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ABSTRACT

GRAPHICS INTERFACED COMPUTER AUTOMATED PROCESS PLANNING

Ajit Nimbvikar

The work is based on the manufacturing of gears in a Job Shop type production plant. The topic is divided into three sections. 1. design, 2. graphics, and 3. process planning and analysis. A program is developed using Fortran for the iterative design procedure. With basic inputs, the program provides the design of gears with dimensions. During the procedure, the user has to intervene to specify some codes for the selection of materials and other parameters. Second section deals with the graphics utility. It provides a drawing of the gear with dimensions according to the input obtained from the design calculations. In the third section, manufacturing process analysis is done. The program provides different options for the selection of tools and other machining parameters. The program also provides the detailed analysis of the resulting parameters. Based on the availability and capacity, the user has to select his own manufacturing processes.

**GRAPHICS INTERFACED
COMPUTER AUTOMATED PROCESS PLANNING**

by

Ajit Nimbvikar

A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science

Department of Manufacturing Engineering

January, 1993

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APPROVAL PAGE

**Graphics Interfaced
Computer Automated Process Planning**

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This thesis is dedicated to
my parents

ACKNOWLEDGEMENT

The author wishes to express his sincere gratitude to his supervisor, Professor Steve Kotefski, for his guidance, friendship, and moral support throughout this research.

Special thanks to Professors Raj Sodhi and Kevin McDermott for serving as members of the committee.

The author appreciates the timely help and suggestions from Abhay Dharkar.

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CHAPTER 1

EXECUTIVE SUMMARY

Since the birth of manufacturing industries, the process planning has remained an art that requires a lot of experience based knowledge to cultivate. The transition period during which an effort is made to bridge the generation gap between old and new process planner is always smaller. Within this small period, transfer of years of knowledge and judgement analysis is impossible. There is a need to provide some means to assist for smooth transition. Here an effort is made to provide some assistance to new generation process planners, an effort to loosen the burden of heavy decision making in the manufacturing of gears.

A lot of process planning is done based on experience. Many times these decisions and their bases are not documented. This works till the same process planner is active. But it is impossible for another process planner to understand such decisions. In such cases there is a great need of a common and intelligent database which can be accessed easily by the different planners. This not only will improve accuracy of the plans but also the consistency of the plans. This effort provides programmed database for decision making. It also provides freedom to the process planner to make his own decisions based on his requirements.

The module works in three steps. In the first step, it provides the design of spur or helical gear. The user specifies his requirements and also available material. Based on it the module provides him detail design, strength analysis and working dimensions of the gear. In the second step, the module works for the part representation purpose. It provides the picture of the designed gear to the user drawn according to the designed gear dimensions. The third step is

dedicated towards the process analysis plan and process analysis. Here this module provides the process plan along with process analysis. With the help of results of process analysis, the user has to define his plan.

This effort is dedicated to establish an intelligent decision making expert system with the help of programming languages and PC based softwares. It develops a link between design, graphics and planning by providing a solid database for all of them. It makes it possible to make logical decisions on highly flexible problems.

CHAPTER 2

BACKGROUND

A production facility may be the most complex system that confronts today's engineer. In spite of the fact that the production function is the primary purpose of a manufacturing industry, the production process often appears completely forgotten in the midst of marketing, accounting, or other organizational planning activities. The impact of declining productivity is so severe that productivity improvement has become the most challenging problem facing this nation. The declining productivity has resulted into a reduced position in the international marketplace and it may affect the standard of living in U.S.

2.1 Automation

Since last decade a new term is spreading all over the industrial world. Production Automation. So also some new terms have been developed to describe various aspects of this technology. Many of these terms such as robotics, CAD/CAM, flexible manufacturing systems, machine vision are totally new. The old terms such as mechanization, are disappearing from the technical vocabulary. Automation represents a continuous evolutionary process. It is a process of technological development that will proceed into the foreseeable future.

Automation is concerned with the application of mechanical, electronic and computer based systems to operate and control the production. It includes,

1. Automatic machine tools to process parts
2. Automatic assembly machines
3. Industrial Robots

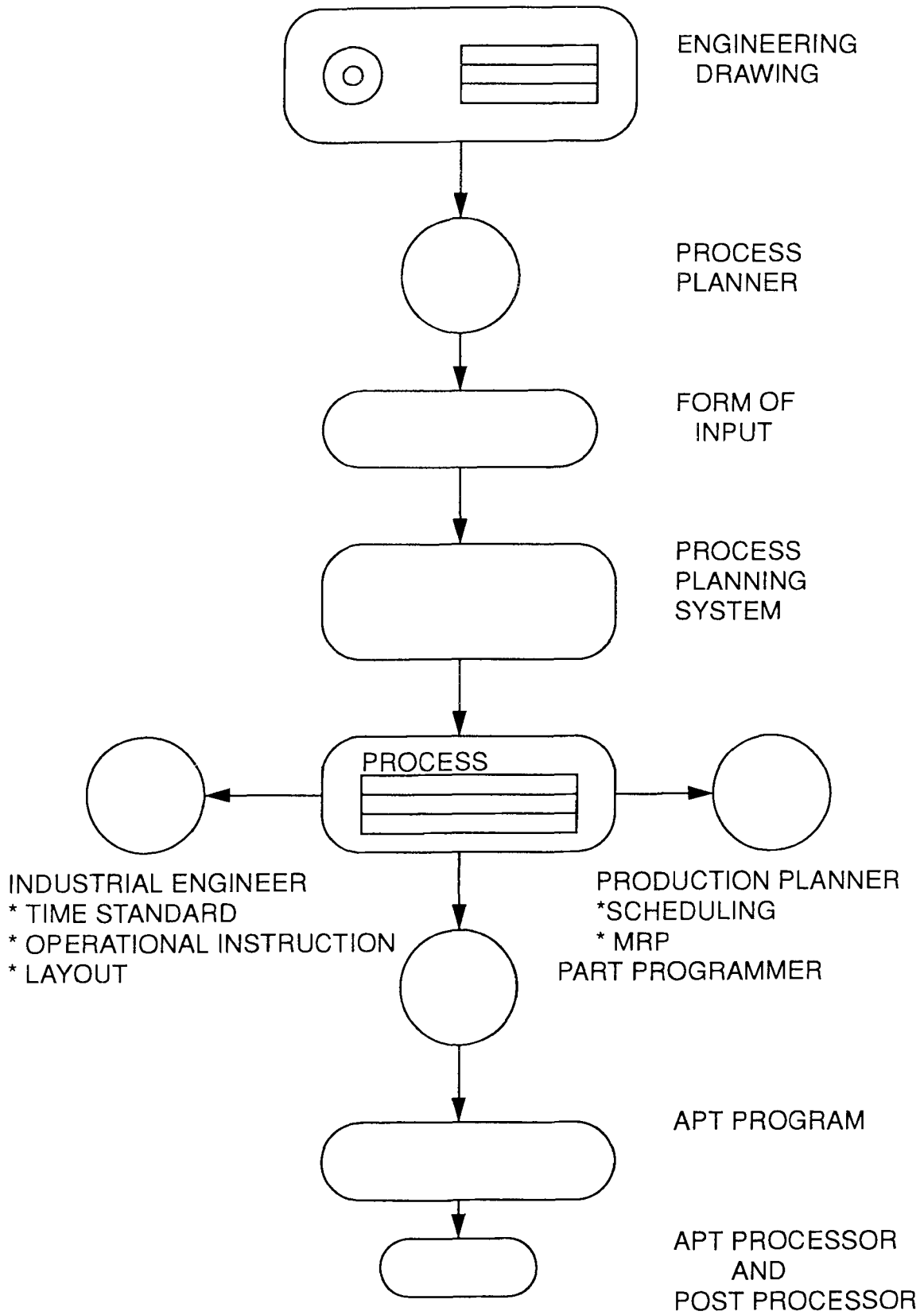


Figure 1 Manufacturing Activities

4. Automatic material handling and storage systems
5. Automatic inspection systems for quality control
6. Feedback control and computer process control
7. Computer systems for planning, data collection, and decision making to support manufacturing activities.

There are some very important reasons for the automation such as,

1. Increased productivity - This means greater output per hour of labor input. Higher production rate i.e. higher output per hour can be achieved by automation.
2. High cost of labor - Due to ever increasing cost of labor, substituting labors by machines has become more economically justifiable. Machines can produce at higher output rates resulting into lower cost per unit of the product.
3. Labor shortages - In many advanced nations labor shortages has stimulated the development of automation to substitute the labor.
4. Safety - Automation makes it possible to transfer the operator from active participation to a supervisory role making the work and work place safer.
5. High cost of raw materials - This creates the need for greater efficiency in using them. Automation reduces scrap to a greater extent.
6. Improved product quality - Automation not only provides higher output rate but also higher consistency as well as conformity to quality specifications.
7. Reduced manufacturing lead time - Automation allows the manufacturer to reduce the time between the customer order and the product delivery. This gives the manufacturer a competitive advantage in promoting good customer service.
8. Reduction of in-process inventory - Inventory holding cost represents a significant cost to the manufacturer. In-process inventory has no value. It's purpose is neither as that of finished goods inventory nor that of raw material stock.

Automation tends to accomplish the goal of reducing in-process inventory by reducing the time a work part spends in the factory. Automation is the key to the shorter work week. It will allow greater leisure time and also provide a higher quality of life. There are 3 types of automation according to the flexibility of manufacturing equipments,

1. Fixed automation,
2. Programmable automation,
3. Flexible automation.

Fixed automation deals with the mass production systems. This type of automation is generally adopted for the industries where the repeatability is the most important factor. Introduction of human factor in such type of industries results into deterioration of the quality of the job done. The programmable automation is considered suitable where the required job changes after a certain time. The flexible automation is considered as the best possible automation. But it is very difficult to achieve. It needs careful study of the operations to be performed. All the elements concerning the production are also required to be flexible.

2.2 Production

Production is a transformation process that converts raw materials into finished products having market value. The transformation process usually involves a sequence of steps to bring the material closer to the desired final state. Production activity is classified according to the product quantity.

1. Job shop production
2. Batch production
3. Mass production

Job Shop Production deals with the low volume production. It meets the specific customer orders and there is a great variety in the plant work. Therefore the production equipment is flexible and general purpose to allow for the variety of work. Also skill level of workers is relatively high to perform a wide range of work assignments. The common examples of job shop production are space vehicles, air crafts, machine tools, etc.

Batch Production deals with the manufacturing of medium sized lots of same product. The purpose is to satisfy continuous customer demands. The plant is capable of production rate exceeding demand rate. Here inventory becomes a must so as to change over to other orders. When stock of the first product falls down, product is repeated to build up the inventory. Equipments used are general purpose but designed for higher rates of production. Machine tools are generally combined with special purpose jigs and fixtures to increase output rate. Batch and Job Shop production constitute important part of manufacturing activity.

Mass Production deals with higher volumes of products. So the equipments are totally dedicated to a particular product. Investments in the machines and specialized tooling are very high. This transfers the production skills from the operator to the machine.

Organization and Information processing is one of the major aspects of manufacturing. Manufacturing firms should organize themselves so as to accomplish various manufacturing functions.

1. Business functions,
2. Product design,
3. Manufacturing planning,
4. Manufacturing control

These are the basic functions of Information and Processing cycle.

2.3 Manufacturing Planning

Manufacturing planning is considered as an application of Computer Aided Manufacturing (CAM). Computer aided manufacturing is generally categorized into manufacturing planning and manufacturing control. Manufacturing planning is concerned with cost estimating, computer aided process planning, computerized machinability data system, computer assisted NC part programming, development of work standards, computer aided line balancing, and production and inventory planning. The functions of these systems start after the design procedure. The designed parameters are used as the input for these systems. The results of these systems are used as the input for the actual production process.

Computer Aided Process Planning is concerned with the preparation of route sheets which list the sequence of operations and work centers required to produce the product and its components with the aid of computers. CAPP is the major link between design and manufacturing in a CAD/CAM system. The processing sequence is documented on a form called a route sheet. The route sheet also specifies the fixtures, tooling and standard time required for each task.

2.4 Need for CAPP

Society of manufacturing engineers predicts a 30% reduction in the efforts devoted to the methods and standards through computer automation by the end of this century. The study conducted by G.E. estimates the maintenance cost of a file cabinet over a period of a year in a manufacturing department as \$ 10,000.

Computer automation replaces the functions of paper, pencil and file cabinet in a wide range. SME's conclusion on computer automation reveals the highest probability for successful implementation and the greatest returns on investment.

According to the studies conducted by Air Force 10 areas within manufacturing environment those need most improved information handling methods are,

1. Automated process planning,
2. Design retrieval
3. Productibility and value analysis,
4. Standardized part information,
5. Part family formation,
6. Machine loading and operation sequence,
7. Structuring and classification of manufacturing methods,
8. Engineering change adaptability,
9. Process plan retrieval,
10. Master database establishment

There are specific reasons for the top 3 priorities. Process planning is a time consuming process. But actual planning consumes only 20% of the process planner's time. The remaining time is consumed in maintaining the process planning database including engineering design changes, quotations, tooling changes, equipment selection, etc. Routine activities such as maintenance can be improved in speed as well as in accuracy with the implementation of automation.

It has been observed that average age of process planners crosses the mark of 50. Process planning requires years of experience. As large number of process planners retire, their successors are much junior in age as well as in experience. They do not have acquired sufficient depth of knowledge to replace their predecessors.

CAPP systems may provide the vehicle that simultaneously captures the expertise of senior personnel in the form of best practice procedures or

standardized process plans. They can also act as a training media that disseminates the accumulated knowledge to the junior personnel i.e. the new users of CAPP. The computer's ability to store, retrieve and update makes it easy to organize the technical data representing the knowledge of senior process engineers.

Earlier attempts to automate process planning consist of building computer assisted systems for report generation, storage and retrieval of plans. 40% savings in process planners time has been observed in Lockheed's CAP system [Tulkoff 1981] CAPP can reduce some of the decision making required during a planning process.

It also provides more advantages such as,

1. reduction in the skill required of a planner,
2. reduction in planning time,
3. reduction in planning and manufacturing cost,
4. more consistent plans,
5. more accurate plans,
6. increase in productivity.

Automation of the discrete goods industries is historically inevitable. It is not yet been accomplished because of one underlying fundamental problem. The total lack of understanding of manufacturing procedures. There are probably many factors those could be listed as causes of this lack of understanding. Most of these causes can be linked back to the failure to recognize and utilize a common geometry language for relating the decision relevant for comparing the manufacturing requirements of a part to the manufacturing facilities of available processes and equipment.

Computer aided design and manufacturing have increased design and manufacturing responsiveness. But more efficient ways have to be developed to

convert the complex geometries produced by CAD into instructions telling CAM how to produce the part. Process planning is the collection of all activities required to convert a part design into a manufactured product.

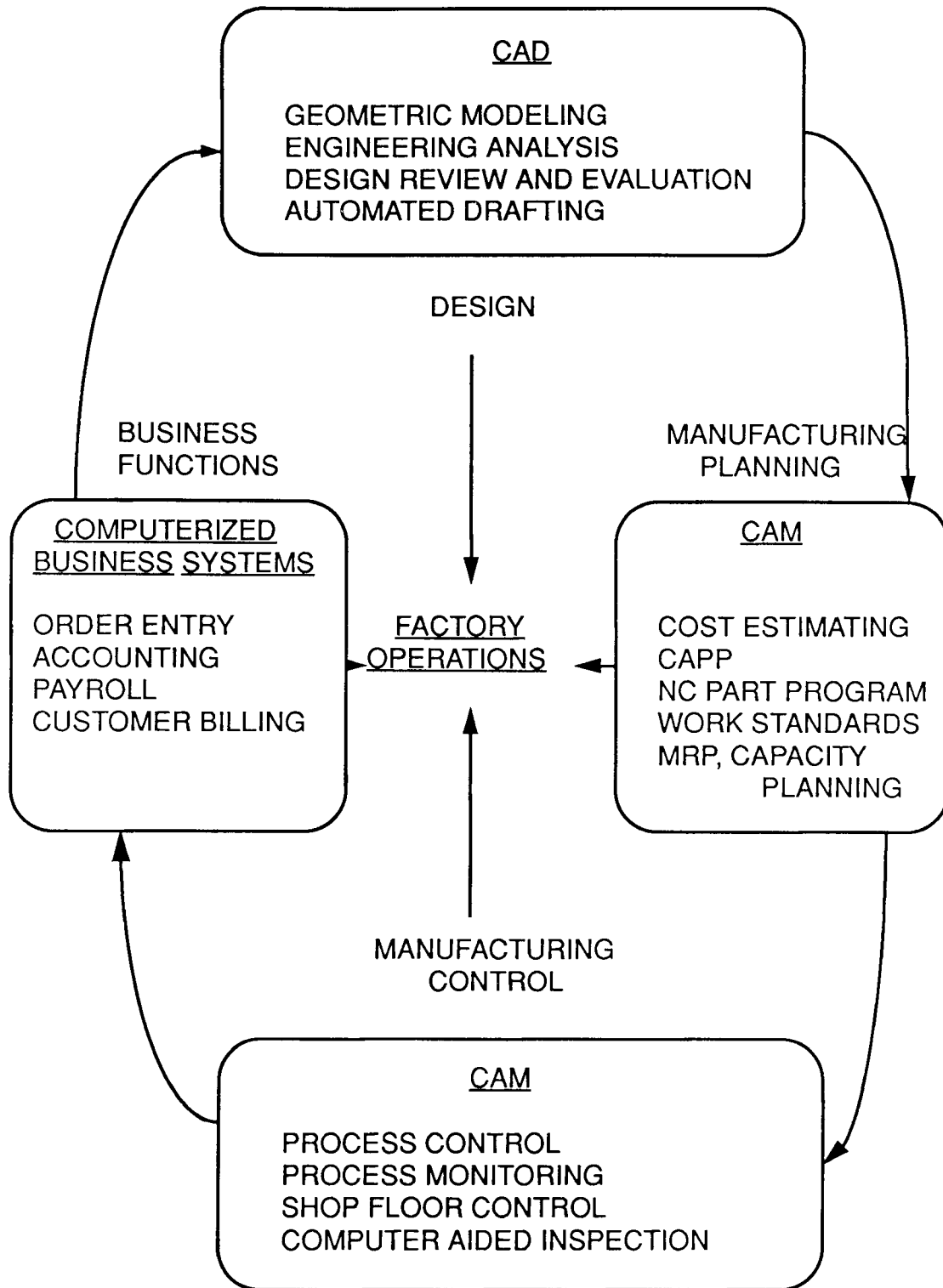


Figure 2 Elements of Modern Manufacturing System

CHAPTER 3

INTRODUCTION

3.1 Process Planning

Process planning is the function within a manufacturing facility that establishes which machining processes and parameters are to be used to convert a part from its raw material form to a final form predetermined from an engineering drawing. It is an act of preparing detailed work instructions to produce a part. The initial material may take a number of forms, such as bar stock, plate, castings, forgings, etc. With these raw materials as a base, the process planner prepares a list of processes needed to convert the normally predetermined material into a predetermined final shape. There are a number of processes used in a manufacturing industry.

The process plan is frequently called as an operational sheet or route sheet. The detailed plan usually contains the route, processes, process parameters, machines and tool selections. In a more general sense, a process is called an operation and the route is the operational sequence. The process plan provides instructions for the production of the part. These instructions dictate the cost, quality and rate of production. In a conventional production system, a process plan is created by a process planner. He generally examines the new product and then determines the appropriate procedures to produce it. The previous experience of the process planner is critical to the success of the plan. Based on the previous experience the process planner is able to select critical parameters. Numerous factors affect process planning. Shape, tolerance, surface finish, size, material, quantity, manufacturing system are some of them. All these factors contribute to the selection of operations and the operational sequence those can be followed for the manufacturing of any particular part.

In addition to operational sequencing and operational selection, the selection of tooling and jigs and fixtures is also a major part of the process planning function. The tooling portion includes the selection of both the tool and the machine on which the tool is used. There are a limited set of commercially available tools with different shapes, diameters, lengths, number of teeth and alternative tool materials. High speed steel (HSS), Tungsten Carbide (TC) are commonly used tool materials. TC can machine at higher cutting speed than HSS but costs more and is difficult to regrind. TC is also brittle. Jigs and fixtures are the devices to guide a tool or hold a work piece for better machining. Jigs and fixtures are mostly non standard. Even with standard devices, application and use is dependent on the operator. Process planner should consider the effect of tooling and jigs & fixtures on the quality of product during the selection of the production operations.

Design data and production and process information are the inputs to a process planning system. The process planners are not the designers. This makes necessary for the designers to provide clear and precise information about the product requirements. The information knowledge base is also input for the decision making. The ultimate goal of an automated process planning system is to integrate design and production data into a system that generates usable process plans. The goal of the entire procedure is like the design. To accomplish the goal, intelligent reports are gathered to provide knowledge, possible resistance and other factors that may result from the action. The general staff in a process planning system is the control and decision making mechanism. A process plan is prepared based on the design data and the process knowledge. Process planning systems capture the useful information and render it useful through different means, manual approach, variant process planning or generative process planning.

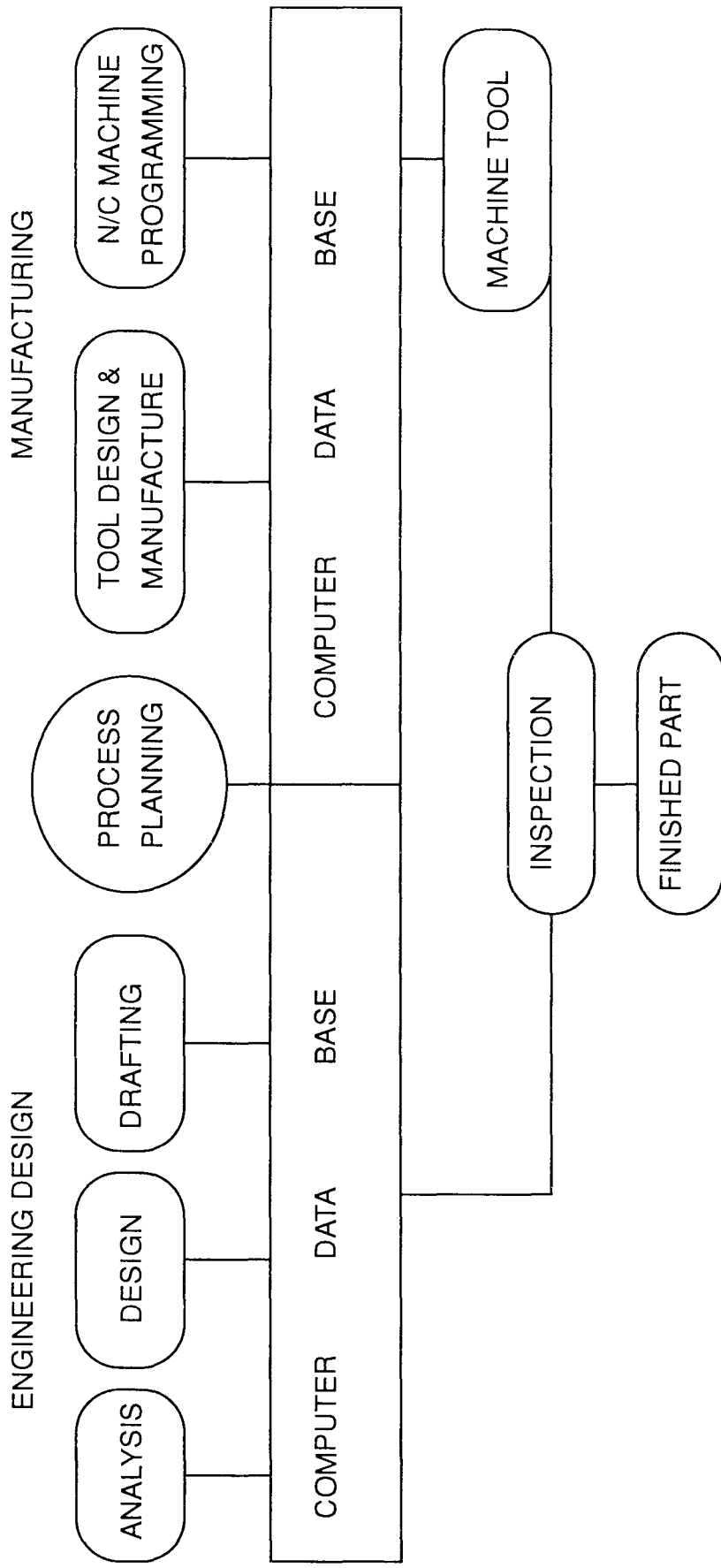


Figure 3 CAD - CAM Integration

3.2 Manual Approach

Manual approach relies heavily upon the experience of the manufacturing analyst to develop feasible, low cost and consistent process plans. Many times this task involves recalling and identifying process plans for a similar part and generating a routing for a part as a unique plan as well. Whatever the case, the activity is highly subjective, labor intensive, time consuming and tedious. Despite the many drawbacks, this approach is the best approach for small companies with a few process plans to generate. A good planner can create process plans which are not only accurate but also fairly consistent and cost effective for a small number of processing alternatives. This approach provides good flexibility and low investment costs. The advantages become limited when the dimensions of the task increase. Extended dimensions in terms of number of parts, tooling result into inconsistent plans and large time requirements. They even start reflecting personal preferences and prejudices of the planner.

The disadvantages of manual approach are basically based on high dependence upon technical activities in the preparation of plans as well as in planning engineer's need to interact with related activities. Here the manufacturing logic is individual and resides in the planner's mind. Recalling and reprocessing this individual logic for every process plan is a laborious process. It is often shortened by guesswork. The results are extended pre-production lead times and inconsistent process plans. As a result, always the shop floor operatives have little respect for the targets set by process planners. Process planning information with such plans is very hard to update according to engineering changes in the product design, alternative material and processes, improved processes and changes in manufacturing quantities. Modern manufacturing systems such as, flexible manufacturing, production scheduling,

demand for more timely and accurate process plans so as to increase their effectiveness.

3.3 Variant Approach

The variant approach uses library retrieval procedures to find standard plans for similar components. It relies on a human operator and the retrieval mechanism which may be a computer aided process planning subsystem or the operator's memory. By editing the standard process plans new variations of preexisting process plans are created: hence the name variant process planning.

The retrieval method and the logic in variant system is predicted on grouping of parts into families. Common manufacturing methods can be then identified for each family. Such common manufacturing methods are represented by standard plans.

The retrieval mechanism is based on part families. In general, variant process planning systems have two operational stages, preliminary and production. During preliminary stage, existing components are coded, classified and grouped into families. The process begins by summarizing process plans already prepared for components in the family. Standard plans are then stored in a database. The preliminary stage is a time consuming process. It keeps on updating several times according to the knowledge of the planner.

The operational stage starts when the system is ready for production. An incoming component is first coded. The code is then input to a part family search routine to find the family to which the component belongs. The family number is then used to retrieve a standard plan. The human planner may modify the standard plan to satisfy the component design. Some other functions such as, parameter selection and standard time calculations, can also be added to make the system more complete.

3.4 Generative Approach

Generative process planning system captures the process knowledge in a different form. Generative approach can be defined as a process plan for a system that synthesizes process information in order to create a process plan for new components automatically. In the variant system, knowledge is represented by the accumulated process plans created over time. In contrast to it, a generative system is captured in the form of processing rules. These rules are generally represented by decision trees. They represent the collective manufacturing knowledge for a particular part family or category of manufacturing processes. Once captured they may be used to generate the required sequence of processing steps for new products within the set of products for which the decision tree was designed. By applying decision logic, process planners decision making process can be limited.

Other process planning functions, such as machine selection, tool selection, process optimization, can also be automated using generative planning techniques.

Generative approach has advantages such as,

1. consistent and rapid process plans
2. easy planning of new components
3. interfacing with an automated manufacturing facility to provide detailed and up-to-date control information.

Transforming component data and existing rules into a computer readable format is still a major obstacle to be overcome before generative planning systems become operational. Successful implementation needs the following developments.

1. identification and capturing of the logic of process planning,

2. clear and precise definition of the part in a computer compatible format,
3. proper incorporation of captured process planning logic and the part description data into a unified manufacturing data base.

Most systems used nowadays are systems with built-in decision logic. The decision logic consists of the unusual ability to check some conditional requirements of the component and select a process. Some systems have decision logic to select several canned process plan fragments and combine them into a single process plan. There are several generative process planning systems used. e.g. Autoplan of Metcut [Vogel 1979, Vogel & Adlard 1981], CAPP of United Technology [Dunn & Mann 1978].

Ideally, a generative process planning system is a turnkey system with all the decision logic contained in the software. The system possesses all the necessary information for process planning. However this is not always possible. In order to generate a more universal process planning system, variables such as, process limitations and capabilities, process costs, must be defined prior to the production stage. CAPP [Kotler 1980] requires user supplied decision logic for each component family.

Many efforts and accomplishments have occurred in the past decade to improve the productivity of design and manufacturing activities by means of computerized automation under the broad scope of CAD/CAM. At present most systems available tend to focus either on the automated design or on the tool path control of N/C equipments. The systems dedicated to integrate design and manufacturing functions are hardly available. The level of technology advancement in process planning is clearly lagging.

The traditional approach of manual planning involves examines a drawing and developing manufacturing process plans and instructions based on knowledge of process and machine capabilities, tooling, materials, related costs

and general practices. It is not possible for a single process planner to maintain the entire database. Many times decisions are taken based on the past experience. Similar process plans developed by different process planners often differ because of the tendency of the planners to refer their past experience rather than the knowledge based database.

CHAPTER 4

COMPUTER AIDED PROCESS PLANNING

The entire logic of the topic is divided into three subtopics, design, graphics and process planning and analysis. The succeeding chapters explain each of these subtopics in detail. The design subtopic explains the basic design procedure and detailed design analysis as well. It explains the features of the program developed for the design of the gear. It provides the quick information about the gear dimensions and strength analysis. The next step, the graphics utility, explains the graphics procedure adopted here. This subsection explains the technical procedure for drawing. It also provides the guidelines to draw the desired shape. Inputs and outputs of the graphics facility are also explained here. This utility accepts the dimensions of the designed gear as input. The graphics program compiles all the parameters to provide a dimensional drawing of the gear. The third subtopic is devoted to the process planning and process analysis. It basically explains the detailed procedure of creating a process plan using the program. It also provides useful information about the manufacturing processes analysis. The output of both design procedure and the graphics utility are used as input for the analysis procedure. The user intervention is necessary here to input the required additional parameters. Such parameters and reasons to add them are explained in this subsection. It compares the available manufacturing facilities and provides useful hints about the successful use of them. The program used for this analysis also provides process plan. Each of the manufacturing process selected by the user is added automatically to the plan. It is the user's responsibility to select the appropriate manufacturing facility according to his availability and capacity.

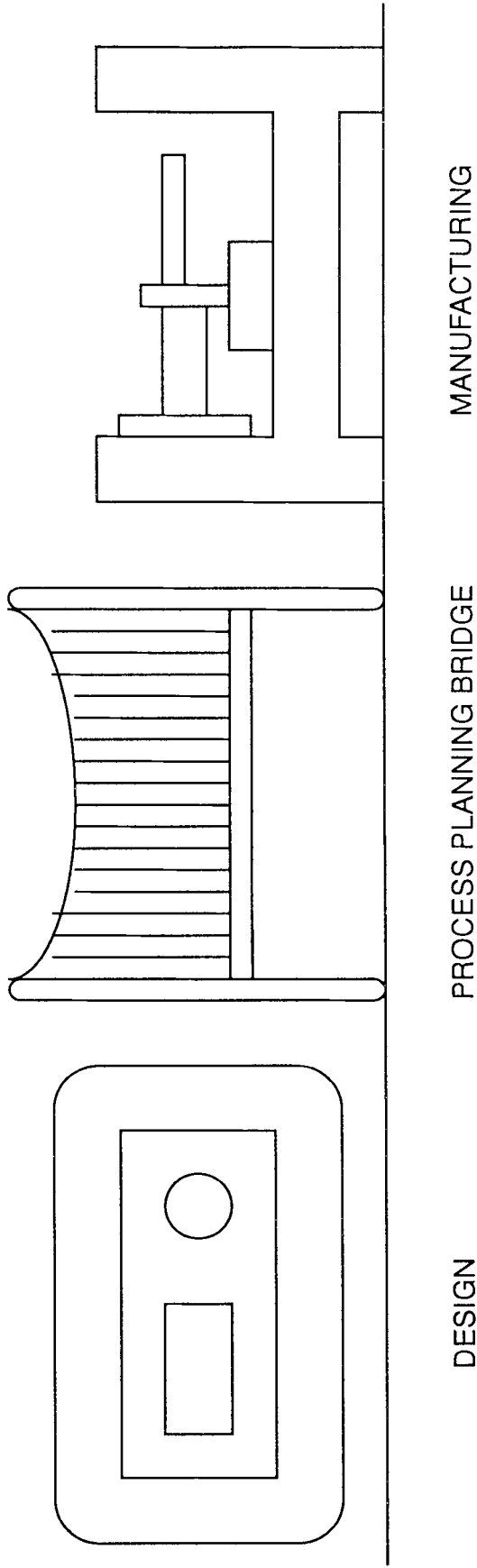


Figure 4 Process Planning Bridge Between Design and Manufacturing

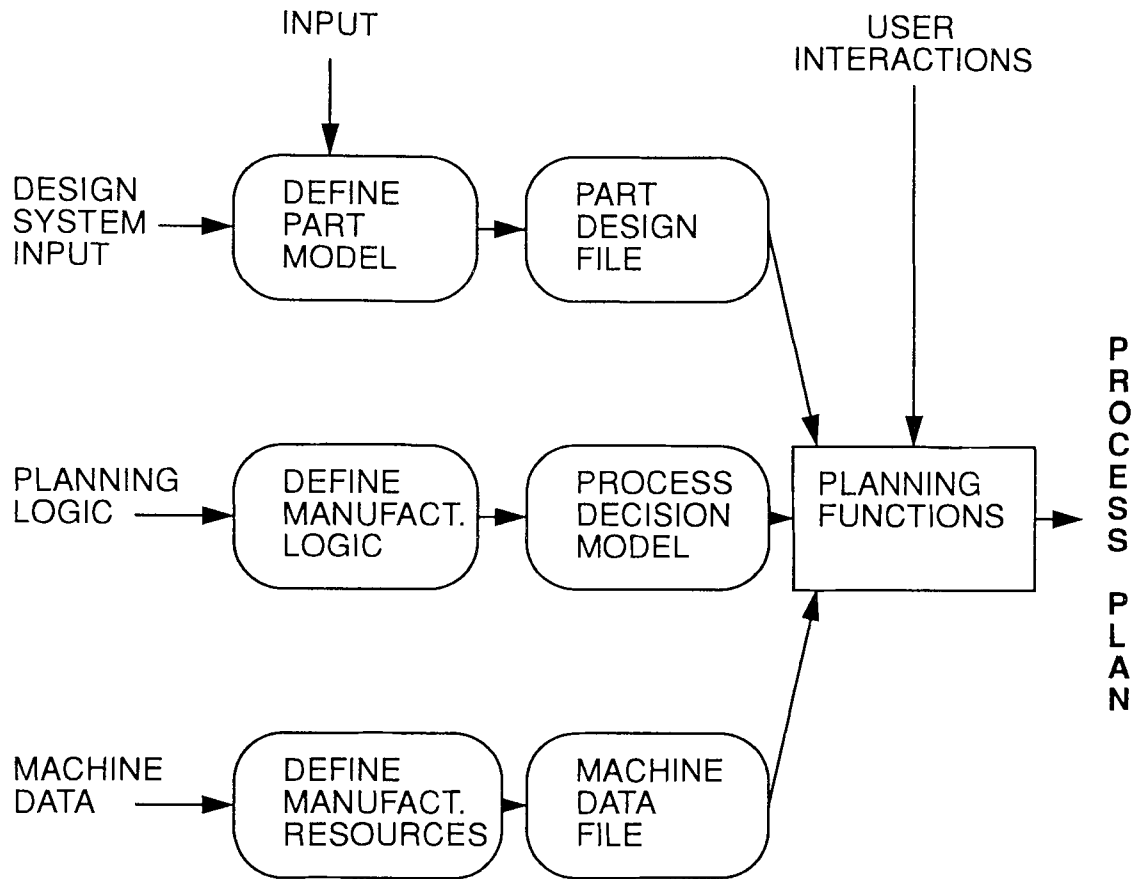


Figure 5 CAPP System Overview

4.1 Design

Engineering design is the partial realization of a designer's concept. The designer normally cannot directly transform a concept into a physical item. Instead, the designer conveys the idea to other people through an alternative medium such as an engineering drawing, and then a manufacturing engineer produces the design. Design is not the function of process planner. A process planner's function starts right after the approval of the design.

Here analysis of a gearset is necessary to determine the reliability corresponding to a specified life and the factor of safety guarding against a failure. For this purpose it is essential to know the size of the gear and their materials. In this section, the preliminary estimate of the size of the gears required to carry a given load is made.

The results are used for further analysis.

Before starting the design procedure it is necessary to clarify some basic terminologies used for gears.

1. Pinion is the smaller of the mating gears. The larger one is called as Gear.
2. Circular pitch is the distance measured on the pitch circle from a point on a tooth to a corresponding point on an adjacent tooth. Circular pitch is equal to the sum of tooth thickness and the width of space.
3. Module is the ratio of pitch diameter to the number of teeth.
4. Addendum is the radial distance between the top land and the pitch circle.
5. Dedendum is the radial distance between the bottom land and the pitch circle.
6. Whole depth is the sum of addendum and dedendum.
7. Clearance is the amount by which the dedendum in a given gear exceeds the addendum of its mating gear.
8. Backlash is the amount by which the width of a tooth space exceeds the thickness of the engaging tooth measured on the pitch circles.

This section is divided into two subsections. The first section provides the detailed design procedure manually done while the second section provides the design procedure done with the aid of computer program. Manual procedure is always considered as most possible accurate method. But it is very difficult to achieve the same accuracy throughout the design procedure. Computerized design procedure provide the advantage of highest accuracy along with highest repeatability. In the manual procedure, the user has to intervene time to time for referring different tables and charts. This interns reduces the ability of the designer to repeat the procedure. But in the design program this is made automatic. The program is well instructed to ask for proper values of different parameters at proper situations. This program is capable of making some of the decisions quickly with minimum intervention of the user. The user intervention is required in the program only the situations where most critical decision is to be made, e.g. for the selection of gear blank material, since the user has less options he has to choose among the available materials only.

During the design procedure, different tables are referred. These tables are provided at the end of the design procedure. In the design program, the tables are used in the form of subroutines. The program refers to these tables at the desired situations. The design procedure provides the design of a typical spur as well as a helical gear. The design procedure as well as the design program provides the strength analysis for the gear also. In the program at the critical points checks are provided. These checks are in the form of conditions. The program proceeds only if these conditions are matched. The program gives indications about the unsatisfactory conditions to the user as soon as they are unmatched. The user has to intervene then to adjust the input parameters to satisfy these conditions.

4.1.1 Design Procedure

1.Design of Spur gears

Initial inputs to start the procedure are,

horse power to be transmitted = 100

gear ratio = 4

RPM of gear drive = 1120

It has been proved that the minimum number of teeth on gears to avoid undercutting are 18.

So let us start with # of teeth on pinion = 18

Therefore # of teeth on gear = # of teeth on pinion * gear ratio

$$= 18 * 4$$

$$= 72$$

1) Calculations for transmitted load,

Let us choose pitch = 4

$$d = 18/4 = 4.5 \text{ in}$$

$$\text{velocity} = \frac{\pi \times d \times \text{RPM}}{12}$$

$$= \frac{\pi \times 4.5 \times 1120}{12}$$

$$= 1319.468$$

$$\text{transmitted load} = W_t = \frac{33000 \times \text{HP}}{V}$$

$$= \frac{33000 \times 100}{1319.468}$$

$$= 2501.006 \text{ lb}$$

This gear drive is capable of transmitted 2501.006 lb load.

2) Calculations for stress analysis,

$$\begin{aligned} \text{velocity factor} = K_v &= \frac{600}{600 + V} \\ &= \frac{600}{600 + 1319.468} \\ &= 0.3125 \end{aligned}$$

Let us choose material as G 10400 Drawn at 1000° F

Yield stress of the selected material, $S_y = 86.0$

Tensile stress, $S_{ut} = 113.0$

Factor of safety = 4

$$\begin{aligned} \text{design stress, } DS &= S_y / FS \\ &= 86.0 / 4.0 = 21.5 \end{aligned}$$

Tooth system selected here is 20 deg full depth

Lewis form factor is chosen from the table 2 based on the # of teeth on pinion

$Y = 0.309$

$$\begin{aligned} \text{face width, } F &= \frac{W_t \times P}{K_v \times Y \times DS \times 1000} \\ &= \frac{2501.006 \times 4}{0.3125 \times 0.309 \times 21.5 \times 1000} \\ &= 4.818 \end{aligned}$$

Face width is not satisfactory if $F < 3 * p$ and or

$$F > 5 * p$$

where p = circular pitch

$$\begin{aligned} p &= \frac{\Pi}{G} \\ &= \frac{\Pi}{4} = 0.785 \end{aligned}$$

$$3 * p = 2.356$$

$$5 * p = 3.926$$

$$F > 5 * p$$

face width is not satisfactory

So we will have to choose another value of pitch

now $P = 3.0$

pinion diameter = $18 / 3 = 6.0$ in

$$\begin{aligned} \text{velocity} &= \frac{\pi \times d \times \text{RPM}}{12} \\ &= \frac{\pi \times 6.0 \times 1120}{12} \end{aligned}$$

$$= 1759.29$$

$$\begin{aligned} W_t &= \frac{33000 \times \text{HP}}{V} \\ &= \frac{33000 \times 100}{1759.29} \\ &= 1875.75 \end{aligned}$$

Calculations for stress analysis,

$$\begin{aligned} K_v &= \frac{600}{600 + 1759.29} \\ &= 0.254 \end{aligned}$$

$$\begin{aligned} \text{new Face width} &= \frac{W_t \times P}{K_v \times Y \times D_S \times 1000} \\ F &= \frac{1875.75 \times 3}{0.254 \times 0.309 \times 21.5 \times 1000} \\ &= 3.334 \end{aligned}$$

circular pitch, $p = \pi / 3.0 = 1.047$

$$3 * p = 3.14$$

$$5 * p = 5.23$$

$$3p < F < 5p$$

Therefore face width is satisfactory.

3) Calculations for Bending Strength,

$$S_e = K_a * K_b * K_c * K_d * K_e * K_f * S_{se}$$

$$S_{se} = \text{Endurance limit} = 0.5 * S_{ut}$$

$$= 0.5 * 113 = 56.5 \text{ kpsi}$$

K_a = Surface factor, is selected according to S_{ut} from table 3 = 0.72

K_b = Size factor, if $P < 5$, $K_b = 0.85$ otherwise = 1.0

K_c = Reliability factor, is chosen from table 4 = 0.753

K_d = Temperature factor, is based on operating temperature

if temperature < 160 , $K_d = 1.0$ otherwise = $620 / (460 + T)$

so in this case $K_d = 620 / (460 + 200.) = 0.939$

K_e = Stress concentration factor = 1.00

K_f = Miscellaneous factor = 1.00

$$\begin{aligned} S_e &= 0.72 * 0.85 * 0.753 * 0.939 * 1.0 * 1.0 * 56.5 \\ &= 24.459 \end{aligned}$$

S_e Endurance limit for the gear tooth = 24.459 kpsi

4) Calculations for surface fatigue strength

$$\text{Bending endurance limit} = S_h = \frac{C_l * C_h}{C_t * C_r} * S_{fe}$$

$$S_{fe} = \text{Surface endurance limit} = 0.4 * H_b - 10$$

H_b = Brinell hardness obtained from table 1 for the selected material = 235

$$S_{fe} = 0.4 * 235 - 10 = 84.00 \text{ kpsi}$$

C_l = Life factor, from table 5 = 1.1

It is based on the predicted life of the gear in terms of # of operating cycles.

C_h = Hardness ratio factor = 1.0

C_t = Temperature factor = 1.0

C_r = Reliability factor = 0.753 (Same as K_c)

$$\begin{aligned} S_h &= \frac{1.1 \times 1.0}{1.0 \times 0.753} \times 84.00 \\ &= 122.709 \text{ kpsi} \end{aligned}$$

This completes the design procedure. Based on the selected parameters, let us calculate basic gear dimensions.

$$\text{addendum} = a = 1.00 / P = 1.00 / 3.0 = 0.33 \text{ in}$$

$$\text{dedendum} = b = (1.2 / P) + 0.002 = (1.2 / 3.0) + 0.002 = 0.40 \text{ in}$$

$$\text{working depth} = 2.00 / P = 2.00 / 3.0 = 0.67 \text{ in}$$

$$\text{whole depth} = (2.2 / P) + 0.002 = (2.2 / 3.0) + 0.002 = 0.74 \text{ in}$$

$$\text{circular tooth thickness} = 1.5708 / P = 1.5708 / 3.0 = 0.52 \text{ in}$$

$$\text{fillet radius} = 0.3 / P = 0.3 / 3.0 = 0.10 \text{ in}$$

$$\text{basic clearance} = (0.2 * P) + 0.002 = (0.2 * 3.0) + 0.002 = 0.07 \text{ in}$$

2. Design of Helical gears

Initial inputs to start the procedure are,

horse power to be transmitted = 100

gear ratio = 4.0

RPM of gear drive = 1120

of teeth on pinion = 18

$$\begin{aligned} \text{\# of teeth on gear} &= \text{\# of teeth on pinion} * \text{gear ratio} \\ &= 18 * 4 = 72 \end{aligned}$$

pressure angle = 20.0

normal pitch = 5.0

$$\begin{aligned}
 \text{transverse pitch} &= P_t = P_n \cdot \cos(\phi) \\
 &= 5.0 \cdot \cos(20) \\
 &= 4.698
 \end{aligned}$$

$$\text{diameter of pinion} = T_p / P_t = 18 / 4.698 = 3.831$$

$$\begin{aligned}
 \text{velocity} &= \frac{\pi \times d \times \text{RPM}}{12} \\
 &= \frac{\pi \times 3.831 \times 1120}{12} = 1123.31
 \end{aligned}$$

1) Calculations for transmitted load

$$\begin{aligned}
 \text{transmitted load} = W_t &= \frac{33000 \times \text{HP}}{V} \\
 &= \frac{33000 \times 100}{1123.31} \\
 &= 2937.75 \text{ lb}
 \end{aligned}$$

2) Calculations for stress analysis

$$\begin{aligned}
 \text{velocity factor, } K_v &= \sqrt{\frac{78}{78 + (\sqrt{V})}} \\
 &= 0.836
 \end{aligned}$$

Let us choose material as G 10400 drawn at 1000° F

as that of prior calculations, design stress = 21.5 kpsi

Tooth system here is also 20 deg. full depth

Lewis factor based on # of teeth on pinion and tooth system is 0.309

$$\begin{aligned}
 \text{Face width} &= \frac{W_t \times P}{K_v \times Y \times DS \times 1000} \\
 &= \frac{2937.75 \times 5}{0.836 \times 0.309 \times 21.5 \times 1000} \\
 &= 2.644 \text{ in}
 \end{aligned}$$

$$\text{circular pitch} = p = \pi / G = \pi / 4 = 0.785$$

$$3 \cdot p = 2.356$$

$$5 \cdot p = 3.926$$

Therefore $3p < F < 5p$.

So face width is satisfactory.

3) Calculations for bending strength

$$S_e = K_a * K_b * K_c * K_d * K_e * K_f * S_{se}$$

$$K_a = 0.72 \quad K_b = 0.85 \quad K_c = 0.753 \quad K_d = 0.939 \quad K_e = 1.00 \quad K_f = 1.00$$

$$S_e = 0.72 * 0.85 * 0.753 * 0.939 * 1.00 * 1.00 * 56.5$$

$$S_e = 24.45 \text{ kpsi}$$

Therefore endurance limit of the gear tooth is 24.45 kpsi.

4) Calculations for the surface fatigue strength

$$\text{Bending endurance limit, } S_h = \frac{C_l * C_h}{C_t * C_r} * S_{fe}$$

$$S_{fe} = 0.4 * H_b - 10 = 84$$

$$C_l = 1.1$$

$$C_h = 1.0$$

$$C_t = 1.0$$

$$C_r = 1.0$$

$$S_h = 122.709 \text{ kpsi}$$

This completes the design procedure for the helical gears. Based on calculated parameters, basic gear dimensions are

$$\text{addendum} = a = 1.00 / P = 1.00 / 5.0 = 0.2 \text{ in}$$

$$\text{dedendum} = b = (1.2 / P) + 0.002 = (1.2 / 5.0) + 0.002 = 0.242 \text{ in}$$

$$\text{working depth} = 2.00 / P = 2.00 / 5.0 = 0.4 \text{ in}$$

$$\text{whole depth} = (2.2 / P) + 0.002 = (2.2 / 5.0) + 0.002 = 0.442 \text{ in}$$

$$\text{circular tooth thickness} = 1.5708 / P = 1.5708 / 5.0 = 0.314 \text{ in}$$

$$\text{fillet radius} = 0.3 / P = 0.3 / 5.0 = 0.06 \text{ in}$$

$$\text{basic clearance} = (0.2 * P) + 0.002 = (0.2 * 5.0) + 0.002 = 0.042 \text{ in}$$

Table 1 Mechanical Properties of Steel

UNS NUMBER	PROCESSING	YIELD STRENGTH kpsi	TENSILE STRENGTH kpsi	BRINELL HARDNESS H _b
G10100	HR	26	47	95
	CD	44	53	105
G10150	HR	27	50	101
	CD	47	56	111
G10180	HR	32	58	116
	CD	54	64	126
G10350	HR	39	72	143
	CD	67	80	163
	DRN 800° F	72	103	201
G10400	HR	42	76	149
	CD	71	85	170
	DRN 1000° F	86	113	235
G10500	HR	49	90	179
	CD	84	100	197
	DRN 900° F	130	155	310
G15216	HR	81	100	192
G41300	HR	60	90	183
	CD	87	98	201
	DRN 1000° F	133	146	293

Table 1 (continued)

UNS NUMBER	PROCESSING	YIELD STRENGTH kpsi	TENSILE STRENGTH kpsi	BRINELL HARDNESS H _b
G41400	CD	90	102	223
	HR	63	90	187
	DRN 1000° F	131	153	302
G43400	HR	69	101	207
	CD	99	111	223
	DRN 1000° F	162	182	363
G46200	DRN 800° F	94	130	256
G61500	HR	58	91	183
	DRN 1000° F	132	155	302
G87400	HR	64	95	190
	CD	96	107	223
	DRN 1000° F	129	152	302
G92550	HR	78	115	223
	DRN 1000° F	160	180	352

* Tabulated in accordance with the Unified Numbering System for metals and alloys (UNS), Society of Automotive Engineers, Warrendale, Pa.

* HR - Hot Rolled, CD - Cold Drawn steels are estimated minimum values which can usually be expected in the size range of 3/4 to 1 1/4 in. These values can be obtained by careful control of the purchase specifications and the heat treatment.

* Multiply strength in kpsi by 6.89 to get the strength in MPa.

Table 2 Form Factors Y for Various Tooth Systems

# OF TEETH ON PINION	TOOTH	SYSTEM
	20 DEG. FULL DEPTH	INTERNAL
18	0.309	0.348
19	0.314	0.358
20	0.322	0.364
21	0.328	0.370
22	0.331	0.374
24	0.337	0.383
26	0.346	0.393
28	0.353	0.399
30	0.359	0.405
34	0.371	0.414
38	0.384	0.424
43	0.397	0.430
50	0.409	0.436
60	0.422	0.446
75	0.435	0.452
100	0.447	0.461
150	0.460	0.468
300	0.472	0.477

Table 3 Surface Finish Factors

ULTIMATE TENSILE STRENGTH (kpsi)	SURFACE FACTOR K_a
80	0.78
100	0.75
120	0.72
140	0.69
160	0.66
180	0.64
200	0.62

* Hint - To refer this table, If Ultimate tensile strength is less than 80 kpsi. then $K_a = 0.78$

Table 4 Reliability Factors

RELIABILITY	RELIABILITY FACTOR K_c
0.50	1.0
0.90	0.897
0.99	0.814
0.999	0.753

Table 5 Life Factors

LIFE OF GEAR (IN TERMS OF # OF OPERATING CYCLES)	LIFE FACTOR C_l
10^4	1.5
10^5	1.3
10^6	1.1
10^7	1.0

4.1.2 The Programmed Design

In the actual program, the user has to specify his options. The program starts with basic inputs for a gear design. The user specifies gear ratio, horse power to be transmitted and the rotational speed. The minimum number of teeth on pinion to avoid undercutting is 18. Based on this fact, the user selects suitable number of teeth on pinion. The program calculates the number of teeth on gear accordingly multiplying the number of teeth on pinion by the gear ratio. The user has to select the pitch. For the selected pitch, the program calculates various parameters and checks if the selected pitch is not overcoming any rules. Face width of the pinion tooth should be 3 to 5 times the circular pitch. If is not, the program gives an indication of unsatisfactory face width. With the selected pitch, the program calculates diameter of the pinion, pitch line velocity and the transmitted load. Velocity factor depends on the pitch line velocity. From this point the real trial and error based design procedure starts.

Gears are commonly made of steel, cast iron, bronze, or resins. Nylon, teflon, titanium and sintered iron can also be used. The great variety of materials available provides the designer with the opportunity to get the material for any particular requirement, such as high strength, long wear life, high reliability, quietness of operation, etc. In many applications, steel is the only satisfactory material because of its high strength and low cost. In many cases the choice of gear material will depend on the relative success of the heat treatment with various steels. When the gear is quenched and tempered, a steel with 40 to 60 points of carbon is used. For case hardening, 20 points of carbon are used. Cast iron is also useful because of its good wear resistance. It is easy to cast and machine. It also transmits less noise than steel. Bronze can also be used when corrosion is a problem and it is useful also for reducing friction and wear when sliding velocity is high. Nonmetallic gears are mated with steel or cast-iron gears

to obtain the greatest load-carrying capacity. To secure good wear resistance, the metal gear should have a hardness of atleast 300 Bhn. A nonmetallic gear carries almost as much load as a good cast iron or mild steel gear because of its low modulus of elasticity. The low modulus permits to absorb the effects of tooth errors so that a dynamic load is not created.

The program gives a listing of 33 different materials along with their processing information, i.e. hot rolled, cold drawn and the drawing temperatures. The user has to select proper material code. This code makes the program to run through a subroutine and returns back to the main program with selected material properties, yield stress, tensile stress and Brinell hardness number. The user has then to select a factor safety between 3 to 5. The program then calculates design stress according to yield stress and factor of safety. The program then turns towards bending stress analysis. According to the number of teeth on pinion and tooth system, the program searches through a subroutine for Lewis form factor. Based on all the calculated and selected data, the program calculates the face width for the gear tooth. If this face width is satisfactory then only this program allows to move over for further analysis. It otherwise returns back and asks for a new value of pitch. This procedure continues until satisfactory face width is obtained.

After getting satisfactory face width, the program proceeds for further bending strength analysis. Based on selected material and its properties, the program runs through different subroutines. For bending strength analysis, the user has to specify reliability and working temperature. Based on calculated surface, size, reliability, temperature, stress concentration factor and miscellaneous factors, the program calculates endurance limit for the gear tooth. Further analysis includes calculations for surface fatigue strength. For this analysis the user has to specify expected life of gears in terms of number of

working cycles. The program then calculates the surface endurance limit and bending endurance limit. The analysis procedure ends here and program then exceeds its limits towards the calculations of different geometry factors. These factors work as input parameters in the further analysis. The program calculates addendum, dedendum, working depth, whole depth, circular tooth thickness, fillet radius of basic rack and the basic clearance.

For the design of helical gears, same procedure is adopted as that of spur gears. But in the design of helical gears various other factors take active part in the design procedure. The program accordingly asks for some additional input parameters such as, pressure angle and normal pitch. The diameter of helical pinion is calculated by using the calculated transverse pitch. The program then undergoes the same design procedure as that of spur gears. The program checks for the satisfactory face width. In case of unsatisfactory face width, program asks for new values of pressure angle and normal pitch. The program then proceeds for the bending strength and surface fatigue analysis. After satisfactory analysis, the program calculates the basic gear dimensions.

The design procedure and analysis programmed here gives quick estimation of gear size. The user can go through the program several times for any number of iterations. Design is an iterative procedure. The best possible design is obtained only after a number of iterations.

Input File for Spur Gear Design**4,100.,1120.****18.****3.****12****4.****1****0.999****200.****1000000**GEAR RATIO = **4**,HP TO BE TRANSMITTED = **100**,ROTATIONAL SPEED = **1120** RPM# OF TEETH ON PINION = **18**PITCH = **3**MATERIAL CODE = **12** i.e. G 10400 DRAWN AT 1000 DEG FFACTOR OF SAFETY = **4**TOOTH SYSTEM CODE = **1** i.e. 20 DEG FULL SEPTHRELIABILITY = **0.999** i.e. 99.9%WORKING TEMPERATURE = **200** DEG FLIFE = **1000000** CYCLES

Output File for Spur Gear Design

WRITE YOUR CHOICE

SPUR=1, HELICAL=2

CHOICE IS = 1

SPUR GEARS

GEAR RATIO = 4 HP = 100.00 RPM = 1120.00

MINI. # OF TEETH TO AVOID UNDERCUTTING=18

OF TEETH ON PINION = 18.000

OF TEETH ON GEAR = 72.000

CHOOSE YOUR PITCH

PITCH = 3.000

PINION DIAMETER = 6.000 INCH

VELOCITY = 1759.292 SFPM

TRANSMITTED LOAD = 1875.755 lb

VELOCITY FACTOR = .254

BASED ON MATERIAL CODE

YIELD STRESS = 86.000 kpsi

TENSILE STRENGTH = 113.000 kpsi

FACTOR OF SAFETY = 4.000

DESIGN STRESS = 21.500 kpsi

LEWIS FACTOR = .309

FACE WIDTH = 3.331 INCH

FACE WIDTH IS SATISFACTORY

CALCULATE FOR BENDING STRENGTH

ENDURANCE LIMIT	=	56.500 kpsi
SURFACE FACTOR	=	.620
SIZE FACTOR	=	.850
RELIABILITY FACTOR	=	.753
TEMPERATURE FACTOR	=	.939
STR CONCENT FACTOR	=	1.000
MISC. FACTOR	=	1.000
ENDURANCE LIMIT FOR GEAR TOOTH	=	21.062 kpsi
LIFE FACTOR	=	1.100
RELIABILITY FACTOR	=	.753
HARDNESS NUMBER	=	235.000
SURFACE ENDURANCE LIMIT	=	84.000 kpsi
BENDING ENDURANCE LIMIT	=	122.709 kpsi
ADDENDUM	=	.333 INCH
DEDENDUM	=	.402 INCH
WORKING DEPTH	=	.667 INCH
WHOLE DEPTH	=	.735 INCH
CIRCULAR TOOTH THICKNESS	=	.524 INCH
FILLET RADIUS OF BASIC RACK	=	.100 INCH
BASIC CLEARANCE	=	.069 INCH

Input File for Helical Gear Design

4,100.,1120.
18.
20.
5.
12
4.
1
0.999
200.
1000000

GEAR RATIO = **4**,

HP TO BE TRANSMITTED = **100**,

ROTATIONAL SPEED = **1120** RPM

OF TEETH ON PINION = **18**

PRESSURE ANGLE = **20**

NORMAL PITCH = **5**

MATERIAL CODE = **12** i.e. G 10400 DRAWN AT 1000 DEG F

FACTOR OF SAFETY = **4**

TOOTH SYSTEM CODE = **1** i.e. 20 DEG FULL SEPTH

RELIABILITY = **0.999** i.e. 99.9%

WORKING TEMPERATURE = **200** DEG F

LIFE = **1000000** CYCLES

Output File for Helical Gear Design

WRITE YOUR CHOICE

SPUR=1, HELICAL=2

CHOICE IS = 2

HELICAL GEARS

GEAR RATIO = 4 HP = 100.00 RPM = 1120.00

# OF TEETH ON PINION	=	18.000
# OF TEETH ON GEAR	=	72.000
PRESSURE ANGLE	=	20.000
NORMAL PITCH	=	5.000
TRANSVERSE PITCH	=	4.698
PINION DIAMETER	=	3.831 INCH
VELOCITY	=	1123.320 SFPM
TRANSMITTED LOAD	=	2937.721 lb
VELOCITY FACTOR	=	.836

BASED ON MATERIAL CODE

YIELD STRESS	=	86.000 kpsi
TENSILE STRENGTH	=	113.000 kpsi
FACTOR OF SAFETY	=	4.000
DESIGN STRESS	=	21.500 kpsi
LEWIS FACTOR	=	.309
FACE WIDTH	=	2.644 INCH

FACE WIDTH IS SATISFACTORY

CALCULATE FOR BENDING STRENGTH

ENDURANCE LIMIT	=	56.500 kpsi
SURFACE FACTOR	=	.620
SIZE FACTOR	=	.850
RELIABILITY FACTOR	=	.753
TEMPERATURE FACTOR	=	.939
STR CONCENT FACTOR	=	1.000
MISC. FACTOR	=	1.000
ENDURANCE LIMIT FOR GEAR TOOTH	=	21.062 kpsi
LIFE FACTOR	=	1.100
RELIABILITY FACTOR	=	.753
HARDNESS NUMBER	=	235.000
SURFACE ENDURANCE LIMIT	=	84.000 kpsi
BENDING ENDURANCE LIMIT	=	122.709 kpsi
ADDENDUM	=	.200 INCH
DEDENDUM	=	.242 INCH
WORKING DEPTH	=	.400 INCH
WHOLE DEPTH	=	.442 INCH
CIRCULAR TOOTH THICKNESS	=	.314 INCH
FILLET RADIUS OF BASIC RACK	=	.060 INCH
BASIC CLEARANCE	=	.042 INCH

4.2 Part Design Representation

Process planning, like other planning activities, has a very specific objective i.e. to identify the detailed processes required for the production of a piece part. Product design is the input for the planning system. The operations planning summary is the output. Although several different input representations are used to describe a part, the most general input representation is engineering design. This is the input to the planning system, which interprets it in order to find the appropriate machining processes, process parameters to satisfy the design. In a computerized planning system, a formal structure and data are required to transform the engineering design information into the production design.

As design becomes complex, a picture becomes necessary to relate the information to others. Multiview orthographic drawing has long been adopted as a tool to represent a design. Design information can be passed from the designer to others. The object a designer draws can be interpreted and reconstructed in the designer's image in a viewer's mind. The capability of transforming an object from one medium to another and an understanding of the rules of drawing are prerequisite to pass design information from the designer to other people without any error.

An engineering drawing therefore contains all the information necessary to represent a design. Since process planning is the function that creates detailed plans for the production of a component, an engineering drawing is the basic input to the process planning function. There are several methods to represent the drawing. The most conventional is drafting on paper with pencil or ink. Manual drafting is tedious and requires tremendous patience and time. Computer aided drafting systems improve drafting efficiency. The major objective of these systems is to assist the draftsman with tedious drawing and redrawing. Partially

completed or completed drawings from graphics tablet or screen can be digitized and stored in a computer and can be retrieved when needed.

Most CAD systems store drawings in a three dimensional representation. Points, lines and curves are represented in (X,Y,Z) space. When a drawing is requested, a series of transformations are performed on the data and a drawing is presented either in two or three dimensional perspective or sectional views. The resultant drawing can then be drawn physically using a plotter, or simply displayed on a cathode ray tube. In recent years, the term geometric modeling in CAD has become common jargon. Geometric modeling is a technique for providing computer compatible description of the geometry of a part. Conventional CAD systems are geometric models that use surface oriented three dimensional models. Recent advances in CAD have focused on the development of bounded shape models for a three dimensional representation. In these bounded shape models, individual surfaces are structured together to define the complete shell. Operators are then be applied to manipulate the shape.

In ancient times before multiview drawing standards were adopted the Renaissance, Leonardo da Vinci, designed several machines and mechanical components using perspective sketches. Today, pictorial drawings are still used to supplement other design representations. A multiview drawing usually contains two or three views. Each view is an orthographic projection of one plane. In US and Canada, the third angle projection system is used. For the third angle projection, we always place the object in the third angle and project the object in three planes.

A drawing is expected to convey a complete description of every detail of a part. However, dimensioning is as important as the geometric information. American National Standards Institute (ANSI) recommends to follow some basic rules for dimensioning such as,

1. Enough dimensions should be shown so that the intended sizes and shapes can be determined without calculating or assuming any distances.
2. Each dimension should be stated clearly so that it can be interpreted in only one way.
3. The dimensions between points, lines, or surfaces which have a necessary and specific relation to each other or which control the location of other components or mating parts should be shown.
4. The dimensions should be selected and arranged to avoid accumulations of tolerances that may permit various interpretations and cause unsatisfactory mating of parts and failure in use.
5. Each dimension should be shown only once.
6. Wherever possible, each feature should be dimensioned in the view where it appears in profile, and where its true shape appears.
7. The dimensions should be specified to make use of readily available materials, parts, tools, and gauges. Savings are often possible when drawings specify commonly used materials in stock sizes, parts recognized as commercially standard, sizes that can be produced with standard tools and inspected with standard gauges and tolerances from accepted published standards.

It is impossible to produce the exact dimension specified. A tolerance is always required to show the acceptable variation in a dimension. There are bilateral and unilateral tolerances. Bilateral tolerances specify dimensional

variation from the basic size while a unilateral tolerance specifies an increase in one direction in relationship to the basic size. The basic location where most dimension lines originate is the reference location. For machining, the reference location provides the base from which all other measurements are taken. By starting tolerances from a reference location, cumulative errors can be eliminated. Conventional methods of dimensioning only provide information concerning size and surface condition. A component can be produced without a guarantee of interchangeability.

Here the above explained procedure and rules are followed to draw the drawing of the designed gear and for dimensioning it. The output of the design program provides the dimensions of the designed gear. These dimensions are treated as inputs for the graphics facility. These dimensions are fed into the program in C language. The program accepts these values and runs to draw a two dimensional picture of the designed gear. Since the program is made to interact automatically, there is no any need for the user intervention into the program logic except for the insertion of gear dimensions. With the change in the input parameters, the graphics representation can also be changed.

The graphics representation kicks off for the actual process planning.

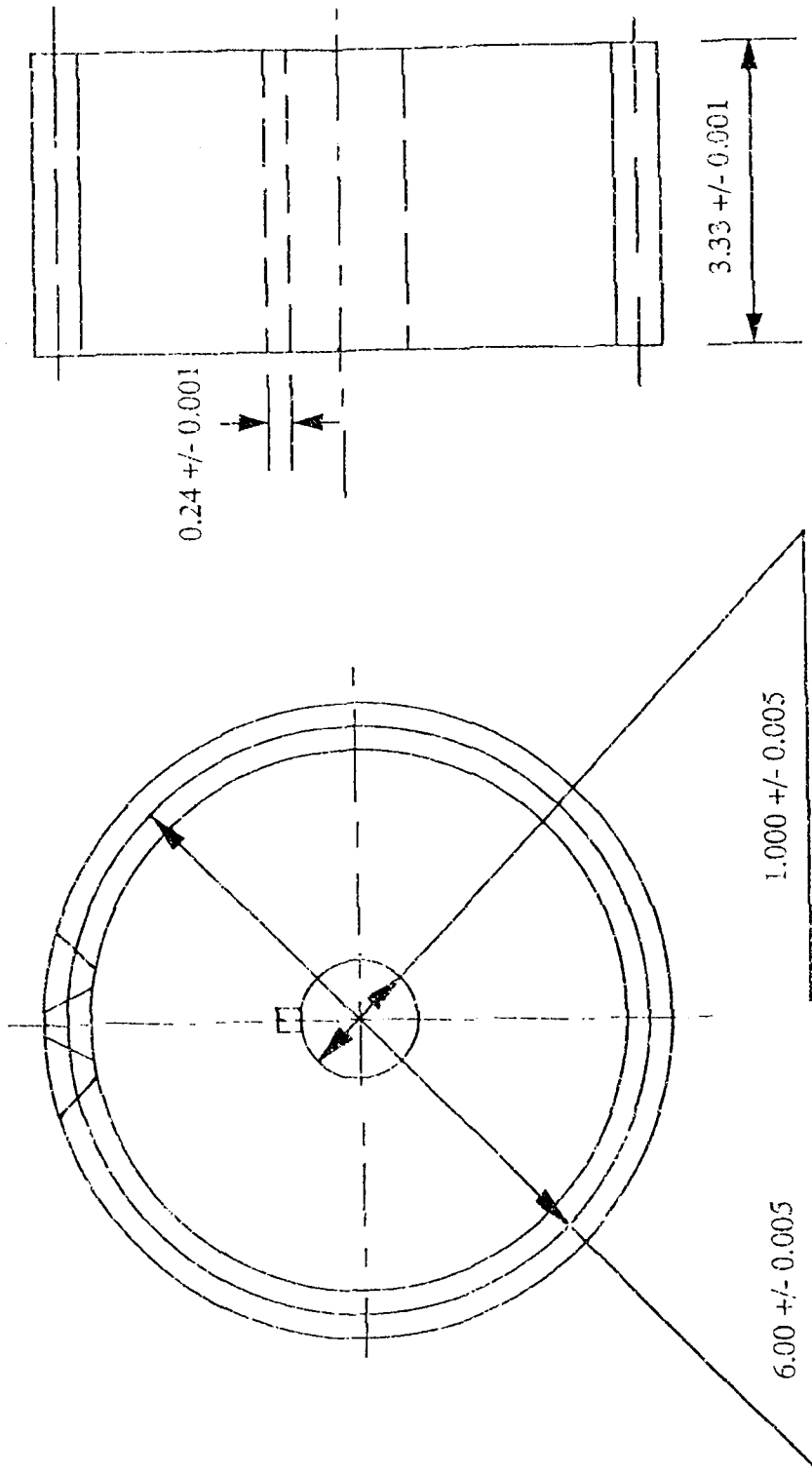


Figure 6 2 - D View of a Spur Gear

4.3 Process Planning

Manufacturing process planning is a common task in small batch and discrete parts metal working industries. It is consisting of translating the part design specifications from an engineering drawing into the manufacturing operation instructions required to convert a part from a rough to a finished state. The geometric features, dimensional sizes, tolerances and material specifications of the part must be first determined. Based on these parameters, the appropriate sequence of processing operations and specific machines can be selected. These parameters also decide operational details such as, speeds, feeds, tools, etc.

Earlier the generative process plan was described as a process in which processing rules, rather than plans, were captured by the computer to generate process plans. But generative plans have a number of advantages. They rely less on group technology code numbers. In generative plans, a process is captured in a decision tree. Maintenance and updating of stored process plans is not necessary since any plan can be regenerated easily by processing through the tree. But the process logic rules are required to be maintained up to date.

The process documentation produced by generative system varies from variant system. They require much less human input in the creation of a process plan since logic is already captured. But ofcourse during their generation a lot of thoughtful analysis is essential. The generative system is menu driven. Each branch in the decision tree logic corresponds to a menu in which the user must select the appropriate option. The generative processing logic has considerable logical and arithmetical capability. For different variables, such as shape, it is possible to include the parameters like the length of bends, thickness of the material. All these variables can be programmed to guide the selection of

branches within the tree. These parameters can thus be used as a basis of logical calculations to select processes or print the data to the generated plan.

Generative process planning system simplifies the problems by first dividing it into logical subsets and then it deals with the different combinations of the features. The structured programming using a building block or modular approach can be employed in which the building blocks consist of process planning logic appropriate for the specific features. A module might consist of sequential process planning rules which govern the sequence in which the building blocks are linked. This modular approach can be easily maintained by both data processing and manufacturing engineering. These are the two sections where a lot of technology changes occur affecting the decision rules which intern affect the sequence of the manufacturing operations. Successful generative systems deal with finite problems for which manufacturing processes have been identified and captured in the computer logic. The occasions where the programmed conditions are not met, generative approach becomes helpless and this makes process planners to look for variant approach.

Some of the current process planning systems exhibit expert capabilities. The system designed here can be best stated as Rule based process planning system managed by computer. This system can be used basically for different types of gears. The entire procedure is generative and it makes automatic process decisions. An interaction capability provides optional review and modification to these decisions. Logic and data specifically for gears are incorporated into the system database. The system executes database logic and uses database parameters to determine manufacturing procedures appropriate to the part geometry. It also calls necessary algorithms to perform different functions. This system has three major components: database Maintenance, part data input and process planning & analysis. The major data is provided by the

design program. It basically provides the analyzed and iterated design information and also desired gear dimensions. The system is designed to facilitate automatic receipt of available data from CAD database followed by interactive input of any data unavailable from CAD. The graphics section provides the bulk of processing data. In the process planning module, the database and standard planning procedures are applied to the parts. Process decisions are made with user intervention. The system performs three major operations. Generation of a summary of operations, selection of machining dimensions and output of process documentation. This system is a generative system. Therefore process decisions are generated from programmed logic and the system database. There is no any dependence on previously stored process plans. Here some of the user based decisions are required.

This system utilizes detailed part data. A complete finished part description is the input to the system. The required data includes functional dimensions, tolerances, material, hardness, etc. Here data about tolerance is provided in the module itself. The module identifies the appropriate tolerances according to the manufacturing process.

4.4 Process Capability Analysis

This section is dedicated to the manufacturing process analysis. This section provides the process analysis of the processes which can be used for the manufacturing of designed gear by the user. The processes analyzed here are decided based on the process plan. Many times there is a variations in the manufacturing processes used for the manufacturing of the same product by different manufacturers. It is very difficult to make a process plan which is applicable for all different facilities. This module provides the access to the user to choose his own processes according to his requirements and availabilities.

The module accepts the input parameters from the design program and it provides freedom to the user to choose some of the independent parameters. Most of the dependent parameters are chosen by the program during its routine procedure.

Process planning is the activity that determines the appropriate procedures to transform a raw material into a final product. The final product is specified in the engineering design. Selecting the manufacturing processes to transform the raw material into finished specification is based on matching the design requirements with process capabilities. Process capabilities is the data base of knowledge for each process. It always includes,

1. the shape and size a process can produce,
2. the dimensions and geometric tolerances that can be obtained by various processes,
3. the surface finish attainable,
4. the material removal rate,
5. the relative cost,
6. other cutting characteristics and constraints.

Process capability does not necessarily imply that all process selection is based on the information explained above. However, the more information considered in selecting a process, the more complete the result will be. For conventional process planning with human planners, all process capability information comes either in the form of experience or in handbook lists and guides. A computer aided process planning system functions based on this process capability information. A variant planning system is purely retrieval system and is analogous to planning based on experience. In a variant planning system, standard plans are stored based on component shape. These plans are then retrieved based on the similarity of a coded part. Only some of very basic

information is through a software logic. To select an appropriate process, the process capabilities must be stored in the system.

It is always true that the accumulation of experience is knowledge. Most of our knowledge comes either from our own experience or is passed on to us by others and based on their experience. Experience requires a significant period to accumulate. It is the representation of not exact but approximate knowledge. Experience is also not directly applicable to new processes or new systems. Because of these problems there is a need to represent the process capability knowledge base so as to preserve and install it as a decision support system on a computer. The process capability information can be stored in handbooks. It is usually in the form of tables, figures and guide lines.

Before any decision can be made, the information required to make the decision must be completed. This information includes a process by process breakdown of elements such as, shape that a process can generate, size limitations, boundaries of the tooling, machine tools, fixtures, tolerances, surface finish, cutting force , power consumption, etc.

Cutting force and power consumption are the two process limitations. They form the constraints that the machinery is bounded by during processing. The shape elements define the basic geometry possible by a process. This feature is very difficult to achieve by using a computer. Interpreting the shape capability in its natural form is very difficult. As an alternative shapes can be represented by codes. The matching of shape capability and machined surface may not be automatic but it can be significantly simplified. For internal machining processes, the size is constrained by the available tool size. In external machining, size is constrained by the available machine table size. One of the way to represent process capabilities is to use process boundaries. The process boundaries can be the size, tolerance or surface finish. Better results can only be

obtained by careful control of the cutting condition and process parameters, such as feed, speed, depth of cut, etc.

In general three manufacturing processes can be used for gear manufacturing viz. milling, hobbing and shaping. Milling is a gear cutting process while the other two are gear generation processes. Of all the manufacturing processes for metal removal, milling is the most widely used process after turning. Economical production of any quantity parts provides high versatility for milling. The gear cutting operation is carried out by cutting each gear tooth individually. The gear blank is held on the table and the milling cutter, which is selected according to the desired gear pitch, rotates and the table is fed towards the cutter to cut the teeth on the gear blank. After the completion of the a gear tooth, the table can be rotated through desired angle so as to cut the adjacent tooth. Hobbing and shaping are carried out in different way where both the cutter and the gear blank rotate to generate the gear teeth.

By the year 1887 the first hobbing machines for cutting straight tooth spur gears were built. In the intervening years the hobbing method has achieved a highly important and necessary place in the production processes. Hobbing process can create many and varied types of gear tooth forms. Special hobs can be used to generate formed sections such as squares, fluted octagons, cam shapes, etc.

Hobbing is a method of gear generation. Unlike a milling cutter a hob is designed so that all the cutting teeth lie in a helical path about the periphery of the tool. Under ideal operating conditions, the teeth of the hob lie along a true helix of the proper lead, concentric with the axis of its rotation. The rotation of the hob is maintained in the exact desired mathematical relation to the rotation of the work piece. Therefore during uninterrupted cutting process, the teeth of the hob pass in positive progression through the work piece with a thick network of cuts.

Each of the cut removes a small shaving to finally generate a smooth form. The cutting action in a hobbing process is continuous and forms are generated in one passage of the hob through a blank. The hob advances uniformly as the blank rotates. This makes the indexing automatic and continuous. Thus a full form outline can be generated at one revolution of a blank. The hobbing process is useful for the forms those regularly repeat themselves on the periphery of a circular part. Each form must be a duplicate of any other forms even if it is not symmetrical. Most recent hobbing machines are capable of hobbing at a maximum metal removal rate of 3 cubic inch per min. on AGMA 9 class. Due to the character of the hobbing process only a small amount of undercutting can be produced on the generated forms. For radial, straight or undercut teeth, a single position hob must be used. The hobbed forms comprise of a multitude of tiny scallops rather than a smooth and even surface. These tiny cuts are made by each tooth. They are created during the generation of the final form. At the requirements of high smoothness and geometrical accuracy of surfaces, the forms must be rough and finish hobbed. Such parts can be finished by shaving process. With fine pitch hobs, gear tooth from 30 to 268 pitch can be produced with profile accuracy of 0.0005 inch. Pitch diameters can be held within 0.0003 to 0.0005 in and runout within 0.001 in.

Generally gear shaping is considered as a special purpose process for the generation of gears and gear teeth. But the versatility and ability of shaping process to produce a variety of machine parts places it among the important mass production processes.

The reciprocation of the cutting tool makes it possible to generate external and internal surfaces by properly controlled movements of the gear blank. The combination of tool reciprocation with controlled generating motion makes shaping universal in its application to the production of unusual machine parts.

Rotational movements and position variations can be imparted to the generating tool or to the work piece. Conjugate or mated surfaces can also be used on the cutting tool to generate a desired shape.

The basic principle used for operations is shear speed method. The work piece is held firmly while the cutting head with a complete set of individual cutting teeth to suit the particular form being generated reciprocates rapidly. At the same time the individual tool feeds in to produce the desired form. The shapers can cut gears ranging from small fine pitch parts 2 inch in diameter to 90 inch diameter. Width range of 3/4 inch to 16 inch is possible. Some special attachments such as, tilting work table, rack shaping attachment, quick change tooling, automatic loading, automatic chip removal are also available. To maintain accuracy on parts which cannot be supported solidly, the finest and slowest feeds must be used. Often more than one revolution is required to get highest accuracy and quality.

Drilling and broaching procedures are basically optional processes. Drilling is adopted to provide additional feature to the designed gear. This drill at the center of the gear blank is provided for the shaft on which the gear is generally mounted. The shaft and the gear are attached with one another by means of a key. This key is one of the critical element in the drive mechanism. This key fails at the overload and saves the gear and the shaft from failure. The key way can be cut on the gear by broaching process. Special clamps are provided to hold the gear. The broach, its face width goes on increasing along its length and its final quarter width is the width of the key way desired, passes through the drilled hole on the gear blank.

The analysis procedure starts with the output of process plan file. The process plan file accepts the inputs from the user and provides the process plan for the required gear. The plan provides dimensions of the gear blank after each

of the manufacturing procedure. For the purpose of analysis, the user has to refer the plan. How? It is explained later.

The process plan has the information of processing parameters, such as blank diameter, width, etc. Based on this data, user has to calculate some analysis parameters such as, length of stroke, diameter to work on, etc. This calculation should be done based on the available tools, machines and their capabilities. As an example, for the drilling operation when a simple drill is used, the drill has nose followed by cup section. The nose meets the work piece and penetrates it. But the required diameter of the drill is provided by the drill cutter edge. This edge starts after a considerable amount of length of drill passes through the work piece. Similarly the drill can pass throughout the work piece only when the cutting edge completes the work piece width. Therefore in this case the length of the stroke of the drill is more than that of the work piece width. The user has to define this stroke length based on the drills he is using. For the turning process where the part processing generally starts, there is necessity to provide original or available blank diameter and the diameter desired after the machining process. For the mathematical calculations purpose, the desired diameter is always taken into consideration and all the related parameters are based on it. By providing the available blank diameter, the program calculates the depth of the tool towards the center of the work piece. Based on this information and the computer provided feed rate, the program calculates the number of passes required to complete the desired turning operation. For the calculations of the cutting time of each tool pass, the program is made more advanced to accept value of desired diameter as the diameter that is obtained after each tool pass. Since for each successive pass the desired diameter goes on reducing the cutting time reduces for each pass. The program also provides the total cutting time after the completion of all tool passes.

The process analysis program works according to the user's choice. The program is provided with analysis for six manufacturing processes used for gear manufacturing from blank to the final finished gear. Turning, Milling, Drilling, Hobbing, Broaching and Shaving are the processes analyzed here.

As explained above the user can get the required data from the design module and from the graphics module. Some of the basic data is same for all the processes. But some of the processes need specific data. The module asks the user about this specific data whenever it is needed. This data includes work piece material, tool material and also in some cases feed rates for the tools or work pieces. This user intervention at some of the points of the module makes it possible to iterate the analysis whenever required.

The module opens with the question about the manufacturing process. According to the user's choice, the module goes over the appropriate input data. The input data is about the work piece diameter, length of the stroke and number of teeth on the cutter or the tool. Number of teeth on cutter make a great difference as far as the machining time is concerned. A three flank drill performs better and also operates for less time than that of the two flank drill. The program also asks for the tool material. For carbide cutters higher cutting speeds are possible to employ than that of high speed steel cutters. For the basic processes like turning where many times a number of passes are required to reach the desired diameter of the work piece. The module asks for the available diameter of the gear blank. It calculates the number of passes required and also the cutting time for each pass.

For milling operations chip load per tooth plays a major role in determining the feed of the cutter. The module determines the appropriate chip load based on the work piece material and the type of the cutter. The user can intervene at this point by providing the material being used and also the type of the milling cutter.

For shaping process, along with feed of the work piece, the frequency of reciprocation of the cutter is the major machining parameter. The module calculates the cutting speed in surface feet per minutes, rotational speed for the spindle, feed and the cutting time for each of the operations.

This module is made interactive with the process plan. Therefore every process chosen by the user is added to the process plan automatically making the process plan updated every time. The process plan is the standard process plan containing information about various machining parameters, tolerances and machining times.

Sample Input File for Process Analysis

1
6.,3.33,1
2
6.1

CHOICE FOR PROCESS = 1, i.e. TURNING PROCESS

DESIRED DIAMETER = 6.00 INCH

LENGTH OF STROKE = 3.33 INCH

OF TEETH ON CUTTER = 1

AVAILABLE BLANK DIAMETER = 6.10 INCH

PROCESS PLAN
-----NEW JERSEY INSTITUTE OF TECHNOLOGY
GENERATIVE PROCESS PLANNING SYSTEM

PART DESCRIPTION : GEAR - SPUR/HELICAL

PART NUMBER :

MATERIAL REQUIRED : DIAM - 6.100 WIDTH - 3.330

NO	PROCESS	DIAM - TOLE	STROKE - TOL	SPEED	FEED	TIME
1	TURNING	6.0+/-0.005	3.3+/-0.005	381.97	.01	264.28
2	MILLING	4.5+/-0.002	3.3+/-0.002	337.28	26.98	133.29
3	DRILLING	1.0+/-0.001	4.0+/-0.001	2291.8	45.84	4.36

Output File for Turning Process

DESIRED DIAMETER = 6.000

LENGTH OF STROKE = 3.330

OF TEETH ON CUTTER = 1

TOOL MATERIAL - CARBIDE CUTTER

PROCESS - TURNING

W/P MATERIALS

TOOL STEEL - 1, CAST IRON - 2

MILD STEEL - 3, BRASS, SOFT BRONZE - 4

ALUMINUM OR MAGNESIUM - 5

CHOICE = 5

AVAILABLE DIAM. = 6.1 INCH

DEPTH OF CUT = .050INCH

OF TOOL PASSES = 5.0000

TIME = 53.0051

TIME = 52.8307

TIME = 52.6564

TIME = 52.4820

TIME = 52.3076

CUTTING SPEED = 600.000 SURF FEET/MIN

RPM = 381.971

FEED = .01000 IN./REV

CUTTING TIME = 264.28180 SEC

Output File for Milling Process

DESIRED DIAMETER = 4.530

LENGTH OF STROKE = 3.330

OF TEETH ON CUTTER = 16

TOOL MATERIAL - CARBIDE CUTTER

PROCESS - MILLING

W/P MATERIALS

TOOL STEEL - 1, CAST IRON - 2

MILD STEEL - 3, BRASS, SOFT BRONZE - 4

ALUMINUM & MAGNESIUM - 5

CHOICE = 5

MILLING CUTTER

CODES FOR MILLING CUTTERS

FACE MILL - 1, SIDE MILL - 2, END MILL - 3

CHOICE = 2

CHIP LOAD PER TOOTH = .005

OF TEETH ON PINION = 18.000

CUTTING SPEED = 400.000 SURF FEET/MIN

RPM = 337.281

FEED = 26.98250 IN./REV

CUTTING TIME = 133.28640 SEC

Output File for Drilling Process

DESIRED DIAMETER = 1.000

LENGTH OF STROKE = 3.330

OF TEETH ON CUTTER = 2

TOOL MATERIAL - CARBIDE CUTTER

PROCESS - DRILLING

W/P MATERIALS

TOOL STEEL - 1, CAST IRON - 2

MILD STEEL - 3, BRASS, SOFT BRONZE - 4

ALUMINUM OR MAGNESIUM - 5

CHOICE = 5

CHIP LOAD = .0100

CUTTING SPEED = 600.000 SURF FEET/MIN

RPM = 2291.826

FEED = 45.83652 IN./REV

CUTTING TIME = 4.35897 SEC

CHAPTER 5

CONCLUSION

A process planning system is the interface between design and manufacturing. In the past two decades, much attention has been given to both design and manufacturing automation. CAD and CAM systems have evolved separately. So called Integrated CAD-CAM systems have become available on the commercial market during past few years. But most of these systems save the geometry definition during past processing. This is a lower level integration. CAD is the upstream portion of design - production flow process and CAM is the downstream portion. Process Planning determines how to execute the operations necessary to fabricate a design in a manufacturing system. Process planners exhibit the important function of deciding the most applicable and available process for a particular part.

During earlier years, researchers were unable to develop intelligent computer softwares to generate process plans automatically because of the complexity of process plans. Assisting a process planner and saving planning time and effort was the main focus. Based on the experience of practitioners, a variant process planning system can save upto 90% of the process planning time. The plans generated are consistent. But the significant problem with such systems is the inability of these systems to provide plans for new components. The success of the final process plan depends on the ability of the planners to develop and modify the plan.

Over the years, some variant process planning systems have evolved into generative systems. They are by nature variant, but some of the auxiliary functions such as parameter selection, tool selection, can be generated automatically. Such systems are one step closer to our goal.

In 1988, Society of Manufacturing Engineers predicted that by the year 1995, 70% of all process plans for parts and assemblies manufactured in US will be computer generated. A number of factors strongly suggest the need for automated process planning to grow continuously. High labor and capital equipment costs, decreasing availability of trained process planners, competition from higher productivity industries are a few reasons. The availability and lower costs of computer hardware and more transportable software will greatly facilitate the feasibility of automated planning. CAPP will continue to be more applicable in larger manufacturing industries. A few of recent developments utilizing low cost microcomputers also provide such indications.

Using a process oriented approach and a universal type of geometry language, the decision logic and related data can be designed and stored in a modular fashion. The planning system worked out here is although applicable to one group of products and related machines at the present time, this work also indicates the application of generative planning systems is beneficial to both large and small companies.

A generative process planning system can be a substitute for a planning engineer in the design and manufacturing process. Knowledge of shop operations must be captured and saved in a unified design and manufacturing data base in order to be used for both design and planning. Such information can provide feedback to the designer.

Still the future of CAPP is not totally clear, but the major focus for future research and development efforts will be to bridge the gap between CAD and CAM. Initially CAD systems were oriented in terms of the final product and its performance. They were very little oriented towards manufacturing aspects. So also CAM systems were related to manufacturing considerations. But it is clear

that future work will be best accomplished by interdisciplinary efforts involving various engineering and computer specializations.

APPENDIX

Program 1

```
C THIS IS PROGRAM IS FOR GEARS
CHARACTER*64 OUTFN,INPFN1,INPFN2
INTEGER N,G,LIFE
REAL Y,Sh,Sut,HP,Wt,Kv,Sy,DS,F,P,R,Ak,Kb,Ck,Kd,Ke,Kf
REAL Cl,Cr,Hb,Sfe,Tp,Tg
WRITE(*,'(A)') ENTER OUTPUT FILE NAME
READ(*,'(A)') OUTFN
OPEN(6, FILE=OUTFN, STATUS='NEW')
WRITE(6,*)'WRITE YOUR CHOICE'
WRITE(*,*) WRITE YOUR CHOICE '
WRITE(6,*) '
WRITE(*,*) SPUR = 1, HELICAL = 2 '
WRITE(6,*)'SPUR=1, HELICAL=2'
READ(*,1)N
1 FORMAT(I1)
WRITE(6,2)N
2 FORMAT(2X,'CHOICE IS = ',I1)
WRITE(6,*) '
PI=3.1415927
IF (N.EQ.1) GOTO 100
IF (N.EQ.2) GOTO 200
100 WRITE(6,*)'          ----- '
WRITE(6,*)'          SPUR GEARS
WRITE(6,*)'          -----'
```

```

WRITE(6,*)' '
WRITE(*,'(A)') ' INPUT FILE FOR SPUR GEARS :
READ(*,'(A)') INPFN1
OPEN(3, FILE=INPFN1, STATUS='OLD')
READ(3,3)G,HP,R
3  FORMAT(I2,F6.2,F6.2)
WRITE(6,4)G,HP,R
4  FORMAT(2X,'GEAR RATIO = ',I2,4X,'HP = ',F6.2,4X,
1'RPM = ',F8.2)
WRITE(6,*)' '
WRITE(6,*)'MINI. # OF TEETH TO AVOID UNDERCUTTING=18'
WRITE(6,*)' '
READ(3,5) Tp
5  FORMAT(F3.1)
WRITE(6,6)Tp
6  FORMAT(2X,'# OF TEETH ON PINION          = ',F8.3)
Tg=Tp*G
WRITE(6,7)Tg
7  FORMAT(2X,'# OF TEETH ON GEAR          = ',F8.3)
C  TRANSMITTED LOAD
19 WRITE(6,*)'CHOOSE YOUR PITCH'
READ(3,*)P
WRITE(6,8)P
8  FORMAT(2X,'PITCH          = ',F8.3)
d=Tp/P
V=(PI*d*R)/12
Wt=33000*HP/V

```

```

WRITE(6,9)d,V,Wt
9  FORMAT(2X,'PINION DIAMETER          = ',F8.3,
12X,'INCH',2X,'VELOCITY              = ',
1F8.3,2X,'SFPM',2X,
1'TRANSMITTED LOAD                    = ',F8.3,2X,'lb')
Kv=600/(600+V)
WRITE(6,10)Kv
10 FORMAT(2X,'VELOCITY FACTOR          = ',F8.3)
WRITE(6,*)'
C FROM THE TABLE 2 PROGRAM WILL CHOOSE YIELD STRESS FOR C
THE MATERIAL. TYPE THE CODE FOR THE APPROPRIATE
C MATERIAL.
500 WRITE(6,*)'BASED ON MATERIAL CODE'
C WRITE(*,*)'1 - G10100HR, 2 - G10100CD, 3 - G10150HR,
C 14 - G10150CD, 5 - G10180HR, 6 - G10180CD, 7 -G10350HR,
C 18 - G10350CD, 9 - G10350DRN, 10 - G10400HR,
C 111 - G10400CD, 12 - G10400DRN, 13 - G10500HR,
C 114 - G10500CD, 15 - G10500DRN, 16 - G15216HR,
C 117 - G41300HR, 18 - G41300CD, 19 - G41300DRN,
C 120 - G41400HR, 21 - G41400CD, 22 - G41400DRN,
C 123 - G43400HR, 24 - G43400CD, 25 - G43400DRN,
C 126 - G46200DRN, 27 - G61500HR, 28 - G61500DRN,
C 129 - G87400HR, 30 - G87400CD, 31 - G87400DRN,
C 132 - G92550HR, 33 - G92550DRN'
READ(3,70)J
70 FORMAT(I2)
CALL STRESS(J,Sy,Sut,Hb)

```

```

WRITE(6,11)Sy
11  FORMAT(2X,'YIELD STRESS           = ',F8.3,
12X,'kpsi')
WRITE(6,333)Sut
333 FORMAT(2X,'TENSILE STRENGTH       = ',F8.3,
12X,'kpsi')
READ(3,12)FS
12  FORMAT(F4.1)
WRITE(6,99)FS
99  FORMAT(2X,'FACTOR OF SAFETY       = ',F8.3)
DS=Sy/FS
WRITE(6,13)DS
13  FORMAT(2X,'DESIGN STRESS          = ',F8.3,
12X,'kpsi')
C   F = FACE WIDTH
C   1 = 20 DEG. FULL DEPTH
C   2 = INTERNAL DRIVES 20 DEG FULL DEPTH PINION
READ(3,14)L
14  FORMAT(I2)
IF (L.EQ.1) GOTO 221
IF (L.EQ.2) GOTO 222
C   LEWIS FORM FACTOR FROM THE TABLE BASED ON # OF TEETH
C   ON PINION AND TOOTH SYSTEM
221 CALL LEWIS1(Tp,Y)
GOTO 60
222 CALL LEWIS2(Tp,Y)
60  WRITE(6,15)Y

```


C FOR THESE FACTORS CHOOSE CODES FROM TABLES

C FROM TABLE GET ULTIMATE TENSILE STRESS

$S_{se} = 0.5 * S_{ut}$

WRITE(6,21)Sse

21 FORMAT(2X,'ENDURANCE LIMIT = ',F8.3,
12X,'kpsi')

CALL FINISH(Sut,Ak)

IF (P .LE. 5) GOTO 36

Kb=1.00

GOTO 22

36 Kb=0.85

22 READ(3,23)RELIAB

23 FORMAT(F8.4)

CALL RELIA(RELIAB,Ck)

READ(3,24)T

24 FORMAT(F6.2)

206 IF (T .LE. 160) GOTO 25

$K_d = (620 / (460 + T))$

GOTO 26

25 $K_d = 1.00$

26 $K_e = 1.00$

$K_f = 1.00$

WRITE(6,27)Ak,Kb,Ck,Kd,Ke,Kf

27 FORMAT(2X,'SURFACE FACTOR = ',F8.3/,

12X,'SIZE FACTOR = ',F8.3/,

12X,'RELIABILITY FACTOR = ',F8.3/,

12X,'TEMPERATURE FACTOR = ',F8.3/,

```

12X,'STR CONCENT FACTOR          = ',F8.3/,
12X,'MISC.    FACTOR            = ',F8.3)
Se=Ak*Kb*Ck*Kd*Ke*Kf*Sse
WRITE(6,28)Se
28  FORMAT(2X,'ENDURANCE LIMIT FOR GEAR TOOTH = ',F8.3,
12X,'kpsi')
C   CALCULATE FOR SURFACE FATIGUE STRENGTH
C   BENDING ENDURANCE LIMIT,  $Sh = ((Ct * Ch) / (Ct * Cr)) Sfe$ 
C   Sfe, SURFACE ENDURANCE LIMIT =  $0.4 * Hb - 10$ 
C   Hb= BRINELL HARDNESS NUMBER
C   Cl = LIFE FACTOR    Ch = HARDNESS RATIO FACTOR = 1.0
C   Ct = TEMPERATURE FACTOR = 1.0 Cr = RELIABILITY FACTOR
C   FOLLOW TABLES AND CODES TO GET Cl AND Cr VALUES
READ(3,29)LIFE
29  FORMAT(I10)
CALL LIFEFACT(LIFE,Cl)
Cr = Ck
WRITE(6,30)Cl,Cr,Hb
30  FORMAT(2X,'LIFE FACTOR          = ',F8.3/,
12X,'RELIABILITY FACTOR          = ',F8.3/,
12X,'HARDNESS NUMBER            = ',F8.3)
Sfe = 0.4*Hb - 10
WRITE(6,33) Sfe
33  FORMAT(2X,'SURFACE ENDURANCE LIMIT = ',F8.3,
12X,'kpsi')
Ct = 1.0
Ch = 1.0

```

$$Sh = (Cl \cdot Ch \cdot Sfe) / (Ct \cdot Cr)$$

WRITE(6,34)Sh

34 FORMAT(2X,'BENDING ENDURANCE LIMIT = ',F8.3,

12X,'kpsi')

$$a = 1.00/P$$

$$b = (1.2/P)+0.002$$

$$hk = 2.00/P$$

$$ht = (2.2/P)+0.002$$

$$t = 1.5708/P$$

$$rf = 0.3/P$$

$$clr = (0.2/P)+0.002$$

WRITE(6,35)a,b,hk,ht,t,rf,clr

35 FORMAT(2X,'ADDENDUM = ',F8.3,

12X,'INCH',2X,'DEDENDUM = ',

1F8.3,2X,'INCH',

12X,'WORKING DEPTH = ',F8.3,2X,

1'INCH',2X,'WHOLE DEPTH = ',

1F8.3,2X,'INCH',

12X,'CIRCULAR TOOTH THICKNESS = ',F8.3,2X,

1'INCH',2X,'FILLET RADIUS OF BASIC RACK = ',

1F8.3,2X,'INCH',2X,

1'BASIC CLEARANCE = ',F8.3,2X,'INCH')

GOTO 1000

200 WRITE(6,*)' ----- '

WRITE(6,*)' HELICAL GEARS

WRITE(6,*)' ----- '

```

WRITE(*, '(A)') ' INPUT FILE FOR HELICAL GEARS : '
READ(*, '(A)') INPFN2
OPEN(3, FILE=INPFN2, STATUS='OLD')
READ(3,51)G,HP,R
51  FORMAT(I2,F6.2,F6.2)
    WRITE(6,52)G,HP,R
52  FORMAT(2X,'GEAR RATIO = ',I2,4X,'HP = ',F6.2,4X,
1'RPM = ',F8.2)
    WRITE(6,*)' '
    READ(3,53)Tp
53  FORMAT(F3.1)
    Tg = Tp*G
    WRITE(6,54)Tp,Tg
54  FORMAT(2X,'# OF TEETH ON PINION          = 'F8.3/,
12X,'# OF TEETH ON GEAR          = ',F8.3)
    READ(3,*)PHI
    READ(3,*)Pn
    Pt = Pn * COS(PHI*PI/180)
    WRITE(6,55)PHI,Pn,Pt
55  FORMAT(2X,'PRESSURE ANGLE          = ',F8.3/,
12X,'NORMAL PITCH          = ',F8.3/,
12X,'TRANSVERSE PITCH          = ',F8.3)
    d = Tp/Pt
    V = (PI*d*R)/12
    Wt = 33000*HP/V
    WRITE(6,56)d,V,Wt
56  FORMAT(2X,'PINION DIAMETER          = ',F8.3,

```

```
12X,'INCH',2X,'VELOCITY          = ',  
1F8.3,2X,'SFPM',2X,  
1'TRANSMITTED LOAD          = ',F8.3,2X,'lb')  
Kv = SQRT(78/(78+SQRT(V)))  
WRITE(6,57)Kv  
57  FORMAT(2X,'VELOCITY FACTOR          = ',F8.3)  
WRITE(6,*)'  
GOTO 500  
62  FORMAT(F8.4)  
1000 STOP  
END
```

```
SUBROUTINE LEWIS1(Tp,Y)
```

```
IF(Tp.EQ.18) Y = 0.309
```

```
IF(Tp.EQ.19) Y = 0.314
```

```
IF(Tp.EQ.20) Y = 0.322
```

```
IF(Tp.EQ.21) Y = 0.328
```

```
IF(Tp.EQ.22) Y = 0.331
```

```
IF(Tp.EQ.24) Y = 0.337
```

```
IF(Tp.EQ.26) Y = 0.346
```

```
IF(Tp.EQ.28) Y = 0.353
```

```
IF(Tp.EQ.30) Y = 0.359
```

```
IF(Tp.EQ.34) Y = 0.371
```

```
IF(Tp.EQ.38) Y = 0.384
```

```
IF(Tp.EQ.43) Y = 0.397
```

```
IF(Tp.EQ.50) Y = 0.409
```

```
IF(Tp.EQ.60) Y = 0.422
```

```
IF(Tp.EQ.75) Y = 0.435
IF(Tp.EQ.100) Y = 0.447
IF(Tp.EQ.150) Y = 0.460
IF(Tp.EQ.300) Y = 0.472
RETURN
END
```

```
SUBROUTINE LEWIS2(Tp,Y)
```

```
IF(Tp.EQ.18) Y = 0.348
IF(Tp.EQ.19) Y = 0.358
IF(Tp.EQ.20) Y = 0.364
IF(Tp.EQ.21) Y = 0.370
IF(Tp.EQ.22) Y = 0.374
IF(Tp.EQ.24) Y = 0.383
IF(Tp.EQ.26) Y = 0.393
IF(Tp.EQ.28) Y = 0.399
IF(Tp.EQ.30) Y = 0.405
IF(Tp.EQ.34) Y = 0.414
IF(Tp.EQ.38) Y = 0.424
IF(Tp.EQ.43) Y = 0.430
IF(Tp.EQ.50) Y = 0.436
IF(Tp.EQ.60) Y = 0.446
IF(Tp.EQ.75) Y = 0.452
IF(Tp.EQ.100) Y = 0.461
IF(Tp.EQ.150) Y = 0.468
IF(Tp.EQ.300) Y = 0.477
RETURN
```

END

SUBROUTINE FINISH(Sut,Ak)

IF(Sut.LE.80.) Ak = 0.78

IF(Sut.LE.100.) Ak = 0.75

IF(Sut.LE.120.) Ak = 0.72

IF(Sut.LE.140.) Ak = 0.69

IF(Sut.LE.160.) Ak = 0.66

IF(Sut.LE.180.) Ak = 0.64

IF(Sut.LE.200.) Ak = 0.62

RETURN

END

SUBROUTINE RELIA(RELIAB,Ck)

IF(RELIAB.EQ.0.50) Ck = 1.0

IF(RELIAB.EQ.0.90) Ck = 0.897

IF(RELIAB.EQ.0.99) Ck = 0.814

IF(RELIAB.EQ.0.999) Ck = 0.753

RETURN

END

SUBROUTINE LIFEFACT(LIFE,CI)

IF(LIFE.EQ.10000) CI = 1.5

IF(LIFE.EQ.100000) CI = 1.3

IF(LIFE.EQ.1000000) CI = 1.1

IF(LIFE.GE.10000000) CI = 1.0

RETURN

END

SUBROUTINE STRESS(J,Sy,Sut,Hb)

IF(J.EQ.1) GOTO 181

IF(J.EQ.2) GOTO 182

IF(J.EQ.3) GOTO 183

IF(J.EQ.4) GOTO 184

IF(J.EQ.5) GOTO 185

IF(J.EQ.6) GOTO 186

IF(J.EQ.7) GOTO 187

IF(J.EQ.8) GOTO 188

IF(J.EQ.9) GOTO 189

IF(J.EQ.10) GOTO 190

IF(J.EQ.11) GOTO 191

IF(J.EQ.12) GOTO 192

IF(J.EQ.13) GOTO 193

IF(J.EQ.14) GOTO 194

IF(J.EQ.15) GOTO 195

IF(J.EQ.16) GOTO 196

IF(J.EQ.17) GOTO 197

IF(J.EQ.18) GOTO 198

IF(J.EQ.19) GOTO 199

IF(J.EQ.20) GOTO 231

IF(J.EQ.21) GOTO 232

IF(J.EQ.22) GOTO 233

IF(J.EQ.23) GOTO 234

IF(J.EQ.24) GOTO 235

IF(J.EQ.25) GOTO 236

IF(J.EQ.26) GOTO 237

IF(J.EQ.27) GOTO 238

IF(J.EQ.28) GOTO 239

IF(J.EQ.29) GOTO 240

IF(J.EQ.30) GOTO 241

IF(J.EQ.31) GOTO 242

IF(J.EQ.32) GOTO 243

IF(J.EQ.33) GOTO 244

181 Sy = 26.

Sut = 47.

Hb = 95.

RETURN

182 Sy = 44.

Sut = 53.

Hb = 105.

RETURN

183 Sy = 27.

Sut = 50.

Hb = 101.

RETURN

184 Sy = 47.

Sut = 56.

Hb = 111.

RETURN

185 Sy = 32.

Sut = 58.

Hb = 116.
RETURN
186 Sy = 54.
Sut = 64.
Hb = 126.
RETURN
187 Sy = 39.
Sut = 72.
Hb = 143.
RETURN
188 Sy = 67.
Sut = 80.
Hb = 163.
RETURN
189 Sy = 72.
Sut = 103.
Hb = 201.
RETURN
190 Sy = 42.
Sut = 76.
Hb = 149.
191 Sy = 71.
Sut = 85.
Hb = 170.
RETURN
192 Sy = 86.
Sut = 113.

Hb =235.

RETURN

193 Sy = 49.

Sut = 90.

Hb = 179.

RETURN

194 Sy = 84.

Sut = 100.

Hb = 197.

RETURN

195 Sy = 130.

Sut = 155.

Hb = 310.

RETURN

196 Sy = 81.

Sut = 100.

Hb = 192.

RETURN

197 Sy = 60.

Sut = 90.

Hb = 183.

RETURN

198 Sy = 87.

Sut = 98.

Hb = 201.

RETURN

199 Sy = 133.

Sut = 146.

Hb = 293.

RETURN

231 Sy = 63.

Sut = 90.

Hb = 187.

RETURN

232 Sy = 90.

Sut = 102.

Hb = 223.

RETURN

233 Sy = 131.

Sut = 153.

Hb = 302.

RETURN

234 Sy = 69.

Sut = 101.

Hb = 207.

RETURN

235 Sy = 99.

Sut = 111.

Hb = 223.

RETURN

236 Sy = 162

Sut = 182

Hb = 363.

RETURN

237 $S_y = 94$

$S_{ut} = 130.$

$H_b = 256.$

RETURN

238 $S_y = 58.$

$S_{ut} = 91.$

$H_b = 183.$

RETURN

239 $S_y = 132.$

$S_{ut} = 155.$

$H_b = 302.$

RETURN

240 $S_y = 64.$

$S_{ut} = 95.$

$H_b = 190.$

RETURN

241 $S_y = 96.$

$S_{ut} = 107.$

$H_b = 223.$

RETURN

242 $S_y = 129.$

$S_{ut} = 152.$

$H_b = 302.$

RETURN

243 $S_y = 78.$

$S_{ut} = 115.$

$H_b = 223.$

RETURN

244 Sy = 160.

Sut = 180.

Hb = 352.

RETURN

END

Program 2

```
#include "def.h"

main(){

    int width;

    /* initialize graphics mode */
    GraphDriver=DETECT;
    initgraph(&GraphDriver,&GraphMode,"");

    /* get center coordinates */
    xmax=getmaxx();
    ymax=getmaxy();
    xcen=xmax/2;
    ycen=ymax/2;

    /* set background color */
    setfillstyle(SOLID_FILL,DARKGRAY);
    setcolor(WHITE);
    bar3d(0,0,xmax,ymax,0,0);
    settextstyle(DEFAULT_FONT,HORIZ_DIR,3);

    /* front view */
    circle(xcen-150,ycen,100);
    circle(xcen-150,ycen,90);
    circle(xcen-150,ycen,80);
    circle(xcen-150,ycen,20);

    /* side view */
    rectangle(xcen+100,ycen+100,xcen+150,ycen-100);
    rectangle(xcen+100,ycen+90,xcen+150,ycen-90);
    rectangle(xcen+100,ycen+80,xcen+150,ycen-80);
    rectangle(xcen+100,ycen+20,xcen+150,ycen-20);
```



```
rectangle(xcen-147,ycen-23,xcen-153,ycen-20);
line(xcen+100,ycen-23,xcen+150,ycen-23);
/* center lines */
line(xcen-180,ycen,xcen-120,ycen);
line(xcen-260,ycen,xcen-200,ycen);
line(xcen-100,ycen,xcen-40,ycen);
line(xcen-150,ycen-30,xcen-150,ycen+30);
line(xcen-150,ycen-50,xcen-150,ycen-110);
line(xcen-150,ycen+50,xcen-150,ycen+110);
line(xcen+80,ycen,xcen+120,ycen);
line(xcen+130,ycen,xcen+170,ycen);
/* text */
setfillstyle(SOLID_FILL,MAGENTA);
setcolor(WHITE);
bar3d(xcen-280,ycen+150,xcen-30,ycen+190,0,0);
outtextxy(xcen-275,ycen+160,"FRONT VIEW");
setfillstyle(SOLID_FILL,MAGENTA);
setcolor(WHITE);
bar3d(xcen,ycen+150,xcen+240,ycen+190,0,0);
outtextxy(xcen+10,ycen+160,"SIDE VIEW");
/* delay of 10 seconds before exiting */
delay(10000);
closegraph();
}
```

Program 3

```

C THIS PROGRAM IS FOR THE PROCESS ANALYSIS
C ENTER PROPER CODE ACCORDING TO THE PROCESS REQUIRED
C CODES ARE TURNING - 1, MILLING - 2, DRILLING - 3
C HOBBING - 4, BROACHING - 5, SHAVING - 6
C INPUTS FOR THIS ANALYSIS ARE DIAMETER IN INCHES,
C MATERIAL CUTTING SPEED, CHIP LOAD PER TOOTH AND NUMBER
C OF TEETH ON CUTTER
C THESE ARE GENERAL INPUT PARAMETERS. FOR FURTHER
C ANALYSIS PROGRAM WILL ASK FOR SPECIFIC INPUTS
  CHARACTER*80 INPFN,OUTFN,OUTFN1
  INTEGER L1,M1,J1,J2
  REAL Ln
  Tt = 1.0
  PI = 3.1416
2  WRITE(*,*) ' WHICH PROCESS '
  WRITE(*,*) ' WRITE TURNING - 1, MILLING - 2'
  WRITE(*,*) ' DRILLING - 3, HOBBING - 4'
  WRITE(*,*) ' BROACHING - 5, SHAVING - 6'
  READ(*,3)J2
3  FORMAT(I1)
  WRITE(*,'(A)') ' ENTER INPUT FILE NAME  :'
  READ(*,'(A)') INPFN
  WRITE(*,'(A)') ' ENTER OUTPUT FILE NAME  :'
  READ(*,'(A)') OUTFN
  OPEN(3, FILE=INPFN, STATUS='OLD')
  READ(3,4)L

```

```
4  FORMAT(I1)
   OPEN(6, FILE=OUTFN, STATUS='NEW')
C  WRITE W/P DIAMETER, LENGTH OF STROKE AND # OF TEETH ON
C  CUTTER
   READ(3,9)Dd,Ln,N
9  FORMAT(2F7.3,I2)
   WRITE(6,71)Dd,Ln,N
71  FORMAT(2X,'DESIRED DIAMETER   = ',F7.3/,
   12X,'LENGTH OF STROKE   = ',F7.3/,
   12X,'# OF TEETH ON CUTTER = ',I2)
   WRITE(6,*)' '
C  CODE FOR TOOL MATERIALS - HSS - 1, CARBIDE - 2
   READ(3,8)L1
8  FORMAT(I1)
   IF(L1.EQ.1) GOTO 6
   GOTO 7
6  WRITE(6,*)'TOOL MATERIAL - HIGH SPEED STEEL'
   WRITE(6,*)' '
   GOTO 5
7  WRITE(6,*)'TOOL MATERIAL - CARBIDE CUTTER'
   WRITE(6,*)' '
5  IF (L.EQ.1) GOTO 100
   IF (L.EQ.2) GOTO 200
   IF (L.EQ.3) GOTO 300
   IF (L.EQ.4) GOTO 400
   IF (L.EQ.5) GOTO 500
   IF (L.EQ.6) GOTO 600
```

```

100 WRITE(6,*)'    PROCESS - TURNING    '
    WRITE(6,*)'    -----    '
    WRITE(*,*)' WRITE FEED IN INCHES PER REVLN'
    READ(*,101)Fr
101 FORMAT(F7.4)
    CALL CUTSPDT(M,Vc)
    IF(L1.EQ.2) Vc = 2*Vc
    READ(3,331)Da
331 FORMAT(F7.3)
    Dc = (Da - Dd)/2.
    Cp = Dc/Fr
    WRITE(6,881)Dc, Cp
881 FORMAT(2X,'DEPTH OF CUT    = ',F7.3,'INCH',
    12X,'# OF TOOL PASSES    = ',F7.4)
    GOTO 772
771 Da = Dw
    IF (Dw.EQ.Dd) GOTO 11
772 Dw = Da - (2 * Fr)
    R = (12*Vc)/(PI*Dw)
    Tm = (Ln*60)/(Fr*R)
    WRITE(6,102) Tm
102 FORMAT(2X,'TIME    = ',F7.4)
    WRITE(6,*)' '
    Tt = Tt + Tm
    IF(Cp.GT.1) GOTO 771
    GOTO 11
200 WRITE(6,*)'    PROCESS - MILLING    '

```

```

WRITE(6,*)' ----- '
CALL CUTSPDM(M,Vc)
CALL FEEDM(M1,M2,T)
WRITE(6,23) T
23  FORMAT(2X,'CHIP LOAD PER TOOTH = ',F10.3)
    WRITE(*,*)' WRITE # OF TEETH ON PINION'
    READ(*,24)Tp
24  FORMAT(F6.2)
    WRITE(6,25)Tp
25  FORMAT(2X,'# OF TEETH ON PINION = ',F10.3)
    IF(L1.EQ.2) Vc = 2*Vc
    R = (12*Vc)/(PI*Dd)
    F = R*T*N
    Tm = (Ln*60)/F
    Tmt = Tm * Tp
    GOTO 11
300 WRITE(6,*)' PROCESS - DRILLING '
    WRITE(6,*)' ----- '
    CALL CUTSPDT(M,Vc)
    IF(L1.EQ.2) Vc = 2*Vc
    WRITE(*,*)' WRITE CHIP LOAD PER TOOTH '
    READ(*,301)T
301  FORMAT(F6.4)
    R = (12*Vc)/(PI*Dd)
    F = R*T*N
    Tm = (Ln*60)/F
    WRITE(6,302)T

```

```

302 FORMAT(2X,'CHIP LOAD      = ',F7.4)
      GOTO 11
400 WRITE(6,*)'  PROCESS - HOBBING  '
      WRITE(6,*)'  -----  '
      GOTO 11
500 WRITE(6,*)'  PROCESS - BROACHING '
      WRITE(6,*)'  -----  '
      GOTO 11
600 WRITE(6,*)'  PROCESS - SHAVING  '
      WRITE(6,*)'  -----  '
11  IF (L.EQ.1) F = Fr
      IF (L.EQ.1) Tm = Tt
      IF (L.EQ.2) Tm = Tmt
      WRITE(6,12)Vc,R,F,Tm
12  FORMAT(2X,'CUTTING SPEED    = ',F7.3,2X,
1'SURF FEET/MIN',
12X,'RPM          = ',F10.3/,
12X,'FEED          = ',F10.5,2X,'IN./REV',
12X,'CUTTING TIME    = ',F10.5,2X,'SEC')
      IF(J2.EQ.2) GOTO 131
      IF(J2.EQ.3) GOTO 132
      WRITE(*,'(A)')' ENTER PLAN OUTPUT FILE NAME  :'
      READ(*,'(A)') OUTFN1
      OPEN(5, FILE=OUTFN1, STATUS='NEW')
      WRITE(5,81)
81  FORMAT(22X,'PROCESS PLAN')
      WRITE(5,*)'  -----'

```

```
WRITE(5,151)
151 FORMAT(' ',' ')
WRITE(5,152)
152 FORMAT(11X,'NEW JERSEY INSTITUTE OF TECHNOLOGY',
111X,'GENERATIVE PROCESS PLANNING SYSTEM')
WRITE(5,153)
153 FORMAT(' ',' ')
WRITE(5,154)
154 FORMAT(2X,'PART DESCRIPTION : GEAR - SPUR/HELICAL')
WRITE(5,155)
155 FORMAT(' ',' ')
WRITE(5,156)
156 FORMAT(2X,'PART NUMBER :      ')
WRITE(5,157)
157 FORMAT(' ',' ')
WRITE(5,158)Da,Ln
158 FORMAT(2X,'MATERIAL REQUIRED : ',7X,'DIAM - ',F7.3,2X,
1'WIDTH - ',F7.3)
WRITE(5,159)
159 FORMAT(' ',' ')
WRITE(5,72)
72 FORMAT('NO',1X,'PROCESS',2X,'DIAM - TOLE',2X,
1'SROKE - TOL',2X,'SPEED',3X,'FEED',3X,'TIME')
WRITE(5,160)
160 FORMAT(' ',' ')
WRITE(5,92)J2,Dd,Ln,R,Fr,Tt
92 FORMAT(11,2X,'TURNING',1X,F4.1,'+/-0. ',1X,
```

```
1F4.1,'+/-0. ',2X,F6.2,2X,F5.2,2X,F6.2)
WRITE(5,*)'
120 WRITE(*,*)' DO YOU HAVE ANY OTHER PROCESS '
WRITE(*,*)' WRITE 1 IF YES AND 2 IF NO '
READ(*,93)J1
93 FORMAT(I1)
IF(J1.EQ.1) GOTO 2
GOTO 170
131 WRITE(5,94)J2,Dd,Ln,R,F,Tmt
94 FORMAT(I1,2X,'MILLING',1X,F4.1,'+/-0. ',1X,
1F4.1,'+/-0. ',2X,F6.2,2X,F5.2,2X,F6.2)
WRITE(5,*)'
GOTO 120
132 WRITE(5,95)J2,Dd,Ln,R,F,Tm
95 FORMAT(I1,2X,'DRILLING',F4.1,'+/-0. ',1X,
1F4.1,'+/-0. ',2X,F7.1,2X,F5.2,2X,F6.2)
WRITE(5,*)'
GOTO 120
170 STOP
END

SUBROUTINE CUTSPDT(M,Vc)
C SUBROUTINE IS FOR MATERIAL AND CUTTING SPEED
WRITE(*,*)'
WRITE(*,*)' WRITE WORK PIECE MATERIAL CODE '
WRITE(6,*)' W/P MATERIALS '
WRITE(6,*)'
```



```

WRITE(*,31)
WRITE(6,31)
31  FORMAT(2X,'TOOL STEEL - 1, CAST IRON      - 2%',
12X,'MILD STEEL - 3, BRASS, SOFT BRONZE - 4%',
12X,'ALUMINUM OR MAGNESIUM - 5')
WRITE(6,*) '
READ(*,2)M
2  FORMAT(I1)
WRITE(6,32) M
32  FORMAT(2X,'CHOICE      = ',I1)
WRITE(6,*) '
IF(M.EQ.1) Vc = 50
IF(M.EQ.2) Vc = 60
IF(M.EQ.3) Vc = 100
IF(M.EQ.4) Vc = 200
IF(M.EQ.5) Vc = 300
RETURN
END

SUBROUTINE CUTSPDM(M,Vc)
WRITE(*,*) '
WRITE(*,*) ' WRITE WORK PIECE MATERIAL CODE '
WRITE(6,*) '      W/P MATERIALS '
WRITE(6,*) '
WRITE(*,31)
WRITE(6,31)
31  FORMAT(2X,'TOOL STEEL - 1, CAST IRON      - 2%',

```

```

12X,'MILD STEEL - 3, BRASS, SOFT BRONZE - 4',
12X,'ALUMINUM & MAGNESIUM - 5')
WRITE(6,*)' '
READ(*,3)M
3  FORMAT(I1)
WRITE(6,32) M
32  FORMAT(2X,'CHOICE  = ',I1)
WRITE(6,*)' '
IF(M.EQ.1) Vc = 40
IF(M.EQ.2) Vc = 50
IF(M.EQ.3) Vc = 80
IF(M.EQ.4) Vc = 160
IF(M.EQ.5) Vc = 200
RETURN
END

SUBROUTINE FEEDM(M,M2,T)
C  SUBROUTINE FOR FEED PER TOOTH FOR MILLING
WRITE(*,*)' '
WRITE(*,*)' WRITE CODE FOR MILLING CUTTER '
WRITE(6,*)'     MILLING CUTTER '
WRITE(6,*)'  CODES FOR MILLING CUTTERS '
WRITE(*,43)
WRITE(6,43)
43  FORMAT(' FACE MILL - 1, SIDE MILL - 2, END MILL - 3')
WRITE(6,*)' '
READ(*,50) M2

```

```
50  FORMAT(I1)
    WRITE(6,42) M2
42  FORMAT(2X,'CHOICE      = ',I1)
    WRITE(6,*) '
    IF(M.EQ.1) GOTO 52
    IF(M.EQ.2) GOTO 53
    IF(M.EQ.3) GOTO 54
    IF(M.EQ.4) GOTO 55
    IF(M.EQ.5) GOTO 56
52  IF(M2.EQ.1) T=0.01
    IF(M2.EQ.2) T=0.005
    IF(M2.EQ.3) T=0.005
    RETURN
53  IF(M2.EQ.1) T=0.009
    IF(M2.EQ.2) T=0.005
    IF(M2.EQ.3) T=0.004
    RETURN
54  IF(M2.EQ.1) T=0.006
    IF(M2.EQ.2) T=0.003
    IF(M2.EQ.3) T=0.002
    RETURN
55  IF(M2.EQ.1) T=0.006
    IF(M2.EQ.2) T=0.004
    IF(M2.EQ.3) T=0.002
    RETURN
56  IF(M2.EQ.1) T=0.012
    IF(M2.EQ.2) T=0.006
```

```
IF(M2.EQ.3) T=0.006
```

```
RETURN
```

```
END
```

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