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ABSTRACT

The work of this thesis is dedicated to the manufacturing industry making production equipment to manufacture plastic products. The main theme of the thesis is to determine the criteria for implementing Computer Numerical Control machining to make parts with complex geometries for production equipment.

A small manufacturing company with job shop type of production was chosen as the subject and study of extruder manufacturing process was performed. The various available alternatives of CNC manufacturing units available in the market were chosen and their feasibility examined.

At present a large variety of CNC machine tools are available in the market, offered by manufacturers following different standards. This thesis is organized with the purpose of comparing various technical and economical considerations for CNC machine tool purchase and its application.

**COMPUTER NUMERICAL CONTROLLED (CNC) MACHINING OF
SCREWS AND DIES FOR PLASTICATING EXTRUDERS
: DETERMINATION OF THE CRITERIA FOR IMPLEMENTING CNC
MACHINING**

by

Nilesh H. Desai

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the New Jersey Institute of Technology in partial fulfillment
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DEDICATION

To my Parents

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I. EXTRUDERS AND THEIR COMPONENTS

The extruder is the melt-supply unit in the extrusion process, and the design of the extruder is a key element in a successful system. The function of the machine is to generate a supply of plasticated material with uniform temperature and composition at a constant and controllable rate. The machines have evolved from the crude devices that were converted from rubber extruders to the sophisticated melt-generating equipment now in use. The construction of the machines has changed substantially from the original simple screw pumps.

The majority of the extruders in current use are single-screw machines. Although the twin-screw and the multiple-screw machines are now in use, the single-screw machines are most widely used.[1]

As the name suggests, an extruder is a machine which uses the principle of extrusion for the manufacture of products. To make a product using the extrusion process, raw polymer in the form of pellets or powder is fed to the screw through the hopper. The solids are conveyed forward, plasticated, homogenized, and pressurized along the screw. Thus a uniformly molten polymer is pumped or pushed across the "die" attached to the extruder head.

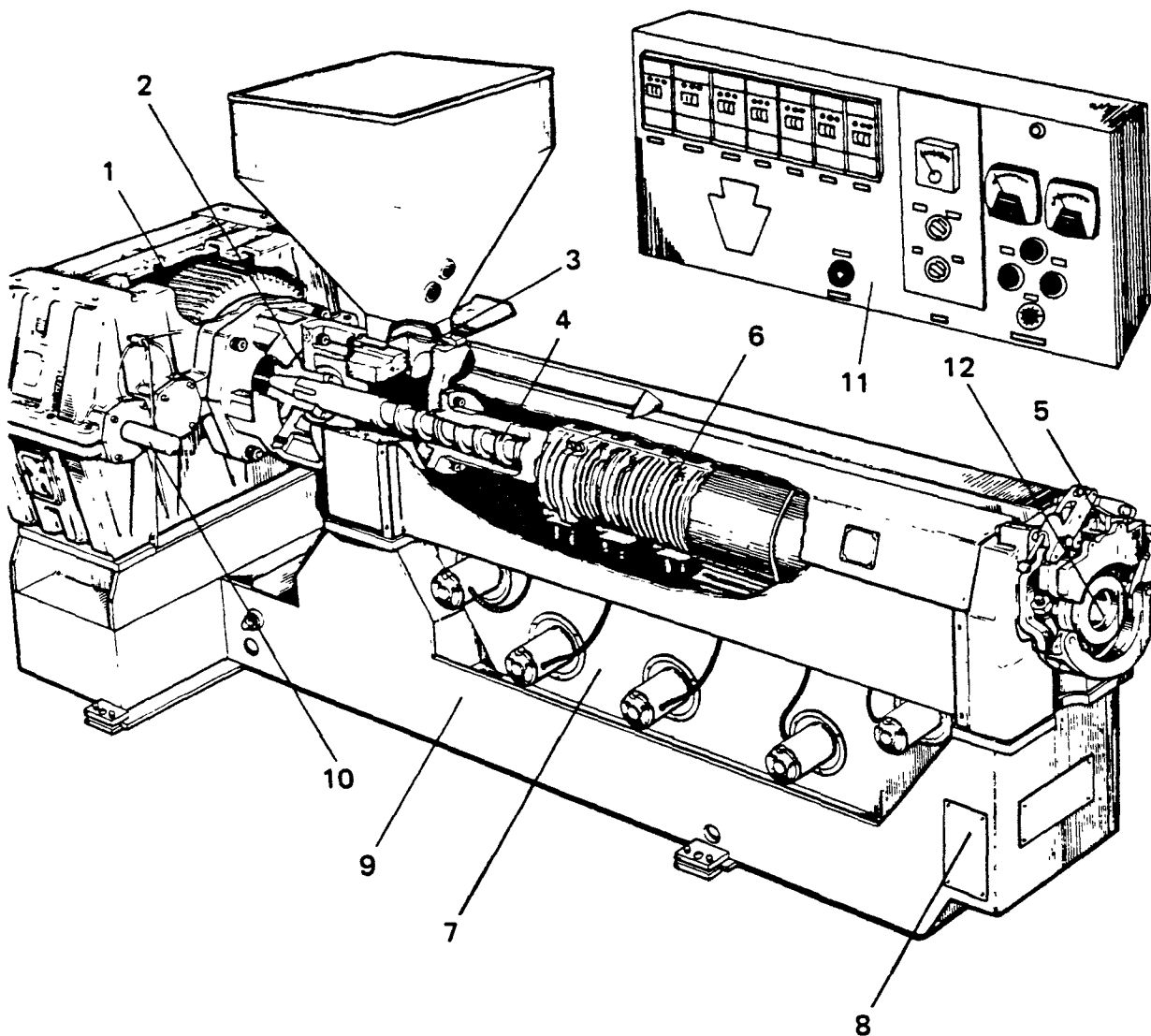


Fig. 1. Extruder

Extruder showing outboard motor arrangement. 1, Gear case; 2, thrust bearing; feed section; 4, barrel and screw; 5, head clamp; 6, barrel heating; 7, cooling systems; 8, electrical wiring; 9, base; 10, drive motors; 11, controls; 12, barrel height.

The finished product is determined by the die, which shapes the product, and by the 'sizing' equipment, the cooling system, and the cutting equipment, which in turn set the final size and surface quality of the product.[2]

Typically a plasticating extruder as shown in fig. 1 consists of the following.

- * Heavy duty fabricated steel base
- * D.C. drive motor
- * Gear Box
- * Barrel
- * Helical Screw
- * Hopper or resin feed system
- * Rupture disc
- * Breaker plate
- * Instrumentation (Panel board of controls)
- * Transformers (if required)

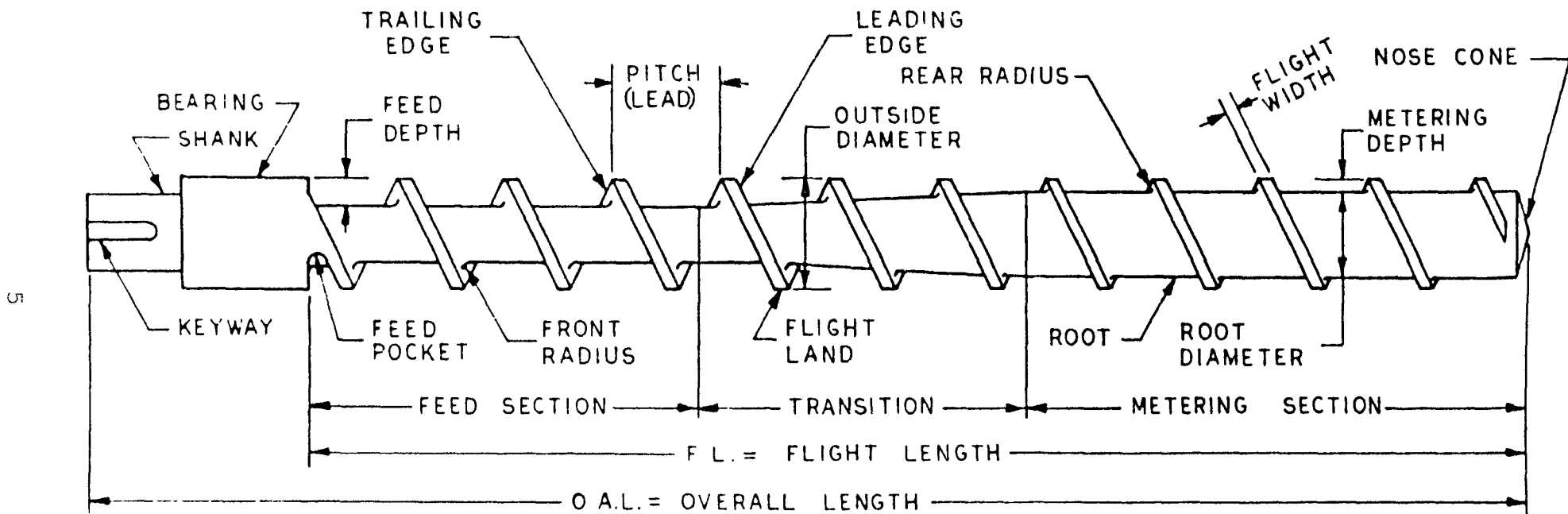
The main component from the above list is the helical screw. The screw and the barrel are the units that act to convey, melt and generate pressure in the plastic material. The drive system rotates the screw at a controlled speed.

I.A. SCREWS

The feed screw is the key component of any extruder. It is fitted into a precision machined cylinder known as the barrel. The screw is rotated at a constant speed by a drive system. The screw consists of a channel wrapped in a helix (spiral) around a cylindrical shaft. The functioning of the extruder to pump the melt is dependent upon the construction of the screw and the characteristics of the polymer material to be extruded.

The turning screw can be imagined as trying to unscrew itself backward out of the barrel full of material. It cannot go back because a thrust bearing holds it in place, but its push against the material forces that material out of the other end. The die at the output end acts as resistance to the flow of the plastic material being pushed out by the screw. The longer it is, the more the screw has to work to push the material out.[3]

The screw channel is deep in the feed zone, where the resin pellets first enter the extruder barrel. As the screw rotates inside the barrel, the resin is conveyed along the length of the extruder. The depth of the channel gradually decreases in the transition zone, in order to compress the plastic and develop pressure for extrusion as the resin



Constant Pitch Gradual Transition Metering Screw

Fig. 2. Extruder Screw

melts. Also for batch mixing the channel is shallow in the metering zone, where fluctuations in temperature, pressure, and flow are alternated.

Screw design is a primary concern when specifying an extruder. Considerations include desired output, melt temperature, mixing homogeneity, and consistency.

A screw works correctly when it is "in balance" i.e when the correct amount of material is delivered to the last part of the screw. The goal is to completely fill the last part, or the metering section, of the screw so that the melt pressure is constant and smoothed out prior to entering the die.

Screws usually have single flights, although screws with multiple flights are being used. There is little or no advantage of increasing the number of flights.[1]

The screws and barrels are manufactured and surface hardened to reduce the wear. The performance of the extruder depends a great deal on the screw design and the operating conditions.

Common terms related to the feed screw include:

Screw OD or the outside diameter;

Screw design - the exact configuration of the screw,

and

The L/D ratio - the length of the screw relative to the diameter

The principle geometric variables of the screw are^[4],

1. The channel depths i.e., the radial distance between the barrel surface and the root of the screw in the various sections of the screw.
2. Lengths of the various sections.

Sometimes screws are described by the compression ratio, which is the ratio of volumes of the first flight to that of the last flight. The flight thickness of a screw is 10 % of the diameter. Any more would waste the screw length and less would risk breakage^[3].

The channel depth in every section and the length of the various sections have a profound effect on the performance of the extruder. As the screw wears down, the clearance between the screw and the barrel increases. Worn screws may give less output per revolution of the screw. The screw rebuilding costs are around 50 - 70 % of the cost of a new screw.^[3]

There are many types of screw designs, depending on the use of the material to be extruded. Some of the popular designs are

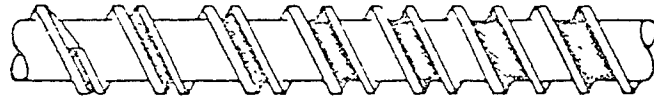


Fig. 2.a Barrier screw



Fig. 2.b Barr screw

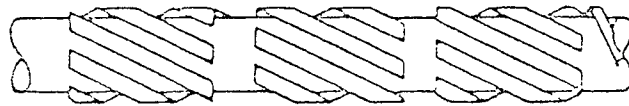


Fig. 2.c Parallel interrupted mixing flights

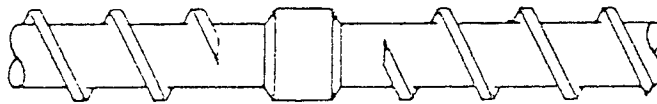


Fig. 2.d Ring barrier



Fig. 2.e Mixing pins

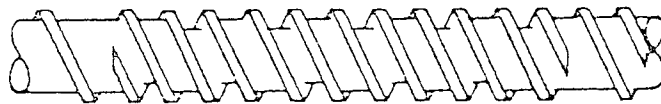


Fig. 2.f Double wave screw

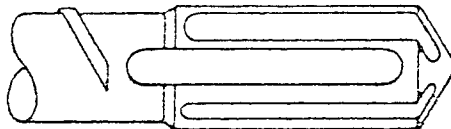


Fig. 2.g Maddock mixing section

Special screw design features.

1. Maddock head type

This type of screw as shown in fig. 2.g. has a 2 diameter long section with large grooves (flutes) parallel to the screw length, instead of flights, so that pellets are sheared and melted in the gap instead of passing over the screw flight.

2. Barrier screw type

This screw as shown in fig. 2.a is a standard type of screw with an extra flight in the melting (compression) zone, dividing it in to 2 channels. The new flight is not full diameter so that melt can pass back over the clearance into the back channel, while the pellets stay in the main channel, and can rub/shear/melt easier.

3. Mixing pins type screw

Rings of studs projecting from the screw root fig. 2.e, disrupt the flow of melt and improve mixing of the resin.

4. Screws for grooved barrels

Barrels with axial or helical grooves improve bite (intake) and help in conveying pellets. These types of barrels need special screws.

5. Vented extrusion screws

An extra long screw with 1/3rd portion near head with deep channels to reduce the pressure can create vacuum

to draw off the moisture, air and/or volatile impurities.

6. Double flighted (waved) screws

There are 2 parallel paths fig. 2.f for part or all the screw length, this helps improve heat transfer and mixing in the metering zone.

7. Dray screw

A small channel is cut in the outer flight surface in the feed zone. Plastic caught in this channel melts quickly, coating the whole barrel surface as well as many pellets. This improves the bite, allows to reduce the RPM for given output, and makes system less sensitive to die resistance.

8. Twin-screw extrusion

Two screws side by side and intermeshing in a single barrel, which can turn in same direction (co-rotating) or in opposite direction (counter-rotating) are termed as twin screw extruders. These screws mix the resin by stream-splitting, rather than by parallel-plane shear as in the case of single screws. Twin screws give more positive bite for easier entry of powders which are often fed by screw-feeders or weight-feeders to control output rate.

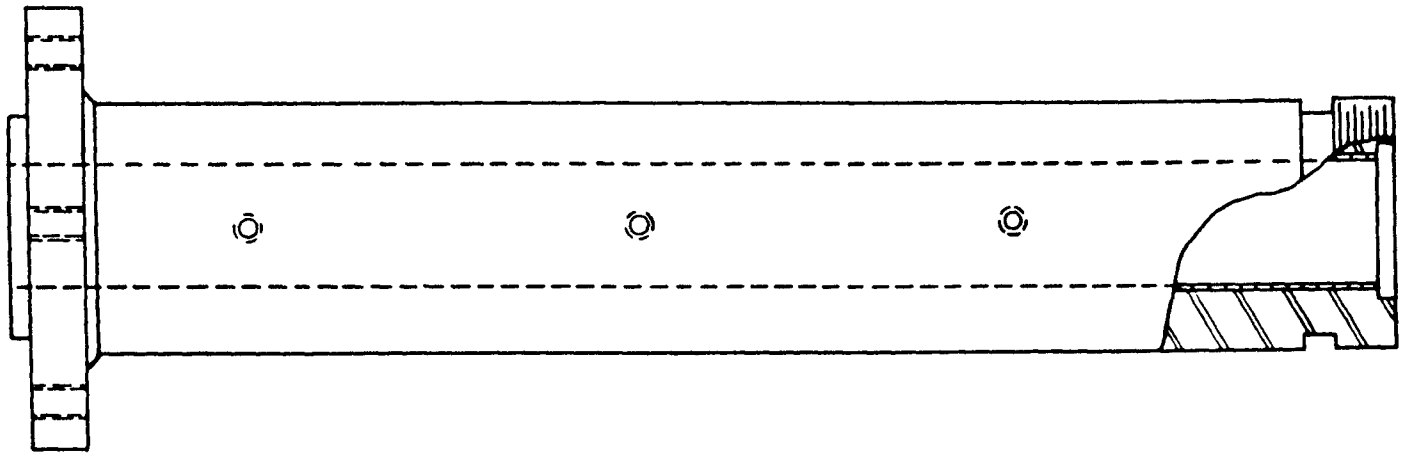


Fig. 3. EXTRUSION BARREL

I.B. BARRELS

The barrel as shown in fig. 3 is a hollow metal cylinder with a wear and corrosion resistant liner on the inner surface. Some barrels, mainly for twin screw extruders, are made of nitrided steel. The barrel must be strong in order to withstand very high pressures and temperatures that are developed during extrusion. The screw fits snugly inside the barrel, with a minimum of clearance between the O.D. of the flight and the I.D. of the barrel. A typical screw-barrel clearance would be between 0.004" - 0.006" radially. Tighter fit would be very difficult to make and would develop excessive heat[5].

The barrel is provided with both a heating and a cooling system. Thermocouples for the temperature control system are placed in wells at equal intervals along the length of the barrel. There is a flange or a clamp at the discharge end of the barrel, to provide a means to attach the tooling to the end of the extruder.

Typically earlier machines had length to diameter ratios of 16:1 to 20:1. Current equipment has ratios from 24:1 to 36:1 and longer. The longer machines have more heat transfer area and are preferred for difficult to melt polymers. The walls of the barrel are heavy in size and are designed to handle pressures up to 5000 psi for strength at working temperatures and, minimum burst pressure of 10000 psi. [5]

I.C. TOOLING

The tooling or DIEHEAD assembly fig. 4 is a set of metal components mounted on the discharge end of the barrel. The function of the tooling is to:

- a. Help control the flow of the melted plastic.
- b. Form and size the extrudate as it leaves the extruder.

The standard tooling includes the following items:

Spider or Breaker plate

Adapter

Die

Mandrel

Sizing tool

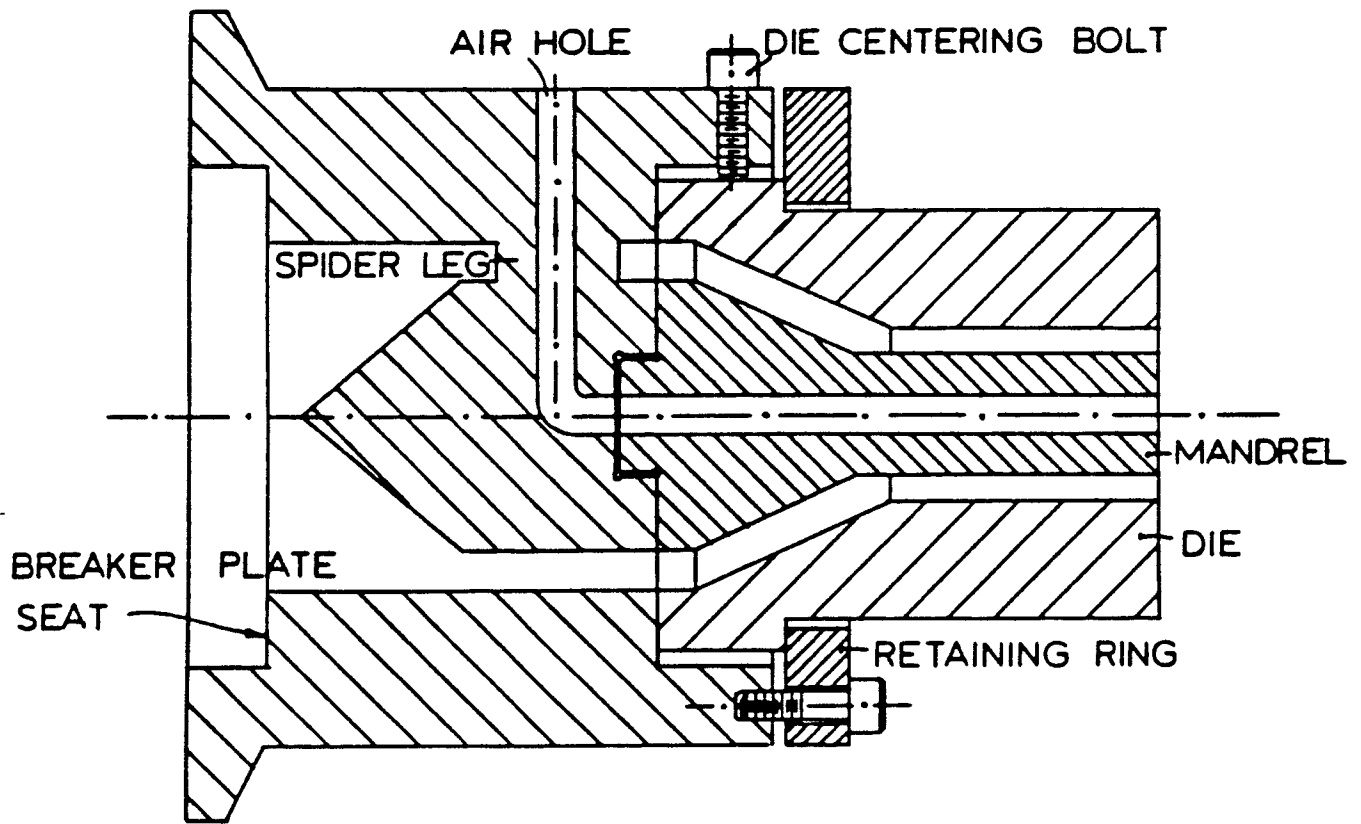


Fig. 4. Head Zone

I.C.1. Breaker plate

In order to get good product from an extruder, it is important that the material be completely melted and reasonably uniformly mixed. If there is an inadequate mixing in the screw, the unmelted granules will be present in the extrudate. Proper melting of resin requires that a suitable screw be used and that adequate back pressure be maintained on the head end of the extruder to get the needed mixing action. This is done by introducing barriers in the flow of the melt by placing screen packs and breaker plate or by spiders, valves, chokes. The pressure drop that the restriction units produce must be added to the pressure drop caused by the die. The breaker plate size is determined by the amount of pressure drop required to produce sufficient working pressure in the extruder and the proper inlet pressure to the die for the desired delivery rate. [4]

For a given extruder speed and delivery rate the die back pressure may be inadequate to produce properly plasticated melt. In such a case the practical approach of machine/die balancing is used. The way to do this is by incorporating pressure dropping devices as screen/s pack, a choke or a valve. This will ensure a desired delivery rate of the melt to the die as well as, sufficiently high head pressure to properly plasticate the polymer. [6]

The main uses of Breaker Plate/Spider are:

1. Remove spiral motion.
2. Provide mounting of mandrel.
3. Support screen packs.
4. Act as a seal between the die and the adapter.

I.C.2. Adapter

There are various arrangements possible to attach the die structure to the barrel. Simplest of all is to bolt the die directly to the flange at the end of the barrel. This requires careful handling of the die when the cleaning operation is to be carried out. The hinged gate arrangement is most widely used with smaller dies. For general purpose use for small pipe dies the barrel gate is bored to take a die-adapter unit. This unit is used to attach the dies to the machine, making it convenient to change the dies. One face of the adapter is fixed to the barrel end, and the other face to die. This arrangement makes it easier for the die removal without touching the barrel and thereby avoiding the opening of the barrel.

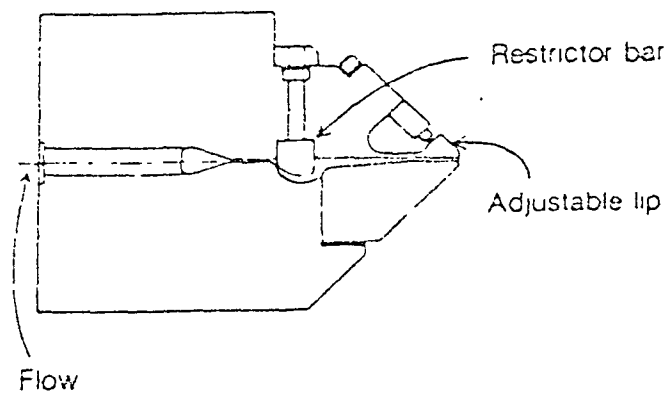


Fig. 5.a Sheet die.

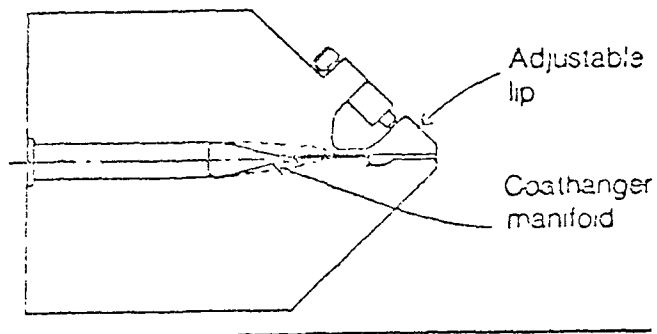


Fig. 5.b Flat film die.

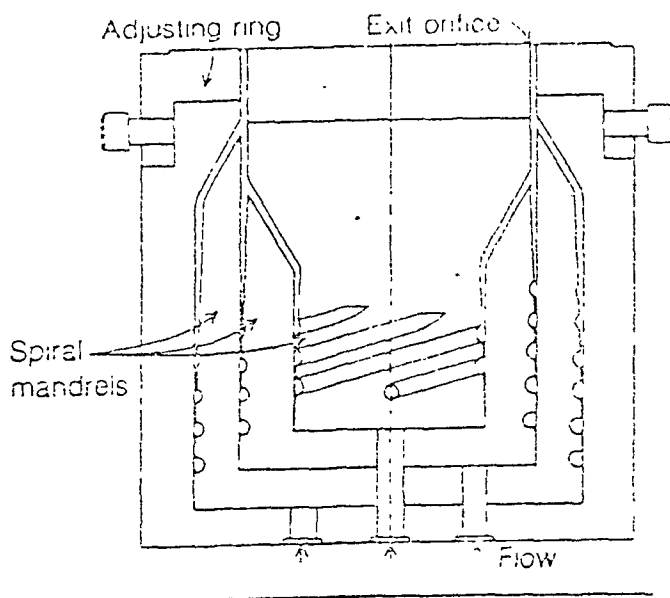


Fig. 5.c Coextrusion blown film die.

I.C.3. Dies

Extrusion dies can be designed to produce stock or special shapes for different end products. The major types of dies used are:

I.C.3.a. Sheet Dies

Plastic sheets of varying thicknesses are used as glazing material, fabrication of tanks, and various products ranging from packaging to chemical tanks. These sheets are produced with sheet dies as shown in fig. 5.a which are of the slit-type and are attached to the adapter of the extruder. The die opening is adjustable to control the thickness of the sheet.

I.C.3.b. Film dies

Film is generally defined as material less than 0.010 in (0.25 mm) thick. There are two different production systems to make films, one is called slot casting, and uses dies similar to thin sheet dies as shown in fig. 5.b; the second is called the blow film process. This uses dies as shown in fig. 5.c to extrude a thin wall tube of material, and then uses air to inflate the tube for a thinner wall. This tube is then slit open to form a film.

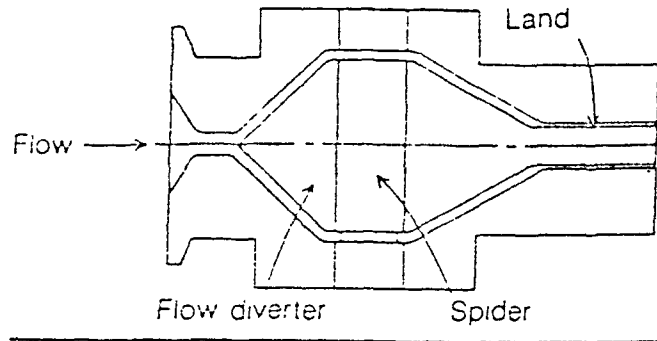


Fig. 5.d Pipe or tubing die.

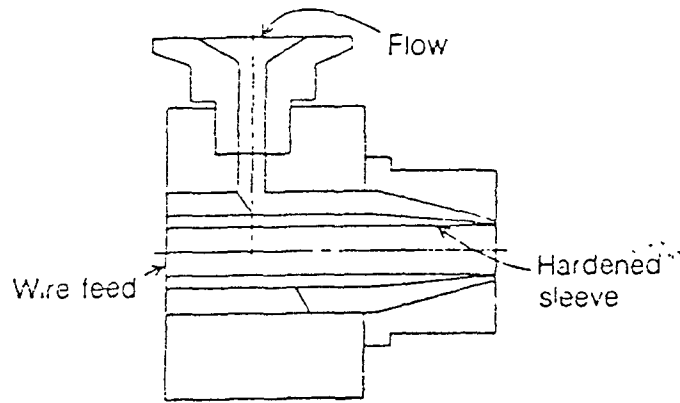


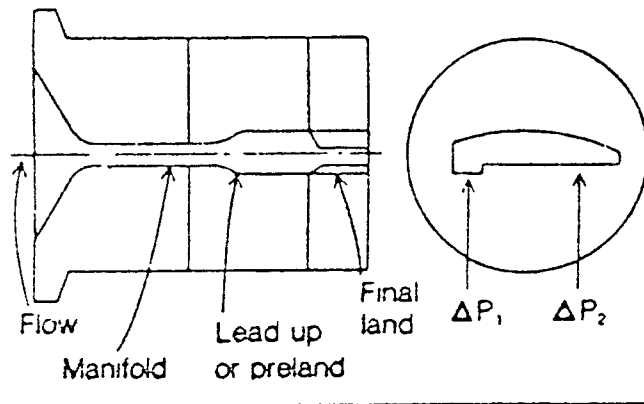
Fig. 5.e Wire or cable die.

I.C.3.c. Pipe and tubing dies

Tubing and pipe are extruded with a die as shown in fig. 5.b as the only element in the production system which is attached to the end of the extruder. The sizing method used will have an effect on the die construction. One method of sizing is internal mandrel sizing, and the other is vacuum sizing.

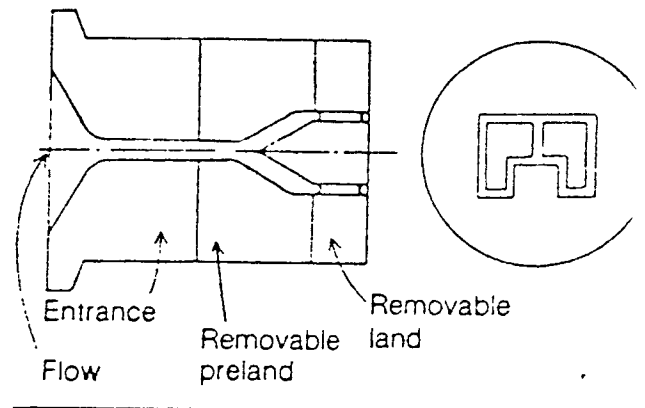
I.C.3.d. Wire covering and other covering dies

Sometimes it is necessary to cover materials with a protective coating or layer of plastic material, eg. insulated wire. This type of process requires a crosshead extrusion process for coating the material. There are two types of die designs used for the covering purpose. In one method the wire or parent material is passed through the crosshead die as shown in fig. 5.e and the secondary or covering material is extruded around it. In the second method the covering material is passed with force on the wire and the wire is pulled through the die by a travelling wire becoming the pulling force of the material out of the die.



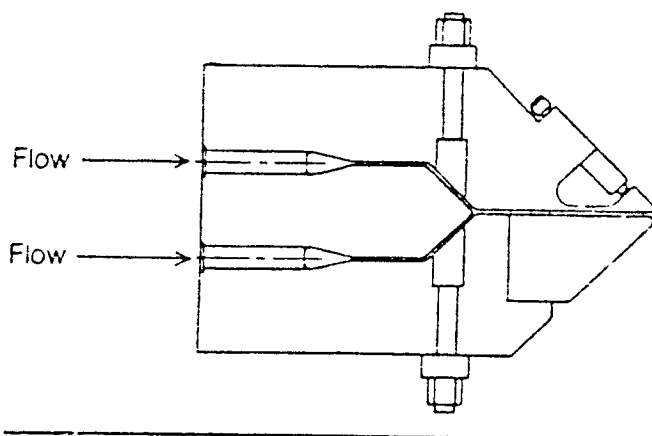
Polymer flow in profile dies.

Fig. 5.g



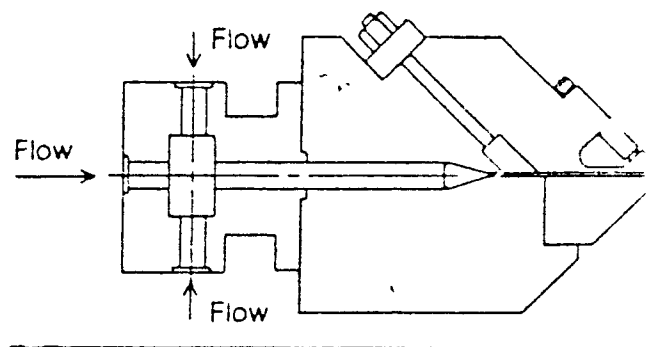
Profile plate die.

Fig. 5.f



Multimaniifold coextrusion.

Fig. 5.h



Coextrusion feedblock

Fig. 5.i

I.C.3.e. Rod and profile dies

The principle used in designing the profile dies apply equally to the stock shapes, the main difference is one of end use rather than of die and process. There are two general categories namely, plate dies fig 5.f and streamline entry dies.

I.C.3.f. Specialty dies

Dies which cannot be classified under the above categories can be included in this group eg. netting dies, multimanifold co-extruding dies fig. 5.h etc.

I.C.3.g. Mandrel

It is usually a cylindrical component of the die which forms a concentric opening with the corresponding die fig. 4. Mandrels are used when tubular or hollow sections such as pipes and tubing are tube extruded.

The gap between the O.D. of the mandrel and the I.D. of the die determines the wall thickness of the tubing.

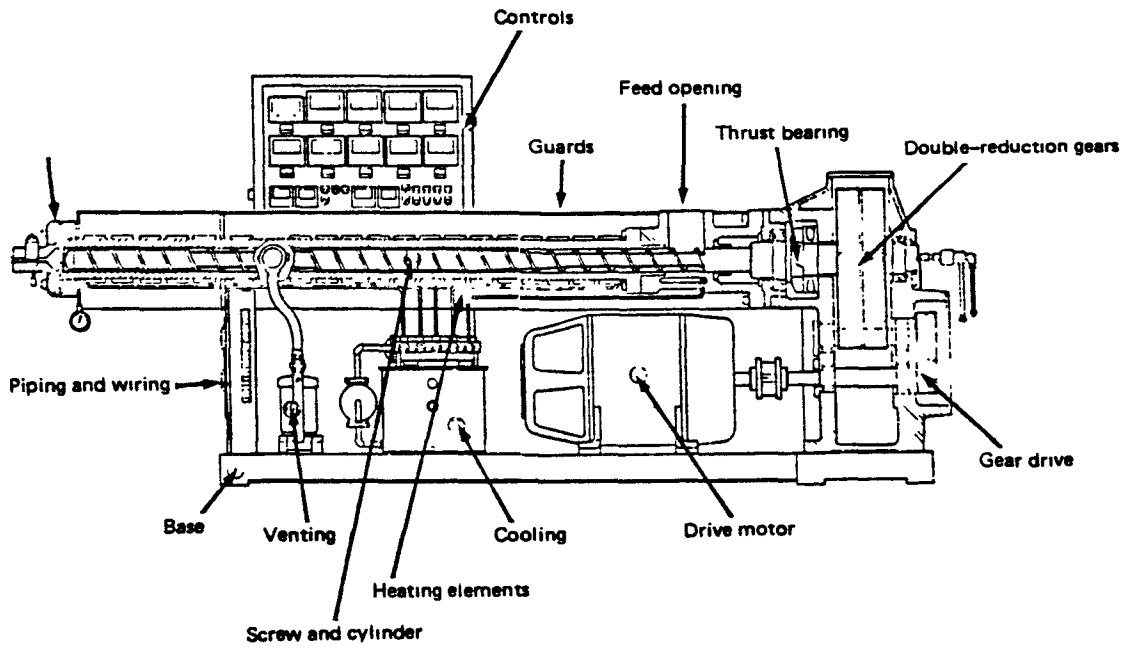


Fig. 6.a Extruder Drive System

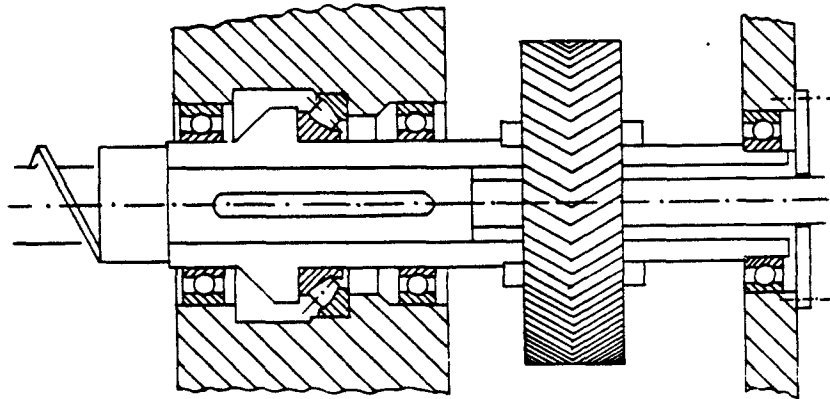


Fig. 6.b Thrust Bearing

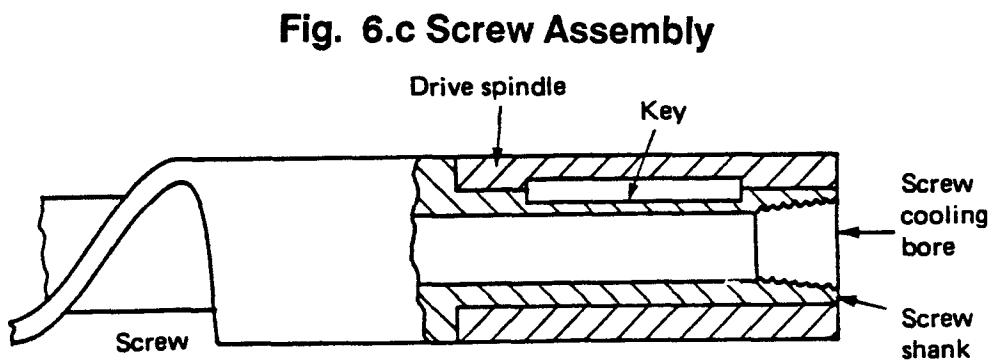


Fig. 6.c Screw Assembly

I.D. Drive System

The drive system as shown in fig. 7.a supplies the power/torque required to turn the screw at the desired speed, and must, in addition, provide speed variation, precise speed uniformity at each speed setting, the ability to retain speed setting with load changes, and efficient use of energy under broad range of operating conditions.

The electrical motor converts the electrical power to rotational mechanical power. The gear box is a mechanical transmission system between the motor and the drive spindle, this permits the operation of the screw within proper ranges of speed and torque. The thrust bearing fig. 7.b transmits the reaction forces due to extrusion pressure, to the structural frame of the machine. The backward thrust produced by the screw is taken by absorbed by a large bearing. Its life can be estimated^[3] as follows

$$li_{10} = \left[\frac{C}{P \times A} \right]^{10/3} \times \frac{16667}{N}$$

where, li_{10} = hours after which 10% of a group of similar bearings will fail.

C = basic dynamic capacity of the bearing in lb.
or Kg.

N = screw RPM

P x A = pressure at head x barrel cross-section area

The life of the bearing used in the extruders is shortened by the following:

- a. High speeds, and
- b. High pressures.

The drive spindle is a keyed hollow metal sleeve, as shown in fig. 7.c that transmits rotary motion from the drive system to the screw, and allows the screw to be easily installed or removed.

The drives may be D.C. motors with rectifying equipment to convert A.C. power to D.C. or A.C. motors with speed variators such as eddy-current couplings or changeable pulley ratios. The D.C. SCR (Silicon Control Rectifiers) package is the most widely used system for extruders. The SCR package consists of a D.C. motor which is connected with a solid state rectifier system which uses SCR's, the package offers mechanical simplicity, accurate speed control, efficient energy use, constant torque over a broad speed range, and low maintenance.[4]

II. EXTRUDER MANUFACTURING INDUSTRY

Killion Extruders have been manufacturing extrusion equipment since 1940 to meet the diversified needs of their customers. They undertake orders for manufacture of all kinds of equipment i.e custom built or standard. They offer a wide range of single and twin screw extruders, as well as, the corresponding dies and downstream equipment for most of the systems. All the equipment are production rated, and may also be used for laboratory environment.

The main policy of the company is, to supply the customer with all the manufacturing equipment and technical help the customer needs to manufacture a product. This helps them enjoy a greater market share, than if they manufactured only standardized equipment. The equipment and services offered by Killion include,

Single Screw Extruders

Co-rotating Twin Screw Extruders

Gear Pumps

Replacement Barrels, Screws, and Dies

Tubing and Profile Equipment

Cast film and Sheet Equipment

Blown Film Equipment

Compounding Equipment

Monofilament and Melt Spinning Equipment

Wire Coating Equipment

The services offered include, include,

Custom Design Engineering
Process Laboratories, and
Educational Training.

Due to the unique requirements of each customer they help them in selecting the right equipment.

The time required to manufacture the equipment is dependent on the type of parts to be manufactured, i.e., either standardized or custom-built. For every new type of part to be manufactured on the shop-floor especially custom built, new designs must be made, and tolerances must be decided. This varies the job completion time and hence the delivery date.

Since their main product is extruders, they must manufacture the different parts to the different size and capacity requirements of the customers. Although sometimes the customers provide the dimensions, most of the dimensions are pre-designed. For different capacities minor alterations must be made.

In addition to the manufacturing of extruders, Killion also builds replacement barrels, screws, and dies for extruders of all makes and models. The maximum screw size which can be specified is 3 1/2 inch. The materials of construction include 4140 tool steel, and various platings can be specified too. The screw design is matched with the

processing requirements. The requirements could be single stage screws, multiple flighted screws with various mixing sections or different design configurations.

Barrels are also matched with the existing operations of the customers. Barrels may be specified for standard processing parameters, or for more exotic applications.

Killion also fabricates dies for the various segments of its product line. They supply adaptors to match the dies with non-Killion equipment.

III. COMPUTER NUMERICALLY CONTROLLED (CNC) MACHINING

III.A. CAD/CAM overview

The various computerized functions under CAD/CAM fall into three general areas:

1. Design/drafting, or computer-aided engineering.
2. Planning/scheduling, or management of information systems.
3. Fabrication, or manufacturing automation.

The design process involves the manufacture of objects from basic elements and, by performing operations like adding, cutting, copying and orienting them to right places a complex model can be generated.

This completely defined model can be evaluated for its physical properties such as weight, volume, surface area, moment of inertia, and center of gravity for use of computers. The finite-element method may be used to determine the stress, deflections, and other structural characteristics. The result of this analysis can be used to animate the model to examine various deflections and vibrations of the structure under operating conditions.

The result is that with a CAD/CAM system, engineers and designers can view the complex forms from various angles at the push of a button instead of having to construct costly, time-consuming models and mock-ups. [7] Changes can be made quickly and inexpensively at the keyboard without requiring drawing changes, or modifications in the physical model.

After the design completion, the resultant geometric data stored in the memory of the computer may be used to produce numerical control instructions for making the parts on the automated machine tools, or to generate drill tapes for automated printed circuit card fabrication. Many CAD/CAM systems can now produce NC instructions automatically for a range of different part types. Tool paths may be simulated on the monitor to validate, verify, and modify the program more rapidly.

In general, a CAD/CAM system comprises distinct functional areas. The experts group CAD functions into four major categories:

- a. Geometric Modelling
 - b. Engineering Analysis
 - c. Kinematics
- and d. Automated drafting.

The CAM technology centers around following four categories:

- a. Numerical Control
- b. Process Planning
- c. Robotics
- and d. Factory Management.

III.B. Computer-Aided Design

In a typical CAD system, geometric features such as points, lines or arcs are entered with a graphic input device such as a mouse, or tablet. A set of cross hairs are used to indicate a reference point. The drawing process is aided by a function menu, which puts the system into different modes to construct basic elements with minimal effort.

There are three basic types of 3-Dimensional models whose manipulation requires CAD systems of varying complexities and cost. The simplest and the least expensive are the wire frame models. They represent the part shapes with interconnected line elements or stick figures. Many ambiguities of the wire frame models are overcome by the surface models, which define the outside part geometries precisely and help produce numerically controlled instructions. This definition of the structure boundaries is critical for proper functioning of the CNC systems. Solid models have the highest level of complexity, completely defining the external and internal geometry of the die or other such parts with complex geometries. This approach uses combinations of elementary solid primitives like cubes, spheres to create complex solid models.

Interactive graphics based NC programming

With an independent NC software package, the part geometry would be generated on an independent CAD system, placed in to electronic format and then transmitted into the NC software system.

The graphics based software lets the users easily define the geometry, to obtain immediate feed back and to visualize the results. The changes can be made quickly and cheaply. It thereby reduces the time required to set up and run the machine tool. To describe a part, the package provides a CAD-like "front end" which permits the user to create the parts using lines, circles, spines and arcs. A close relationship between model creation and machining of that model is very important. Major CAD/CAM vendors provide software that has integrated design and drafting functions. Thus, operating off the same database or a co-existent one, the NC software can directly access a model which was created within the design module of the CAD/CAM system.[8]

III. C. Computer Aided Manufacturing

There are lot of companies which offer a variety of CAD/CAM systems with a heterogeneous computing environment, so it becomes increasingly important to provide an effective means of exchanging data among the systems. This was required because each system "speaks its own language".[6] The first such standard format with a neutral database for geometric translation was IGES (Initial Graphics Exchange Specification). IGES was initiated in 1979 by the U.S. Air Force and was supported by other Department of Defense groups, industrial users, and other CAD/CAM suppliers.

PDES (Product Data Exchange Specification) is likely to replace IGES, because in addition to the geometric information provided by IGES, PDES also provides information such as material specifications, tolerances, surface finishes, knowledge-based engineering definitions, and form-feature definitions.[8] PDES is aimed at communicating a complete product model. It will provide sufficient information content to be directly interpretable by CAD/CAM applicable programs such as FEM (Finite Element Modelling), product and structure and generative process planning, CAD directed inspection, and automatic generation of the NC cutter path data.

Other data exchange options include,

1. DXF, an AutoCAD standard;
 2. SET, a french standard;
 3. VDA/FS, a german standard for 3D automobile surfaces;
- and 4. PDES/STEP, an evolving international standard that is based upon PDES.

Within CAM, the data processing capabilities have been exploited for production scheduling and inventory control, while the mathematical capabilities have been exploited for aiding the production of NC tapes. CAM can use or share the same database that the CAD system uses with the condition that they are compatible. This helps in reducing the time which would be needed to transfer the data from one system to another.

The CAM advances make it possible to produce instructions for complex shapes, and the tool paths can be verified quickly with computer simulations. In addition, the CAM systems nowadays also have process planning features for determining a sequence of fabrication steps and factory management capabilities for directing the flow of work and materials through the factory.

The CAM programs initially inspect the work space data and attempt to split up the data into various machining sections. This discrimination of data by the NC programs is aided by the fact that it is possible to determine which of the CAD modules was used to generate the data in the workpiece. Where the machine is unable to discriminate between the surfaces, the user is called upon to interact and help to specify the surfaces more clearly.

When the basic machining processes have been decided, the component is inspected to determine whether any rough cutting is necessary prior to the accurate machining. The user has the option of supplying all the information regarding the cutter sizes, feed rates, spindle speeds, and depth of cuts or of allowing the computer to calculate suitable ones or retrieving appropriate ones from a machineability database. This information enables the computer to automatically generate the cutter location data points, and with the aid of a postprocessor or an APT program to generate the NC part program. On completion of the process, all the tool movements over the component can be displayed on the graphics screen, or a hard copy of the drawing can be produced. This procedure acts also as a quality control aid, to ensure that the NC part program is correct and that no collisions will occur between the cutting tools and the machine tool.

Machining Strategy

Once the part is defined, interactive graphics software helps the programmers to create the tool path. There can be many different ways to machine a part, the only requirement is strict adherence to the part geometry and its associated tolerances. NC programs must handle design inadequacies such as surface discontinuities over the multisurfaced parts. The tool movement can be point-to-point or continuous-path motion.

There are basically five different types of NC or CNC machine tools according to the number of axes which are controlled by the controller of the machine tool. They are,

- a. 2 axis machining, in which movement is controlled in X and Y directions,
- b. 2 1/2 axis machining, in this, in addition to the movements in X and Y axis, the Z axis can be positioned, but cannot be automatically controlled,
- c. 3 axis machining, the tool can be moved or controlled simultaneously in the X, Y and Z directions,
- d. 4 axis machining, in addition to the simultaneous control of X, Y, and Z axis, rotary movement of the job/work is also provided, and
- e. 5 axis machining, this adds spindle or table movement to the four axis machining.

Proper machining strategies must^[9]:

- a. Avoid gouging of tool into the work piece.
- b. Avoid interference between the tool and the machine or fixtures.
- c. Control the scallop height between the cuts and avoid leaving excess material,
- d. Avoid tool breakage from too deep a cut or too rapid a motion,
- e. Compensate for the tool and machine wear,
- f. Avoid excessive machine chatter and vibration,
- g. Create continuous smooth surfaces over multisurfaced parts,
- h. Generate a consistent indent or tolerance over across numerous surfaces,
- i. Properly handle pockets, corners, and crevices that are difficult to reach,
- j. Recognize the changes in the properties of the materials being cut, such as change in the hardness from heat treating,
- and k. Optimize tool path sequences and tool changes minimize machining time within other constraints.

III.D. Numerical Control

Numerical Control is defined as a form of programmable automation in which the processing equipment is controlled by means of numbers, letters, and other symbols. The numbers, letters, and symbols are required to be coded in an appropriate format to define the program of instructions to perform any particular operation, [10]. The application of numerical control ranges over wide variety of processes. The most widely used applications of numerical control are,

1. Machine tool applications
as turning, drilling, milling, and other metal working processes, and
2. Non-machine tool applications
like assembly, drafting, inspection, and transfer of goods.

A numerical control system consists of the following three basic components,

1. Program of instructions,
2. Machine control unit, and
3. Processing equipment.

The program of instructions is the detailed step-by-step commands that direct the processing equipment. The program of instructions is coded on a suitable medium to be transferred to the machine control unit.

The machine control unit (MCU) consists of electronics and hardware that control the movement of the tools and other devices that are involved in the operation or the process. The control hardware reads and interprets the programmed instructions and converts them into mechanical actions of the machine tool or other devices which are under its control.

The processing equipment constitutes the third basic component of the NC system. This component performs the useful work for the system. An example of such an NC system can be, the processing equipment performing machining operations where the machine spindle, worktable, tool motors form the processing equipment.

Need of Numerical Control

The main reasons for the need to develop control systems for machine tools are the high accuracy in the manufacturing of complicated control parts, and saving of the working time.

The accuracy is most important when two parts that have to be adapted to one another are produced, as in case of piston and cylinder or in our case screw and barrel. Producing a part that has to be cut within accuracy of 0.01 mm or better may take considerable amount of time on the part of the worker, who has to stop the cutting process frequently and measure the dimensions to ensure that the part is within the dimensioned limits. It was proved that the time wasted on such measurements was in range of 70 to 80 percent of the total working time[10].

There are number of reasons why NC systems are being adopted so widely in the industry. The advantages of numerical control when utilized for small production quantities include,

1. Reduced non-production time.

Numerical control cannot change the basic metal-cutting process, but it can increase the proportion of the time the machine is engaged in cutting the metal. It accomplishes this decrease in the nonproductive time by means of fewer setups, less setup time, reduced work piece

handling time, automatic tool changes on some machines, and so on.

2. Reduced fixturing.

Numerical Control requires simpler fixtures because the positioning is done by the NC program rather than the fixture or jig.

3. Reduced lead time.

Jobs can be set up more quickly with NC.

4. Greater manufacturing flexibility.

NC adapts better to the changes in jobs, production schedules, and hence the delivery dates, and so on.

5. Easier to accommodate engineering design changes on the work piece. Instead of making alterations in a complex fixture, the program can be altered.

6. Improved accuracy and reduced human error.

NC is a deal for complicated parts where the chances of human mistakes are high.

and 7. Earlier payback period.

Since the machine can be operated for more than one shift, the payable period becomes shorter due more utilization of the machine in same period of time.

III.E. Advantages of Numerical Control

From the above it can be observed that NC is appropriate for,

1. Parts which are processed frequently and in small to medium lot sizes.
 2. Part geometry is complex.
 3. Close tolerance must be held on the work part.
 4. Many operations must be performed on the part in processing.
 5. Engineering design changes are likely.
 6. The part to be manufactured is expensive, and mistakes in processing would be costly.
- and, 7. Parts requiring 100 % inspection.

III.F. Computer Numerical Control

With the advent of computers in the this field some of the drawbacks of the NC systems are overcome and the performance and abilities of the process are improved. There have been several enhancements and extensions of NC technology, including,

1. Direct Numerical Control
2. Computer Numerical Control
3. Adaptive Control

Direct Numerical Control (DNC) involves the use of a central large computer to direct the operations of a number of separate NC machines in real time. Computer Numerical Control (CNC) involves use of a single dedicated microcomputer as a machine control unit of the NC machine.

Adaptive control determines the proper speeds and/or feeds during any machining as a function of variations in factors such as work-material hardness, width or depth of cut, air gaps in the part geometry, and so on. Adaptive control denotes a control system that measures output variables and uses them to control the inputs to the process.[11]

III.G. Advantages of Computerized Numerical Control Systems

Automation has become necessary in the manufacturing industry because of,

1. Increased Competition,
 2. Demand for Quality Products,
 3. Increasing the Production,
 4. Improving Safety in the Working Environment,
- and 5. Reduced Supervision.

The increased competition in the market with competitors providing better quality of products at affordable prices makes the producers situation more sensitive in terms of stability in the market. This forces the producer to manufacture the products with saleable features of quality and reliability[11].

The demand for high quality goods at lower price in the market puts pressure on the producer to reduce the cost of manufacture of the goods. This can be performed in many ways. Use of automation can be one of them depending on the type of production and the cost implications.

III. H. PROCESS PLANNING

Process planning is an area of manufacturing that can yield rich fruits of time and money saving. Parts in processing spend 95% of the time required to make them in waiting. [12] Process planning deals with manufacturing processes. It helps in developing of a logical sequence of manufacturing operations for a given part. The physical aspects of these operations is most obvious, but the economic and social aspects are the fields in which determination of their degree of logic is made.

The job of a process planner is to determine the sequence of operations and interpose the appropriate inspection and testing processes while taking into account factors like, availability of machine tools, deadlines, and the present mix of jobs in the shop.

The plan is usually expressed in the form of a process sheet which lists the sequence of operations, the machines on which the operations are to be performed, the estimated time needed for each operation, and the required tooling. The process sheet is often illustrated, and it may be accompanied by setup and work instructions and routings.

A variety of considerations, including delivery schedules, machine utilization, and economic processing quantities, as well as material availability and work in process (WIP)

inventory, must be balanced in the production of a process plan in addition to the simpler physical issues of determining the appropriate machine and tooling for achieving a particular effect.

Process planning belongs to the category of problems mathematicians call scheduling problems. The difficulty in scheduling issue is: for n jobs and m machines, there can be $n!^m$ schedules generated.[13] Basic to process planning systemization attempts is the recognition of the need for part classification. Relatively few new parts are produced in any industry, and process planners rely heavily on their ability to identify the similarity of a new part to a part for which a plan already exists. The new plan can then be created by copying and modifying the old one.

The awareness that parts with similar geometry and processing requirements are more efficiently produced in groups than separately has led to the birth of a manufacturing philosophy called Group Technology (GT). The driving principle of GT is part classification and coding. Parts are grouped and coded according to their similarities such as size, machining processes, and materials, using alphanumeric codes. Benefits of GT are many and varied, with respect to process planning. It implicitly performs the first step in process planning i.e. classification. This

coding is a prerequisite to the introduction of computers in process planning activity.

In the earliest attempts to use computers in process planning, now called *variant process planning*, the computer was used as file management and word processing equipment.

In *generative process planing*^[13], descriptions of the parts, the manufacturing processes, the machine tools, and the tooling (in the form of codes, as mentioned above) are entered in to the computer system and the system generates a process plan.

Both variant and generative CAPP (Computer Aided Process Planning) depend on GT, to great extent, for high productivity gains. CAPP provides feedback regarding the producibility of designs and this helps the manufacturer by making better use of capital equipment and reducing the lead times. In a full computer-aided manufacturing (CAM) environment, feedback from the automated manufacturing processes can be routed directly to the CAPP system to further enhance its performance.

III. I. Productivity increases due to CAD/CAM

1. Drawings which are frequently updated can be much more efficiently drafted with a CAD system.
2. Bills of material and technical illustrations are very quickly produced if they can be derived from a common database shared by a CAD system.
3. Calculations of arc, volume, weight, and deformation are best performed by a computer. Also, design tasks that involve fitting together or housing a number of parts are very efficiently performed.
4. The use of CAM software to plan the manufacturing process from the design data greatly reduces the effort necessary to get a part into production.
5. Scheduling and shop loading is improved by the CAM software due to standardization of operation sequences, tooling and machine tool selection. [14]
6. The CAD/CAM system allows for a quick response to changing market demands because product changes and improvements can be made without costly downtime.

7. Productivity of the overall system is improved by the use of better methods, better tool selection and optimum speeds/feeds.

IV. COMMERCIALY AVAILABLE EQUIPMENT

There are lot of companies in the market which offer a wide range of CNC equipment. They offer machine tools of different kinds according to the basic machining operations performed by the machine tools. Each family or each product line of these machine tools includes equipment of various sizes and capacity.

The main product lines which can be classified according to the elementary machining operations are,

1. CNC turning centers,
 2. CNC machining centers,
 3. CNC profiling centers,
 4. Flexible cells and systems,
 5. CNC grinding machines,
- and 6. Other specialty products such as,
- CMM's - co-ordinate measuring machines
 - EDM's - electrical discharge machines.

IV. A. CNC Turning Centers

This machine tool product line, as the name suggests, includes machine tools which perform the basic operation of turning and in some cases boring and drilling. The job is held in the chuck and turned, while the tool is held against the job. There are two axis X and Z, under the control of NC controller. Jobs with complex cylindrical shapes can be easily machined on the machine tools. These machine tools can be used for high volume production as well as low volume production purposes.

The major specifications to be considered while selecting a turning center include:

- a. The size of the chuck used on the machine tool.
- b. The number of axis available on the machine.
- c. The travel of the tool table along the Z axis.
- d. The number of turrets that are available or can be installed on the machine tool.
- e. The number of tools that can be used on the turret/s.
- f. The maximum depth of thru hole which can be drilled on the machine tool.
- g. The maximum speed (RPM) at which the machine tool can be used.
- and h. The power of the main spindle drive.

Comparision between different Machine tools available in the Market

The following machine tools are Horizontal Machining Centers (Company name, Model)

Properties	Leblond Makino, A55	Hitachi, HG-500	K &T, Milwaukee 1015	
<u>Axes of Travel</u>				
X-axis	22"	28"	24"	
Y-axis	22"	27"	24"	
Z-axis	22"	24"	20"	
Table size	400 mm x 400 mm	20" x 20"	18" x 18"	
Max. Table Load (lbs)	400 Kg.	1760	2000	
<u>Power Requirement</u>				
Spindle Power (HP)	22 Kw.	20	15	
Drives Power (HP)	3.5 Kw.			
CNC Controller	FANUC / YASNAC	FANUC 15M	KT- GEMINI -D	
<u>Automatic Tool Changer</u>				
Number of tools	12 (40, 60, 120)*	40 (60, 90, 120)*	30 (45)*	
Max. weight of tool (lbs.)	8 kg	44	33	

* Optional

TABLE 1. Horizontal Machining Centers

IV. B. CNC Machining centers

This product line includes the machine tools which can perform most of the machining operations using a single set up. Hence it is known as a machining center. The basic design of the machining center, allows a manufacturer to combine a number of operations such as drilling, tapping, milling, and turning, into a single machine. In most cases the job is stationary while the tool is in motion and performs the cutting operation. There are times when the work table is indexed while the tool remains the same and, machining is to be performed on another surface.

Prior to the NC machining center, it was necessary to run a work piece or job through a number of machines to accomplish what could be now performed on a single machine[15]. There was an enhanced improvement in the manufacturing efficiency of small lot size jobs. There was a reduction in the time to move the jobs from one place to other. There was also a reduction of labor by 33 % and more.[12]

There are two types of machining centers available in the market. They are classified according to the orientation of the spindle of the machine tool. They are, Vertical Machining Centers for vertical axes of rotation of the main spindle, and the Horizontal Machining Centers for horizontal axes of rotation of the main spindle.

Comparision between different Machine tools available in the Market

The following machine tools are **Vertical Machining centers** (Company, Model)

Properties	HASS VF-1	Hitachi VK-45	Kearny&Tucker 1300V	Mitsubishi, MV 60 C
<u>Axes of Travel</u>				
X-axis	20"	30"	20"	39.4"
Y-axis	16"	18"	16"	23.6"
Z-axis	20"	18"	18"	21.7"
Table size	26" x 14"	44" x 19.1"	16.5" x 28"	23.6" x 55.1"
Max. Table Load (lbs)	750	1650	1100	3300
<u>Power Requirement</u>				
Spindle Power (HP)	5.0 / 7.5	10	5.0 / 7.5	15 / 20
Drives Power (HP)	.75			
CNC Controller	FANUC / YASNAC	Seicos M II	G.E. FANUC	M-NAP II
<u>Automatic Tool Changer</u>				
Number of tools	16	20 (30,50,80,120)*	24	24
Max. weight of tool (lbs.)	12	22	15.4	33

* Optional

TABLE 2. Vertical Machining Centers

The major specifications to be considered while selecting these machine tools include,

- a. The permissible axes of movement of the table or job and the maximum limits of travel of the table or job.
- b. The size of the table or the maximum size of the job that can be accommodated on the table.
- c. The maximum load which can be carried on the table.
- d. The power of the main spindle motor.
- e. The type of spindle nose.
- f. The spindle speed range.
- g. The cutting feed rates.
- h. The maximum rapid traverse rate.
- i. The tool capacity of the Automatic Tool Changer (ATC)
- and j. The type of CNC controller used by the machine tool.

This is most important because it should be compatible with the CAD / CAM with which it is used.

However a machining center loses its edge when it comes to high volume production[12]. The primary reason being, only one spindle is available for performing any operation. When there are number of operations to be performed, there are an equal amount of tool changes to be performed. This takes away time along with the time taken by the operator to replace the parts. To some extent this was taken care of by the use of pallet magazines, creating "Flexible Manufacturing System"[12].

IV. C. CNC Profiling Centers

This product line of machine tools includes the heavy duty type of machines. There are situations when the CNC machining centers cannot be used for some reason, such as in the case of the machining of a car body die or a huge stamping die. As these dies are complex in their shapes and typical in their sizes (longer length, short height and width), and they need to be machined mostly on the surface, a new type of machine tool has been developed, called the CNC profile machining center. The job is fixed on the table, and there can be both types of motions i.e the tool moving (cutting) the work-piece or job and, the job moving with movement of the table. These machine tools are capable of machining large size jobs such as a whole car body molds or die. They are designed on the basic planing type of operation, and can have one or more tool heads on the cross head of the column. The more the number of tool heads, the cost of machine tools increases. Most of their specifications remain the same as those of the machining centers.

IV. D. Flexible Cells and Systems

For several years a gap existed in manufacturing efficiency between the more flexible but slower single spindle machining center, and the faster but inflexible, dedicated transfer machine. A new concept, which essentially bridges the gap between a single spindle machining center and a rotary dial indexing machine, offers manufacturers an alternative method to achieve flexibility and high volume production. The machining units which are, in effect, small CNC machining centers are spaced around the rotary transfer unit and perform simultaneous operations as the work piece is indexed from station to station. The replacement of the conventional machining units allows total flexibility within the travel range. The setup is accomplished through loading the appropriate part program in the CNC systems memory. The program then commands each machining unit to perform the designed machining operation. All functions, such as index, tool change, and spindle speed change are under the control of the CNC system program.

This concept thus combines the best of the both worlds. It requires no set-up time like the CNC machining centers, and has metal cutting efficiency of conventional rotary dial index machines. [12]

V. MATCHING NEEDS TO EQUIPMENT

CNC equipment is primarily required in the extruder manufacturing industry for the manufacture of,

1. Helical screws,
- and 2. Dies.

The type of resin for which the equipment is to be used determines the design of the equipment for the required purpose. The main changes necessary in the screw design are because due to the fact that polymers have different physical and chemical properties like, melting points, bulk densities and melt viscosities. This difference in the properties requires changes to be made in the design of the screw.

For example, a certain polymer has a low melting point and at the same time it cannot be kept under a hot environment for more than 3-5 min., else it would start degrading. For such a polymer it becomes necessary to quickly form the required shape and cool it. In other words the residence time for the polymer in the extruder has to be kept minimal. This can be conducted in two ways, either reducing the channel depths of the extruder screw or increasing the speed of the extruder screw. The first option can be implemented by the changing design of the screw, while the second one can be implemented by increasing the speed of the extruder

screw so that the polymer is pumped out as soon as it is melted. However, the second approach has limitations of the maximum speed (rpm) at which the extruder can be operated. Hence it becomes important to make the design changes in the extruder screw rather than in the operating characteristics of the process. The changes in design are usually to be made in the feed section and the metering sections.

This is because depending upon the properties of the polymer they require either higher or lower residence times inside the extruder to be properly melted but not degrade. By making appropriate changes in the feed zone, thereby reducing the intake of polymer, and in the metering zone, thereby controlling the exit time for the polymer, the right design can be accomplished.

Thus it is necessary to design several types of screws for a whole range of extruders for every product line.

A library of screw designs of different types has already been developed using CAD technology. The conversion of these designs into products can be performed in many ways.

One of the ways to accomplish this task is to interface the CAD system with a CAM system which further connects it to an NC or a CNC machine tool. The interfacing can be achieved by means of telecommunication cables.[13]

The actual process of conversion of a product from its design in the CAD system to a finished product using the computer technology can be performed as follows. The design performed using the CAD system has to be first coded in a suitable code which can be understood by the CNC machine tool. There are many different types of software available in the market for this purpose, one of the most widely used is SmartCAM.

SmartCAM converts the code of the designed part into a code which can be understood/read by the NC or the CNC machine tool on which the actual machining of the part is to be conducted. Once this is completed the new object code can be transmitted to the CNC machine tool using the telecommunication lines or RS-232 cables.[16] The transmitted code is in a form that can directly give commands to the controller unit of the CNC machine tool for the various operations to be carried out. Once the code is loaded and the tool path is verified the product can be manufactured directly.

In the absence of CNC machine tools, the part design from the CAD system has to be converted into an object code manually. This is a cumbersome and tedious task, and in addition, skilled personnel are required to do the job.

Since the parts under consideration are, an extruder screw and a die, all of the conditions mentioned above are appropriate to them. Hence a CNC machine is most appropriate machine tool for the manufacture of these parts.

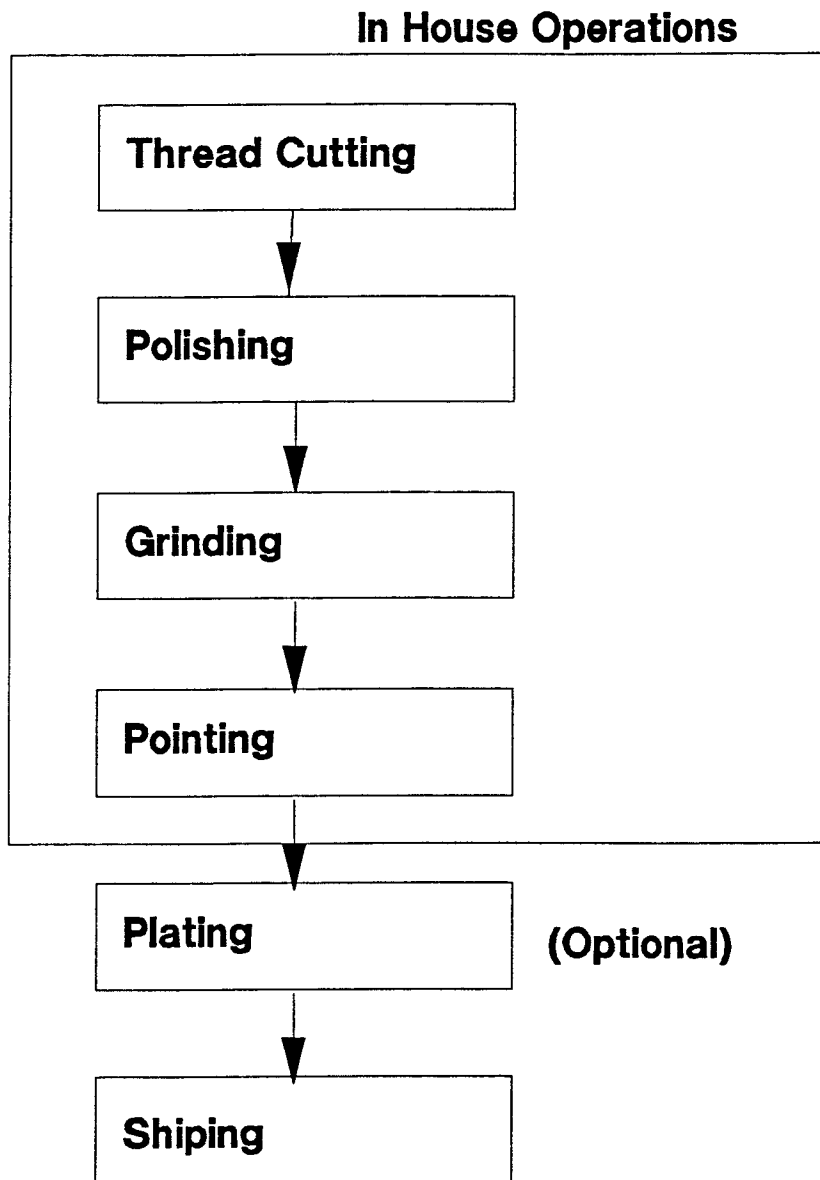


Fig. 7. Routing for a Extruder Screw
at Killion Extruders

V. A. Manufacture of Extruder Screws

Extruder screws are manufactured from cold rolled bars of high grade steels, and special alloy steels. The industrial manufacturing unit under study uses three main grades of steel. They are SAE 4140, SAE 416 stainless steel, and Hastalloy.

A typical single threaded 1" diameter screw is manufactured as follows. The screw is cut by[4],

1. A cold drawn bar of required size slightly greater than the final O.D. of the screw (in our case the size of the bar can be between 1.01" to 1.015") is loaded on the lathe and facing and center drilling is performed.
2. In the next step the bar is properly adjusted between the chuck and the center, and the milling cutter is positioned at the end of the bar from where the cutting is to be initiated. The milling cutter is attached on the tool slide of the lathe.

3. The cut is taken to a predetermined depth and then, the tool slide is engaged with the lead screw of the lathe, the pitch being equal to the diameter of the screw being cut (in our case 1").
4. The tool slide is disengaged from the screw at the end of the each of the three sections. This is defined by the screw design, which in turn depends on the usage of the screw.
5. The tool slide is taken back to the point where the previous cutting was started. The depth of the cut is increased if required, else the cut is started from the adjacent point. The process is repeated until the desired design geometry of that section is achieved.
6. Once one section is completed the same procedure is applied to make the other sections of the screw.
7. If there is a particular type of mixer to be cut at the end of the screw it is cut.
8. After completing the cutting of the thread and the mixer the keyway is cut to finish cutting of the screw.

The screw is then, polished.

1. The cut screw is loaded on the polishing machine. This is a lathe with a polishing belt attachment on the tool slide. The polishing belt is set at the helix angle of the screw.
2. The belt is made to pass inside and over the channels of the screw to remove burrs and rough edges on the screw surface.
3. The belt, as well as, the screw are in motion, and hence there is uniform material removal from the surface of the screw. The grit size of the belt is reduced as the number of passes increases. This is performed in order to obtain good surface characteristics for the screw.

The polished screw is removed and set on the grinding machine to grind off the excess material (0.01" - 0.002") left from previous operations, to obtain the exact O.D. dimensions and to eliminate any defects (bending) caused by the preceding operations.

After the grinding operation is completed at the head end of the screw, a cone is made or is pointed off. This is performed to assist screw alignment with the tooling head

while assembling it with the extruder and to avoid stagnation of material. [6]

The operation of plating the screw is performed only if the customer specifies it or if there is any need for it in the design itself.

The hardening of the screw is performed prior to all the machining operations.

The most popular type of coating operations performed are,

1. Chrome-plating,
 2. Nitriding,
- and 3. Cyaniding.

These operations are performed in order to make the surfaces of the extruder screw and the barrel hard and wear-resistant. This is because under the operating conditions the barrel surface and the surfaces of the extruder screw are under heavy thermal and physical stresses due to the high pressure build up by the melt. This can easily wear off the surfaces of the screw and the barrel. Hence the hardening of their surfaces increases their life.

Nitriding

This process, also known as carbonitriding or gas cyaniding is a case hardening process which produces a hard surface layer on ferrous alloys. In the process carbon and alloy steels are held at an elevated temperature in a atmosphere containing carbon and nitrogen. These elements are then absorbed simultaneously by the hot metal, and when the metal parts are cooled to room temperature at a controlled rate the desired case and core properties can be derived.

The process of nitriding is carried out at temperature range of 705 to 1650 C.

The final properties of the surface layer (case) and the interior (core) are achieved by appropriate heat treatment on the part after nitriding.[17]

The process can be performed using three methods:

- a. Gas Nitriding,
 - b. Liquid Nitriding,
- and c. Ionitriding.

The mechanism of nitriding is as follows. Ammonia is added to gas nitriding mixture. Ammonia dissociates to produce hydrogen and monoatomic nitrogen. The latter is absorbed into the surface of the workpiece along with the carbon from the other gases in the mixture.[17]

The addition of nitrogen has two important effects:

1. It inhibits the diffusion of the carbon, which favors production of a shallow case.
2. It enhances hardenability which favours attainment of a very hard case that is easily polished and highly wear resistant.

The liquid nitriding cases have higher nitrogen content than gas nitriding. [17]

After the thread or channel is cut the screw is given a finish turning cut over the length of the screw. The finished screw at this stage is further processed for hardening of the screw surface. This operation of surface hardening is performed according to the different requirements for which the screw is to be used.

Once the heat treatment is completed the screw is polished and properly packed.

V. B. Manufacture of Dies

The manufacturing of the dies for the extrusion process follow the same lines as that of the extruder screw. They are also manufactured from higher grades of steel and special alloy steels. Killon extruders do not manufacture extrusion dies, they get them made from external resources.

The operations to be performed depend on the purpose for which the die will be used e.g. for tube extrusion the required shape of the die is cylindrical, so fine hole drilling of the die, and boring can be the primary operations. Then honing the hole can be the finishing operation on the die. If the die is to be used for profile extrusion, then the die can be cut using wire cutting operation as well as other manufacturing processes.

If the die is to be used for sheet extrusion then most of the above mentioned operations are required to be performed on the work piece. These sheet extrusion dies are wide in size and need a well machined cavity to be sunk in it, in order to evenly spread the melt pool coming out from the extruder.

V. C. Requirements from the machine tool

The machine tool required for our purpose can be selected on the basis of production priorities.

The manufacturing operations as mentioned above indicate that, the machine is required to perform operations like thread cutting, milling, drilling and polishing. A machine tool which can perform all these operations requires,

- a. 2 axes for horizontal movements of the table,
- b. 1 axis for vertical motion of the cutter motion,
- and c. 1 rotational axis required for the indexing mechanism to perform indexing for thread cutting.

There is no machine available which can provide all the above mentioned movements. Hence two or more pieces of equipment are combined in order to achieve the required movements. This can be performed by combining a 3-axis CNC vertical machining center with an additional indexing mechanism which can be attached on the machines table.

All of the above mentioned operations to manufacture extruder screws and dies can be incorporated using the above mentioned CNC machine tool set up. The chuck of the lathe used for holding the bar while cutting threads on the conventional machine is replaced by the rotary indexer, which can hold the bar. The rotation of the bar by the

indexing mechanism can be programmed to index the bar with a linear motion of the machine table.

This same setup of machine tool can be used for machining of dies needed for extrusion and other purpose. The number of operations to be performed to manufacture the die and the number of the tools which are required will determine the number of tool changes that will be required to manufacture a single die. This in turn will allow the capacity requirement of the automatic tool changer to be determined.

With the use of a CNC machine tool the same process of cutting the screw becomes easier because all the operator has to do is to load the raw material bar on the machine setup and set the zero of the machine. Then the machine can be allowed to take over all the operations of cutting the screw to polishing. The use of CNC will not eliminate the grinding operation as the speeds needed for the grinding process (18000 rpm) cannot be achieved on a CNC machining center[18].

The use of CNC machine tool for the manufacture of extrusion dies becomes easier for the same reasons as above.

VI. DISCUSSION

A machine tool or a major piece of equipment represents a major investment of company resources with long-term consequences. The machine or equipment specification should thoroughly define the performance requirements of, what the machine is to be used for, its warranty requirements, spare parts and service needs, as well as acceptance criteria[19].

The selection for a new machine tool or equipment becomes necessary due to

1. Obsolescence,
 2. Refurbishment,
- and 3. Worn Beyond Repair.

Obsolescence

In any capital equipment evaluation analysis, two series of costs must be considered. The first is known as the capital recovery costs, that is the recovery of the initial investment for the new equipment or machine. The second series is the annual operating and maintenance costs.

Normally, these costs increase each year as the maintenance costs increase with the age of the machine. The rate at which these costs are recovered depends on the method of depreciation used. The net savings in any of the machine tools or major equipment items to be purchased can be divided into direct and indirect savings.

Direct savings consist of savings in machining time through the use of the machine tool which will replace the existing equipment. That is the hours it takes for the existing equipment to complete the work minus the time it would take to do the same work by the use of new equipment or machine tools. Savings in hours are then converted into equivalent dollars by using the appropriate operators rate of pay of the machine.

Indirect savings occur in all facets of total machining costs. These usually include the maintenance costs, tooling costs, programming costs in case of NC or CNC equipment, scrap, floor space and material handling.[19]

After years of no real advance in machine tools, the state of the art technology in machine tools has in many instances, made it more economical to dispose of an otherwise good piece of equipment with new equipment that offers improvements in production rate and quality.[7]

The method to justify an equipment purchase under such a condition is known as a "aggressive" justification[20].

Refurbishment

There are many instances where a major machine tool or a piece of equipment has given good service over several years, but now shows signs of excessive wear and requiring maintenance and downtime. Under this situation there are two options, either replace the machine tool with a new one when it is not possible to repair it due to technological improvement over the present item or to refabricate / refurbish it. In the first case, if that decision is going to put a severe strain on company resources, then it is always better to choose the second solution. The refurbishment of the machine can extend the machine life for several more years. Usually the refurbishment can be performed by the original manufacturer and often costs less than buying a new machine. In most cases a rebuilt machine carries a limited warranty and performs like a new machine.

The method to justify an equipment purchase under such a condition is known as a "cost saving" or conservative approach for justification[20].

Worn Beyond Repair

Equipment that is worn beyond economical repair should be replaced. Such equipment should be taken into the capital equipment budget for the fiscal year and a 5-year capital equipment plan. To identify such machines, periodic checks must be made on the machines used for the production of,

- a. machine tool accuracy,
 - b. table travel,
 - c. spindle run-out,
- and d. host of other checks to indicate whether the machine tool can maintain the tolerances it was designed to meet.

One of the worst possible situations is to have a worn out machine tool which cannot be used for production, occupying valuable floor space. Such worn-out surplus equipment should be disposed of as quickly as possible.

The selection of a particular type of machine tool will depend on the actual use of the buyer. The following questions may be able to guide the buyer in the decision to buy a CNC machine tool.

The method to justify an equipment purchase under such a condition is known as a "defensive" approach of justification_[20].

Economic analysis

There are two aspects of economic analysis, namely

- a. Introduction of computerized numerical control in the facility,
- and b. Justification of a particular CNC machine tool.

As far as the introduction of a CNC machine tool is concerned the machine tool is important from the following point of view,

1. The quality of the parts to be manufactured using this machine tool.
2. The increase in production of the machined parts.
3. Reduction in the WIP of the machine shop.
- and 4. Reduction in inventory and material handling in the machine shop.

The justification for purchase of a machine tool can be viewed in two forms,

1. The right type of machine tool required for the manufacturing purpose,
- and 2. The economic considerations for introducing the machine tool to the shop floor.

The machine tool selected for the purpose of replacing the existing machine tool (lathe) is a 3-axis CNC machine tool with an indexing mechanism substituting for the 4th axis.

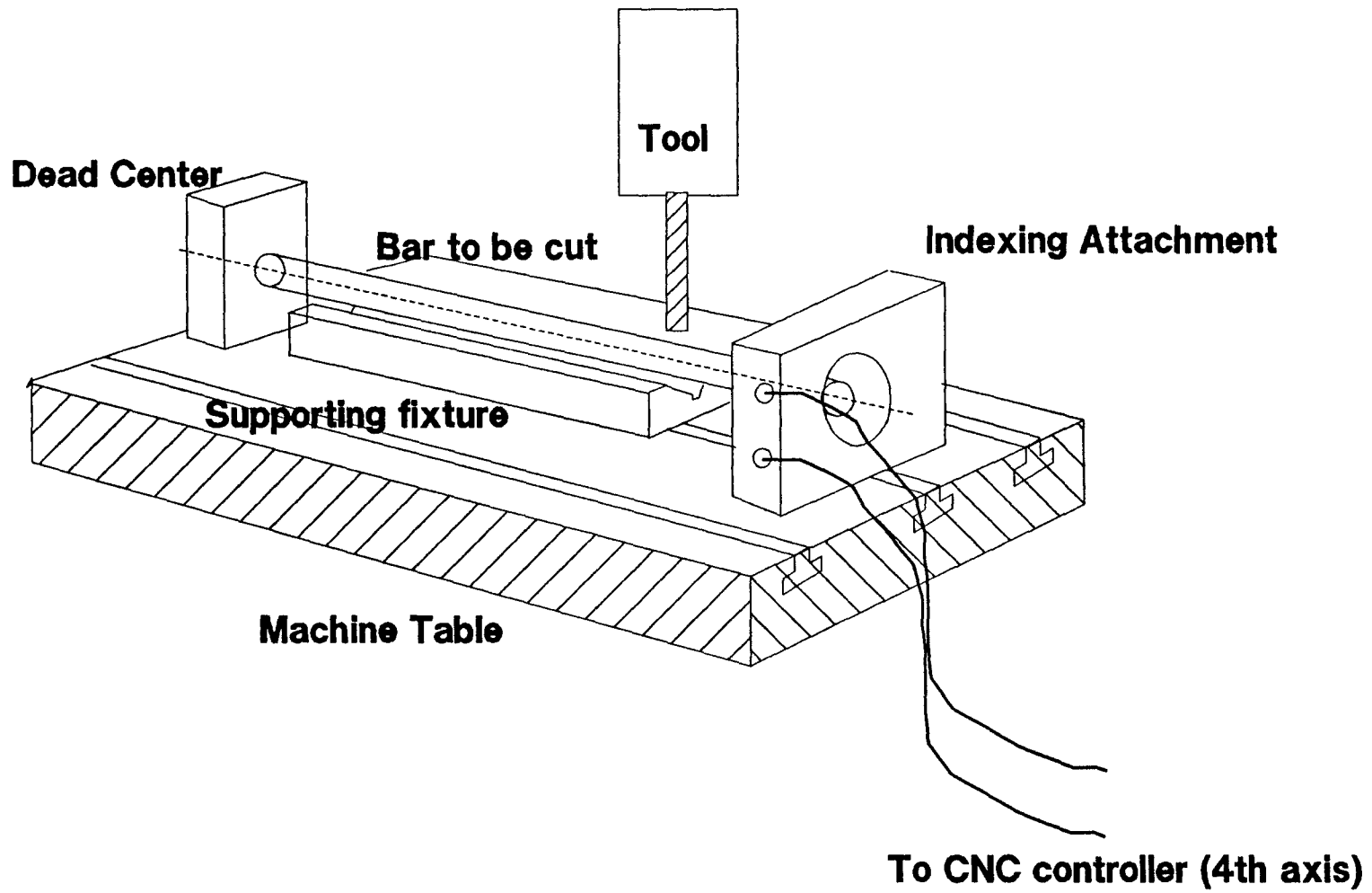


Fig. 8. SET UP ON THE CNC MACHINE TABLE

The reason for selecting this particular machine tool are:

1. The 2 axes X and Z under CNC control help in controlling the motions on the horizontal and vertical planes while cutting a screw, and the indexing mechanism attached on the machine table fig. 8 controls the indexing of the bar.

This helps in reducing the setup time to load the screw by allowing the zero positioning feature available on most the controllers of CNC machine tools. The zero positioning feature of the CNC controller just needs the reference point. This allows the operator to setup the bar on the indexing mechanism / indexer and then just take the machine table under the cutter at the particular reference point and start the pre-programmed screw cutting (machining) cycles.

2. The control of X, Y and Z axis of this machine become useful while cutting / machining a die required for a extrusion process.

This is because the extrusion dies are of various types as discussed earlier. Each of them has different design characteristics and accordingly different machining operations to be performed, the types of operations decide the tools required and the time at which they need to be changed. The use of CNC eliminates the frequent changing of the tools by using a proper tool changer, an ATC.

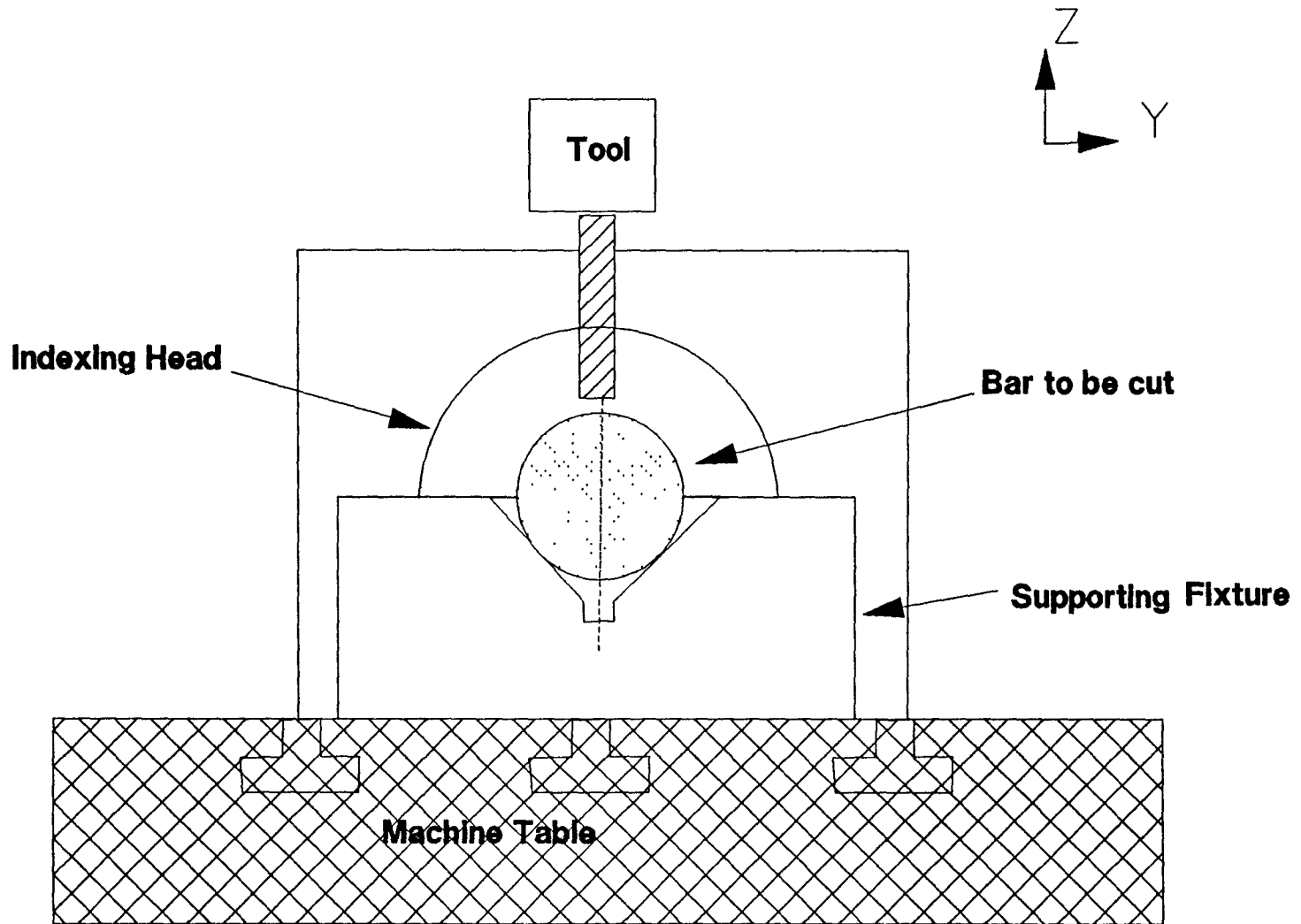


Fig. 9. CROSS-SECTIONAL VIEW AT MACHINE TABLE

The Automatic Tool Changer (ATC) can store from 12 upto 120 different tools, but there are changers of lower capacity available which can be selected depending upon the different tools required. The decision as regards to the size of the tool changer depends entirely on the types of the jobs the machine tool is required to handle. The selection of a tool changer should be done only after the operations to be performed are properly are planned and sequenced using process planning. The ATC capacity selection process can aided by knowledge of machining of such parts in the past. This gives the number of tools required while the operation was performed, allowing a safe margin for additional tools in the future a estimate can be made. The use of the tools changer reduces the tool change time and the resetting time needed after the tools are changed.

The time required to make a screw depends on

1. The diameter D of the screw.
2. The material of the screw i.e. either 4140 or Hastalloy, because both of them have different cutting speeds and feed rates.
3. The L/D ratio of the screw.
4. The variations in the depth of each sections

Check List for the selection of a CNC machine tool

Since CNC machine tool is a capital item of purchase, the decision making process becomes more important. There are few guidelines to select right type of the machine tool according to the required purpose.

1. The parts which are to be machined on the machine tool should be distinctly defined.

This helps in visualizing the further selection procedure of a machine tool.

2. The maximum dimensions of the parts that will be machined using the new machine tool.

This helps in determining the size of the machine table needed for performing the operations.

3. The number of axis on which numerical or computerized numerical control is required.

This helps in deciding the machine tool configuration which will be most suitable for the purpose. Because if a 2-1/2 axis machine can do the job, and we select a 3 axis or a 4 axis machine tool, there is vast difference in the base costs (approximately \$5,000 to \$9,100 for each additional axis).

4. The number of operations that will be required for each of the parts to be manufactured using the machine tool.

From this number of operations, how many of them will be required to be performed on the machine tool. This will help in determining the number of tools required to perform those operations. This leads to make decision regarding the capacity of the automatic tool changer (ATC). The tool changer is a important part of the CNC machine tool, because if we want to reduce the human interference (due to safety reasons) in any processing the process needs some form of automation which can eliminate human element from the process. By using a tool changer the machine tool does the changing of the tools for each operation as required by the program sequence. There by the machine can be allowed to work on its own once the programmed cycle is started. Use of the tool changer reduces delays caused due to absence of operator at the time when tool change is required and/or the operator is busy with other tasks.

The economic considerations for introducing this machine on the shop floor can be analyzed on following lines as discussed in the case study.

CASE STUDY

General Replacement Minimum Cost Model

One of the most widely used model for economic justification of CNC machine purchase is General replacement Minimum Cost Model[21].

The model shown below can be used to develop minimum costs for both the present and proposed investment. However, to calculate minimum costs, it must be assumed that exact costs of present equipment can be collected and future costs of the proposed equipment can be predicted with some degree of accuracy.

To develop data for the model it is desirable to use present worth and capital recovery factors. This use allows for the recognition of the time value of money. The cost of finance available is a variable, a dollar received today has greater value than a dollar received one year from now. This discounting is accomplished through the use of present worth factors. In addition, once the total present worth of a time series is known, time adjusted annual costs can be calculated through the use of capital recovery factor.

In any comparative study between two or more alternative purchases, similar activities should be used for the cost comparison[22]. Refined methods of cost analysis suggest collecting detailed cost data on both conventional and NC machines for making a typical part manufactured by the company. Three important parameters appear to be batch size, workpiece complexity, and operator wage rates. The operating time data for the purpose of the study was obtained from the company[3].

The first calculations are done to transform the capital costs of depreciation and interest on the investment to equivalent uniform annual costs for both CNC machine and the conventional machine. The table 3 shows the capital costs, and the table 4 shows the operating Costs.

The case study is carried out using General Replacement Minimum Cost Model for the following given data.

	Conventional <u>Machine</u>	CNC <u>Machine(3 axis)</u>
<u>CAPITAL COSTS</u>		
1. Purchase cost (\$)	7000	60950
2. Freight in cost (\$)	250	450
3. Tooling cost (\$)	800	1500
4. Auxiliary cost (for Indexing attachment)		6500
5. Installation cost	<u>200</u>	<u>600</u>
	8250	70000
<u>MAINTENANCE COSTS</u>		
6. Maintenance (\$/yr.)	1000	2400
7. Direct Labor cost (\$/hr.)	7.50	9.00
8. Overheads (\$)	1000	1800
<u>MISCELLANEOUS</u>		
9. Expected life	7 years	7 years
10. Depreciation method	Double-Declining Balance	
11. Interest Rate	20 %	20 %
12. Hours per year	2000	2000

CASE STUDY COMPARING INVESTMENT FOR CNC V/S CONVENTIONAL M/C TOOL

ANALYSIS FOR C.N.C MACHINE TOOL

YEAR	A	B	C	D	E	F	G	H	I	J	II
n	\$ REALIZABLE AT FIRST OF n th YEAR	\$ DEPRICIATION IN THE n th YEAR * (A*(2/7))*	INTEREST (20 %) ON THE REALIZED VALUE, n th YEAR (B x .2)	DEPR. + INT. IN THE n th YEAR (B + C)	PRESENT WORTH FACTOR (1/(1.2)^n	PRESENT WORTH OF CAPITAL COSTS IN n th YEAR (D * E)	CUMULATIVE P.W. FOR n YEARS	CAPITAL RECOVERY FACTOR (C.R.)	TIME ADJUSTED CAPITAL COSTS ANNUAL (\$) (G * H)	TIME ADJUSTED CAPITAL COSTS HOURLY (\$/hr) (R/2000 Hrs)	II
1.00	70000.00	20000.00	14000.00	34000.00	.83	28333.33	28333.33	1.20	34000.00	17.00	II
2.00	50000.00	14285.71	10000.00	24285.71	.69	16865.08	45198.41	.65	29378.97	14.69	II
3.00	35714.29	10204.08	7142.86	17346.94	.58	10038.74	55237.15	.48	26513.83	13.26	II
4.00	25510.20	7288.63	5102.04	12390.67	.48	5975.44	61212.59	.39	23872.91	11.94	II
5.00	18221.57	5206.16	3644.31	8850.48	.40	3556.81	64769.40	.33	21373.90	10.69	II
6.00	13015.41	3718.69	2603.08	6321.77	.33	2117.15	66886.55	.30	20065.96	10.03	II
7.00	9296.72	2656.21	1859.34	4515.55	.28	1260.21	68146.75	.28	19081.09	9.54	II

ANALYSIS FOR CONVENTIONAL MACHINE TOOL

YEAR	A	B	C	D	E	F	G	H	I	J	II
n	\$ REALIZABLE AT FIRST OF n th YEAR	\$ DEPRICIATION IN THE n th YEAR * (A*(2/7))*	INTEREST (20 %) ON THE REALIZED VALUE, n th YEAR (B x .2)	DEPR. + INT. IN THE n th YEAR (B + C)	PRESENT WORTH FACTOR (1/(1.2)^n	PRESENT WORTH OF CAPITAL COSTS IN n th YEAR (D * E)	CUMULATIVE P.W. FOR n YEARS	CAPITAL RECOVERY FACTOR (C.R.)	TIME ADJUSTED CAPITAL COSTS ANNUAL (\$) (G * H)	TIME ADJUSTED CAPITAL COSTS HOURLY (\$/hr) (R/2000 Hrs)	II
1.00	8250.00	2357.14	1650.00	4007.14	.83	3339.29	3339.29	1.20	4007.14	2.00	II
2.00	5892.86	1683.67	1178.57	2862.24	.69	1987.67	5326.96	.65	3462.52	1.73	II
3.00	4209.18	1202.62	841.84	2044.46	.58	1183.14	6510.09	.48	3124.84	1.56	II
4.00	3006.56	859.02	601.31	1460.33	.48	704.25	7214.34	.39	2813.59	1.41	II
5.00	2147.54	613.58	429.51	1043.09	.40	419.20	7633.54	.33	2519.07	1.26	II
6.00	1533.96	438.27	306.79	745.07	.33	249.52	7883.06	.30	2364.92	1.18	II
7.00	1095.69	313.05	219.14	532.19	.28	148.52	8031.58	.28	2248.84	1.12	II

TABLE 3. Capital Cost Calculations

 CALCULATIONS
For Conventional MachineCapital Costs

Dollars realizable at first year	= 8250
Dollars depreciated in first year	= 8250 * (200/7 %)
	= 2357.14
Interest on realizable value for 1st year	= (20/100) * 8250
	= 1650
Working hours per week	= 40 * 50
	= 2000 hours.

Operating and Maintenance Costs

Maintenance cost (\$/year)	1000
Labor cost (\$/year)	
(labor cost * Workhours per year=7.50 * 2000)	15000
Overhead allocations (\$/year)	<u>1000</u>
Total operation cost (\$/year)	17000

For CNC Machine toolCapital Costs

Dollars realizable at first year	= 70000
Dollars depreciated in first year	= 70000 * (200/7 %)
	= 20000
Interest on realizable value for 1st year	= (20/100) * 70000
	= 34000
Working hours per week	= 40 * 50
	= 2000 hours.

Operating and Maintenance Costs

Maintenance cost (\$/year)	1800
Labor cost (\$/year)	
(labor cost * Workhours per year=9.00 * 2000)	18000
Overhead allocations (\$/year)	<u>2400</u>
Total operation cost (\$/year)	22200

Substituting these values in table 4 following results are obtained.

CASE STUDY COMPARING INVESTMENT FOR CNC V/S CONVENTIONAL M/C TOOL

K	L	M	N	O	P	Q	
OPERATING & MAINTENANCE COST, n th YEAR	PRESENT WORTH FACTOR (20 %) $(1/(1.2)^n)$	PRESENT WORTH IN n th YEARS(\$) (K x L)	CUMULATIVE P.W. IN n th YEARS	CAPITAL RECOVERY FACTOR(%)	TIME ADJUSTED OP. & MNT. COST ANNUAL (N * O)	TIME ADJUSTED OP. & MNT. COST ANNUAL (P/2000 Hrs)	TOTAL CAP.COST + MAIN. COST HOURLY (J + Q)
22200.00	.83	18500.00	18500.00	1.20	22200.00	11.10	28.10
22600.00	.69	15694.44	34194.44	.65	22226.39	11.11	25.80
23000.00	.58	13310.19	47504.63	.48	22802.22	11.40	24.66
23400.00	.48	11284.72	58789.35	.39	22927.85	11.46	23.40
23800.00	.40	9564.69	68354.04	.33	22556.83	11.28	21.97
24200.00	.33	8104.53	76458.57	.30	22937.57	11.47	21.50
24600.00	.28	6865.41	83323.98	.28	23330.71	11.67	21.21

K	L	M	N	O	P	Q	
OPERATING & MAINTENANCE COST, n th YEAR	PRESENT WORTH FACTOR (20 %) $(1/(1.2)^n)$	PRESENT WORTH IN n th YEARS(\$) (K x L)	CUMULATIVE P.W. IN n th YEARS	CAPITAL RECOVERY FACTOR(%)	TIME ADJUSTED OP. & MNT. COST ANNUAL (N * O)	TIME ADJUSTED OP. & MNT. COST ANNUAL (P/2000 Hrs)	TOTAL CAP.COST + MAIN. COST HOURLY (J + Q)
17000.00	.83	14166.67	14166.67	1.20	17000.00	8.50	10.50
17200.00	.69	11944.44	26111.11	.65	16972.22	8.49	10.22
17400.00	.58	10069.44	36180.56	.48	17366.67	8.68	10.25
17600.00	.48	8487.65	44668.21	.39	17420.60	8.71	10.12
17800.00	.40	7153.42	51821.63	.33	17101.14	8.55	9.81
18000.00	.33	6028.16	57849.79	.30	17354.94	8.68	9.86
18200.00	.28	5079.29	62929.08	.28	17620.14	8.81	9.93

TABLE 4. Operating And Maintenance Costs

Substituting these values in table 4 following results are obtained. Now above results are analyzed to economically justify machine purchase.

The data for the fixed time and variable time for extruder screws was used from production records[3] in order to estimate production costs. The times for the CNC machine tool are estimated from the data provided by Killion Extruders.

	Conventional machine	CNC machine
A. Fixed Time (Hrs.)		
Setup time	1.00	0.75
Teardown time	<u>0.40</u>	<u>0.25</u>
Total fixed time	1.40	1.00
B. Variable Time (Hrs.)		
	4.5 (avg.)	3.2 (estimated)

We get two equations for total time

$t_c = 1.4 + 4.5 (P)$	conventional machine
$t_n = 1.0 + 3.2 (P)$	CNC machine tool

Where **P** is the number of pieces to manufactured.

Total production costs

Using the data from table 4 the cost per piece can be determined as below.

$$\text{Cost per piece} = \frac{\text{Total O.C./hr} * \text{Time reqd. to prod. } P \text{ pcs.}}{P}$$

Conventional machine

$$\begin{aligned} \text{Cost per piece} &= 10.50 * t_c \\ &= \frac{10.50 (1.4 + 4.5 (P))}{P} \dots\dots\dots A \end{aligned}$$

CNC machine tool

$$\begin{aligned} \text{Cost per piece} &= 28.10 * t_n \\ &= \frac{28.10 (1.0 + 3.2 (P))}{P} \dots\dots\dots B \end{aligned}$$

From the above equations A and B, the costs of production are determined and are as follows,

<u>Batch Size</u>	<u>CNC machine</u>	<u>Conventional machine</u>
1	118.02	61.95
10	92.77	48.72
50	90.70	48.10
100	90.06	47.40
1000	89.95	47.25

Above results shows that for conventional machine is more economical over CNC machine. But the conventional machine needs 2 to 3 setups where as the CNC machine can finish all the operations in one setup. Hence the actual costs will be as follows,

<u>Batch Size</u>	<u>CNC machine</u>	<u>Conventional machine</u>
1	118.02	115.50
10	92.77	87.15
50	90.70	84.32
100	90.06	84.20
1000	89.95	84.01

The above costs show that the difference of the costs between the 2 machines is very small. This difference can be justified by the fact that the movement of the part from one machine to another is reduced due to single setup on the CNC machine.

VII. CONCLUSION

There are variety of CNC machines available in the market according to the customers needs. The selection of the right type of a CNC machine depends on the need of a particular customer.

The CNC machining practice in a extruder manufacturing industry is advantageous with respect to the machining of variety of extruder screws and dies. At the same time due to the high initial equipment cost of the CNC equipment the financial justification for a CNC machine tool will vary from one application to another. Although the economics for the justification in the case study show that, cost of production for a conventional machine tool are lower to a CNC machine, in broader view of the accuracy and quality of output from the CNC machine, the CNC machine has upper edge over the conventional machine tool.

The CNC machine tool is justified due to the fact that there are wide variety of extruder screw and die designs. These designs which are developed and stored in memory of computers, can be used to cut a screw or die on a CNC machine tool, with proper adjustments and set up on the CNC machine tool.

Since the CNC machine tool requires less number of setups than a conventional machine tool, there is reduction in the work in process inventory of the parts to be machined. The saving of this time from the reduced setups and machining time can allow the management to rent the facility for the rest of the time. This not only improves the cash flow of the company but also helps in effectively using of the equipment.

The use of the CNC in a job shop kind of environment improves the capabilities of the machine shop because, more variety of jobs can be machined using CNC machine tools which can not be machined with the conventional machine tools. This versatility of the shop can help in handling more jobs leading to higher throughput of the shop.

Hence CNC implementation is feasible for a industry manufacturing Extruders for the manufacture of dies and extruder screws which also fall in the job shop type of classification.

VIII. FUTURE WORK

The work from this thesis gives a start for implementing of a CNC machine in a extruder manufacturing industry with a job shop kind of environment.

The analysis of the CNC implementation takes in to consideration that in the future there are chances of *networking* the CNC machine tools to the other machine tools on the shop floor.

Use of *relational database* to retrieve machinability data or other design data to accomplish designing of a complete extrusion system.

Linking of the CNC machines to the *financial information system* of the organization, which will allow the sales people to estimate the time period in which the product can be delivered. There by giving a cutting edge over the competition.

The *optimal machining time* for the parts like extruder screw and the dies of various types can be determined and a common database can be created. This database can contain properties of all the resins and the various screw and die designs. This will make it possible that, when the specifications for a particular design and the resin are given the right type of the screw is designed.

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