the parameters affecting surface roughness of machine roughness with an emphasis on the dominance of feed along with practical recommendations to improve surface quality. It was inferred that there is an increase in feed up until a cut off surface roughness is reached and then increase the surface speed within the roughness range, to maximize productivity.

Kumanan *et al.*[34] proposed the methodology for prediction of machining forces using multi-layered perception trained by Genetic Algorithm. The data obtained from experimental results of a turning process were explored to train the proposed Artificial Neural Networks with three inputs to get machining forces as output. The optimal Artificial Neural Networks weights were obtained using Genetic Algorithm search. This function replacing hybrid made of Genetic Algorithm and Artificial Neural Networks was found computationally efficient as well as accurate to predict the machining forces for the input machining conditions.

Thamizhmanii *et al.*[35] applied Taguchi method for finding out the optimal value of surface roughness under optimum cutting condition in turning SCM 440 alloy steel. The experiment was designed by using Taguchi method and experiments were conducted and results thereof were analyzed with the help of Analysis of Variance method. The causes of poor surface finish as detected were machine tool vibrations, tool chattering whose effects were ignored for analysis. The authors concluded that the results obtained by this method would be useful to other researches for similar type of study on tool vibrations, cutting forces etc. The work concluded that depth of cut was the only significant factor which contributed to the surface roughness.

Shetty *et al.*[36] discussed the use of Taguchi and response surface methodologies for minimizing the surface roughness in turning of Discontinuously Reinforced Aluminium Composites having aluminium alloy 6061 as the matrix and containing 15% volume of silicon Uncoated Carbide Insert particles of mean diameter 25μm under pressured steam jet approach. The measured results were then collected and analyzed with the help of the commercial software package MINITAB15. The experiments were conducted using Taguchi's experimental design technique. The matrix test conditions included cutting speeds of 45, 73 and 101 m/min, feed rates of 0.11, 0.18 and 0.25 mm/rev and steam pressure 4,7,10 bar while the depth of cut was kept constant of 0.5 mm. The effect of cutting parameters on surface roughness was evaluated and the optimum cutting condition for minimizing the surface roughness was also determined finally. A second-order model was established between the cutting parameters and surface roughness using response surface methodology. The experimental results revealed that the most significant machining parameter for surface roughness was steam pressure followed by feed. The predicted values and measured values were fairly close, which indicated that the developed model could be effectively used to predict the surface roughness in the machining of Discontinuously Reinforced Aluminium composites.

Abburi *et al.*[37] developed a knowledge-based system for the prediction of surface roughness in turning process. Fuzzy set theory and neural networks were utilized for this purpose. The authors developed rule for predicting the surface roughness for given process variables as well as for the prediction of process variables for a given surface roughness.

Wang *et al.*[38] used Orthogonal Array of Taguchi method coupled with grey relational analysis considering four parameters viz. Speed, cutting depth, feed rate, tool nose run off etc. For optimizing three responses: surface roughness, tool wear and material removal rate in precision turning on an ECCOCA-3807 CNC LT16 XI lathe. The MINITAB software was explored to analyze the mean effect of Signal-to-noise (S/N) ratio to achieve the multi-objective features. This study not only proposed an optimization approaches using Orthogonal Array and grey relational analysis but also contributed a satisfactory technique for improving the multiple machining performances in precision CNC turning with profound insight.

E. Daniel Kirby *et al.*[39] conducted an effective Taguchi Parameter Design study requires of literature regarding turning parameters and similar studies. Of course, the most readily controlled factors in a turning operation are feed rate, cutting speed, and depth of cut: each of which may have an effect on surface finish. Several studies exist which explore the effect of federate, spindle speed, and depth of cut on surface finish. These studies all supported the idea that feed rate has a strong influence on surface finish. Spindle speed and depth of cut were found to have differing levels of effect in each study, often playing a stronger role as part of an interaction. This would seem to indicate that these controlled parameters would play an important role in optimizing surface roughness. Vibration as an uncontrolled noise factor can also affect surface finish.

Lin and chang[40] studied the effect of radial vibrations on surface finish, and found that the amplitude and frequency due to spindle speed both had strong effects on the surface topography. Spindle vibrations due to damaged or unbalanced jaws, for example, would therefore have an effect of surface finish depending on the degree of out-of-balance condition and the speed of the spindle.

Vernon A and Ozel T[41] conducted studies using the Taguchi Parameter Design method for the purpose of optimizing turning parameters. These studies made use of various work piece materials and controlled parameters to optimize surface roughness, dimensional accuracy, or tool wear. Each utilized different combinations and levels of cutting tool geometry, coolant, and other machining parameters. This would indicate that there are a number of different parameters that can be included in this type of study, and unique combination of parameters can be tailored to suit a given situation.

Davim J P[42] studied to efficiently determine the optimum turning operation parameters for achieving the lowest surface roughness in that range of parameters, while considering a noise factor. The study will include the following feature in order to meet this purpose:

The use of an array with the fewest experimental runs possible.
Relationships between the control parameters and the response parameter.
The use of damaged chuck jaws as a noise factor.
Effects of the noise parameters on the response parameter.
Optimum turning operation parameters for surface roughness, given this noise factor.

Dr.S.S Chaudari *et al.*[43] has conducted investigation of turning parameters using this technique is directly inclined towards economic solution for the user machining industry. MQL is a technique that could reduce many cutting problems coming from high consumptions of lubricant, like high machining costs or environmental and worker health problems. Taguchi’s robust orthogonal array design method is most suitable for analysis of the surface roughness and tool wear problem during turning operation. The cutting performance of MQL machining with flood cutting fluid supply. In the turning of mild steel, the experimental results shows that the cutting speed, feed rate and depth of cut are the main parameters that can control the tool wear.

W.H.Yang, Y.S. Tarng *et al.*[20] has discussed an application of the Taguchi method for optimizing the cutting parameters in turning operations. As shown in this study, the Taguchi method provides systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for the most optimization techniques. It has been shown that tool life and surface roughness can be improved significantly for turning operations. The confirmation experiments were conducted to verify the optimal cutting parameters. The improvement of tool life and surface roughness from the initial cutting parameters to the optimal cutting parameters is about 250%.

Majid Tolouei-Rad *et al.*[44] has proposed for optimum tool path planning in this paper improves the performance of the pocket milling operations via a combined mathematical graphical approach. The improvement is achieved by maintaining material removal rate and resultant cutting forces and chatter within limits, and eliminating shocks on the cutting tool. This increases tool life and reduces the risk of tool breakage. Results have been verified by practical experiments during which smoother surface finishes and noticeable reduction in machining vibration and noise have been observed. This is in addition to approximately 15% increase of the tool life and achieving more stable and safer machining operations. However, machining time has slightly increased due to reduction of average material removal rate and longer tool paths. It is intended to extend the research in order to cover a wider range of milling operations particularly when machining sculptured surfaces requiring a 5-axis CNC machine. Initial experiments show that the same principle can be applied to these operations.

Kamal Hassan, Anish Kumar, M.P Garg et al.[21] has done a detailed study was carried out to study the effect of input parameters on the material removal rate. The following conclusions have been drawn from the study:

1. The material removal rate is mainly affected by cutting speed and feed rate. With the increase in cutting speed the material removal rate increases & as the rate increases the material removal rate increases.
2. From ANOVA analysis, parameters making significant effect on material removal rate feed rate, and interaction between feed rate & cutting speed were found to be significant effect on material removal rate for reducing the variation.
3. The parameters considered in the experiments are optimized to attain maximum material removal rate. The best setting of input process parameters for detect free turning(Maximum material removal rate) within the selected range is as follows:

i. Cutting speed i.e., 55m/min.
ii. Feed rate i.e., 0.35mm/rev.
iii. Depth of cut should be 0.2mm.

Satyanarayana kosaraju *et al.*[45] discussed an application of the Taguchi method for optimizing the cutting parameters in turning operation. As shown in this study, the Taguchi method provides a systematic and efficient methodology for the design and optimization of cutting parameters with far less effort than would be required for most optimization techniques. It has been shown that cutting force and temperature were reduced significantly for turning operation by conducting experiments at the optimal parameter combination and also by analyzing S/N ratio.

Anderson P. Paiva *et al.*[46] have been conduct experiment on AISI 52100 with different parameter like cutting speed (V), feed rate (f) and depth of cut (d) .The outputs considered were: the mixed ceramic tool life (T), processing cost per piece (Kp), cutting time (Ct), the total turning cycle time (Tt), surface roughness (Ra) and the material removing rate (MRR). The aggregation of these targets into a single objective function is conducted using the score of the first principal component (PC1) of the responses' correlation matrix and the experimental region (Ω) is used as the main constraint of the problem. Considering that the first principal component cannot be enough to represent the original data set, a complementary constraint defined in terms of the second principal component score (PC2) is added. The original responses have the same weights and the multivariate optimization lead to the maximization of MRR while minimize the other outputs. The kind of optimization assumed by the multivariate objective function can be established examining the eigenvectors of the correlation matrix formed with the original outputs. The results indicate that the multi response optimization is achieved at a cutting speed of 238 m/min, with a feed rate of 0.08 mm/rev and at a depth of cut of 0.32 mm.

Tian-Syung Lan *et al.*[47] have been investigate the effect of cutting speed, feed, cutting depth, tool nose runoff with three levels (low, medium, high) on MRR in finish turning based on L9(34) orthogonal array. It have been found that the material removal rates from the fuzzy Taguchi deduction optimization parameters are all significantly advanced comparing to those from the benchmark. Also it has been declare that contributed the satisfactory fuzzy linguistic approach for the MRR in CNC turning with profound insight.

C. Velmurugan *et al.*[48] concluded that metal removal rate of the composite increases with increase in current, pulse on time and flushing pressure of the dielectric fluid while it decreases with increase in voltage. Tool wear rate of the developed composite increases with increase in current and voltage and it decreases with increase in pulse on time and flushing pressure of the dielectric fluid. Surface roughness of the composite during electric discharge machining increases with increase in current, pulse on time, voltage and flushing pressure. It was found that all the four machining parameters have significant effect on the response variables.

Analysis of variance (ANOVA) was introduced by Sir Ronald Fisher[49]. This analysis was carried out for a level of significance of 5%, i.e., for 95% level of confidence. The purpose of ANOVA is to investigate which turning parameter significantly affects the performance characteristics.

Ishwer Shivakoti *et al.*[50] presents a genetic algorithm optimization approach for finding the optimal parameter setting during turning operation in conventional Lathe machine. It was found that material removal rate in-creases with the increase of feed rate. However, at low spindle speed of rotation, the material removal rate is high compared to high spindle speed of rotation. The regression equation for material removal rate (MRR) has been developed using statistical Minitab software. The regression equation was validated through comparative results of MRR achieved during experimentation. Genetic Algorithm (GA) has been used to achieve the optimum machining parametric combination in order to obtain the value of optimal result of material removal rate. The results obtained in this paper can be effectively utilized for machining, particularly turning operation of mild steel material in shop floor manufacturing.

Tian-Syung Lan[51] studied the Taguchi optimization and TOPSIS, applying it to achieve the optimum process parameters in CNC turning under the considerations of multiple objectives. A validation experiment within the optimum parameters was conducted to indicate the effectiveness of the proposed optimization method. Parametric optimization is a hard-solving matter because of the interactions between parameters.

Keartisak Sriprateep et al.[52] discussed an application of the Taguchi method for investigating the effects of cutting parameters on surface roughness, tool wear and power required in turning metal matrix composite. From the analysis of the results in this work, the conceptual signal-to-noise(S/N) ratio approach, analysis of variance (ANOVA) provides a systematic and efficient methodology for the optimization of cutting parameters. It has been shown that surface roughness, tool wear and power required can be improved significantly for turning MMC.

Nikul D. Patel et al.[74] show that the surface roughness is affected by all the three cutting parameters viz. Cutting speed, feed rate and Depth of Cut. It was also found that cutting speed has the maximum impact on the surface roughness than the other parameters. This analysis can be utilized for selecting proper value of cutting parameters.