VISVESVARAYA TECHNOLOGICAL UNIVERSITY

JNANASANGAMA, BELAGAVI – 590 018

An Internship Report On

CNC MILLING MACHINING

Submitted in partial fulfillment of the award of degree

Master of Technology

In

MACHINE DESIGN

Submitted by

ARUN MOHAN

4AD14MMD02

Internship Carried Out at

GOVERNMENT TOOL ROOM AND TRAINING CENTER, MYSYRDEPARTMENT OF MECHANICAL ENGINEERING

Internal Guide

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JNANASANGAMA, BELAGAVI – 590 018

DEPARTMENT OF MECHANICAL ENGINEERING
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CERTIFICATE

This is to certify that the Internship Report entitled **CNC MILLING MACHINING** is carried out and submitted by **ARUN MOHAN** (4AD14MMD02**)** in partial fulfilment of the requirements of 3rd semester of M. Tech (Machine Design) during the academic year 2015-16. It is certified that all corrections and suggestions indicated by the guides have been incorporated in the report. The report has been approved as it satisfies the academic requirements in respect of Internship Report for Post-Graduate Studies.

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13th Kilometer, Bannur Road,
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Govt. Tool Room & Training Centre

(An Indo - Danish Project)

Plot No.93 & 94, Belagola Industrial Area,

K.R.S. Road, MYSORE - 570 016, INDIA.

(Govt. of Karnataka Society)

Ref: GTTC/STU4B/Indl.Trg/PG/2015-2016

Date: 30.11.2015

CERTIFICATE

This is to certify that **ARUN MOHAN** bearing **USN 4AD14MMD02** is a student of ATME college of Engineering Mysore, studying third semester M.Tech in Machine Design, has successfully completed the Internship at our organization from 03/08/2015 to 30/11/2015.

His performance and conduct during the Internship was satisfactory.

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DECLARATION

I, **ARUN MOHAN (USN: 4AD14MMD02)** student of 3rd Semester, M.Tech, (Machine Design), Department of Mechanical Engineering, ATME College of Engineering, Mysore, hereby declare that the Internship Report entitled **CNC MILLING MACHINE**, is an authentic record of the Internship Training undergone at GT&TC, Mysore during 03-08-2015 to 30-11-2015 under the guidance of **Mr. L G SANNAMANI** and **Dr. SURESHA S.** This report is submitted to **VTU, Belagavi,** in partial fulfillment of the requirements for the award of Degree **MASTER OF TECHNOLOGY** in Machine Design during the year 2015-16. Further, the content of this report either in part or in full has not been submitted previously by me and also by others for the award of any degree.

ARUN MOHAN

Date: 17-12-2015

Place: Mysore

EXECUTIVE SUMMARY

This report documents the work done during the internship program from 3-8-2015 to 30-11-2015 at Government Tool Room and Training Centre, Mysore. The report gives an overview of the tasks completed and technology learnt during the period of internship. The report also elaborates on the technical details of CAD/CAM and CNC Milling.

The Major tasks that were handled during the Internship at GT&TC are:

- Association in process planning of components by using CNC milling machines
- Association in process planning of high precision components
- Association in manufacturing of components using Vertical Machining Centre
- Association in machining of High precision tooling components using CNC Milling Machines.

CONTENTS

CHAPTER 1: GOVERNMENT TOOL ROOM AND TRAINING CENTRE

CHAPTER 2: CNC MILLING DEPARTMENT

CHAPTER 1: GOVERNMENT TOOL ROOM AND TRAINING CENTRE

1.1 Government Tool Room and Training Centre Profile

GTTC was established in 1972 at Bangalore with the participation of the Karnataka State Government, in collaboration with the Government of Denmark under the Bilateral Development Co-operation Agreement and GTTC expanded its branch at Mysore in 1992.

GTTC is an autonomous society, and a recognised Scientific and Research Organisation by the Government of India. Govt. Tool Room and Training Centre (GTTC), is serving industry by way of precision tooling and providing in well trained craftsmen the area of tool and die making. GTTC has advanced equipment like CAD / CAM, CNC machines for tooling, Laser for Industries, Rapid prototyping, vacuum casting etc.

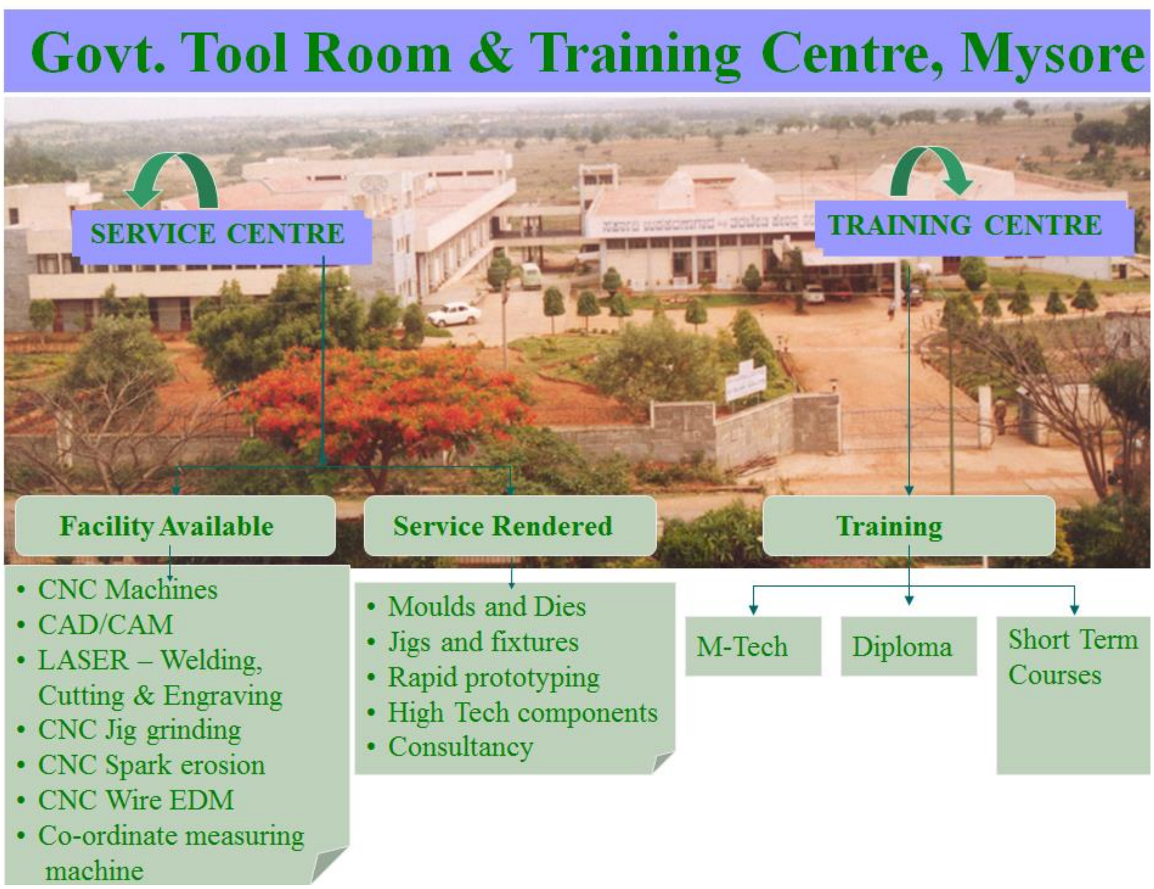


Fig1.1: Government Tool Room & Training Centre

GT&TC was established in I972 at Bangalore with the participation of the Karnataka State Government, in collaboration with the Government of Denmark under the Bilateral Development

Co-operation Agreement. The excellent performance of GT&TC Bangalore, proactive Government of Karnataka which saw the need for expansion, got second unit of GT&TC started in 1992 with DANIDA assistance. Proliferation of technology for development of the industries with supply of skilled manpower is the key to meet the needs of the global requirement. With this Government of Karnataka encouraged GT&TC to start 10 more sub-centres to train in the area of tool and die making in various parts of Karnataka.

Today, the GT&TC have acquired mastery in mould and die making technology and have blossomed into an epitome of precision and quality in the development and manufacture of sophisticated moulds, dies and tools. Fully aware of the rapid advancement in technology the world over, the GT&TC is periodically adding new technologies to the existing set of advanced equipment like CAD / CAM, CNC machines for tooling, Precision Components, Laser for Industries, Rapid prototyping, vacuum casting etc.

GT&TC is concentrating on the Integrated Development of the related segments of industries by way of providing international quality tools, trained personnel and consultancy in tooling and related areas. In future, the focus would be more on turnkey projects in Tooling, Aerospace components &their assemblies, and also to support the development of small and medium scale enterprises.

The main objective of the Industrial Training is to experience and understand real life situations in industrial organizations and their related environments and accelerating the learning process of how student's knowledge could be used in a realistic way. In addition to that, industrial training also makes one understand the formal and informal relationships in an industrial organization so as to promote favourable human relations and teamwork. Besides, it provides the exposure to practice and apply the acquired knowledge "hands – on" in the working environment. Industrial training also provides a systematic introduction to the ways of industry and developing talent and attitudes, so that one can understand how Human Resource Development works.

Moreover, students can gain hands-on experience that is related to the students majoring so that the student can relate to and widen the skills that have been learnt while being in university. Industrial training also exposes the students to the real career world and accustoms them to an organizational structure, business operation and administrative functions.

Furthermore, students implement what they have learned and learn more throughout this training. Besides, students can also gain experience to select the optimal solution in handling a situation. During industrial training students can learn the accepted safety practices in the industry. Students can also develop a sense of responsibility towards society.

1.2 Methods of Carrying out Training

There are many methods used to assist me in gathering sufficient information for my report. The main source of information was gathered through interviews with particular employees and managers. They were very approachable and assisted in providing information and knowledge. Next, is discussion method to gather information and discussion with the staffs on certain task they helped to explain briefly about their job description and also about the organization.

Apart from that, observation method to gather information for project. Observation how the task is carried out, how the staffs interact among themselves, how the working culture is practiced, how the relationship between the manager and the employees is and the how the working environment is. Finally, gather information through the websites provided too. A computer with internet access therefore browsing the net for information was indeed very easy. GT&TC is an autonomous society, and a recognised Scientific and Research Organisation by the Government of India. Govt. Tool Room and Training Centre (GT&TC), is serving industry by way of precision tooling and providing in well trained craftsmen the area of tool and die making.

1.3 Mission:

To continuously improve efficiency, innovate process and adopt technologies so as to meet all stake holders needs and be financially self-sufficient.

1.4 Vision

To emerge as an International Centre of Excellence in Research, Training and Applications on all aspects of Tooling Technology from concept to end Product.

1.5 Major Departments and their Activities

1. Purchase and Marketing Department

This section is responsible for collecting Tentative Budgetary Quotation Request from customer and Submitting Quotation back. It involves Receiving Supply order asking Supplies/Services from customer and Negotiation on delivery date and then Receiving Amendment for supply order delivery schedule date from customer and then Requesting for Product design approval by giving product drawing and then Getting Approval of Design from customer Submission of Manufactured samples and Requesting for Approval and finally Getting Acceptance and Approval Report about samples from customer.

2. Planning And Engineering Office

Planning and Engineering Office is the main coordinating department which receives requests for manufacturing components, test setups along with drawings and process details. The scrutiny of the same for scheduling, processing at various work centers till the accepted components are delivered to the indenter is the prime responsibility of this department. This department has been actively involved in the processing of aerospace and automobile field components. The Planning and Engineering Office maintains the details of works carried out such as cost summary, personnel involvement, machinery utilization etc.

3. Central Manufacturing Facilities

The Central Manufacturing Facilities has been completely equipped with a number of latest conventional and CNC machinery including Turn-Mill centre, Jig Grinding machine, Numerical controlled Electrical discharge machine, Wire-EDM machine and Laser machines for Engraving, Welding and Cutting operations. The latest addition is the 5 Axes CNC Vertical Machining Centre. All these machinery has been utilized to the maximum for the manufacture of aerospace, automobile and other related components.

4. Metrology Laboratory

The Metrology Laboratory has been well equipped with latest equipment such as Computerized Co-ordinate Measuring Machine, Height Masters, Surface Tester and all basic measuring instruments etc.

5. Die casting and Press tools facility

This consists of Die casting and Press tools machines to manufacture the components.

6. Maintenance Department

This section is responsible for the regular maintenance and upkeep of all the Machine tools and equipments. Records pertaining to the maintenance, spares used, and utilizations are maintained in a systematic way.

7. Long term Courses and Training Programs

GT&TC is conducting Diploma in Tool and die making and Diploma in instrumentation regular courses. As part of Human Resource Development Program, GT&TC has been engaged in the training of Trainees in various Technical professions every year.

8. CAD/CAM/CAE computer integrated manufacturing facility

CAD/CAM/CAE department consist of CAD/CAM/CAE software like Siemens NX8, CATIA V5-R20, Pro-E, Mastercam-X5, SolidWorks, AutoCAD, C-Mold, Mold Flow and Pro-Cast.

1.6 Plant Layout

LAYOUT OF GOVERNMENT TOOL ROOM & TRAINING CENTER, MYSURU

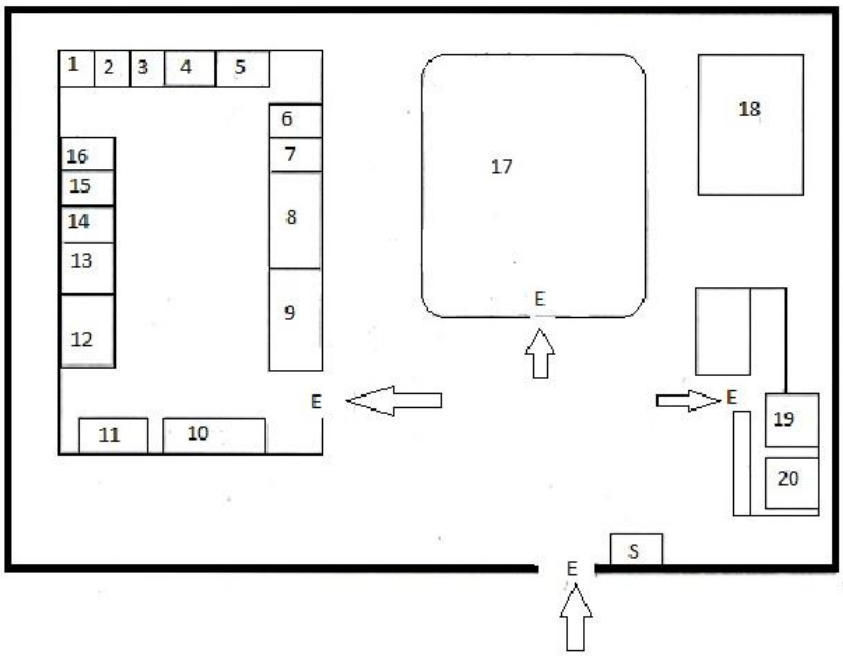


Fig 1.2: Plant Layout

1. HSM M/C
2. MAINTENANCE
3. ASSEMBLY
4. BENCH WORK
5. DNC
6. QUALITY ANALYSIS
7. CMM
8. CNC MILLING
9. CNC MILLING
10. MARKETING DEPARTMENT
11. PLANING DEPARTMENT
12. SURFACE GRINDING
13. CNC TURNING
14. JIG GRINDING
15. WIRE EDM
16. EDM
17. SHOP FLOOR
18. CANTEEN
19. CAD CENTRE
20. LASER M/C

1.7 Quality Policy:

- WE are committed to customer satisfaction in terms of quality, cost, delivery schedule and services through technological excellence.

We will strive for excellence through continuous improvement of techno log, process and competence of our employees.

1.8 Manufacturing Facilities in Production

GT&TC's excellence in execution of the time bound projects involving precision machining of components for Aero Space, Aeronautical and Precision Engineering Industry, has brought laurels. GT&TC has built up expertise in the latest concept of rapid prototyping in plastics and metals&We can also undertake projects in rapid tooling.

Our Commitment to development has enabled us to be associated with leading research and development organisations, space research organisations and Hi-tech engineering organisations. In recognition of our efforts in technology development, GT&TC is recognised as a Research

And Development Organisation by the department of Science & Technology.

1.9 Activities in GT&TC

1.9.1 Design & Manufacture of

Plastic and Die-cast Components

Jigs and Fixtures

Press Tools

Plastic Moulds

Die Casting Dies

1.9.2 Research & Development

Laser Technology Centre

Heart Valve Cage

Patient Lift

Tri-Cycle for Disabled

Patient Lift

1.9.3 Areas of Operation

Bangalore

Mysore

Hassan

Mangalore

Hubli

Haveri

Bijapur

Belgaum

1.10 Major Services of GT&TC in Brief

GT&TC is an autonomous society, and a recognised Scientific and Research organisation by the Government of India. Government Tool Room and Training Centre (GT&TC), is serving industry by way of precision tooling and providing in well trained craftsmen the area of tool and die making.

- Design, development and production of high precision Tools, Moulds and Dies using the latest, state-of-the-art equipment.
- Special technical consultancy assistance to small and medium scale industries
- Manufacture and assemblies for aerospace components for Aircrafts, Satellites, and related activities.
- Design, prototyping and development of new products.
- Short-term courses both regular and tailor made (full – time or part – time), for the upgrading of skills of personnel at various levels in the organisation.
- Manufacturing of high precision components on CNC machines and vacuum heat treatment of precision parts and toolings.

CHAPTER 2: CNC MILLING DEPARTMENT

2.1 CNC Milling

Chapter 2 mainly contains the process that is carried out in milling at Government tool Room and Training Centre. It also includes the process which are carried out to complete a specific task. There is a brief description of the machines currently available in the Company. Tools offered for different operations.

A milling machine is a power driven machine that cuts by means of a multitooth rotating cutter. The mill is constructed in such a manner that the fixed workpiece is fed into the rotating cutter. Varieties of cutters and holding devices allow a wide rage of cutting possibilities.

The mills in the Student Shop are vertical milling machines, commonly called Bridgeport style mills. These versatile mills are capable of performing many operations, including some that are similar to those performed on the drill press like drilling, reaming, countersinking, and counterboring. Other operations performed on the mill include but are not limited to: side and face milling, flycutting, and precision boring. Mills are classified on the basis of the position of their spindle. The spindle operates in either a vertical or horizontal position. The amount of horsepower the mill is able to supply to the cutter is also often important.

2.2 Mill Construction

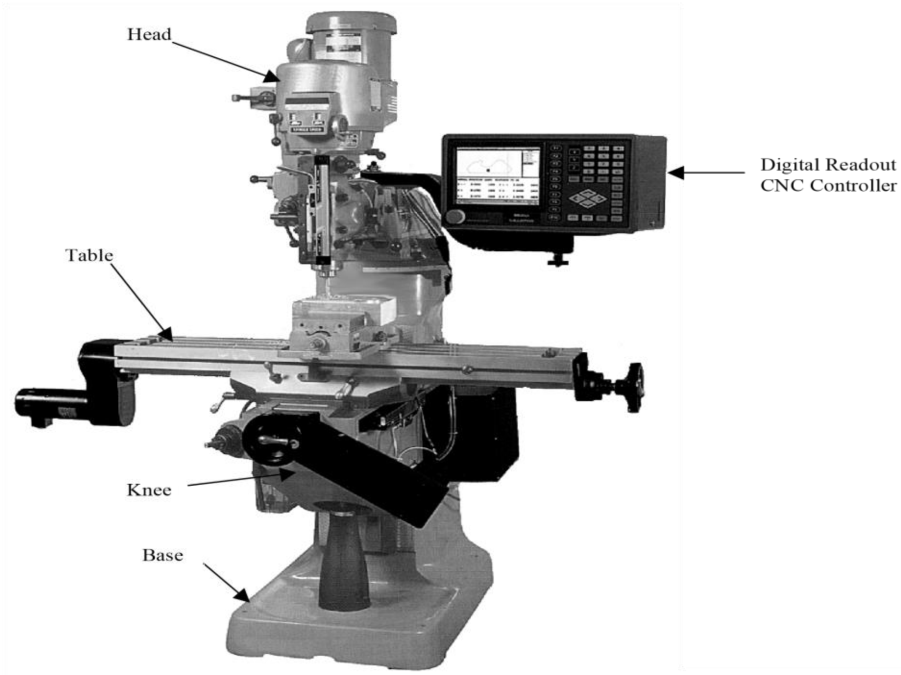
The vertical milling machine is made up of five major groups: base and column, knee, saddle, table, and head, (see figure). The base and column are one piece that forms the major structural component of the milling machine. They are cast integrally, ad provide the mill with its stability and rigidity. The front of the column has a machined face which provides the ways for the vertical movement of the knee. The knee supports the saddle and table. It contains the controls for raising and lowering the saddle. Sitting atop the knee is the saddle which supports the table. The saddle slides in dovetailed grooves into and away from the machine, providing the mill with its Y-axis movement. On top of the saddle sits the table. Being moved side-to-side, left-right, over the saddle furnishes the mill with its X-axis movement. The workpiece is secured to the table through the use of various types of holding devices.

The head is the most complex assembly in the major parts groups. This contains the following components:

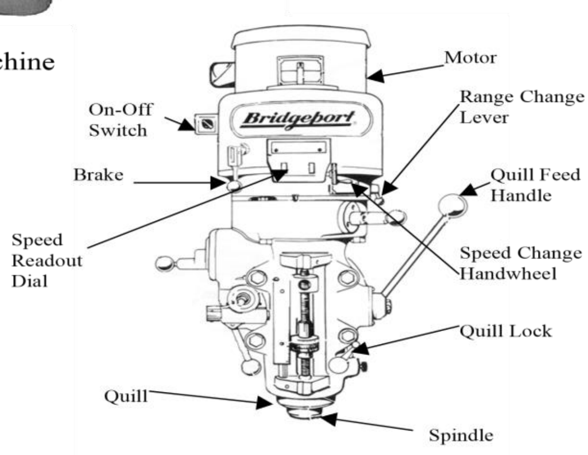
1. The drive motor and on/off switch.
2. Drive belt, gear train, and range lever selector.
3. Quill, spindle, and draw bar.
4. Quill feed, lock, and digital depth read out (Z-axis).

Fig 2.1 Vertical Milling Machine

Milling is the machining process of using rotary cutters to remove material from a workpiece advancing in a direction at an angle with the axis of the tool. It covers a wide variety of



Vertical Milling Machine



Vertical Milling Machine-Head

different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

Milling can be done with a wide range of machine tools. The original class of machine tools for milling was the milling machine. After the advent of computer numerical control (CNC), milling machines evolved into machining centers generally classified as vertical machining centers and horizontal machining centers (HMCs). The integration of milling into turning environments and of turning into milling environments, begun with live tooling for lathes and the occasional use of mills for turning operations, led to a new class of machine tools, multitasking machines (MTMs), which are purpose-built to provide for a default machining strategy of using any combination of milling and turning within the same work envelope.

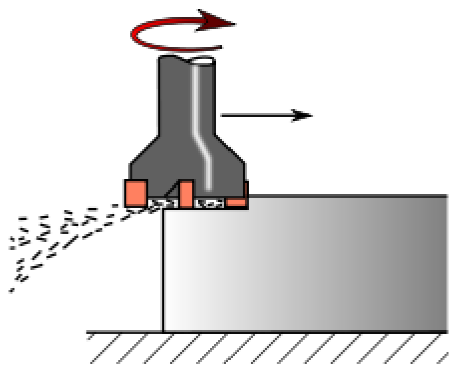


Fig. 2.2 Milling Operation

2.3 Process

Milling is a cutting process that uses a milling cutter to remove material from the surface of a workpiece. The milling cutter is a rotary cutting tool, often with multiple cutting points. As opposed to drilling, where the tool is advanced along its rotation axis, the cutter in milling is usually moved perpendicular to its axis so that cutting occurs on the circumference of the cutter. As the milling cutter enters the workpiece, the cutting edges of the tool repeatedly cut into and exit from the material, shaving of from the workpiece with each pass. The cutting action is shear deformation; material is pushed off the workpiece in tiny clumps that hang together to a greater or lesser extent to form chips. This makes metal cutting somewhat different (in its mechanics) from slicing softer materials with a blade.

The milling process removes material by performing many separate, small cuts. This is accomplished by using a cutter with many teeth, spinning the cutter at high speed, or advancing the material through the cutter slowly; most often it is some combination of these three approaches.[2] The speeds and feeds used are varied to suit a combination of variables. The speed at which the piece advances through the cutter is called feed rate, or just feed; it is most often measured in length of material per full revolution of the cutter.

There are two major classes of milling process:

- In face milling, the cutting action occurs primarily at the end corners of the milling cutter. Face milling is used to cut flat surfaces into the workpiece, or to cut flat-bottomed cavities.
- In peripheral milling, the cutting action occurs primarily along the circumference of the cutter, so that the cross section of the milled surface ends up receiving the shape of the cutter. In this case the blades of the cutter can be seen as scooping out material from the work piece. Peripheral milling is well suited to the cutting of deep slots, threads, and gear teeth.

2.4 Milling Cutters

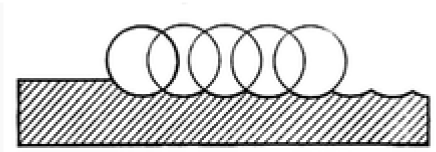
2.4.1 Milling Cutter

Many different types of cutting tools are used in the milling process. Milling cutters such as end mills may have cutting surfaces across their entire end surface, so that they can be drilled into the workpiece. Milling cutters may also have extended cutting surfaces on their sides to allow for peripheral milling. Tools optimized for face milling tend to have only small cutters at their end corners.

The cutting surfaces of a milling cutter are generally made of a hard and temperature-resistant material, so that they wears slowly. A low cost cutter may have surfaces made of high speed steel. More expensive but slower-wearing materials include cemented carbide. Thin film coatings may be applied to decrease friction or further increase hardness.

They are cutting tools typically used in milling machines or machining centres to perform milling operations . They remove material by their movement within the machine (e.g., a ball nose mill) or directly from the cutter's shape .

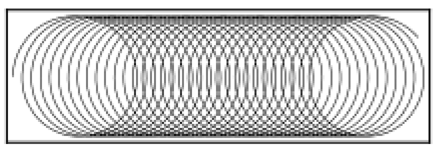
2.4.2 Surface Finish



A diagram of revolution ridges on a surface milled by the side of the cutter, showing the position of the cutter for each cutting pass and how it corresponds with the ridges

Fig. 2.3 Surface Finish

As material passes through the cutting area of a milling machine, the blades of the cutter take swarfs of material at regular intervals. Surfaces cut by the side of the cutter therefore always contain regular ridges. The distance between ridges and the height of the ridges depend on the feed rate, number of cutting surfaces, and the cutter diameter. With a narrow cutter and rapid feed rate, these revolution ridges can be significant variations in the surface finish.



Trochoidal marks, characteristic of face milling.

Fig.2.4 Trochoidal Marks of Face Milling

The face milling process can in principle produce very flat surfaces. However, in practice the result always shows visible trochoidal marks following the motion of points on the cutter's end face. These revolution marks give the characteristic finish of a face milled surface. Revolution marks can have significant roughness depending on factors such as flatness of the cutter's end face and the degree of perpendicularity between the cutter's rotation axis and feed direction. Often a final pass with a slow feed rate is used to compensate for a poor milling setup, in order to reduce the roughness of revolution marks. In a precise face milling operation, the revolution marks will only be microscopic scratches due to imperfections in the cutting edge.

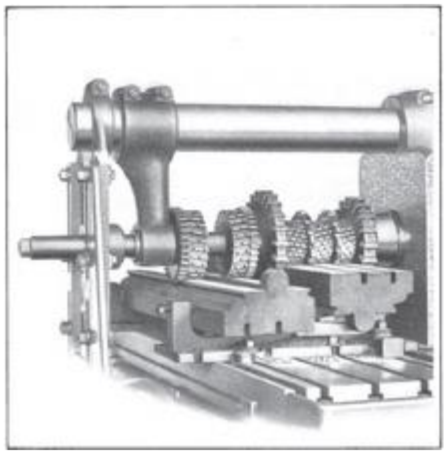


Fig. 2.5 Face Milling Operation

2.5 Gang milling

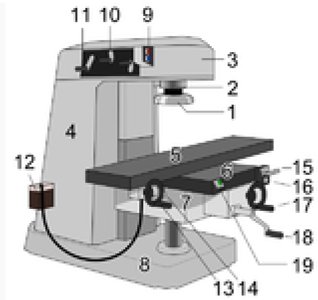
Heavy gang milling of milling machine tables

Gang milling refers to the use of two or more milling cutters mounted on the same arbor in a horizontal-milling setup. All of the cutters may perform the same type of operation, or each cutter may perform a different type of operation. For example, if several workpieces need a slot, a flat surface, and an angular groove, a good method to cut these would be gang milling. All the completed workpieces would be the same, and milling time per piece would be minimized.

Gang milling was especially important before the CNC era, because for duplicate part production, it was a substantial efficiency improvement over manual-milling one feature at an operation, then changing machines (or changing setup of the same machine) to cut the next op. Today, CNC mills with automatic tool change and 4- or 5-axis control obviate gang-milling practice to a large extent.

Mill orientation is the primary classification for milling machines. The two basic configurations are vertical and horizontal. However, there are alternate classifications according to method of control, size, and purpose and power source.

Vertical mill



Vertical milling machine. 1: milling cutter 2: spindle 3: top slide or overarm 4: column 5: table 6: Y-axis slide 7: knee 8: base

Fig. 2.6 Vertical Milling Machine

In the vertical mill the spindle axis is vertically oriented. Milling cutters are held in the spindle and rotate on its axis. The spindle can generally be extended (or the table can be raised/lowered, giving the same effect), allowing plunge cuts and drilling. There are two subcategories of vertical mills: the bed mill and the turret mill.

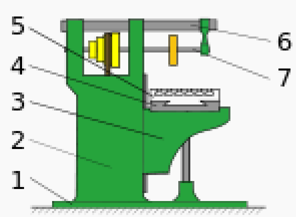
- A turret mill has a stationary spindle and the table is moved both perpendicular and parallel to the spindle axis to accomplish cutting. The most common example of this type is the Bridgeport, described below. Turret mills often have a quill which allows the milling cutter to be raised and lowered in a manner similar to a drill press. This type of machine provides two methods of cutting in the vertical (Z) direction: by raising or lowering the quill, and by moving the knee.

- In the bed mill, however, the table moves only perpendicular to the spindle's axis, while the spindle itself moves parallel to its own axis.

Turret mills are generally considered by some to be more versatile of the two designs. However, turret mills are only practical as long as the machine remains relatively small. As machine size increases, moving the knee up and down requires considerable effort and it also becomes difficult to reach the quill feed handle (if equipped). Therefore, larger milling machines are usually of the bed type.

A third type also exists, a lighter machine, called a mill-drill, which is a close relative of the vertical mill and quite popular with hobbyists. A mill-drill is similar in basic configuration to a small drill press, but equipped with an X-Y table. They also typically use more powerful motors than a comparably sized drill press, with potentiometer-controlled speed and generally have more heavy-duty spindle bearings than a drill press to deal with the lateral loading on the spindle that is created by a milling operation. A mill drill also typically raises and lowers the entire head, including motor, often on a dovetailed vertical, where a drill press motor remains stationary, while the arbor raises and lowers within a driving collar. Other differences that separate a mill-drill from a drill press may be a fine tuning adjustment for the Z-axis, a more precise depth stop, the capability to lock the X, Y or Z axis, and often a system of tilting the head or the entire vertical column and powerhead assembly to allow angled cutting. Aside from size and precision, the principal difference between these hobby-type machines and larger true vertical mills is that the X-Y table is at a fixed elevation; the Z-axis is controlled in basically the same fashion as drill press, where a larger vertical or knee mill has a vertically fixed milling head, and changes the X-Y table elevation. As well, a mill-drill often uses a standard drill press-type Jacob's chuck, rather than an internally tapered arbor that accepts collets. These are frequently of lower quality than other types of machines, but still fill the hobby role well because they tend to be benchtop machines with small footprints and modest price tags.

Horizontal mill



Horizontal milling machine. 1: base 2: column 3: knee 4 & 5: table (x-axis slide is integral) 6: overarm 7: arbor (attached to spindle)

Fig. 2.7 Horizontal Milling Machine

A horizontal mill has the same sort but the cutters are mounted on a horizontal arbor (seeArbor milling) across the table. Many horizontal mills also feature a built-in rotary table that allows milling at various angles; this feature is called a *universal table*. While endmills and the other types of tools available to a vertical mill may be used in a horizontal mill, their real advantage lies in arbor-mounted cutters, called side and face mills, which have a cross section rather like a circular saw, but are generally wider and smaller in diameter. Because the cutters have good support from the arbor and have a larger cross-sectional area than an end mill, quite heavy cuts can be taken enabling rapid material removal rates. These are used to mill grooves and slots. Plain mills are used to shape flat surfaces. Several cutters may be ganged together on the arbor to mill a complex shape of slots and planes. Special cutters can also cut grooves, bevels, radii, or indeed any section desired. These specialty cutters tend to be expensive. Simplex mills have one spindle, and duplex mills have two. It is also easier to cut gears on a horizontal mill. Some horizontal milling machines are equipped with a power-take-off provision on the table. This allows the table feed to be synchronized to a rotary fixture, enabling the milling of spiral features such as hypoid gears.

2.6 Comparative Merits

The choice between vertical and horizontal spindle orientation in milling machine design usually hinges on the shape and size of a workpiece and the number of sides of the workpiece that require machining. Work in which the spindle's axial movement is normal to one plane, with an endmill as the cutter, lends itself to a vertical mill, where the operator can stand before the machine and have easy access to the cutting action by looking down upon it. Thus vertical mills are most favored for diesinking work (machining a mould into a block of metal).[6] Heavier and longer workpieces lend themselves to placement on the table of a horizontal mill.

Prior to numerical control, horizontal milling machines evolved first, because they evolved by putting milling tables under lathe-like headstocks. Vertical mills appeared in subsequent decades, and accessories in the form of add-on heads to change horizontal mills to vertical mills (and later vice versa) have been commonly used. Even in the CNC era, a heavy workpiece needing machining on multiple sides lends itself to a horizontal machining center, while diesinking lends itself to a vertical one.

2.7 Alternate Classifications

In addition to horizontal versus vertical, other distinctions are also important:

Criterion	Example classification scheme	Comments
Spindle axis orientation	Vertical versus horizontal; Turret versus non-turret	Among vertical mills, "Bridgeport-style" is a whole class of mills inspired by the Bridgeportoriginal, rather like the IBM PC spawned the industry of IBM-compatible PCs by other brands
Control	Manual; Mechanically automated via cams; Digitally automated viaNC/CNC	In the CNC era, a very basic distinction is manual versus CNC. Among manual machines, a worthwhile distinction is non-DRO-equipped versus DRO-equipped
Control (specifically among CNCmachines)	Number of axes (e.g., 3-axis, 4-axis, or more)	Within this scheme, also: • Pallet-changing versus non-pallet-changing • Full-auto tool-changing versus semi-auto or manual tool-changing
Purpose	General-purpose versus special-purpose or single-purpose	

Criterion	Example classification scheme	Comments
Purpose	Toolroom machine versus production machine	Overlaps with above
Purpose	"Plain" versus "universal"	A distinction whose meaning evolved over decades as technology progressed, and overlaps with other purpose classifications above. Not relevant to today's CNC mills. Regarding manual mills, the common theme is that "plain" mills were production machines with fewer axes than "universal" mills; for example, whereas a plain mill had no indexing head and a non-rotating table, a universal mill would have those. Thus it was suited to universal service, that is, a wider range of possible toolpaths. Machine tool builders no longer use the "plain"-versus-"universal" labeling.
Size	Micro, mini, benchtop, standing on floor, large, very large, gigantic	
Power source	Line-shaft-driveversus individual electric motor drive	Most line-shaft-drive machines, ubiquitous circa 1880-1930, have been scrapped by now

Criterion	Example classification scheme	Comments
	Hand-crank-power versus electric	Hand-cranked not used in industry but suitable for hobbyist micromills

Table:-2.1

Variants

A Sieg X2 miniature hobbyist mill plainly showing the basic parts of a mill.

Fig:-2.8 Hobbiyst Mill Showing Basic Parts

- Bed mill this refers to any milling machine where the spindle is on a pendant that moves up and down to move the cutter into the work, while the table sits on a stout *bed* that rests on the floor. These are generally more rigid than a knee mill. Gantry mills can be included in this bed mill category.
- Box mill or column mill Very basic hobbyist bench-mounted milling machines that feature a head riding up and down on a column or box way.

- C-Frame mill these are larger, industrial production mills. They feature a knee and fixed spindle head that is only mobile vertically. They are typically much more powerful than a turret mill, featuring a separate hydraulic motor for integral hydraulic power feeds in all directions, and a twenty to fifty horsepower motor. Backlash eliminators are almost always standard equipment. They use large NMTB 40 or 50 tooling. The tables on C-frame mills are usually 18" by 68" or larger, to allow multiple parts to be machined at the same time.
- Floor mill these have a row of rotary tables, and a horizontal pendant spindle mounted on a set of tracks that runs parallel to the table row. These mills have predominantly been converted to CNC, but some can still be found under manual control. The spindle carriage moves to each individual table, performs the machining operations, and moves to the next table while the previous table is being set up for the next operation. Unlike other mills, floor mills have movable floor units. A crane drops massive rotary tables, X-Y tables, etc., into position for machining, allowing large and complex custom milling operations.
- Gantry mill the milling head rides over two rails which lie at each side of the work surface.
- Horizontal boring mill Large, accurate bed horizontal mills that incorporate many features from various machine tools. They are predominantly used to create large manufacturing jigs, or to modify large, high precision parts. They have a spindle stroke of several feet, and many are equipped with a tailstock to perform very long boring operations without losing accuracy as the bore increases in depth. A typical bed has X and Y travel, and is between three and four feet square with a rotary table or a larger rectangle without a table. The pendant usually provides between four and eight feet of vertical movement. Some mills have a large (30" or more) integral facing head. Right angle rotary tables and vertical milling attachments are available for further flexibility.
- Jig borer Vertical mills that are built to bore holes, and very light slot or face milling. They are typically bed mills with a long spindle throw. The beds are more accurate, and the hand wheels are graduated down to .0001" for precise hole placement.
- Knee mill or knee-and-column mill refers to any milling machine whose x-y table rides up and down the column on a vertically adjustable knee. This includes Bridgeport.
- Planer-style mill large mills built in the same configuration as planers except with a milling spindle instead of a planing head. This term is growing dated as planers themselves are largely a thing of the past.

- Ram-type mill this can refer to any mill that has a cutting head mounted on a sliding ram. The spindle can be oriented either vertically or horizontally. In practice most mills with rams also involve swiveling ability, whether or not it is called "turret" mounting. The Bridgeport configuration can be classified as a vertical-head ram-type mill. Norman specialized in ram-type mills through most of the 20th century. Since the wide dissemination of CNC machines, ram-type mills are still made in the Bridgeport configuration (with either manual or CNC control), but the less common variations (such as were built by Van Norman, Index, and others) have died out, their work being done now by either Bridgeport-form mills or machining centers.
- Turret mill more commonly referred to as Bridgeport-type milling machines. The spindle can be aligned in many different positions for a very versatile, if somewhat less rigid machine.

A milling machine is often called a mill by machinists. The archaic term miller was commonly used in the 19th and early 20th centuries.Since the 1960s there has developed an overlap of usage between the terms milling machine and machining center. NC/CNC machining centers evolved from milling machines, which is why the terminology evolved gradually with considerable overlap that still persists. The distinction, when one is made, is that a machining center is a mill with features that pre-CNCmills never had, especially an automatic tool changer (ATC) that includes a tool magazine , and sometimes an automatic pallet changer (APC). In typical usage, all machining centers are mills, but not all mills are machining centers; only mills with ATCs are machining centers.

Computer numerical control

Thin wall milling of aluminium using a water based cutting fluid on the milling cutter

Most CNC milling machines are computer controlled vertical mills with the ability to move the spindle vertically along the Z-axis. This extra degree of freedom permits their use in die sinking, engraving applications, and 2.5Dsurfaces such as relief sculptures. When combined with the use of conical tools or a ball nose cutter, it also significantly improves milling precision without impacting speed, providing a cost-efficient alternative to most flat-surface hand-engraving work.

Five-axis machining center with rotating table and computer interface

Fig. 2.8 Five Axis Machining Centre

CNC machines can exist in virtually any of the forms of manual machinery, like horizontal mills. The most advanced CNC milling-machines, the multi axis machine, add two more axes in addition to the three normal axes (XYZ). Horizontal milling machines also have a C or Q axis, allowing the horizontally mounted workpiece to be rotated, essentially allowing asymmetric and eccentric turning. The fifth axis (B axis) controls the tilt of the tool itself. When all of these axes are used in conjunction with each other, extremely complicated geometries, even organic geometries such as a human head can be made with relative ease with these machines. But the skill to program such geometries is beyond that of most operators. Therefore, 5-axis milling machines are practically always programmed with CAM.

The operating system of such machines is a closed loop system and functions on feedback. These machines have developed from the basic NC (NUMERIC CONTROL) machines. A computerized form of NC machines is known as CNC machines. A set of instructions (called a program) is used to guide the machine for desired operations. Some very commonly used codes, which are used in the program are:

G00 - Rapid Traverse
G01 - linear interpolation of tool.
G21 - Dimensions in metric units.
M03/M04 - spindle start (clockwise/counter clockwise).
T01 M06 - Automatic tool change to tool 1
M30 - program end.

Various other codes are also used. A CNC machine is operated by a single operator called a programmer. This machine is capable of performing various operations automatically and economically.

With the declining price of computers and open source CNC software, the entry price of CNC machines has plummeted.

High speed steel with cobalt end mills used for cutting operations in a milling machine.

Fig. 2.9 Cobalt End Mills

2.7 Tooling

The accessories and cutting tools used on machine tools (including milling machines) are referred to in aggregate by the mass noun "tooling". There is a high degree of standardization of the tooling used with CNC milling machines, and a lesser degree with manual milling machines. To ease up the organization of the tooling in CNC production many companies use a tool management solution.

Milling cutters for specific applications are held in various tooling configurations.

CNC milling machines nearly always use SK (or ISO), CAT, BT or HSK tooling. SK tooling is the most common in Europe, while CAT tooling, sometimes called V-Flange Tooling, is the oldest and probably most common type in the USA. CAT tooling was invented by Caterpillar Inc. of Peoria, Illinois, in order to standardize the tooling used on their machinery. CAT tooling comes in a range of sizes designated as CAT-30, CAT-40, CAT-50, etc. The number refers to the Association for Manufacturing Technology (formerly the National Machine Tool Builders Association (NMTB)) Taper size of the tool.00000000.3

An improvement on CAT Tooling is BT Tooling, which looks similar and can easily be confused with CAT tooling. Like CAT Tooling, BT Tooling comes in a range of sizes and uses the same NMTB body taper. However, BT tooling is symmetrical about the spindle axis, which CAT tooling is not. This gives BT tooling greater stability and balance at high speeds. One other subtle difference between these two tool holders is the thread used to hold the pull stud. CAT Tooling is all Imperial thread and BT Tooling is all Metric thread. Note that this affects the pull stud only, it does not affect the tool that they can hold, both types of tooling are sold to accept both Imperial and metric sized tools.

SK and HSK tooling, sometimes called "Hollow Shank Tooling", is much more common in Europe where it was invented than it is in the United States. It is claimed that HSK tooling is even better than BT Tooling at high speeds. The holding mechanism for HSK tooling is placed within the body of the tool and, as spindle speed increases, it expands, gripping the tool more tightly with increasing spindle speed. There is no pull stud with this type of tooling.

For manual milling machines, there is less standardization, because a greater plurality of formerly competing standards exist. Newer and larger manual machines usually use NMTB tooling. This tooling is somewhat similar to CAT tooling but requires a drawbar within the milling machine. Furthermore, there are a number of variations with NMTB tooling that make interchangeability troublesome. The older a machine, the greater the plurality of standards that may apply. However, two standards that have seen especially wide usage are the Morse #2 and the R8, whose prevalence was driven by the popularity of the mills built by Bridgeport Machines of Bridgeport, Connecticut. These mills so dominated the market for such a long time that "Bridgeport" is virtually synonymous with "manual milling machine". Most of the machines that Bridgeport made between 1938 and 1965 used a Morse taper #2, and from about 1965 onward most used an R8 taper.

2.8 Preliminary Operations

Cleaning- The first, (and last), procedure in any machining operation. Without clean equipment and tools, the accuracy of the finished product diminishes quickly. The accuracy, durability, and longevity of the equipment and tools depend on being kept clean. In today’s high tolerances in engineering, cleanliness is critical.

Set-up- For most jobs performed on a milling machine, setting up the workpiece is the most difficult, critical, and time consuming part of the job. The workpiece must not only be securely clamped, but held in such a way so that very surface to be machined will accurately align with other surfaces when finished. Several types of holding devices are used in mounting the workpiece o the milling machine. The most common used in the Student Shop are the vice, table clamps, index chuck, and rotary table. The vice is probably the most widely used fixture. There are two configurations for the vise. The plain vise, which rests with the jaws parallel to the X-axis. The second style is with the swivel-base mounted under the vise allowing it to be rotated and set at a variety of angles. Large workpieces can be held directly on the table surface through a combination of T-nuts, bolts, and clamps. An index chuck permits the rapid positioning of the work, usually indexing in 15° increments. The rotary table gives the mill its 4th axis with its circular movement. Circles, partial curves, angularly spaced holes, curved slots, and Oring grooves. This fixture is graduated in degrees and minutes of a degree.

Tooling- End mills are the most common cutter used on the vertical milling machine. They are extremely versatile in that they can be used for surface cuts, slotting, and side (or profiling) cuts. End mills come in many types, each being suited for a particular application. End mills are fluted, much like drills, and the number of flutes determines what the end mill can do. Two fluted end mills are used for machining aluminum, and are favored for plunge cuts. Four fluted end mills are used in machining the harder metals like steel. Generally, it is not a good idea to use a four fluted end mill when machining aluminum or brass however, since the flutes can fill with material, and no longer cut. The other main characteristic of the end mill is the cutting end of the tool its self. Some end mills are bottom cutting, meaning they can be plunged into material much like a drill, while some are not, and are only useful for cutting on the side. Be careful not to plunge an end mill that is not bottom cutting. Other types of end mills includes the ball end mill, which has a radiused end used to produce a fillet, and corner radiusing end mills, used to round the edges of a workpiece.

Other types of cutters include slitting saws for cutting grooves, shell milling cutters for faster milling of surfaces than is possible with an end mill, flycutters (which are single point cutters for facing large workpieces), formed cutters for cutting special shapes like gears; and groove cutters like T-slot and dovetail cutters.

Milling cutters are expensive and easily ruined if not taken care of when using or storing. Failure to obtain satisfactory results on a job can many times be attributed to inappropriate selection of the proper milling cutter.

Machine Controls- The speed or RPM of the spindle is set through a variable speed changing mechanism. This is a *dynamic* adjustment. Speed changes are done only with the motor running. This is different than the range changes, which are done only with the motor turned off, *static*. The feed is the rate that the workpiece is fed into the cutter. The shop mills are equipped with a variable power feed. This means that while it is easy to feed at a very slow feed, it is also easy to accidentally feed too fast when using a small cutter, possibly breaking the cutter while in operation. May factors and conditions influence the speed and feed at which the material is worked. The operator must take into account rigidity of the workpiece and cutter, the depth of cut, and the desired finish. It is generally a good idea to start with a slow feed rate, and increase it until an efficient removal rate is achieved. Feed rates are decreased for finer finishes or greater depths of cut, and maximized for roughing cuts.

Once the preliminary operations and selections have been accomplished, a quick check should be made to be sure that work and fixtures will clear any parts of the machine, and that the cutter will not strike the table or fixtures. All table movements that will not be used on a cut should be locked, and those that will be used should be unlocked. The head controls should be checked for proper range and speed. When starting the motor, make certain the cutter is rotating in the proper direction. Do not stop the cutter in mid cut and make no adjustments with the cutter in contact with the workpiece.

There are two types of milling to be discussed. Conventional milling is where the workpiece is fed opposite the direction of the rotation of the cutter, and climb milling is when the workpiece is fed in the direction of rotation of the cutter. Each has its own advantages and disadvantages. Climb milling draws the part into the cutter, and can violently take up any backlash in the table. However, it does produce a smoother finish. Conventional milling is the more preferred method, and will be used for every cut except the finishing cut.

2.9 Parameters

1. Load/Unload time - The time required to load the workpiece into the milling machine and secure it to the fixture, as well as the time to unload the finished part. The load time can depend on the size, weight, and complexity of the workpiece, as well as the type of fixture.

2. Cut time - The time required for the cutter to make all the necessary cuts in the workpiece for each operation. The cut time for any given operation is calculated by dividing the total cut length for that operation by the feed rate, which is the speed of the cutter relative to the workpiece.

3. Idle time - Also referred to as non-productive time, this is the time required for any tasks that occur during the process cycle that do not engage the workpiece and therefore remove material. This idle time includes the tool approaching and retracting from the workpiece, tool movements between features, adjusting machine settings, and changing tools.

4. Tool replacement time - The time required to replace a tool that has exceeded its lifetime and therefore become to worn to cut effectively. This time is typically not performed in every cycle, but rather only after the lifetime of the tool has been reached. In determining the cycle time, the tool replacement time is adjusted for the production of a single part by multiplying by the frequency of a tool replacement, which is the cut time divided by the tool lifetime.

Following the milling process cycle, there is no post processing that is required. However, secondary processes may be used to improve the surface finish of the part if it is required. The scrap material, in the form of small material chips cut from the workpiece, is propelled away from the workpiece by the motion of the cutter and the spraying of lubricant. Therefore, no process cycle step is required to remove the scrap material, which can be collected and discarded after the production.

2.9.1 Cutting Parameters

In milling, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the workpiece material, tool material, tool size, and more.

- Cutting feed - The distance that the cutting tool or workpiece advances during one revolution of the spindle and tool, measured in inches per revolution (IPR). In some operations the tool feeds into the workpiece and in others the workpiece feeds into the tool. For a multi-point tool, the cutting feed is also equal to the feed per tooth, measured in inches per tooth (IPT), and multiplied by the number of teeth on the cutting tool.

- Cutting speed - The speed of the workpiece surface relative to the edge of the cutting tool during a cut, measured in surface feet per minute (SFM).
- Spindle speed - The rotational speed of the spindle and tool in revolutions per minute (RPM). The spindle speed is equal to the cutting speed divided by the circumference of the tool.
- Feed rate - The speed of the cutting tool's movement relative to the workpiece as the tool makes a cut. The feed rate is measured in inches per minute (IPM) and is the product of the cutting feed (IPR) and the spindle speed (RPM).
- Axial depth of cut - The depth of the tool along its axis in the workpiece as it makes a cut. A large axial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is typically machined in several passes as the tool moves to the specified axial depth of cut for each pass.

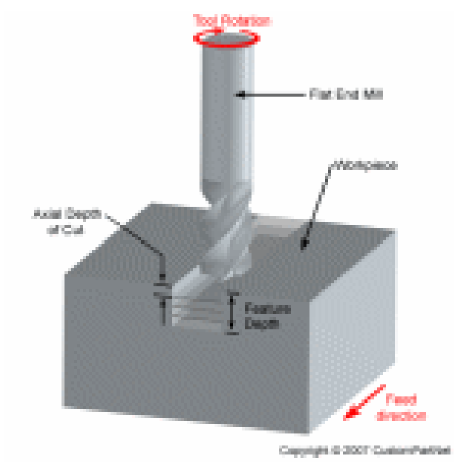
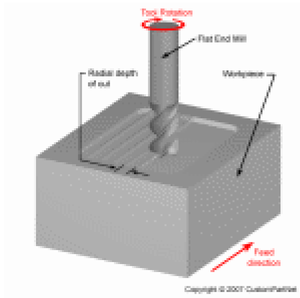
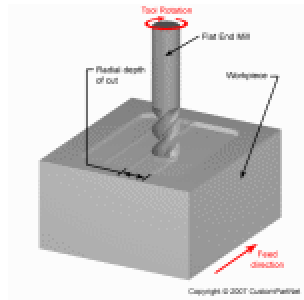


Fig:-2.10

- Radial depth of cut - The depth of the tool along its radius in the workpiece as it makes a cut. If the radial depth of cut is less than the tool radius, the tool is only partially engaged and is making a peripheral cut. If the radial depth of cut is equal to the tool diameter, the cutting tool is fully engaged and is making a slot cut. A large radial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life. Therefore, a feature is often machined in several steps as the tool moves over the step-over distance, and makes another cut at the radial depth of cut.





Peripheral Cut Fig:-2.11 **Slot cut Fig. 2.12**

Operations

During the process cycle, a variety of operations may be performed to the workpiece to yield the desired part shape. The following operations are each defined by the type of cutter used and the path of that cutter to remove material from the workpiece.

- End milling - An end mill makes either peripheral or slot cuts, determined by the step-over distance, across the workpiece in order to machine a specified feature, such as a profile, slot, pocket, or even a complex surface contour. The depth of the feature may be machined in a single pass or may be reached by machining at a smaller axial depth of cut and making multiple passes.

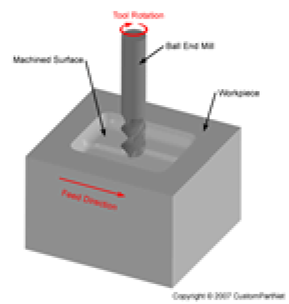


Fig.2.13 End Milling

- Chamfer milling - A chamfer end mill makes a peripheral cut along an edge of the workpiece or a feature to create an angled surface, known as a chamfer. This chamfer, typically with a 45 degree angle, can be machined on either the exterior or interior of a part and can follow either a straight or curved path.

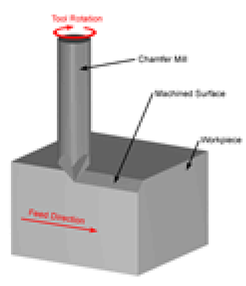


Fig.2.13 Chamfer Milling

- Face milling - A face mill machines a flat surface of the workpiece in order to provide a smooth finish. The depth of the face, typically very small, may be machined in a single pass or may be reached by machining at a smaller axial depth of cut and making multiple passes.

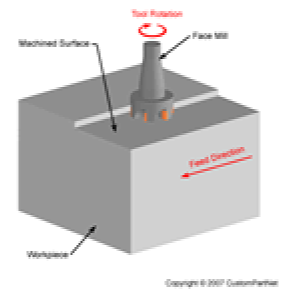


Fig. 2.14 Face Milling

- Drilling - A drill enters the workpiece axially and cuts a hole with a diameter equal to that of the tool. A drilling operation can produce a blind hole, which extends to some depth inside the workpiece, or a through hole, which extends completely through the workpiece.

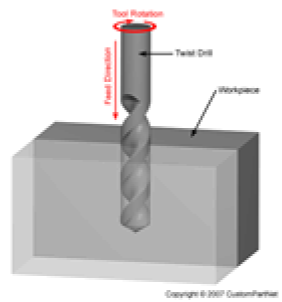


Fig. 2.14 Drilling

- Boring - A boring tool enters the workpiece axially and cuts along an internal surface to form different features. The boring tool is a single-point cutting tool, which can be set to cut the desired diameter by using an adjustable boring head. Boring is commonly performed after drilling a hole in order to enlarge the diameter or obtain more precise dimensions.

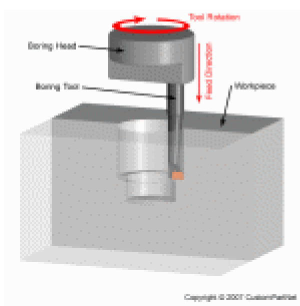


Fig.2.15 Boring

- Counterboring - An counterbore tool enters the workpiece axially and enlarges the top portion of an existing hole to the diameter of the tool. Counterboring is often performed after drilling to provide space for the head of a fastener, such as a bolt, to sit below the surface of a part. The

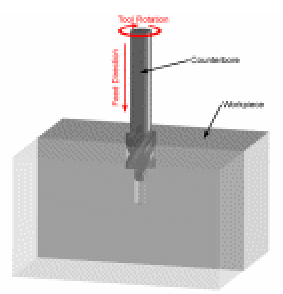


Fig:-2.16
Counterboring

counterboring tool has a pilot on the end to guide it straight into the existing hole.

- Countersinking - A countersink tool enters the workpiece axially and enlarges the top portion of an existing hole to a cone-shaped opening. Countersinking is often performed after drilling to provide space for the head of a fastener, such as a screw, to sit flush with the workpiece surface. Common included angles for a countersink include 60, 82, 90, 100, 118, and 120 degrees.

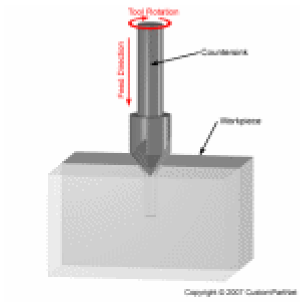


Fig.2.17 Counter Sinking

- Reaming - A reamer enters the workpiece axially and enlarges an existing hole to the diameter of the tool. Reaming removes a minimal amount of material and is often performed after drilling to obtain both a more accurate diameter and a smoother internal finish.

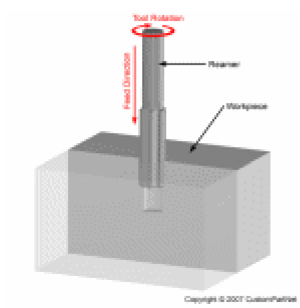


Fig. 2.18 Reaming

- Tapping - A tap enters the workpiece axially and cuts internal threads into an existing hole. The existing hole is typically drilled by the required tap drill size that will accommodate the desired tap. Threads may be cut to a specified depth inside the hole (bottom tap) or the complete depth of a through hole (through tap).

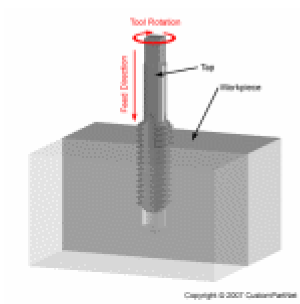


Fig.2.19 Tapping

2.10 Equipment

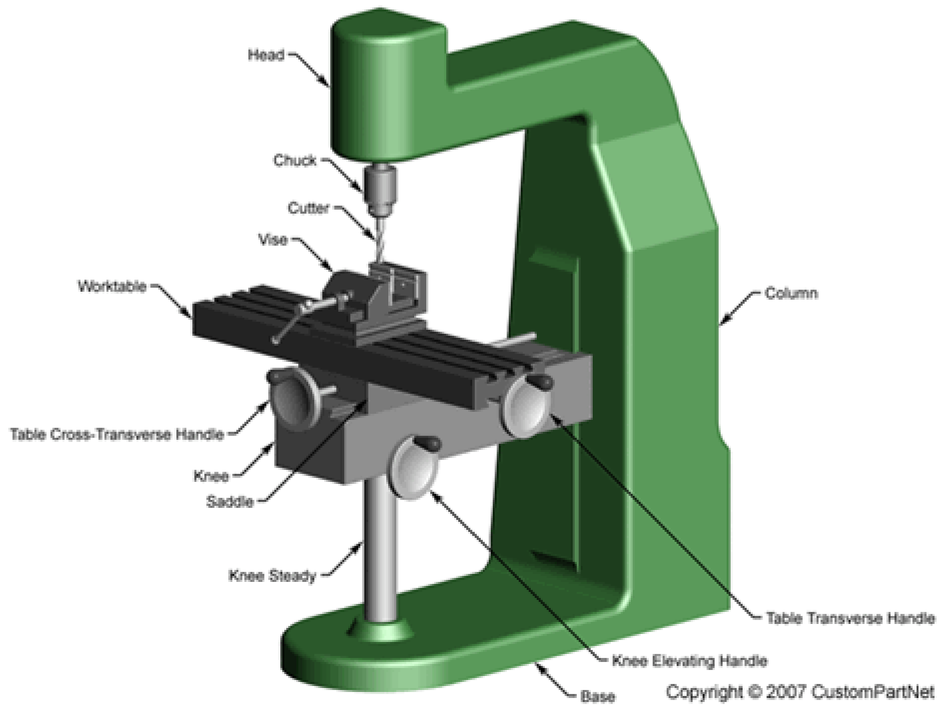
Milling machines can be found in a variety of sizes and designs, yet they still possess the same main components that enable the workpiece to be moved in three directions relative to the tool. These components include the following:

- Base and column - The base of a milling machine is simply the platform that sits on the ground and supports the machine. A large column is attached to the base and connects to the other components.

- Table - The workpiece that will be milled is mounted onto a platform called the table, which typically has "T" shaped slots along its surface. The workpiece may be secured in a fixture called a vise, which is secured into the T-slots, or the workpiece can be clamped directly into these slots. The table provides the horizontal motion of the workpiece in the X-direction by sliding along a platform beneath it, called the saddle.

- Saddle - The saddle is the platform that supports the table and allows its longitudinal motion. The saddle is also able to move and provides the horizontal motion of the workpiece in the Y-direction by sliding transversely along another platform called the knee.

- Knee - The knee is the platform that supports the saddle and the table. In most milling machines, sometimes called column and knee milling machines, the knee provides the vertical motion (Z direction) of the workpiece. The knee can move vertically along the column, thus moving the workpiece vertically while the cutter remains stationary above it. However, in a fixed bed machine, the knee is fixed while the cutter moves vertically in order to cut the workpiece.



Manual vertical milling machine

Fig. 2.19

The above components of the milling machine can be oriented either vertically or horizontally, creating two very distinct forms of milling machine. A horizontal milling machine uses a cutter that is mounted on a horizontal shaft, called an arbor, above the workpiece. For this reason, horizontal milling is sometimes referred to as arbor milling. The arbor is supported on one side by an overarm, which is connected to the column, and on the other side by the spindle. The spindle is driven by a motor and therefore rotates the arbor. During milling, the cutter rotates along a horizontal axis and the side of the cutter removes material from the workpiece. A vertical milling machine, on the other hand, orients the cutter vertically. The cutter is secured inside a piece called a collet, which is then attached to the vertically oriented spindle. The spindle is located inside the milling head, which is attached to the column. The milling operations performed on a vertical milling machine remove material by using both the bottom and sides of the cutter.

Milling machines can also be classified by the type of control that is used. A manual milling machine requires the operator to control the motion of the cutter during the milling operation. The operator adjusts the position of the cutter by using hand cranks that move the table, saddle, and knee. Milling machines are also able to be computer controlled, in which case they are referred to as a computer numerical control (CNC) milling machine. CNC milling machines move the workpiece and cutter based on commands that are preprogramed and offer very high precision. The programs that are written are often called G-codes or NC-codes. Many CNC milling machines also contain another axis of motion besides the standard X-Y-Z motion. The angle of the spindle and cutter can be changed, allowing for even more complex shapes to be milled.

Tooling

The tooling that is required for milling is a sharp cutter that will be rotated by the spindle. The cutter is a cylindrical tool with sharp teeth spaced around the exterior. The spaces between the teeth are called flutes and allow the material chips to move away from the workpiece. The teeth may be straight along the side of the cutter, but are more commonly arranged in a helix. The helix angle reduces the load on the teeth by distributing the forces. Also, the number of teeth on a cutter varies. A larger number of teeth will provide a better surface finish. The cutters that can be used for milling operations are highly diverse, thus allowing for the formation of a variety of features. While these cutters differ greatly in diameter, length, and by the shape of the cut they will form, they also differ based upon their orientation, whether they will be used horizontally or vertically.

A cutter that will be used in a horizontal milling machine will have the teeth extend along the entire length of the tool. The interior of the tool will be hollow so that it can be mounted onto the arbor. With this basic form, there are still many different types of cutters that can be used in horizontal milling, including those listed below.

- Plane (helical) mill
- Form relieved mill
- Staggered tooth mill
- Double angle mill

Another operation known as a straddle milling is also possible with a horizontal milling machine. This form of milling refers to the use of multiple cutters attached to the arbor and used simultaneously. Straddle milling can be used to form a complex feature with a singlecut.

For vertical milling machines, the cutters take a very different form. The cutter teeth cover only a portion of the tool, while the remaining length is a smooth surface, called the shank. The shank is the section of the cutter that is secured inside the collet, for attachment to the spindle. Also, many vertical cutters are designed to cut using both the sides and the bottom of the cutter. Listed below are several common vertical cutters.

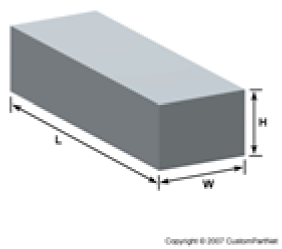
- Flat end mill
- Ball end mill
- Chamfer mill
- Face mill
- Twist drill
- Reamer
- Tap

All cutters that are used in milling can be found in a variety of materials, which will determine the cutter's properties and the workpiece materials for which it is best suited. These properties include the cutter's hardness, toughness, and resistance to wear. The most common cutter materials that are used include the following:

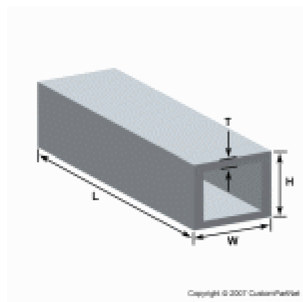
- High-speed steel (HSS)
- Carbide
- Carbon steel
- Cobalt high speed steel

The material of the cutter is chosen based upon a number of factors, including the material of the workpiece, cost, and tool life. Tool life is an important characteristic that is considered when selecting a cutter, as it greatly affects the manufacturing costs. A short tool life will not only require additional tools to be purchased, but will also require time to change the tool each time it becomes too worn. The cutters listed above often have the teeth coated with a different material to provide additional wear resistance, thus extending the life of the tool. Tool wear can also be reduced by spraying a lubricant and/or coolant on the cutter and workpiece during milling. This fluid is used to reduce the temperature of the cutter, which can get quite hot during milling, and reduce the friction at the interface between the cutter and the workpiece, thus increasing the tool life. Also, by spraying a fluid during milling, higher feed rates can be used, the surface finish can be improved, and the material chips can be pushed away. Typical cutting fluids include mineral, synthetic, and water soluble oils.

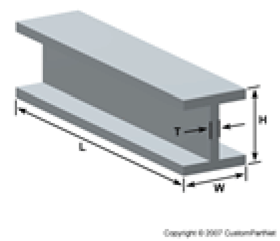
In milling, the raw form of the material is a piece of stock from which the workpieces are cut. This stock is available in a variety of shapes such as flat sheets, solid bars hollow tube, and shaped beams . Custom extrusions or existing parts such as castings or forgings are also sometimes used.



Rectangular bar



Rectangular tube



I-beam

Fig. 2.20

Milling can be performed on workpieces in variety of materials, including most metals and plastics. Common materials that are used in milling include the following:

- Aluminum
- Brass
- Magnesium
- Nickel
- Steel
- Thermoset plastics
- Titanium
- Zinc

When selecting a material, several factors must be considered, including the cost, strength, resistance to wear, and machinability. The machinability of a material is difficult to quantify, but can be said to posses the following characteristics:

- Results in a good surface finish
- Promotes long tool life

- Requires low force and power to mill
- Provides easy collection of chip

2.12 Possible Defects

Most defects in milling are inaccuracies in a feature's dimensions or surface roughness. There are several possible causes for these defects, including the following:

- Incorrect cutting parameters - If the cutting parameters such as the feed rate, spindle speed, or axial depth of cut are too high, the surface of the workpiece will be rougher than desired and may contain scratch marks or even burn marks. Also, a large depth of cut may result in vibration of the cutter and cause inaccuracies in the cut.

- Dull cutter - As a cutter is used, the teeth will wear down and become dull. A dull cutter is less capable of making precision cuts.

- Unsecured workpiece - If the workpiece is not securely clamped in the fixture, the friction of milling may cause it to shift and alter the desired cuts.

2.13 Design

- Select a material that minimizes overall cost. An inexpensive workpiece may result in longer cut times and more tool wear, increasing the total cost
- Minimize the amount of milling that is required by pre-cutting the workpiece close to the desired size and shape
- Select the size of the workpiece such that a large enough surface exists for the workpiece to be securely clamped. Also, the clamped surface should allow clearance between the tool and the fixture for any cuts

2.14 Features

- Minimize the number of setups that are required by designing all features on one side of the workpiece, if possible
- Design features, such as holes and threads, to require tools of standard sizes
- Minimize the number of tools that are required
- Ensure that the depth of any feature is less than the tool length and therefore will avoid the collet contacting the workpiece
- Lower requirements for tolerance and surface roughness, if possible, in order to reduce costs

- Design internal vertical edges to have a corner radius equal to that of a standard tool. If another component with an external sharp edge must fit, then drill a hole to provide a relief area
- Avoid very long and thin features
- Use chamfers rather than a corner radius for outside horizontal edges
- Avoid undercuts

2.15 Material Cost

The material cost is determined by the quantity of material stock that is required and the unit price of that stock. The amount of stock is determined by the workpiece size, stock size, method of cutting the stock, and the production quantity. The unit price of the material stock is affected by the material and the workpiece shape. Also, any cost attributed to cutting the workpieces from the stock also contributes to the total material cost.

2.16 Production Cost

The production cost is a result of the total production time and the hourly rate. The production time includes the setup time, load time,cut time, idle time, and tool replacement time. Decreasing any of these time components will reduce cost. The setup time and load time are dependent upon the skill of the operator. The cut time, however, is dependent upon many factors that affect the cut length andfeed rate. The cut length can be shortened by optimizing the number of operations that are required and reducing the feature size if possible. The feed rate is affected by the operation type, workpiece material, tool material, tool size, and various cutting parameters such as the axial depth of cut. Lastly, the tool replacement time is a direct result of the number of tool replacements which is discussed regarding the tooling cost.0

2.17 Tooling Cost

The tooling cost for machining is determined by the total number of cutting tools required and the unit price for each tool. The quantity of tools depends upon the number of unique tools required by the various operations to be performed and the amount of wear that each of those tools experience. If the tool wear exceeds the lifetime of a tool, then a replacement tool must be purchased. The lifetime of a tool is dependant upon the tool material, cutting parameters such as cutting speed, and the total cut time. The unit price of a tool is affected by the tool type, size, and material.

CHAPTER 3: PROGRAMMING AND MILLING OF COMPONENTS

3.1 CNC Milling Operation on Components

In chapter 2 the various machine available in CNC Milling Department, and the process carried out by each machines are described. The different types of tool s available for different operation.In this chapter mainly two work models there CNC program and and the drawing of the component.

G00 - Rapid traverse

When the tool is moving to a position preparatory to executing a cutting motion or when it is moving to the tool change position, the motion is a essentially a waste of time and is executed as fast as possible. The motion is called Rapid traverse, and is executed at the rapid traverse rate that the machine is capable of. Typical rapid traverse rates on machines are 20 to 40 m /min., but can be as high as 100 m/min. The time taken to execute a rapid motion is also called the Air cut time.

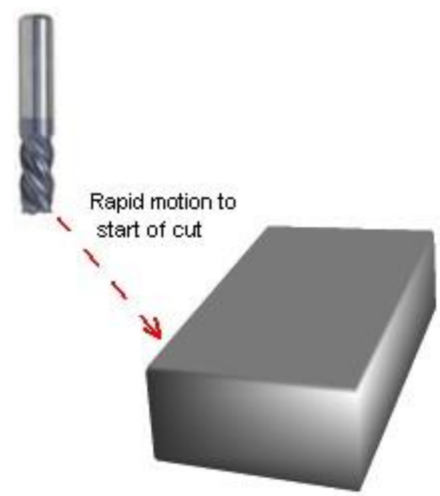


Fig.3.1 Rapid Transverse

Format

G00 X_ Y_ Z_

X, Y, Z = coordinates of destination point

The block consists of the rapid traverse command G00 followed by the destination coordinates.

3.2 Example 1

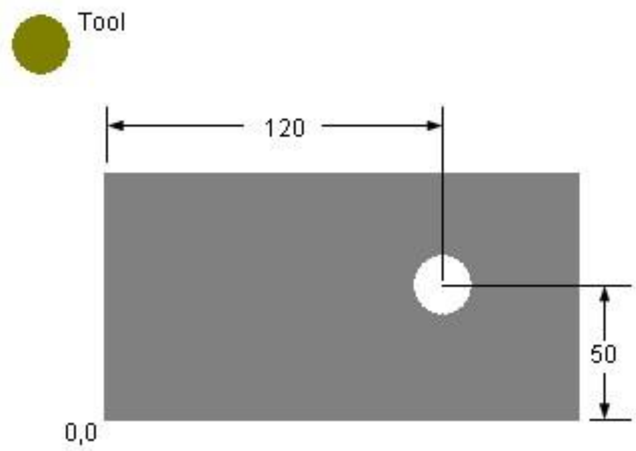


Fig. 3.2 Rapid Transverse

G00 X120.0 Y50.0 Z10.0

This moves the tool at rapid from itcurrent position to the center of the hole.

3.3 Example 2

G01 - Linear interpolation

The tool moves along a straight line in one or two axis simultaneously at a programmed linear speed, the feed rate.

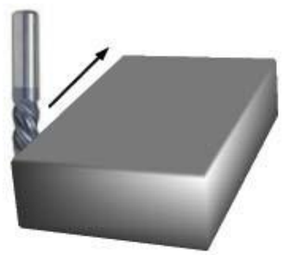


Fig.3.3 Linear Interpolation

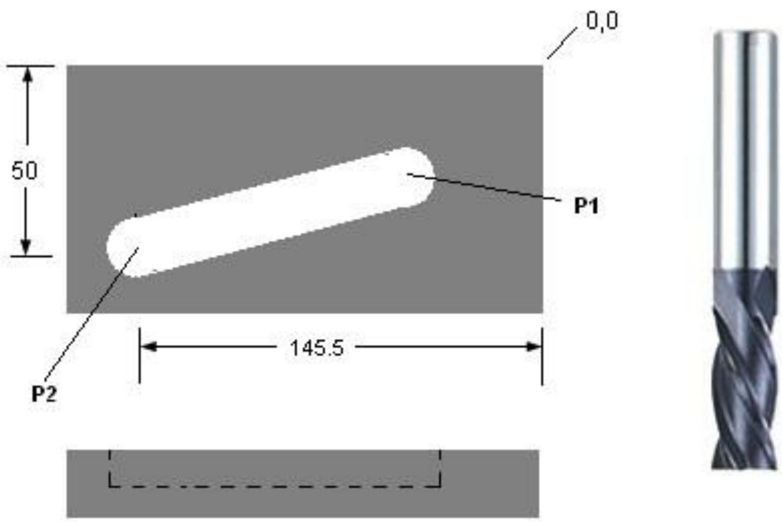
Format

G01 X_ Y_ Z_ F_

X, Y, Z = coordinates of destination point

F = Feed rate

The block consists of the linear interpolation command G01 followed by the destination coordinates and the feed rate.



3.4 Example 3

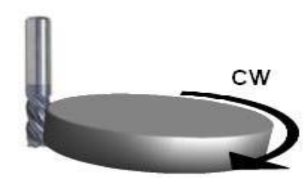
Fig. 3.4 Linear Interpolation

G01 X-145.5 Y-50.0 F250.0

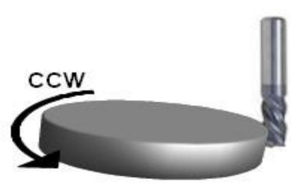
This does a linear interpolation motion from point P1 to P2 at a feed rate of 250 mm/min.

G02 / G03 - Circular interpolation

The tool moves along a circular arc at a programmed linear speed, the feed rate.



Clockwise - G02



Counterclockwise - G03

Fig.3.5 Circular Interpolation

An arc can be programmed using its radius or the coordinates of its center point.

Format

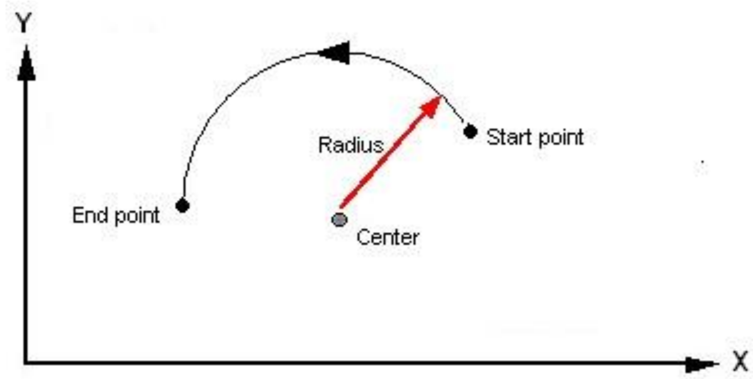
Command format using arc radius:

G02/03 X__ Y__ R__ F__

X, Y = coordinates of destination point

R = radius of arc

F = feed rate



Arc radius programming

Command format using arc center coordinates:

G02/03 X__ Y__ I__ J__ F__

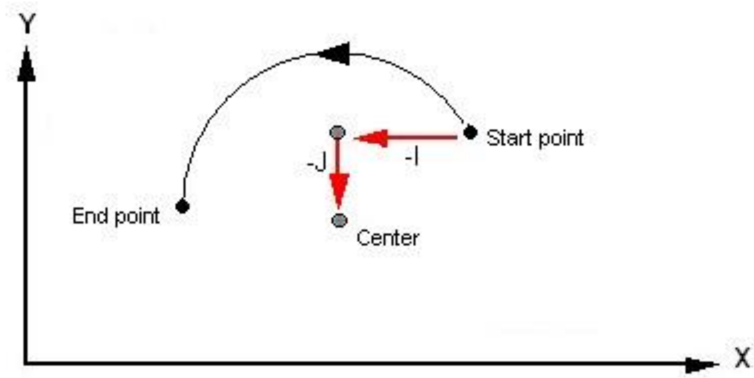
X, Z are the destination coordinates

I and J are the relative distance of the arc center with respect to the start point

I = X coord. of center - X coord. of start point of arc

J = Y coord. of center - Y coord. of start point of arc I and J

must be written with their signs



Arc center programming

Example 4

G02 X-120.0 Y60.0 R35.0 F300.0

G03 X-50.0 R35.0

This moves the tool along the groove from point P1 to P2. The Y coordinate and feed rate need not be specified in the second block since they are modal and same as in the first block. Note the calculation of the arc radius for the center of the arc.

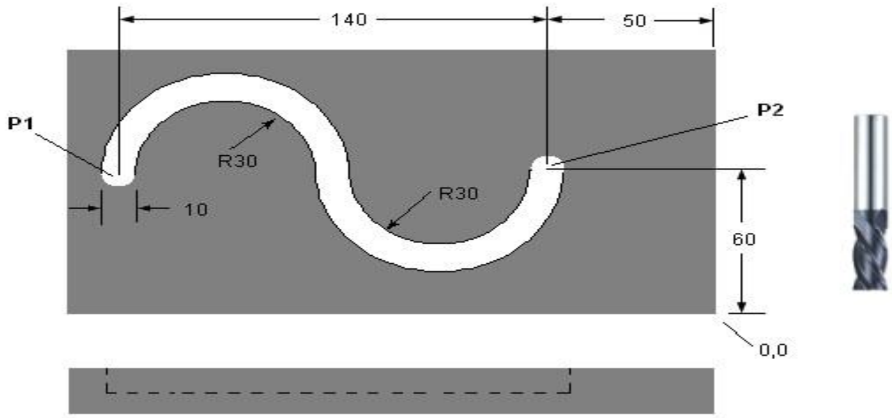


Fig:-3.6 Arc radius programming:

Example – arc radius programming:

G02 X-120.0 Y60.0 I35.0 J0 F300.0

G03 X-50.0 I35.0 J0

G04 – Dwell

A dwell command results in a temporary stoppage of all axis motions for a specified duration. The spindle motion is not affected. It is typically used when the tool has reached the final position in an operation and needs to stay there for a few spindle rotations to obtain good dimensional accuracy or surface finish. For example, in a countersinking operation when the tool reaches the final position and needs to stay there for at least one full revolution.

Format G04 X_

X is the dwell time in seconds.

3.5 Example 5

G04 X1.0

This results in a dwell of 1 second. F, S, T commands

Feedrate

The feed rate is specified in mm. per minute.

Format

F_

F is specfied in mm. per minute.

Example

F250.0

This means a feed rate of 250 mm/min.

Spindle rotation

Spindle rotation is started by specifying a spindle direction command and a spindle speed command.

Spindle direction:

This is specified by an M code.

M03 : Spindle clockwise (CW)

M04 : Spindle counter-clockwise (CCW)

M05 : Spindle stop

Spindle speed:

The spindle speed is specified in rpm with the address S.

Example 6

S1250 M03

This block commands a spindle speed of 1250 rpm with the spindle rotating clockwise.

Tool change

The tool change command typically has the tool number and a tool change command. When the command is executed, the tool changer causes the commanded tool to come to the spindle.

Format

Taa M06

aa is the tool number

M06 is the tool change command

Typical G and M Codes

G codes

G codes on a machine are decided by its controller's programming format. Machines of different makes with the same controller will have the same set of G codes.

Sample List of G Codes

G00 Positioning rapid traverse

G01 Linear interpolation (feed)

G02 Circular interpolation CW

G03 Circular interpolation CCW

G04 Dwell

G20 Inch unit

G21 Metric unit

G28 Automatic zero return

G30 2nd reference point return

G32 Thread cutting (single motion)

G40 Tool radius compensation cancel

G41 Tool radius compensation Left

G42 Tool radius compensation Right

G54-59 Work coordinate system

G73 Peck drilling cycle

G76 Finish boring cycle

G80 Cancel cycle cycle

G81 Drilling cycle

G82 Counter boring cycle

G83 Deep drilling cycle

G84 Tapping cycle

G85 Reaming cycle

G87 Back boring cycle
G90 Absolute mode
G9 Incremental mode
G94 Feed per minute
G95 Feed per revolution
G98 Return to initial point in canned cycle
G99 Return to safe position point in canned cycle

M-codes

Most M codes activate machine functions like the coolant, spindle, etc. These are decided by the machine manufacturer, and depend on the features that are available on the machine. E.g., a machine with a pallet changer will have an M code for pallet change. A few (like M00, M01, M02, M98, etc. in the list below) are fixed and based on the controller.

Sample list of M Codes
M00 Program stop
M01 Optional program stop
M02 Program end
M03 Spindle ON clock wise (CW)
M04 Spindle ON counter clock wise (CCW)
M05 Spindle stop
M06 Tool change
M08 Coolant ON
M09 Coolant OFF
M30 End of program and reset to start
M98 Sub program call
M99 Sub program end

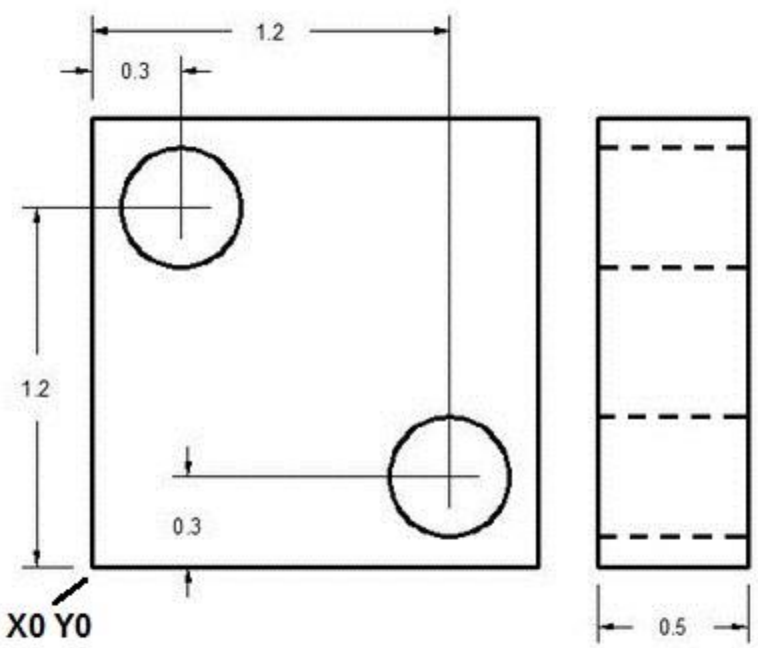
Program block	**Explanation**
%	Program start character
O998	Program number 998
G00 G91 G28 Y0 Z0	Move to position away from part for tool change
T01 M06	Tool change to tool number 1 (16 dia. End mill)
S500 M03	Spindle speed 500 RPM, CW
G00 X-32.0 Y-40.0 M08	Move at rapid to position for milling, coolant ON
G43 H1 Z-3.0	Rapid to depth for first cut
G01 Y40.0 F350.0	Cut 1
G00 Z-6.0	Rapid to depth for second cut
G01 Y-40.0	Cut 2
G00 Z2.0 M05	Rapid above part and spindle OFF
M09	Coolant OFF
G00 G91 G28 Y0 Z0	Rapid to tool change position and spindle OFF
T02 M06	Tool change to tool number 2 (Drill)
S1400 M03	Spindle speed 1400 RPM, CW
G00 X0 Y0 M08	Rapid to hole position, coolant ON
G43 H2 Z3.0	Rapid above part
G01 Z-23.0 F200.0	Feed into hole
G00 3.0	Rapid out of hole

X-64.0 Y0	Rapid to next hole position
G01 Z-23.0 F200.0	Feed into hole
G00 3.0	Rapid out of hole
M05	Spindle OFF
G00 G91 G28 Y0 Z0 M09	Rapid to tool change position and coolant OFF
M02	Program end
%	End character

Table 3.1 Program Block

CASE STUDY

Drilling a circular hole in a square plate



Material Selected :- Mild steel

Youngs Modulus :-210 GPa (30000000 psi)

CNC Program

N1 T1 M06

```
N2 G90 G54 G00 X.3 Y1.2
N3 S1200 M03
N4 G43 H01 Z1. M08
N5 G81 Z-.6 R.1 F10
N6 X1.2 Y.3
N7 G80 G00 Z1. M09
N8 G28 G91 Z0. M05
N9 M30
```

List of G Codes and M Codes

M00 Unconditional stop

M02 End of program

M03 Spindle clockwise

M04 Spindle counterclockwise

M05 Spindle stop

M06 Tool change (see Note below) M30

End of program

CHAPTER 4: CONCLUDING REMARKS

4.1 Introduction

My internship experience in the Government tool room and training centre allowed me to work with the areas of CNC milling machine. I had an opportunity to work on CNC machines and gained ideas about the programming sequence used in CNC milling Machine. Over the course of internship, I was involved in several projects carried out their. While none were failure, there werecertainly varying levels of accomplishment with those having the greatest success the most support from higher administration. My internship was a valuable experience in that it gave me a greater appreciation and I gained new ideas on working with the CNC.

4.2 Advancements in CNC

Just as in all other industries, CNC technology has come a long way in the last 20 years. However, adoption of this new CNC technology has been very slow, especially compared to consumer industries. There are many valid reasons to remain very conservative with CNC technology since the resulting parts manufactured by CNC machines are often critical components in tightly controlled industries like aerospace. Most people are more comfortable knowing that the manufacturing of a particular part that passed extensive testing is not allowed to change without going through significant retesting when they are flying at 30,000 feet. Due to the slow adoption of new CNC technology and limited qualified manufacturing resources, even new parts are typically programmed and manufactured using traditional legacy techniques. However, there are many advanced features that are simple to implement with minimal investment. The hard part as a programmer or manufacturing engineer is finding the time to investigate and be comfortable with a new paradigm. It's possible to bridge that resource gap by using the CNC vendor's expertise as a resource to help find ways to easily implement these technologies into your manufacturing.

To update our current programming and machining processes and reap the benefits of the technology advancements of the last few decades, it's important to view the process as a whole instead of focusing on a specific aspect of manufacturing the part. For aerospace parts, the process typically requires four or five-axis contouring and the geometry is modeled using a CAD system. Below is the definition of the four common steps for generating a part using the traditional CAD-CAM-post-CNC processes.

- Accurately model the part in a CAD system.
- From the accurate CAD model, a CAM system generates a map of the part as an approximated series of points that are within a defined tolerance around the CAD model surfaces.
- With traditional and commonly used programming, a complex post-processor takes the CAM-generated series of points and orientations and translates them into a specific machine setup calculating the physical axis positions so the planned tool tip ends up at the CAM-generated points. Common features and processes used include "inverse time—G93" and "pivot point programming." In this process, any changes in the machine, tool, or fixturing typically require the program be "reposted" with the new information.
- In traditional processes, the CNC simply connects the points calculated by the CAM and post-processor.

For a common five-axis gantry style machine, when the CNC connects the dots the tool tip will actually scallop into the material between every programmed point due to "pivot-point programming." The common traditional solution is to redo the CAM-Post processes at a tighter tolerance resulting in significantly more points and lengthier programs. The closer the points are together, the less the scalloping effect is noticeable in the part. If the servos are tuned too aggressively, the machine will run “rough,” due to the scalloping motion and the machine tool builder or control manufacturer will typically de-tune the servo system to make it less responsive and therefore less accurate.

▪ 4.3 The Modern Process

Modern controls have the ability to bypass this madness and effectively translate the CAM-generated series of points back into the original smooth surface defined in the CAD system without a major change in programming. The majority of the changes required to take advantage of the power currently available are actually simplifying the systems between the CAD system and the CNC. In simplifying these steps to take advantage of the modern advanced CNC features, significant costs are reduced, the time from model to manufacture is reduced, and manufacturing flexibility is increased. All are good things.

Using the processes and features described above, part programs are definitions of the part rather than machine-specific motion and commands. The information in the part program is the tool location and orientation relative to the material surface required to produce the part. The CNC takes care of the math to translate that information into specific machine motion to produce the part regardless of tooling, fixture location and orientation, and machine kinematics.

There are other concepts that different organizations have developed to attempt to improve the errors and difficulties caused by the traditional programming process. Some systems drastically change the programming language well known by operators and programmers throughout the industry. Some systems add additional processors between the CAM and CNC to manipulate feed rates or even change the point locations defined in the programs. These systems require significant investment in training, support, and product costs on top of the current investment for the end user.

Rather than reinvent the wheel or try to add an additional system to make up for the problems and lack of flexibility caused by traditional CAD-CAM-post-CNC processes, utilize the advanced features available in the control already driving your machine to drastically reduce costs, improve part accuracy, reduce cycle times, and increase manufacturing flexibility.

4.4 Non Technical Skills

Engineering is a profession where candidates are expected to have a high level of technical skill and knowledge. However, engineers don't just deal with tools and machines, and it is no longer an industry in which strong technical skills are all it takes to have a long and successful career. As we know, the role of an engineer often calls for managing teams or interacting with customers, management, suppliers and colleagues of varying ages, career stages and nationalities. So you need to know how to lead, communicate and co-operate with a diverse team of people around you.

- **Communication**

Strong writing skills, as well as the ability to communicate verbally clearly and with confidence in a range of situations - both online and in-person - is critical. After all, a breakdown in communication in the engineering field could spell a costly disaster. But communication doesn't just mean the ability to string more than a few sentences together. It also includes the intangible skill of being able to adapt communication style depending on the situation, while still expressing yourself professionally.

- **Creativity**

Creativity sparks innovation.Company depends on these new ideas for products and services that keep you relevant. Creative thinking is also just as vital to problem solving situations as technical acumen is. Therefore, a creative, fast-thinking candidate who is not afraid to challenge the status quo will be invaluable to your business.

- **Flexibility**

Engineering is an industry that is rapidly being reshaped by technology. Working in an environment in which you must change in order to keep up means you need employees who are open and accepting of unexpected or alternative ways of doing things. Get a team onboard who can demonstrate their adaptability and willingness to seek and implement new solutions.

- **Collaboration**

The internet has changed the way we work. Connectivity means engineers are experiencing an increasing requirement to collaborate on a global scale. It's possible that your potential employees may be required to work on a project with a team on the other side of the world. How will they cope firstly with managing a collaborative approach to a project within their own team, and secondly adapting to differences in language, culture and working style with external stakeholders.

- **Emotional Intelligence**

Emotional intelligence relates to being able to understand your own emotions, and read and react to the emotions of others appropriately. Organizations with high EI levels have a competitive advantage - they have better customer service, improved communication, better teamwork and morale and improved employee retention. Interview questions should focus on how the candidate manages themselves and manages their relationships with others. The industrial training is experienced the real life situations in industrial organization and their related maintenance environment and accelerating the learning process of how knowledge could be used in a realistic way. In additional to that, industrial training also makes one understand the formal and informal relationship in an industrial organization so as to promote favorable human relations and team work. Besides, it provides the exposure to practice and apply the acquired knowledge in the maintenance works. Industrial training also provides a systematic introduction to the ways of industrial and developing maintenance activities

4.5 Benefits of Internship

- Gained work experience and transferable skills

    All have their educational experience in common. What stands out to employers is those who have work experiences by the time they graduate. This automatically makes them more marketable; as they may require less training and are assumed to be able to handle more responsibilities. In addition to the specialized skills of our field, transferable skills are generally required at any job, e.g. communication/interpersonal skills, computer proficiency, and team work.

- Earn course credit

Earned four month work experience of working with CNC milling machine

- Gain practical experience ,by applying methods and theories learned in classes

Gained idea of using codes mainly G codes and M codes in CNC programming. Many people learn best by being hands on. But everyone can benefit from seeing the things that they have been learning in class, put to action; whether it's in a chemistry research lab, a marketing development meeting, or a substance abuse counselling session.

- Network with professionals in our field , for references and future job opportunities

As a student, we are surrounded by professionals in the industry that you are seeking access to. It's more than just about getting a grade, earning credit, or making money. This is an opportunity to learn from everyone around you, ask questions, and impress them with your eagerness. These people can be your future colleagues or can be the connection to your first job.

- Develop new skills and refine others

Learn our strengths and weaknesses by creating learning objectives and receiving feedback from my supervisor. This is a unique learning opportunity that you may never have again as a working adult. Embrace the mistakes that you'll make and the many things that you won't know. Ask questions, observe, and take risks

- Gain confidence in our abilities

Practice makes perfect. If we've learned about a specific technique in the classroom, we're able to test it out in the world of work. Then, we'll be much more equipped with the technique

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