MODEL FOR LOADING IN FLEXIBLE MANUFACTURING SYSTEM (F.M.S.)

Thesis submitted in partial fulfilment of the requirements for the award of the degree of
MASTER OF ENGINEERING IN MECHANICAL ENGINEERING
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of BHARATHIAR UNIVERSITY

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1998 - 1999

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This is to certify that this thesis work entitled " **MODEL FOR LOADING IN FLEXIBLE MANUFACTURING SYSTEM (F. M. S.)** " being submitted by **V. D. SENTHIL MOHAN,** (Reg. No. 9837H0006) for the award of the degree of **MASTER OF ENGINEERING IN MECHANICAL ENGINEERING (INDUSTRIAL ENGINEERING),** is a bonafide work carried under my guidance. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any Degree or Diploma.

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SYNOPSIS

Flexible manufacturing systems have been a bridge in linking conventional manufacturing systems and transfer lines. Though, they offer very good flexibility like choices in machine flexibility, tool flexibility and process plan flexibility, Loading of FMS has been a big problem for process planners. Loading when done in a random and unmethodological fashion may often result in non-optimal utilization of resources, one of the most important of them, the machine improper selection of process plan leads to more movement of material.

Since the movement of materials/material handling inside the industry is one of the most money consuming activities, more movement means more money. This leads to improper utilization of another important resource "the money". This will automatically reflect in the increase in "cost of manufacturing".

Therefore, depending upon the tooling requirements of various operations of the selected parts, the problem is to assign the part operations belonging to only one of the alternate process plans to machines such that the part handling is minimum.

Hence, this thesis has been aimed to take a step in that direction of solving the loading problem in F.M.S. environment. This thesis is a "MODEL FOR LOADING IN F.M.S"

i. Modeling an FMS environment with constraint and flexibilities.

ii. Deciding on the objective function to be optimized.

iii. Applying a two-stage heuristic method for solving this optimization problem.

iv. Collecting the data from "C.K.P. Industries Ltd" on "Milling machine attachment for drilling machine".

v. Applying the algorithm on the data and find the results.

The results have been found and the best loading plan has been obtained.

CONTENTS

CHAPTER - 1

Introduction

Intense competition in the global market for mechanical parts manufactured on machine tools and other metal working equipment has compelled manufacturers to reduce delivery times and quote competitive prices even for relatively small orders. The batch size is ever-decreasing and the need to meet specific customer requirements call for considerable flexibility in the working of the manufacturing system.

In this situation, the requirements that a modern manufacturing facility has to meet can be detailed as follows:

- High productivity for all batch sizes, large or small
- Shorter throughout times
- Lower storage costs
- Reduced labour if not altogether avoiding labour
- Reduced handling
- Flexible production system to incorporate product changes at short notice to meet customer's specific requirements.

Conventiona high volume production facilities such as automatic equipment and transfer lines do not fulfil these requirements. This provided sufficient reason for manufacturing engineers to turn attention to alternative manufacturing methods. Flexible manufacturing cells and flexible manufacturing systems have been evolved to meet the requirements listed above.

1.1 Definition of FMS:

FMS consists of a group of processing stations interconnected by means of an automated material handling and storage system and controlled by an integrated computer system.

An FMS can be defined as a "computer controlled configuration of semi independent work stations and a material handling system designed to efficiently manufactures more than one part at medium volumes".

1.2 Types of F.M.S

Flexible manufacturing systems can be classified into

1. Dedicated F.M.S
2. Random -order F.M.S

1.2.1 Dedicated F.M.S

It is used to produce a much more limited variety part configurations. The geometry differences are minor and the product design is considered stable. Therefore the machine sequence is identical (or) nearly identical for all parts processed on the system. This means that a flow line configuration is generally more appropriate, and that the system can be designed with a certain amount of process specialization to make the operations more efficient. Instead of using general purpose machines, the machines can be designed for the specific processes required to make the limited part family.

1.2.2 The random order F.M.S

It is the most appropriate type under the following conditions

i) The part family is large

ii) There are substantial variations in the part configurations

iii) There will be new part designs produced on the system and engineering changes in parts currently made on the system.

iv) The production schedule is subject to change from day to day.

To accommodate these variations, the random order F.M.S must be more flexible than the dedicated F.M.S. It is equipped with general purpose machines to deal with the variations in product and is capable of processing parts in various sequences. A more sophisticated computer control system is required for this F.M.S type.

1.3 Subsystems of FMS

There are three major subsystems in FMS

i) Computer - controlled manufacturing equipment (e.g., numerically controlled machine tools).

ii) Automated materials storage, transport and transfer system.

iii) Manufacturing control system (Including both tool and logistics control).

Some FMS's may have additional subsystems. For example, in a machining application there may also be systems for storing and retrieving tools, disposing of chips and cutting fluids, washing and inspection workpieces. These sybsystems must be linked together to achieve inegrated manufacturing operation.

1.4 FMS Compared to Other Manufacturing Systems

One-off and flow volumes of production are normally carried out by conventional general purpose machine tools. When the number of parts in a production run is more it is called batch production. A batch production shop is best suited for very small quantities of many different types of parts. The very nature of production makes the operations of a job shop less efficient than an automated production line.

Since the job shop must be provided the greatest degree of flexibility, most of its operations are manual. They are normally provided with general purpose CNC machine tools. Hard automation with dedicated equipment is best suited for the production of very large quantities of identical parts.

Production of automobile components in a transfer line fall under this category. A large portion of the manufacturing industry involves the intermediate level of batch operations that lend themselves to the FMS approach. In this case volume is less but varieties are more.

FMS thus basically attempts to efficiently automate batch manufacturing operations. They are an alternative that fits in between the manual job shop and hard automation. FMS is best suited for applications that involve an intermediate level of flexibility and low (or) medium quantities. Fig.1.1 shows the different types of production systems and it can be seen from the figure that FMS in to the intermediate range of production.

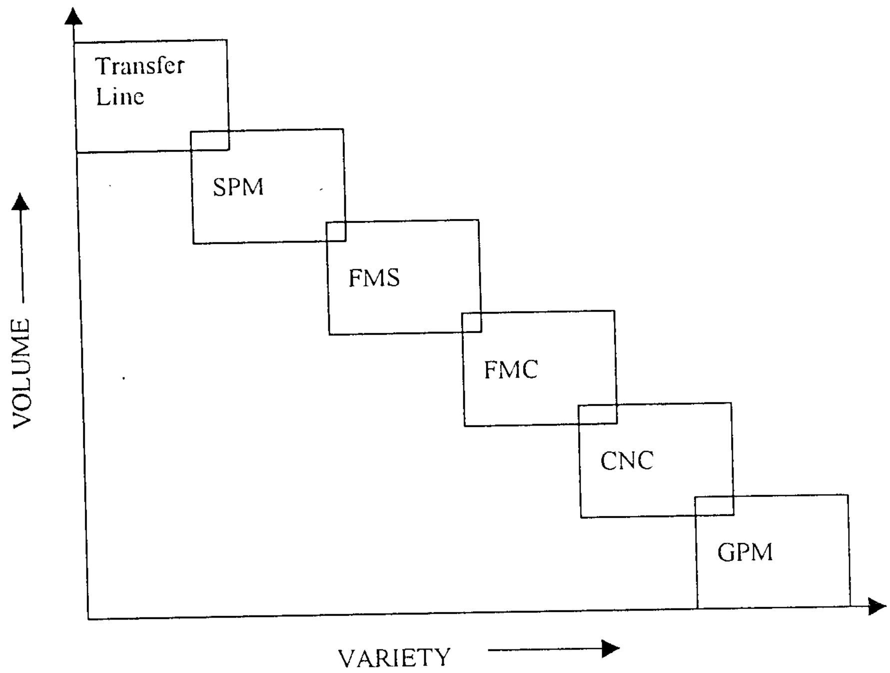

Fig. 1.1 TYPES OF PRODUCTION SYTEMS

1.5 FMS Layout Configurations

The types of layout configurations commonly found in today's FMS can be divided into the following five categories.

1. In-line
2. Loop
3. Ladder
4. Open-field
5. Robot-centered cell

1.5.1 In-line configuration

It is most appropriate for systems in which part progress from one work station to the next in a well defined sequence with no back flow. The operation of this system is similar to the transfer line. The work always flows in one direction as shown in Fig 1.2. Depending on the flexibility and storage features of the handling system, it is possible to accommodate back flow of work in the system.

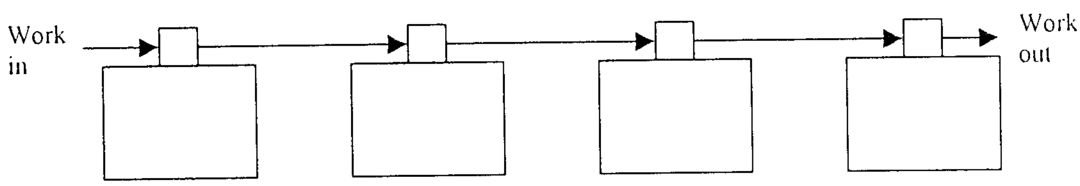

Fig.1.2. In – line Configuration Layout

1.5.2 Loop Configuration

In this, parts usually flow in one direction around the loop with the capability to stop at any station. The load and unload stations are typically located at end of the loop as shown in fig 1.3.

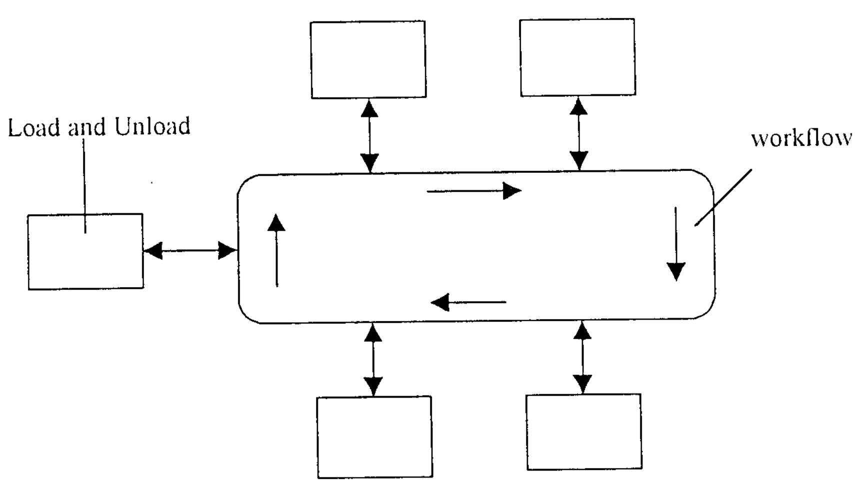

Fig.1.3 Loop Configuration Layout

1.5.3 Ladder Configuration

It is an adaption of the loop configuration. It contains rungs on which workstations are located as shown in fig 1.4

The rungs increase the possible ways of getting from one machine to next. This reduces the average travel distance, thereby reducing the transfer time between work stations.

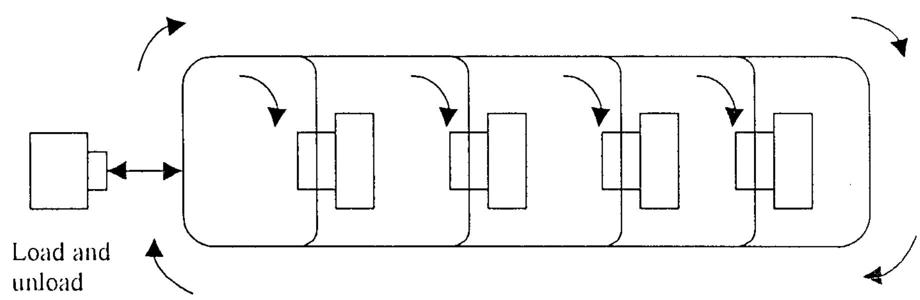

Fig.1.4. Ladder Configuration Layout

1.5.4 Open Field Layout

It is also an adaption of the loop configuration. It consists of loops and ladders requirements. This layout is generally appropriate for the processing of a large family of parts. The number of different machine types may be limited, and parts are routed to different workstations depending upon which one becomes available first.

1.5.5 Robot - Centred Cell

It is a relatively new form of flexible system in which one (or) more robots are used as the material handling system. Industrial robots can be equipped with grippers that make them well suited for the handling of rotational parts.

1.6 Planning the FMS

The purchase and implementation of a FMS represents a major investment and commitment by the user company. It is important that the installation of the system be preceded by a through procedure of planning and design. As outlined in this section, these following factors include:

1. Volume of work to be produced by the system

The amount of production planned for the FMS determines how many machines will be required in the system and the type of material handling equipment that would be used.

2. Variations in Process Routings

If the variations in process sequence are minimal, an in-line flow is most appropriate, perhaps approaching the configuration of a transfer line. As product variety increases, the loop and open-field layouts become candidates. If there is significant variation in the processing, a ladder layout becomes attractive.

3. Physical Characteristics Of the Work Parts

The size and weight of the parts determine the size of the machines used at the workstation and the type of material handling system used.

4. FMS Manpower Requirements

To keep the FMS running smoothly, klahorst recommends the following man power.

- One part loader/unloader for each five m/c's.

- One tool setup person for every 10 m/c's to exchange tools in the tool
- storage magazine.
- One utility worker for each 10 m/c's. The utility worker performs minor repairs and maitenance.
- One system manager per FMS

5. Appropriate Production Volume Ranges

5000 to 75,000 parts per year. If annual prodcution volume lies below this range, an FMS is likely to be an expensive alternative.

6. Minimum Normal Tolerance on Work in an F.M.S

$\pm$ 0.002

1.7. Benefits of FMS

There are many benefits to be obtained through the use of FMS technology.

- **High Capital equipment Utilization**

Typically, the throughput achieved for a set of machines in an FMS will be upto 3 times that achieved by the same machines in a stand alone job shop environment. The F.M.S achieves high efficiency by having the computer schedule every part to a machine as soon as it is free.

- **Reduced Equipment Cost**

The high utilization of equipment results in the need for fewer machines in the F.M.S to do the same work load.

➢ **Reduced Direct Labour Costs**

Since machines are operated completely under computer control, men are not required to run them. The only direct labour involved is the less skilled personnel for fixture and defixture the parts at the load station and a system supervisor.

➢ **Reduced Work in Process and Lead Time**

The reduction work in process in an F.M.S is quite dramatic when compared to a jobshop environment, reductions of 80% have been reported at some installations.

➢ **Responsiveness to Changing Production Requirements**

An F.M.S has the inherent flexibility to manufacture different products as the demands of the market place changes or as engineering design changes are introduced. Also, required spare part production can be mixed in without significantly disturbing the normal F.M.S production activities.

➢ **Ability to Maintain Production**

Mainly F.M.S are designed to degrade gracefully when one or more machines fail. This is accomplished by incorporating redundant machining capability and a material handling system which allows failed machines to be by passed. Thus, throughput F.M.S is maintained at a reduced rate.

- **High Product Quality**

Sometimes overlooked advantages of an FMS especially when compared to N/C machines that have not been federated into a co-operative system, is improved product quality. The high level automation, reduction in the number of fixturings and the number of machines visited, better designed permanent fixtures and greater attention in alignment of machine part, all results in good individual part quality and excellent consistency from one work place to another.

- **Operational Flexibility**

Operational flexibility offers another increment in the productivity. In some systems, the F.M.S can run virtually untended during the second and third shifts. This nearly "Unmanned" mode of operation is currently the exception rather than the role. But it should become increasingly common as better sensors. Computer controls are developed to detect and handle unanticipated problems such as tool breakages, part flow jams etc.

In this operational mode, inspection, fixturing and maintenance can be performed during the first shift.

- **Capacity Flexibility**

With correct planning for available floor space, a F.M.S can be designed for low production volumes initially and as demand increases, new machines can be added easily to provide the extra capacity required.

1.8 Problems in F.M.S

In a F.M.S two groups of problems are of particular importance:

(1) Design problems

(2) Operational Problems

The first group is concerned with the optimal selection of all FMS components and the second with their optimal utilization.

1.8.1 Design Problems

Many of the deficiencies in the design of FMSs could be avoided, if sufficient research works were done in this area. To design a FMS, the following problems should be solved.

(1) Organizational problem, that is selection of the part families to be manufactured. Because current FMS technology restricts the shape of parts designed for flexible manufacturing.

(2) Selection of an FMS production system.

(3) Selection of a Material - handling system

(4) Selection of fixtures and pallets.

(5) Selection of an appropriate computer system and

(6) Layout and integration of all the above systems.

Each of these problems is very complex.

1.8.2 Operational Problems

Because FMSs have a high capital cost, a high rate of utilization is necessary to ensure a short return on investment and such a rate can only be assured if the following operational problems are effectively solved.

(1) Planning problem

(2) Grouping problem

(3) Machine Loading problem and

(4) Scheduling problem

1.8.2.1 Planning Problem

In FMSs forecasting, long and intermediate range planning are much different from classical cases. Forecasting is losing its traditional significance mainly because of the flexibility of these new systems. Long and intermediate horizon planning will still be of great importance but the criteria and constraints will change.

In the classical system, determination of the optimal values of the production parameters [cutting speed and feed rate] was assumed to be uninfluenced by a production planner, who would use some other parameters such as overtime hours or number of workers. These last two parameters do not work in the same way in an FMS, because of the high degree of automation. To influence the production rate, the FMS planning model has to incorporate production parameters as decision variables. This also influences the form of the objective function in the planning model and changes the constraints.

1.8.2.2 Grouping Problem

In some classes of FMSs, grouping of parts and some of the production system components is desirable to reduce the size of loading problems. By analogy to group technology, these groups are called:

a group of machines a FMC,

a group of part a part family,

a group of fixtures a fixture family,

a group of grippers a gripper family, etc.

From this grouping of parts and production system components, it would be desirable to obtain a disjoint situation as shown in Fig. 1.5 where it is obviously much easier to manage each of the subsystems 1 to N than the entire FMS. In practice, there will always be some overlap amongst subsystems 1 to N.

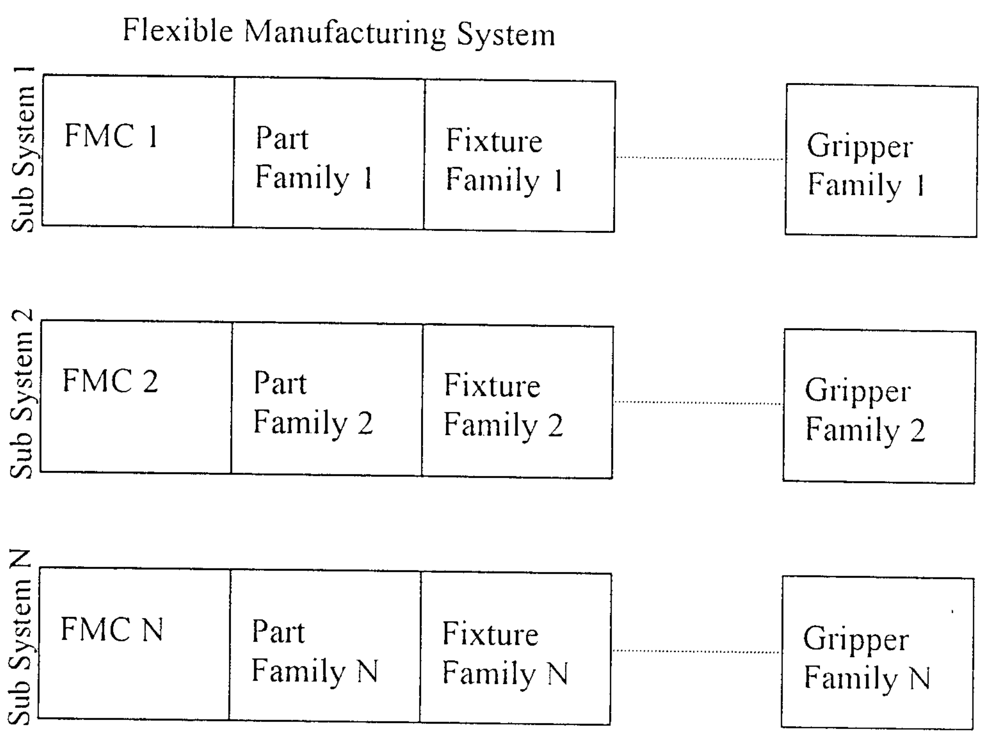

Fig:1.5.Disjoint structure of production system components and parts in an F.M.S.

1.8.2.3 Machine Loading Problem

A short-horizon (one month) planning problem for any of the FMCs that result from the grouping of parts and production system components might still be difficult to solve because of its complexity.

Such a problem may be solved by applying the two-stage procedure.

(1) Machine loading and

(2) scheduling.

Which decomposes the short-horizon planning problem to sub problems which should be solved more easily. Unfortunately, the optimal solutions for these two problems (machine loading and scheduling) are not necessarily optimal for the short-horizon planning problem. That risk can be diminished, if the machine loading problem is formulated correctly.

The machine loading problem in FMSs has been formulated and solved by a relatively large number of authors. One of the most complex non-linear integer programming formulations being presented by stecke (1983). A number of linear integer programming formulations are discussed in Kusiak (1983). Formulations of the FMS loading problem are machine and tool -design dependent.

The non-linearity in the formulations of stecke was due to the design of the tools and tool magazines. Currently, many different types of tool magazine are available and in most of them, the sequence of tools does not influence their capacity. This allows much simpler formulation of the FMS loading problem.

1.8.2.4 Scheduling Problem

Considerable effort has been spent in traditional manufacturing systems on solving the part-scheduling problem. In a FMS, because of the high cost of components, the part-scheduling problem is only one of the scheduling issues. The scheduling problem in FMSs is a multi-criteria problem involving :

(i) Scheduling of parts.

(ii) Scheduling of pallets and fixtures.

(iii) Scheduling of tools and

(iv) Scheduling of the material - handling system. (AGVS)

Such as multi-criteria problem is extremely difficult to solve; it is therefore more convenient to consider each of the four sub problems separately, even though each of them can be very difficult to solve in practice.

This thesis work is carried out with FMS loading as its main area of concentration.

1.9. Introduction to F.M.S loading

Loading problem in manufacturing involves the assignment of various resources (such as machines, tools, material handling system, pallets and fixtures) to the operations of different part types that are already planned to be produced during a planning period. The loading decisions being in tactical level planning period. The decision receive their inputs from the preceding decision levels like aggregate planning, resource grouping and part mix selection, and provide the inputs to the succeeding decisions of resource scheduling and dynamic operations planning and control. Thus loading decisions constitute important link between strategic and operational level decisions in manufacturing.

Part movement minimization is indeed one of the most widely attended to objectives in manufacturing planning and control. The problem finds an important seat at the system design and strategic levels of decision making under the garb of minimization of material handling costs. Facilities location and layout, selection of material handling equipment, etc are some of the important and well known decisions in this regard.

The context of part movement minimization at the stage of loading, however, is to optimally allocate the resources to part operations in such a manner that most of the operations of a part are carried out at the same location.

Such a problem has gained relevance in the context of FMS especially because the machine tools in FMS are multifunctional and are provided with magazines to hold several tools of different kinds, and an automatic tool changes for changing a tool within a very short time.

CHAPTER - 2

Problem Definition and Objectives

Assuming that part type selection, machine grouping, production ratio and resource allocation problems have been solved, the loading problem is specified as selecting a subset of jobs from the job pool, and assigning their operations to the appropriate machines in the ensuring planning period so as to achieve certain specified objectives while meeting the system constraints.

Six objectives of loading are generally used in F.M.S.

1. Balancing the machine processing times.
2. Minimizing the number of movements.
3. Balancing the workload per machine for a system of groups of pooled machines of equal sizes.
4. Unbalancing the work load per machine for a system of groups of pooled machines of unequal sizes.
5. Filling the tool magazines as densely as possible.
6. Maximizing the sum of operation priorities.

The loading objectives are mainly oriented towards some production and time related measures with respect to parts, utilization related measures with respect to machines and in some cases objectives are based on the total operation costs.

Part movement minimization is indeed one of the most widely attended to objectives in manufacturing planning and control. Such a problem has gained relevance in the context of FMS especially because the machine tool in FMS are multifunctional and are provided with magazines to hold several tools of different kinds, and an automatic tool changer for changing a tool within a very short time.

This thesis considers the loading problem in a wider environment, where machines in the cells are machining centers capable of performing several types of operations; an operation can be performed by several tool types and a part type may have alternative process plans for its processing. The emerging loading problem involves simultaneous selection of a process plan for every part type and the assignment of machines and the required tools to the operations in the selected process plan.

2.1. Literature survey

A number of papers have been published in the area of FMS problems. The various problems are analyzed by different authors. However, there is a lot of scope available for analyzing FMS problems as they will differ to the environment in which it is applied.

The interrelationship of various decisions and their hierarchies in FMS environment have been discussed by Singhal[8], Bitran and Hax [2], Stecke [12] and several other authors. Formulation and solution methodologies for various scenarios and combinations of parameters of loading problems have been discussed by numerous authors in the recent past including Stecke and solberg [9], Stecke and Tallbot [10], Sarin and Chen [6], just to name few. Issues on the contents and scope of loading problems in FMS have also been brought out from time to time by several researches.

The loading objectives are mainly oriented towards some production and time related measures with respect to parts, utilization related measures with respect to machines (Stecke [11]); and in some cases objectives are based on the total operation costs (Sarin and Chen [6]). Stecke [11] has discussed several such loading criteria like balancing the assigned machine processing times, minimizing the number of movement of parts from machine to machine, balancing the work load per machine for the system, filling the tool magazines as densely as possible, and maximizing the sum of operation priorities. Subsequently, several authors have considered a spectrum of multi objective loading problems by combining two or more of these criteria (Shanker and Tzen [7], Kusiak [13], Chen and Askin [1], etc)

Stecke [11], and subsequently Shanker and Tzen [7] have addressed to the operation assignment problem from the view point of part movement minimization.

Several authors (Stecke [12], O' Grady and Menon [5], Na et al. [4], Sarin and Chen [6], Stecke [11], etc.), have considered the machine loading problem in conjuction with tool allocation problem.

In their paper, Kripa Shanker and Ya-Juei Jeffrey Tzen [9] have used heuristic methods for solving FMS loading and sequencing problems. According to Merchant (1982), there is a trend of gradual shift from dedicated to random type FMS. In a dedicated type, limited variety of processing requirements would be there and special purpose machines will be used. On the other hand, in random type FMS, the process requirements vary and hence general purpose machine tools are employed.

At the beginning of planning an FMS, two issues, the part types to be produced in the FMS and its configuration should be assumed. FMS environment and the constraints have been explained by many papers by Andrew Kusiak [14], S.K. Mukhopadhyay, M.K. Singh and R. Srivastava [15], S.C. Sarin and C.S. Chen [6] and many other authors.

FMS system selection and justification, part family selection system components selection, system loading and part allocation, machine loading and tool allocation have been treated by Buzaco and Yao (1980). A 0-1 non-linear mixed integer program was formulated by Stecke (1983)

2.2. Problem Environment

We consider an FMS consisting of a mixture of general purpose (or) machining centres and special purpose machines, multi-operational tools, material handling system and other facilities, where different types of parts arrive with varying processing requirements. Out of the parts available, based on certain organizational goals, some are selected for processing during a loading period.The system possesses three types of flexibilities: machine, tool and process plan lexibilities.

2.2.1. Machine flexibility

It is an essential feature of FMS consisting general purpose machines. These machines are large machining centres capable of performing a variety of operations and equipped with tool magazines and automatic tool changers.

Machine Flexibility is the ease of making changes required to produce a given set of part types. i.e., it gives us the optimum of using the same machine for a number of operation.

2.2.2. Tool flexibility

It's refers to the ability of a tool to perform several operations. Such flexibility, although of limited interest in manufacturing systems with conventional machines, is considered an important feature in FMS having CNC machines with automatic tool changers. As a popular example of tool flexibility, a turning tool can perform operations like rough and finish turning, threading, facing, taper turning chamfering, etc. other examples include: a multicut drill can perform step drilling, counter boring and counter sinking; counterbores can be used for boring as well as for spot facing.

2.2.3. Process plan flexibility

Where a part may have several possible process plans arises because of the availability of alternative machining processes. For example, several options are available for gear making like gear milling (using endmill type cutter or disc type form cutter), gear hobbing, broaching, gear shaping (using pinion or rack type tool) etc.

Another example is thread making which can be performed by thread cutting on a lathe using a single-point tool, thread chasing, thread milling, thread grinding, etc.

It is possible, in general, to have different number of operations in various alternative process plans of a part.

Say if you are going according to process plan 1, it may include 6 operation. For the same job to be done while going according to process plan 2, it may include 4 operation. For example a small nut may be done in a lathe which may include more than one operation while it may be made by casting which is a single operation (or) by using a die it is more simpler.

2.3. Case Study problem

A case study for the F.M.S. loading problem for the expansion of "C.K.P. Industries Ltd., Velandi palayam, C.B.E." has been selected. The company is involved in manufacturing "Drilling Machines". The area where the case study is applied, is the "Milling attachment of the drilling machine". The parts that are to be manufactured and its process plans are given in Appendix.

The three types of "Milling attachments" are referred hereafter as type 1, type 2, and type 3, respectively. The details about the cells and the machines in the cells for cellular type of manufacturing for these parts, are also known [17]. However, the machines are considered to be general purpose machines on this work.

2.4 Assumptions

Following assumptions, in addition to summarizing the above, further characterize the problem environment.

1. Part types have already been selected for production during a loading period and their processing requirements are completely known. A part type may have multiple process plans.
2. An operation may be performed by several types of tools, similarly, a tool type may perform several operation
3. Machines have different technological capabilities (i.e., some operations may not be possible on certain machines). The system may have multiple copies of a machine type.
4. Tool magazines on different machines may have different number of slots but of identical size and shape.

5. Slot requirements of a tool are independent of the part type, machine and tool magazine. Thus, a tool type will occupy the same number of slots on each machine.
6. The life of a tool is adequate for all the operations assigned in a loading period, thus duplication of tools in a tool magazine is not needed. In case a tool wears out during a loading period, it is assumed that the tool is replaced with an identical type.

An operation is to be assigned to only one machine that is splitting of operations is not permitted.

CHAPTER -3

Methodology

3.1 Mathematical Model

The objective function and various constraints related to part movement minimization are presented in this section.

3.1.1 Notations

The following notations are used for the formulation of the generated loading problem.

Subscripts

i	=	Part type index.
s	=	Process plan index for a part type.
j	=	Operation index for a part type.
m	=	Machine index.
t	=	tool type index.

(t^1,t^2 = tool type indices corresponding to a pair of two consecutive operations of a part type)

Parameters and sets

$\phi(i,s,j)$	=	a triplet indicating the operation type for operation j of part type i in this process plan 's'.
p	=	set of part types
S_i	=	set of operations of part type i in process plan`s`.

$M^{\phi(i,s,j)}$ = Set of all machines available.

= $\bigcup_{i \in p,\ s \in S_i,\ j \in O_{is}} M^{\phi(i,s,j)}$

$T_m^{\phi(i,s,j)}$ = Set of types of tools available for operation type ϕ (i,s,j) on machine m.

T = Set of all the tool types.

= $\bigcup_{(i,s,j,m)} T_m^{\phi(i,s,j)}$

where $i \in p$, $s \in S$, $j \in O_{is}$, $m \in M^{\phi(i,s,j)}$

M^1_{isj} = Set of m/c's on which either of the successive operations.

$M^2_{i,s,j}$ = set of m/c's on which both the successive operations.

b_m = tool magazine capacity of machine m.

C_t = tool copies available of tool type t.

h_t = number of slots required by tool type t.

Decision Variables

X^{mt}_{isj} = 1, if for part type i, process plan s is selected and operation j in this process plan is performed on machine m using tool type t,

0, otherwise.

W_{mt} = 1, if tool type t is asigned to machine m.

0, otherwise

Z_{is} = 1, if process plan s is selected for part type i,

0, otherwise.

3.1.2 Objective Function

The objective of part movement minization in the present context is the minimization of the separation of the successive operations of all the part types. This in turn, is equivalent to the maximization of the assignment of successive operations of each part type together. If j and j+1 represent any two consecutive operations belonging to the plan 's' of part type 'i'

$X^{mt1}_{isj} . X^{mt2}_{is(j+1)}$ = 1, if operation j and j+1 are assigned to the same machine m, using the same or different tool, types.

= 0, otherwise.

Hence, the objective of maximizing the assignment of successive operations together can be expressed as

$$\text{Max} \sum_{i}\sum_{s}\sum_{j}\sum_{m}\sum_{t^1}\sum_{t^2} \left\{X^{mt1}_{isj} \cdot X^{mt2}_{is(j+1)}\right\} \longrightarrow (1a)$$

where, $i \in p$, $s \in S_i$, $j \in O_{is}$, $m \in M^2{}_{isj}$, $t^1 \in T_m{}^{\phi(i,s,j)}$, $t^2 \in T_m{}^{\phi(i,s,j)}$

Since the consecutive operations are paired, the number of such pairs in the process plan's' of part type 'i' will be one less than the total number of operations in that process plan . i.e., $(|O_{is}| - 1)$

The objective function in Eq (1a) represents the successive operations of each part type, which are assigned together on the same machine.

The objective function can also be expressed as the minimization of the total number of successive operations of each parts type assigned on different machines by taking the summation for machines (m) over the proper set. The objective function in Eq (1a) remains the same except that it changes to minimization form and the summation for machine m is over the set $(M^1{}_{isj} / M^2{}_{isj})$

i.e., successive operations assigned to different machines

The set $(M^1{}_{isj} / M^2{}_{isj})$ represents the set of machines on which only one of the operations, i.e., either j or (j+1) can be performed. It is obvious that if the number of machines on which both the operations (j and j+1) can be performed is less than the number of machines on which only one of these operations can be performed, i.e., if $|M^2{}_{isj}| < |M^1{}_{isj} / M^2{}_{isj}|$ then, in order to reduce the size of the problem, the maximization form should be used; otherwise the minimization form.

The objective function expressed above is modified to maximize the negative of the total number of pairs of successive operations which are not assigned together by subtracting from (1a) the total number of possible pairs of successive operations for the selected process plan. The modified objective function is

$$\text{Max}\left(\sum_{i}\sum_{s}\sum_{j}\sum_{m}\sum_{t^1}\sum_{t^2} X^{mt1}_{isj} \cdot X^{mt2}_{is(j+1)} - \sum_{i}\sum_{s}(|O_{is}| - 1)Z_{is}\right) \rightarrow (1b)$$

where, $i \in p$, $s \in S_i$, $j \in O_{is}$, $m \in M^2{}_{isj}$, $t^1 \in T_m{}^{\phi(i,s,j)}$, $t^2 \in T_m{}^{\phi(i,s,j)}$

3.1.3 Constraints

3.1.3.1 Tool Slot Constraint

The tool slot constraint relates the total number of slots required by a tool for an operation allocated to a machine with the tool magazine capacity of that machine and can be expressed as

$$\sum_{t \in T} h_t \cdot W_t \leq b_m, \quad m \in M \qquad \rightarrow (2)$$

In this constraint, the total slot requirement is obtained by adding the individual requirement of the tools. The savings due to tool overlapping etc. are not considered.

3.1.3.2 Tool Assignment Constraint

The number of tool copies assigned to all the machine combined should not exceed the available tool copies . i.e.,

$$\sum_{m \in M} W_{mt} \leq c_t, \quad t \in T \qquad \rightarrow (3)$$

3.1.3.3 Unique Process Plan Constraint

Only one process plan should be selected for each part type. This can be stated as

$$\sum_{s \in S_i} Z_{is} = 1, \quad i \in p \qquad \rightarrow (4)$$

3.1.3.4 None Splitting of Operations

Each part operation belonging to the selected process plan should be assigned to only one machine and only one tool type. i.e.,

$$\sum_{m \in M^{\phi(i,s,j)}} \sum_{t \in T_m^{\phi(i,s,j)}} X_{isj}^{mt} = Z_{is}, \; i \in p, \; s \in S_i, j \in O_{is} \qquad \rightarrow (5)$$

3.1.3.5 Integrality Constraint

$$X_{isj}^{mt}, \; Z_{is}, \; W_{mt} \in \{0,1\} \; ; \qquad \rightarrow (6)$$

where $i \in p$, $s \in S_i$, $j \in O_{is}$, $m \in M2_{isj}$, $t \in T_m^{\phi(i,s,j)}$

3.2 Solution Methodology

3.2.1 Heuristic Method

A two-stage heuristic is suggested as an solution methodology. The two stage are

1. Allocation of Neighbouring Operation Types of each Operation type and required tool type (s) to machines (ANOP).
2. Part Movement Minimization for each part type (PMM) ;

3.2.1.1 Allocation of Neighbouring Operation Types of each Operation type and required tool type (s) to machines (ANOP)

At first, all the different types of operations over all the process plans of all part types are identified. Then, for each operation type, its neighbouring group is identified. The neighbouring group for an operation type is the set of operation types which occur as immediate preceding or immediate succeeding operation type to this operation type in any of the process plans of all the part types combined.

At this stage, using LINDO computer package, a small 0-1 mixed integer program is solved with the objective as the maximization of assignment of all operation types and their neighbouring group members together on all the machines subject to capacity (tool magazine capacity and tool copies available) and capability (operation type- tool type- machine compatibility) constraints. Once the operation and tool types are allocated to machines, the part movement is minimized at the second stage by taking these assignments of operation types to m/c's ie., the set $M^{\phi(i,s,j)}$ as input.

3.2.1.2 Part Movement Minimization for each part type (PMM) ;

At this stage, the heuristic selects the process plan for each part type and assigns the individual operations in the selected process plans of all part types to machines such that the part movement is minimum.

Following notations and decision variables are further introduced in addition to the ones mentioned earlier in section 3.1.1 to explain the various steps of the heuristic;

$$Q = \text{Set of all operation types} = \bigcup_{t \in T} Q_t$$

$$U_{qm} = \begin{cases} 1, & \text{if operation type 'q' is assigned to machine 'm'} \\ 0, & \text{otherwise.} \end{cases}$$

j^q = the neighbouring group for operation type 'q' i.e., the set of operation types which appear as immediate preceding or immediate succeeding operation type(s) to operation type 'q' in any of the process plans for any part type.

m^q = machines available for operation type 'q' and any of its neighbouring group members.

3.2.1.3.The problmes (ANOP) and $(PMM)_i$ are as follows:

(ANOP) : $$\text{Max} \sum_{q \in Q} \sum_{m \in M^q} U_{qm} \quad \rightarrow (7)$$

subject to

Tool slot constraint

$$\sum_{t \in T} h_t \cdot W_{mt} \leq b_m, \quad m \in M \quad \rightarrow (2)$$

Tool copies constraint

$$\sum_{m \in M^q} W_{mt} \leq C_t, \quad t \in T \quad \rightarrow (3)$$

$$U_{qm} \leq \sum_{t \in t^q_m} W_{mt}, \quad q \in Q, \quad m \in M^q \quad \rightarrow (8)$$

$$\sum_{m \in M^q} U_{qm} \geq 1, \quad q \in Q, \quad m \in M^q \quad \rightarrow (9)$$

$$U_{qm} \leq 1, \quad q \in Q, \quad m \in M^q \quad \rightarrow (10)$$

$$W_{mt} \in \{0, 1\}, \quad m \in M^q, \; t \in T, q \in Q \quad \rightarrow (11)$$

$$U_{qm} \geq 0, \quad m \in M^q, t \in T, \; q \in Q \quad \rightarrow (12)$$

It may be noted that the optimal value of U_{qm} will be in terms of 0 or 1. The constraint (8) implies that an operation can be performed on a machine only if one of the required tools is assigned to that machine. The constraint (9) and (10) express the conditions that an operation must be assigned at least to a machine, and only once to a machine, respectively. The solution of ANOP results into the operation type tool type-machine assignments.

3.2.2 Algorithm

3.2.2.1 Solution Procedure for $(PMM)_i$

Step 0 : Select a process plan arbitrary, i.e., fix any one of the "Z_{is}" as 1 and others as 0.

Step 1 : For each pair of successive operations j and (j+1) in the selected process plan, identify the set of common machines.

Step 2: Count the frequency of occurrence of each machine for each pair of successive operations. Let "f_m" be the frequency for machine 'm'

Step 3 : Select the machine with the highest frequencies (f_s). If there is a tie, break the tie arbitrarily.

Step 4 : If the list of process plans is not empty; select the next process plan and go to step 1: otherwise go to step 5.

Step 5 : Select the process plan which has got the minimum value for the expression ($|O_{is}| - 1 - f_s$) which represents the number of pairs of successive operations which can not be assigned together .

Step 6 : From the process plan, assign the operations (which can be assigned) to the machine. If all the operations in the selected process plan are assigned to this machine then stop. (the optimal solution has been obtained); otherwise go to step 7.

Step 7 : Select the machine with the next highest frequency and assign the corresponding operations to this machine. Continue doing this until all the operations are not assigned to any machine stop . (the optimal solution has been obtained)

The above procedure terminates with the selection of process plan and assignment of its operation to machine (s).

3.2.2.2 The steps for the proposed two-stage heuristic are as follows

Step 1 : Let Z be the number of pairs of successive operations which are not assigned together.

Set $Z = -\infty$

Step 2 : Solve the problem (ANOP) using LINDO Package. Use the output of (ANOP). i.e., the information regarding operation type- tool type- machine assignments for formulating $(PMM)_i$.

Step 3 : For each part type 'i' save the problem $(PMM)_i$ using the procedure suggested above. Let 'Z_1' be the sum of objective values of all the $(PMM)_i$. If $Z_1>Z$, save the current solution. Set $Z = Z_1$ and go to step IV;

otherwise stop. (the optimal solution has been obtained)

Step 4 : If Z= 0, stop (the best possible solution has been obtained); otherwise from the final solution of ANOP, select the operation type 'q' (assigned to machine) which causes maximum movement of parts and can be assigned to a different machine. For an operation type, the movement is counted as 1 when a part type is brought from some other machine for performing this operation or the part type is moves to some other machine for performing the next operation.

Set the value of corresponding U_{qm} as 0 in model (ANOP) and go to step 1. If there is a tie, break the tie arbitrarily. If no alternate machine is available for any of the operation type that causes movement. Stop (the optimal solution has been obtained).

CHAPTER - 4

Problem Solving

The above explained algorithm for the loading problems of FMS has been adopted to a real data collected in "C.K.P. Industries Ltd., Velandipalayam, C.B.E." where the thesis has concentrated on the milling attachment of the drilling machine.

The cells needed for cellular type of manufacturing of these parts are also assumed to be readily available. Having obtained all these details, for the purpose of the assumption of FMS manufacturing, the machines have been assumed to be general purpose machines with more process capabilities shown in Table:1, thus reducing the number of machines in each cells.

The problem has been solved using the before explained algorithm and for solving ANOP (Allocation of Neighbouring operation), a software called LINDO has been used. LINDO (Linear Interactive Discrete Optimizer) was developed by LINUS SCHRAGE (1986). It is a user-friendly computer package that can be used to solve linear, integer and quadratic programming problems.

TABLE 1: PROCESS CAPABILITIES FOR EACH CELL

← PARTS →

m \ i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1ST CELL PARTS																	
	I TYPE						II TYPE						III TYPE					
	4	18	19	20	21	22	5	19	20	21	22	23	3	6	10	15	19	20
M1-H.M.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M2-V.M.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M3-LATHE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M1-H.M.C																		
M2-V.M.C																		
M3-LATHE																		
M1-V.M.C																		
M2-SHAPING																		
M3-LATHE																		

m \ i	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	2ND CELL PARTS													
	I TYPE				II TYPE				III TYPE					
	9	10	12	14	10	11	13	15	5	7	9	13	14	16
M1-H.M.C														
M2-V.M.C														
M3-LATHE														
M1-H.M.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M2-V.M.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M3-LATHE	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M1-V.M.C														
M2-SHAPING														
M3-LATHE														

m \ i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
	3RD CELL PARTS																																
	I TYPE												II TYPE													III TYPE							
	1	2	3	5	6	7	8	11	13	15	16	17	1	2	3	4	6	7	8	9	12	14	16	17	18	1	2	4	8	11	12	17	18
M1-H.M.C																																	
M2-V.M.C																																	
M3-LATHE																																	
M1-H.M.C																																	
M2-V.M.C																																	
M3-LATHE																																	
M1-V.M.C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M2-SHAPING	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M3-LATHE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

↑ MACHINES ↓

4.1.SOLVING FOR FIRST CELL

Table 2: Part Type Details for First Cell

Part Type (i)		No.of Process plans (s_i)	No.of Operations (O_{is})	Operation sequence (Operation type) j = 1	2	3	4	5	6
1	4^{I}	1	3	5	1	2			
2	18^{I}	2	6	4	5	1	7	2	6
			6	4	1	7	2	5	6
3	19^{I}	2	6	4	5	1	7	2	6
		2	6	4	1	7	2	5	6
4	20^{I}	2	6	4	5	1	7	2	6
			6	4	1	7	2	5	6
5	21^{I}	1	3	5	1	2			
6	22^{I}	1	3	5	1	2			
7	5^{II}	1	3	5	1	2			
8	19^{II}	2	6	4	5	1	7	2	6
			6	4	1	7	2	5	6
9	20^{II}	2	6	4	5	1	7	2	6
			6	4	1	7	2	5	6
10	21^{II}	2	6	4	5	1	7	2	6
			6	4	1	7	2	5	6
11	22^{II}	1	3	5	1	2			
12	23^{II}	1	3	5	1	2			
13	3^{III}	2	5	4	5	1	7	2	6
			5	4	1	7	2	5	6
14	6^{III}	1	3	4	5	1			
15	10^{III}	1	3	5	1	2			
16	15^{III}	2	4	4	5	7	1		
			4	4	7	5	1		
17	19^{III}	2	6	4	5	1	7	2	6
			6	4	1	7	2	5	6
18	20^{III}	2	6	4	5	1	7	2	6
			6	4	1	7	2	5	6

Operation Type for first cell:

Number of Operations	Operation Type (q)
1	Drilling
2	Tapping
3	Shaping
4	Facing
5	Turning
6	Slotting
7	Boring

Tool Type for first cell:

No. of Tools	Tool Type (t)
1	Drilling bit (5mm 10mm 20mm)
2	Tapping tool "M6"
3	Milling cutter (10mm)
4	Facing tool
5	Turning tool
6	Milling cutter (10mm 30mm)
7	Boring tool

Machine type for first cell:

No. of machines	Machine Type (m)
1	Horizontal machining center
2	Vertical machining center
3	CNC Lathe

Table 3: Tool types details for first cell

Tool type (t)	Slots required (h_t)	Tool copies Available (c_t)	Set of operation types for tool type 't' (Q_t)
1	4	2	(1)
2	4	2	(2)
3	2	2	(3)
4	2	2	(4)
5	1	1	(5)
6	3	3	(3,6)
7	2	1	(7)

Table 4: Machine Details for first cell

Machine (m)	Tool magazine capacity (b_m)	Process capability						
		1	2	3	4	5	6	7
1	32	x	√	x	√	x	√	√
2	64	√	√	√	x	x	√	x
3	12	√	x	x	√	√	x	x

√ : Operation possible

x : Operation not possible

Stepwise solution for first cell :-

Step I: $Z = -\infty$

Iteration 1 of two-stage heuristic:

Step II: The list of neighboring operation types for all the operation types for the 1st cell as obtained from Tables 2,3 and 4, is shown in Table 5.

Table 5: Neighbouring operation types

Operation Type (q)	Set of Neighboring operation types (j^q)	Set of machines (m^q)
1	2,4,5,6,7	(2)
2	1,5,6,7	(1,2)
3	5,6	(2)
4	1,5	(3)
5	1,3,4,7	(3)
6	1,2,3,5	(1,2)
7	1,2,5	(1)

I Objective of the model (ANOP) is

LINDO PACKAGE :

INPUT:

$$\text{Max} \sum_{q \in Q} \sum_{m \in M^q} U_{qm} \quad \rightarrow (A)$$

Max = u12+0u13+u21+u22+u32+0u41+u43+u53+u61+u62+u71
+0w11+0w12+0w13+0w14+0w15+0w16+0w17
+0w21+0w22+0w23+0w24+0w25+0w26+0w27
+0w31+0w32+0w33+0w34+0w35+0w36+0w37

subject to

Tool slot constraint

$$\sum_{t \in T} h_t \,.\, W_{mt} \leq b_m, \quad m \in M \quad \rightarrow (1)$$

4w11+4w12+2w13+2w14+w15+3w16+2w17<=32
4w21+4w22+2w23+2w24+w25+3w26+2w27<=641
4w31+4w32+2w33+2w34+w35+3w36+2w37<=12

Tool copies constraint

$$\sum_{m \in M^q} W_{mt} \le C_t, \quad t \in T \qquad \rightarrow (2)$$

w11+w21+w31<=2
w12+w22+w32<=2
w13+w23+w33<=1
w14+w24+w34<=2
w15+w25+w35<=1
w16+w26+w36<=2
w17+w27+w37<=1

$$U_{qm} \le \sum_{t \in t^q_m} W_{mt}, \quad q \in Q,\ m \in M^q \rightarrow (3)$$

u12-w21<=0
u13-w31<=0
u21-w12<=0
u22-w22<=0
u32-w23-w26<=0
u41-w14<=0
u43-w34<=0
u53-w35<=0
u61-w16<=0
u62-w26<=0
u71-w17<=0

$$\sum_{m \in M^q} U_{qm} \ge 1, \quad q \in Q,\ m \in M^q \qquad \rightarrow (4)$$

u12+u13>=1
u21+u22>=1
u32>=1
u41+u43>=1
u53>=1
u61+u62>=1
u71>=1

$$U_{qm} \le 1, \quad q \in Q,\ m \in M^q \qquad \rightarrow (5)$$

u12<=1
u13<=1

u21<=1
u22<=1
u32<=1
u41<=1
u43<=1
u53<=1
u61<=1
u62<=1
u71<=1

$W_{mt} \quad \in \quad \{0, 1\}, \quad m \in M^{q}, \ t \in T, q \in Q \qquad \rightarrow (6)$

w21>=0
w31>=0
w12>=0
w22>=0
w23>=0
w14>=0
w34>=0
w35>=0
w16>=0
w26>=0
w17>=0
w21<=1
w31<=1
w12<=1
w22<=1
w23<=1
w14<=1
w34<=1
w35<=1
w16<=1
w26<=1
w17<=1

$U_{qm} \quad \geq \quad 0, \quad m \in M^{q}, t \in T, q \in Q \qquad \rightarrow (7)$

u12>=0
u13>=0
u21>=0

```
u22>=0
u32>=0
u41>=0
u43>=0
u53>=0
u61>=0
u62>=0
u71>=0
END
gin u12
gin u13
gin u21
gin u22
gin u32
gin u41
gin u43
gin u53
gin u61
gin u62
gin u71
gin w11
gin w12
gin w13
gin w14
gin w15
gin w16
gin w17
gin w21
gin w22
gin w23
gin w24
gin w25
gin w26
gin w27
gin w31
gin w32
gin w33
gin w34
gin w35
gin w36
gin w37
```

OUTPUT:

VARIABLE	VALUE
U12	1.000000
U13	.000000
U21	1.000000
U22	1.000000
U32	1.000000
U41	.000000
U43	1.000000
U53	1.000000
U61	1.000000
U62	1.000000
U71	1.000000
W11	.000000
W12	1.000000
W13	.000000
W14	.000000
W15	.000000
W16	1.000000
W17	1.000000
W21	1.000000
W22	1.000000
W23	1.000000
W24	.000000
W25	.000000
W26	1.000000
W27	.000000
W31	1.000000
W32	.000000
W33	.000000
W34	1.000000
W35	1.000000
W36	.000000
W37	.000000

The Machine – tool type and Machine – operation type assignments are shown in Table: 6 as Obtain through LINDO

Table 6: Solution for model ANOP

Operation Type	Machines $M^{\varphi(i,s,j)}$	
1	2	
2	1,2	
3	2	
4	3	
5	3	
6	1,2	
7	1	

Machine	1	2	3
Tool Types	2,6,7	1,2,6	1,4,5

Step III : The solution for $(PMM)_i$ is presented below using the suggest Procedure

Step 0: Set $Z_{11} = Z_{51} = Z_{61} = Z_{71} = Z_{111} = Z_{121} = Z_{151} = 1$

Iteration 1 for $(PMM)_1$, $(PMM)_5$, $(PMM)_6$, $(PMM)_7$, $(PMM)_{11}$, $(PMM)_{12}$, $(PMM)_{15}$:-

Step 1: Process Plan =(5-1-2)

Each pair of Successive operation	Set of common m/c's
5-1	φ
1-2	2

Step 2: Frequency of m/c '2', f_2=1

Step 3: $F_{max} = f_s = f_2 = 1$

Step 4: Since the list of process plan is empty, we proceed to next step

Step 5: Objective value = $(0_{is}) - 1 - f_s$ = 3 – 1 – 1 = 1

- $(PMM)_1 = (PMM)_5 = (PMM)_6 = (PMM)_7$
  $= (PMM)_{11} = (PMM)_{12} = (PMM)_{15} = 1$

Step 6:

- Since the operations (1,2) can be assigned to m/c '2'
- Operation (5) can not be assigned to m/c '2'

Step 7:

- Hence the next highest frequency is = 0
- Ie, of m/c'3' where operation(5) can be allocated.

Step 0:

Set $Z_{21} = Z_{31} = Z_{41} = Z_{81} = Z_{91} = Z_{101} = Z_{171} = Z_{181} = 1,$

$Z_{22} = Z_{32} = Z_{42} = Z_{82} = Z_{92} = Z_{102} = Z_{172} = Z_{182} = 0$

Iteration 1 for $(PMM)_2$, $(PMM)_2$, $(PMM)_3$, $(PMM)_4$, $(PMM)_8$, $(PMM)_9$, $(PMM)_{10}$, $(PMM)_{17}$, $(PMM)_{18}$:-

Step 1: Process plan (1) = (4-5-1-7-2-6)

Each pair of successive operation	Set of common m/c' s
4-5	3
5-1	Φ
1-7	Φ
7-2	1
2-6	1, 2

Step 2:

Frequency of occurrence of m/c '1' $f_1 = 2$

Frequency of occurrence of m/c '2' $f_2 = 1$

Frequency of occurrence of m/c '3' $f_3 = 1$

Step 3: $F_{max} = f_s = f_1 = 2$

Step 4: Set $Z_{22} = Z_{32} = Z_{42} = Z_{82} = Z_{92} = Z_{102} = Z_{172} = Z_{182} = 1$,

$Z_{21} = Z_{31} = Z_{41} = Z_{81} = Z_{91} = Z_{101} = Z_{171} = Z_{181} = 0$

and go to step 1

Iteration 2 for $(PMM)_2$, $(PMM)_3$, $(PMM)_4$, $(PMM)_8$, $(PMM)_4$, $(PMM)_{10}$, $(PMM)_{17}$, $(PMM)_{18}$:-

Step 1: Process plan (2) = (4-1-7-2-5-6)

Each pair of successive operation	Set of common m/c' s
4-1	Φ
1-7	Φ
7-2	1
2-5	Φ
5-6	Φ

Step 2: Frequency of occurrence of m/c "1" $f_1 = 1$

Step 3: $F_{max} = f_s = f_1 = 1$

Step 4: Since the list of process plans is empty, we proceed to next step.

Step 5: Objective value of process plan 1 = (6-1-2 = 3)

Process plan 2 = (6-1-1= 4)

We select process plan 1 which has got the minimum objective valve

- $(PMM)_2 = (PMM)_3 = (PMM)_4 = (PMM)_8 = (PMM)_9$
  $= (PMM)_{10} = (PMM)_{17} = (PMM)_{18} = 3$

Step 6: Process plan '1'

- Operations (7, 2, 6) can assigned to m/c '1'
- Operations (4,5,1) can not assigned to m/c '1'

Step 7:

- Hence next highest frequency (f_3=1)
- Since operations (4,5) can be assigned to m/c '3'
- Operation (1) can not assigned to m/c " 1 & 3"
- Hence next highest frequency (f_s=0)
- i.e., of m/c '2' where operation(1) can be allocated

Step 0: Set $Z_{131} = 1, Z_{132} = 0$

Iteration 1 for $(PMM)_{13}$:-

Step 1: Process Plan (1) =(4-1-5-3-6)

Each pair of successive operation	Set of common m/c' s
4-1	Φ
1-5	Φ
5-3	Φ
3-6	2

Step 3: $F_{max} = f_x = f_2 = 1$

Step 4: Set $Z_{132} = 1, Z_{131} = 0$ and go to step 1

Iteration 2 for $(PMM)_{13}$

Step 1: Process plan(2) = (4-5-1-6-3)

Each pair of successive operation	Set of common m/c' s
4-5	3
5-1	φ
1-6	2
6-3	2

Step 2: Frequency of m/c '2' $f_2 = 2$

Frequency of m/c '3' $f_3 = 1$

Step 3: $F_{max} = f_s = f_2 = 2$

Step 4: Since the list of process plan is empty, we process next step.

Step 5: Objective value for process plan 1 = (5-1-1=3)

Process plan 2 = (5-1-2=2)

We select process plan '2' which has got the minimum objective value

- $(PMM)_{13} = 2$

Step 6: Process plan '2'

- Operations (1,3,6) can assigned to m/c '2'

Step 7:

- Hence next highest frequency (f_3=1)
- Operations (4,5) can be assigned to m/c '3'.
- Hence next highest frequency (f_s=0)
- i.e., of m/c'2' where operation(1) can be allocated

Step:0 Set $Z_{141} = 1$, $Z_{142}=0$

Iteration 1 for $(PMM)_{14}$

Step 1: Process plan = (4-5-1)

Each pair of successive operation	Set of common m/c' s
4-5	3
5-1	φ

Step 2: Frequency of m/c '3' $f_3 = 1$

Step 3: $F_{max} = f_s = f_3 = 1$

Step 4: Since the list of process plan is empty, we proceed to next step.

Step 5: Objective value = (3-1-1 = 2)

➢ $(PMM)_{14} = 2$

Step 6: Since operations (4,5) can be assigned to m/c '3'

Step 7: Hence next highest frequency (f_s=0)

➢ i.e., of m/c '2' where operation (1) can be allocated.

Step 0: Set $Z_{151} = 1, Z_{152} = 0$

Iteration 1 for $(PMM)_{16}$:

Step 1: Process plan(1) =(4-5-7-1)

Each pair of successive operation	Set of common m/c' s
4-5	3
5-7	φ
7-1	φ

Step 2: Frequency of m/c '3' f_3=1

Step 3: $F_{max} = f_s = f_3 = 1$

Step 4: Set $Z_{152} = 1, Z_{151} = 0$ and go to step 1

Iteration 2 for $(PMM)_{15}$:

Step 1: Process plan (2) =(4-7-5-1)

Each pair of successive operation	Set of common m/c' s
4-7	Φ
7-5	Φ
5-1	Φ

Step 3: $F_{max} = 0$

Step 4: Since the list of process plan is empty, we process to next step.

Step 5: Process plan 1 = (3-1-1=1)

Process plan 2 = (3-2-0=2)

We select process plan 1 $(PMM)_{16}$= 1

Step 6: Operations (4,5) can assigns to m/c '3'

Step 7: Hence next highest frequency (fs=0)

- i.e., of m/c '1' where Operation(7) can be allocated

  and m/c '2' where Operation(1) can be allocated.

The machine operation assignment for the selected process plan is Presented below in the form j/m (i.e.) Operation j assigned to machine m.

Table 7: Solution for All $(PMM)_i$

Part Type (i)	Process plan selected	Operation (j) – Machine (m) Assignment –(j/m)
1	1	5/3-1/2-2/2
2	1	4/3-5/3-1/2-7/1-2/1-6/1
3	1	4/3-5/3-1/2-7/1-2/1-6/1
4	1	4/3-5/3-1/2-7/1-2/1-6/1
5	1	5/3-1/2-2/2
6	1	5/3-1/2-2/2
7	1	5/3-1/2-2/2
8	1	4/3-5/3-1/2-7/1-2/1-6/1
9	1	4/3-5/3-1/2-7/1-2/1-6/1
10	1	4/3-5/3-1/2-7/1-2/1-6/1
11	1	5/3-1/2-2/2
12	1	5/3-1/2-2/2
13	2	4/3-5/3-1/2-6/2-3/2
14	1	4/3-5/3-1/2
15	1	5/3-1/2-2/2
16	1	4/3-5/3-7/1-1/2
17	1	4/3-5/3-1/2-7/1-2/1-6/1
18	1	4/3-5/3-1/2-7/1-2/1-6/1

Therefore

$$Z_I = [-1-3-3-3-1-1-1-3-3-3-1-1-2-2-1-1-3-3] = -36$$

Since $Z_I > Z$ we save the current solution up date $Z = Z_I = -36$, $Z_I \# 0$

Step IV:

- Operation types 1,7 each causes two movement and operation type '5' causes one movement.
- Operation type '7' cannot be selected because it is already assigned to m/c '1' and no alternate machine is left.

➢ Select operation type '1' and set U12 = 0 Go to Step II

Iteration 2 of two-stage heuristic:

Step II : The model (ANOP) remains the same as in the previous iteration but with the additional constraint **U12 = 0**

II Objective of the model (ANOP) is

LINDO PACKAGE :

INPUT:

```
Max = u12+0u13+u21+u22+u32+0u41+u43+u53+u61+u62+u71
      +0w11+0w12+0w13+0w14+0w15+ w16+0w17
      +0w21+0w22+0w23+0w24+0w25+0w26+0w27
      +0w31+0w32+0w33+0w34+0w35+0w36+ 0w37
subject to

4w11+4w12+2w13+2w14+w15+3w16+2w17<=32
4w21+4w22+2w23+2w24+w25+3w26+2w27<=64
4w31+4w32+2w33+2w34+w35+3w36+2w37<=12
w11+w21+w31<=2
w12+w22+w32<=2
w13+w23+w33<=1
w14+w24+w34<=2
w15+w25+w35<=1
w16+w26+w36<=2
w17+w27+w37<=1
u12-w21<=0
u13-w31<=0
u21-w12<=0
u22-w22<=0
u32-w23-w26<=0
u41-w14<=0
u43-w34<=0
u53-w35<=0
u61-w16<=0
u62-w26<=0
u71-w17<=0
```

u12+u13>=1
u21+u22>=1
u41+u43>=1
u61+u62>=1
u32>=1
u53>=1
u71>=1
u12<=1
u13<=1
u21<=1
u22<=1
u32<=1
u41<=1
u43<=1
u53<=1
u61<=1
u62<=1
u71<=1
w21>=0
w31>=0
w12>=0
w22>=0
w23>=0
w14>=0
w34>=0
w35>=0
w16>=0
w26>=0
w17>=0
w21<=1
w31<=1
w12<=1
w22<=1
w23<=1
w14<=1
w34<=1
w35<=1
w16<=1
w26<=1
w17<=1
u12>=0

```
u13>=0
u21>=0
u22>=0
u32>=0
u41>=0
u43>=0
u53>=0
u61>=0
u62>=0
u71>=0
u12=0
END
gin u12
gin u13
gin u21
gin u22
gin u32
gin u41
gin u43
gin u53
gin u61
gin u62
gin u71
gin w11
gin w12
gin w13
gin w14
gin w15
gin w16
gin w17
gin w21
gin w22
gin w23
gin w24
gin w25
gin w26
gin w27
gin w31
gin w32
gin w33
gin w34
```

gin w35
gin w36
gin w37

<u>OUTPUT:</u>

VARIABLE	VALUE
U12	.000000
U13	1.000000
U21	1.000000
U22	1.000000
U32	1.000000
U41	1.000000
U43	1.000000
U53	1.000000
U61	1.000000
U62	1.000000
U71	1.000000
W11	.000000
W12	1.000000
W13	.000000
W14	1.000000
W15	.000000
W16	1.000000
W17	1.000000
W21	.000000
W22	1.000000
W23	.000000
W24	.000000
W25	.000000
W26	1.000000
W27	.000000
W31	1.000000
W32	.000000
W33	.000000
W34	1.000000
W35	1.000000
W36	.000000
W37	.000000

- The machine – tool type and Machine – operation type assignments are shown in Table:8 as Obtain through LINDO

Table 8: Solution for model ANOP

Operation Type	Machine's $M^{\varphi(i,s,j)}$	
1	3	
2	1,2	
3	2	
4	1,3	
5	3	
6	1,2	
7	1	
Machine	1	2	3
Tool Types	2,4,6,7	2,6	1,4,5

Step 0: Set $Z_{21} = Z_{31} = Z_{41} = Z_{81} = Z_{91} = Z_{101} = Z_{171} = Z_{181} = 1$

$Z_{22} = Z_{32} = Z_{42} = Z_{82} = Z_{92} = Z_{102} = Z_{172} = Z_{182} = 0$

Step 1: Process plan (1) =(4-5-1-7-2-6)

Each pair of successive operation	Set of common m/c' s
4-5	3
5-1	3
1-7	Φ
7-2	1
2-6	1, 2

Step 2: Frequency of m/c1, $f_1 = 2$

Frequency of m/c2, $f_2 = 1$

Frequency of m/c3, $f_3 = 2$

Step 3: $F_{max} = f_3 = f_1 = f_3 = 2$

Step 4: Set $Z_{22} = Z_{32} = Z_{42} = Z_{82} = Z_{92} = Z_{102} = Z_{172} = Z_{182} = 1$

$Z_{21} = Z_{31} = Z_{41} = Z_{81} = Z_{91} = Z_{101} = Z_{171} = Z_{181} = 0$

and go to step 1

Step 1: Process plan (2) = (4-1-7-2-5-6)

Each pair of successive operation	Set of common m/c' s
4-1	3
1-7	Φ
7-2	1
2-5	Φ
5-6	Φ

Step 2: Frequency of m/c1, $f_1 = 1$

m/c3, $f_3 = 1$

Step 3: Fmax = $f_s = f_1 = f_3 = 1$

Step 4: Since the list of process plan is empty, we proceed to next step

Step 5: Objective value for process plan 1 (6-1-2=3)
Process plan 2 (6-1-1=4)

We select process plan 1 which has got the minimum objective value.

- $(PMM)_2 = (PMM)_3 = (PMM)_4 = (PMM)_8 = (PMM)_9 = (PMM)_{10}$

  $= (PMM)_{17} = (PMM)_{18} = 3$

Step 6:

- Operations (1,4,5) can assigned to m/c '3'
- Operations (2,6,7) can assigned to m/c '1'

Same procedure for the other part the objective value for

- $(PMM)_1 = (PMM)_5 = (PMM)_6 = (PMM)_7 = (PMM)_{11}$

  $= (PMM)_{12} = (PMM)_{15} = 1$
- $(PMM)_3 = (PMM)_4 = (PMM)_8 = (PMM)_9 = (PMM)_{10} = (PMM)_{17}$

  $= (PMM)_2 = (PMM)_{18} = (PMM)_2 = 2$
- $(PMM)_{13} = 2$
- $(PMM)_{14} = 0$
- $(PMM)_{16} = 1$

The machine operation assignment for the selected process plan is presented below in the form j/m ie. Operation j assigned to machine m.

Table 9: Solution for all $(PMM)_i$

Part type (i)	Process plan selected	Operation (j) – machine(m) Assignment (j/m)
1	1	5/3-1/3-2/2
2	1	4/3-5/3-1/3-7/1-2/1-6/1
3	1	4/3-5/3-1/3-7/1-2/1-6/1
4	1	4/3-5/3-1/3-7/1-2/1-6/1
5	1	5/3-1/3-2/2
6	1	5/3-1/3-2/2
7	1	5/3-1/3-2/2
8	1	4/3-5/3-1/3-7/1-2/1-6/1
9	1	4/3-5/3-1/3-7/1-2/1-6/1
10	1	4/3-5/3-1/3-7/1-2/1-6/1
11	1	5/3-1/3-2/2
12	1	5/3-1/3-2/2
13	2	4/3-5/3-1/3-6/2-3/2
14	1	4/3-5/3-1/3
15	1	5/3-1/3-2/2

16	1	4/3-5/3-7/1-1/3
17	1	4/3-5/3-1/3-7/1-2/1-6/1
18	1	4/3-5/3-1/3-7/1-2/1-6/1

Therefore

$$Z_2=[-1-2-2-2-1-1-1-2-2-2-1-1-2-0-1-1-2-2] =-26$$

Since $Z_2 > Z_1$ we save the current solution update $Z_1=Z_2 = -26$, $Z_2 \# 0$

Step IV:

- Operation types 1,2,5 and 7, each causes one movement of a part type.
- All the operation types can not be selected because no alternate machine is left and This gives the final solution.

4.2. SOLVING FOR SECOND CELL:

Table 10: Part Type Details For Second Cell

Part Type (i)		Number of Process plans (s_i)	Number of Operations (O_{is})	Operation sequence (Operation type) j = 1	2	3	4	5	6
1	9^{I}	2	4	3	2	6	1		
			3	2	1	6			
2	10^{I}	2	4	3	2	6	1		
			4	4	2	1	6		
3	12^{I}	1	2	4	5				
4	14^{I}	1	2	4	5				
5	10^{II}	2	4	3	2	6	1		
			3	2	1	6			
6	11^{II}	2	4	3	2	6	1		
			4	4	2	1	6		
7	13^{II}	1	2	4	5				
8	15^{II}	1	2	4	5				
9	5^{III}	1	2	4	5				
10	7^{III}	1	3	3	4	2			
11	9^{III}	1	3	4	1	5			
12	13^{III}	2	4	3	2	6	1		
			3	2	1	6			
13	14^{III}	2	4	3	2	6	1		
			4	4	2	1	6		
14	16^{III}	1	2	4	5				

Operation Type for second cell:

Number of Operations	Operation Type (q)
1	Drilling
2	Milling
3	Shaping
4	Facing
5	Turning
6	Slotting

Tool Type for second cell:

No. of Tools	Tool Type (t)
1	Drilling bit (5mm, 10mm, 20mm)
2	Milling cutter (10mm)
3	Milling cutter (10mm, 30mm)
4	Facing tool
5	Turning tool
6	Milling cutter (10mm, 40mm)

Machine type for second cell:

No. of machines	Machine Type (m)
1	Horizontal machining center
2	Vertical machining center
3	CNC Lathe

Table 11 : Tool types details for second cell

Tool type (t)	Slots required (h_t)	Tool copies Available (c_t)	Set of operation types for tool type 't' (Q_t)
1	3	2	(1)
2	2	2	(2)
3	2	1	(2,3)
4	4	3	(4)
5	3	1	(5)
6	4	2	(2,6)

Table 12: Machine Details for second cell

Machine (m)	Tool magazine capacity (b_m)	Process capability						
		1	2	3	4	5	6	7
1	32	X	√	X	√	X	√	√
2	24	√	√	√	X	X	√	X
3	8	√	X	X	√	√	X	X

√ : Operation possible

X : Operation not possible

Stepwise solution for second cell :-

Step I: $Z = -\infty$

Iteration 1 of two-stage heuristic:

Step II: The list of neighboring operation types for all the operation types for the 2nd cell as obtained from Tables 10,11 and 12 is shown in Table 13.

Table 13: Neighbouring operation types

Operation Type (q)	Set of Neighboring operation types (j^q)	Set of machines (m^q)
1	2,4,5,6	2,3
2	1,4	1,2
3	4	1
5	1,5	3
6	1	2

I Objective of the model (ANOP) is

LINDO PACKAGE :

INPUT:

```
Max= u12+u13+u21+u22+u31+u41+u42+0u43+u53+u62+0u61
     +0w11+0w12+0w13+0w14+0w15+0w16
     +0w21+0w22+0w23+0w24+0w25+0w26
     +0w31+0w32+0w33+0w34+0w35+0w36
subject to
3w11+2w12+2w13+4w14+3w15+4w16<=32
3w21+2w22+2w23+4w24+3w25+4w26<=24
3w31+2w32+2w33+4w34+3w35+4w36<=8
w11+w21+w31<=2
w12+w22+w32<=2
w13+w23+w33<=1
w14+w24+w34<=3
w15+w25+w35<=1
w16+w26+w36<=2
u12-w21<=0
u13-w31<=0
u21-w12-w13-w16<=0
u22-w22-w23-w26<=0
u31-w13<=0
u41-w14<=0
u42-w24<=0
u43-w34<=0
u53-w35<=0
u61-w16<=0
```

u62-w26<=0
u12+u13>=1
u21+u22>=1
u31>=1
u41+u42+u43>=1
u53>=1
u61+u62>=1
w21>=0
w31>=0
w12>=0
w22>=0
w13>=0
w23>=0
w14>=0
w24>=0
w34>=0
w35>=0
w16>=0
w26>=0
u12<=1
u13<=1
u21<=1
u22<=1
u31<=1
u41<=1
u42<=1
u43<=1
u53<=1
u61<=1
u62<=1
w21<=1
w12<=1
w22<=1
w13<=1
w23<=1
w14<=1
w24<=1
w34<=1
w35<=1
w16<=1
w26<=1

```
u12>=0
u13>=0
u21>=0
u22>=0
u31>=0
u41>=0
u42>=0
u43>=0
u53>=0
u61>=0
u62>=0
END
gin u12
gin u13
gin u21
gin u22
gin u31
gin u41
gin u42
gin u43
gin u53
gin u62
gin u61
gin w11
gin w12
gin w13
gin w14
gin w15
gin w16
gin w21
gin w22
gin w23
gin w24
gin w25
gin w26
gin w31
gin w32
gin w33
gin w34
gin w35
gin w36
```

OUTPUT:

VARIABLE	VALUE
U12	1.000000
U13	1.000000
U21	1.000000
U22	1.000000
U31	1.000000
U41	1.000000
U42	1.000000
U43	1.000000
U53	1.000000
U61	1.000000
U62	1.000000
W11	.000000
W12	.000000
W13	1.000000
W14	1.000000
W15	.000000
W16	1.000000
W21	1.000000
W22	.000000
W23	.000000
W24	1.000000
W25	.000000
W26	1.000000
W31	1.000000
W32	1.000000
W33	.000000
W34	.000000
W35	1.000000
W36	.000000

The machine – tool type and Machine – operation type assignments are shown in Table: 14 as Obtained through LINDO

Table 14: Solution for model ANOP

Operation Type (q)		Machines $M^{\varphi(i,s,j)}$	
1		2,3	
2		1,2	
3		1	
4		1,2	
5		3	
6		1,2	
Machine	1	2	3
Tool Types	3,4,6	1,4,6	1,2,5

Step III : The solution for $(PMM)_i$ is presented below using the suggested procedure.

Step 0: Set $Z_{11} = Z_{51} = Z_{121} = 1$,

$Z_{12} = Z_{52} = Z_{122} = 0$

Iteration 1 for $(PMM)_1$, $(PMM)_5$, $(PMM)_{12}$:-

Step 1: Process Plan (1) =(3-2-6-1)

Each pair of Successive operation	Set of common m/c's
3-2	1
2-6	1,2
6-1	2

Step 2: Frequency of m/c '1', $f_1 = 2$

Frequency of m/c '2', $f_2 = 2$

Step 3: $F_{max} = f_s = f_2 = 2$

Step 4: Set $Z_{12} = Z_{52} = Z_{122} = 1$,

$Z_{11} = Z_{51} = Z_{121} = 0$ and go to step:1

Iteration 2 for $(PMM)_1$, $(PMM)_5$, $(PMM)_{12}$, :-

Step 1: Process plan (2) = (2-1-6)

Each pair of successive operation	Set of common m/c' s
2-1	2
1-6	2

Step 2: Frequency of m/c "2" $f_2 = 2$

Step 3: $F_{max} = f_s = f_1 = 2$

Step 4: Since the list of process plans is empty, we proceed to next step.

Step 5: Objective value of process plan (1) = (4-1-2 = 1)

Process plan (2) = (3-1-2= 0)

We select process plan (2) which has got the minimum objective valve

➢ $(PMM)_1 = (PMM)_5 = (PMM)_{12} = 0$

Step 6:

➢ Operations (1, 2, 6) can assigned to m/c '2'

Step 0: Set $Z_{21} = Z_{61} = Z_{131} = 1$,

$Z_{22} = Z_{62} = Z_{132} = 0$

Iteration 1 for $(PMM)_2$, $(PMM)_6$, $(PMM)_{13}$:-

Step 1: Process Plan (1) =(3-2-6-1)

Each pair of successive operation	Set of common m/c' s
3-2	1
2-6	1,2
6-1	2

Step 2: Frequency of m/c '1', f1 = 2

Frequency of m/c '2', f2 = 2

Step 3: $F_{max} = f_x = f_2 = 2$

Step 4: Set $Z_{22} = Z_{62} = Z_{132} = 1$

$Z_{21} = Z_{61} = Z_{131} = 0$ and go to step 1

Iteration 2 for $(PMM)_2$, $(PMM)_6$, $(PMM)_{13}$:-

Step 1: Process plan(2) = (4-2-1-6)

Each pair of successive operation	Set of common m/c' s
4-2	1,2
2-1	2
1-6	2

Step 2: Frequency of m/c '1' $f_1 = 1$

Frequency of m/c '2' $f_2 = 3$

Step 3: $F_{max} = f_s = f_2 = 3$

Step 4: Since the list of process plan is empty, we proceed to next step.

Step 5: Objective value for process plan (1) = (4-1-2=1)

Process plan (2) = (4-1-3=0)

- $(PMM)_2 = (PMM)_6 = (PMM)_{13} = 0$

Step 6: Since the operations (1,2,4,6) can be assigned to m/c '2'.

Step 0: Set $Z_{31} = Z_{41} = Z_{71} = Z_{81} = Z_{91} = Z_{141} = 1,$

$Z_{32} = Z_{42} = Z_{72} = Z_{82} = Z_{92} = Z_{142} = 0$

Iteration 1 for $(PMM)_3$, $(PMM)_4$, $(PMM)_7$, $(PMM)_8$, $(PMM)_9$, $(PMM)_{14}$:-

Step1: Process plan (1) = (4-5)

Each pair of successive operation	Set of common m/c' s
4-5	Φ

Step 3: $F_{max} = f_s = 0$

Step 4: Since the list of process plan is empty, we proceed to next step.

Step 5: Objective value for process plan (1) = (2-1-0 = 1)

- $(PMM)_3 = (PMM)_4 = (PMM)_7 = (PMM)_8 = (PMM)_9 = (PMM)_{14} = 1$

Step 6:

- Since operation (4) can be assigned to m/c '1'

  and operation (5) can be assigned to m/c '3'

  Same procedure for the other parts

- $(PMM)_{10} = 0$
- $(PMM)_{11} = 1$

The machine – operation assignment for the selected process plan is presented below in the form j/m.i.e. Operation 'j' assigned to machine 'm'.

Table 15: Solution for All $(PMM)_i$

Part Type (i)	Process plan selected	Operation (j) – Machine (m) Assignment –(j/m)
1	2	2/2-1/2-6/2
2	2	4/2-2/2-1/2-6/2
3	1	4/1-5/3
4	1	4/1-5/3
5	2	2/2-1/2-6/2
6	2	4/2-2/2-1/2-6/2
7	1	4/1-5/3
8	1	4/1-5/3
9	1	4/1-5/3
10	1	3/1-4/1-2/1
11	1	4/1-1/3-5/3
12	2	2/2-1/2-6/2
13	2	4/2-2/2-1/2-6/2
14	1	4/1-5/3

Therefore

$$Z_1 = 0+0-1-1+0+0+0-1-1-1+0-1+0+0-1 = -7$$

Since $Z_1 > Z$ we save the current solution up date $Z = Z_1 = -7$, Z_1 # 0

Step IV:

- Operation types (1,4,5) each causes one movement.
- Operation type '1' cannot be selected because it is already assigned to m/c '2' and m/c '3' and no alternate machine is left.
- Select operation type '4' and set **U41 = 0** Go to Step II

Iteration 2 of two-stage heuristic:

Step II : The model (ANOP) remains the same as in the previous iteration but with the additional constraint **U41 = 0**

II Objective of the model (ANOP) is

LINDO PACKAGE :

INPUT:

```
Max=u12+u13+u21+u22+u31+u41+u42+0u43+u53+u62+u61
    +0w11+0w12+0w13+0w14+0w15+0w16
    +0w21+0w22+0w23+0w24+0w25+0w26
    +0w31+0w32+0w33+0w34+0w35+0w36

subject to

3w11+2w12+2w13+4w14+3w15+4w16<=32
3w21+2w22+2w23+4w24+3w25+4w26<=24
3w31+2w32+2w33+4w34+3w35+4w36<=8
w11+w21+w31<=2
w12+w22+w32<=2
w13+w23+w33<=1
w14+w24+w34<=3
w15+w25+w35<=1
w16+w26+w36<=2
u12-w21<=0
u13-w31<=0
u21-w12-w13-w16<=0
u22-w22-w23-w26<=0
u31-w13<=0
u41-w14<=0
u42-w24<=0
u43-w34<=0
u53-w35<=0
u61-w16<=0
```

u62-w26<=0
u12+u13>=1
u21+u22>=1
u31>=1
u41+u42+u43>=1
u53>=1
u61+u62>=1
w21>=0
w31>=0
w12>=0
w22>=0
w13>=0
w23>=0
w14>=0
w24>=0
w34>=0
w35>=0
w16>=0
w26>=0
u12<=1
u13<=1
u21<=1
u22<=1
u31<=1
u41<=1
u42<=1
u43<=1
u53<=1
u61<=1
u62<=1
w21<=1
w12<=1
w22<=1
w13<=1
w23<=1
w14<=1
w24<=1
w34<=1
w35<=1
w16<=1
w26<=1

```
u12>=0
u13>=0
u21>=0
u22>=0
u31>=0
u41>=0
u42>=0
u43>=0
u53>=0
u61>=0
u62>=0
u41=0
END
 gin u12
 gin u13
 gin u21
 gin u22
 gin u31
 gin u41
 gin u42
 gin u43
 gin u53
 gin u62
 gin u61
 gin w11
 gin w12
 gin w13
 gin w14
 gin w15
 gin w16
 gin w21
 gin w22
 gin w23
 gin w24
 gin w25
 gin w26
 gin w31
 gin w32
 gin w33
 gin w34
 gin w35
```

gin w36

OUTPUT:

VARIABL	VALUE
U12	1.000000
U13	1.000000
U21	1.000000
U22	1.000000
U31	1.000000
U41	.000000
U42	1.000000
U43	1.000000
U53	1.000000
U61	1.000000
U62	1.000000
W11	.000000
W12	.000000
W13	1.000000
W14	1.000000
W15	.000000
W16	1.000000
W21	1.000000
W22	.000000
W23	.000000
W24	1.000000
W25	.000000
W26	1.000000
W31	1.000000
W32	.000000
W33	.000000
W34	1.000000
W35	1.000000
W36	.000000

The machine – tool type and Machine – operation type assignments are shown in Table: 16 as Obtain through LINDO

Table 16: Solution for model ANOP

Operation Type (q)	Machine's $M^{\varphi(i,s,j)}$	
1	2,3	
2	1,2	
3	1	
4	2,3	
5	3	
6	1,2	

Machine	1	2	3
Tool Types	3,4,6	1,4,6	1,4,5

Step III: The solution for $(PMM)_i$ is presented below using the suggested procedure.

Step 0: Set $Z_{31} = Z_{41} = Z_{71} = Z_{81} = Z_{91} = Z_{141} = 1$

Iteration 1 for (PMM)3, (PMM)4, (PMM)7, (PMM)8, (PMM)9, (PMM)14:-

Step 1: Process plan (1) =(4-5)

Each pair of successive operation	Set of common m/c' s
4-5	3

Step 2: Frequency of m/c (3), $f_3 = 1$

Step 3: $F_{max} = f_s = f_3 = 1$

Step 4: Since the list of process plan is empty, we proceed next step.

Step 5: Objective value for process plan(1) = (2-1-1=0)

- $(PMM)_3 = (PMM)_4 = (PMM)_7 = (PMM)_8 = (PMM)_9 = (PMM)_{14} = 0$

Step 6: Since the operations (4,5) can be assigned to m/c '3'.

Step 0: Set $Z_{111} = 1$,

Iteration for $(PMM)_{11}$:-

Step 1: Process plan (1) = (4-1-5)

Each pair of successive operation	Set of common m/c's
4-1	2,3
1-5	3

Step 2: Frequency of m/c '2', $f_2 = 1$

Frequency of m/c '3', $f_3 = 2$

Step 3: $Fmax = f_s = f_3 = 2$

Step 5: Objective value for process plan (1) = (3-1-2=0)

- $(PMM)_{11} = 0$

Step 6: Since the operations (1,4,5) can be assigned to m/c '3'.

Table 17: Solution for all $(PMM)_i$

Part type(i)	Process plan selected	Operation (j) – machine(m) Assignment (j/m)
1	2	2/2-1/2-6/2
2	2	4/2-2/2-1/2-6/2
3	1	4/3-5/3
4	1	4/3-5/3
5	2	2/2-1/2-6/2
6	2	4/2-2/2-1/2-6/2
7	1	4/3-5/3
8	1	4/3-5/3
9	1	4/3-5/3
10	1	3/1-4/1-21
11	1	4/3-1/3-5/3
12	2	2/2-1/2-6/2
13	2	4/2-2/2-1/2-6/2
14	1	4/3-5/3

Therefore

$$Z_1 = 0+0+0+0+0+0+0+0+0+0+0+0+0+0 = 0$$

Since $Z_1 > Z$ update $Z = Z_1 = 0$

Step IV: If $Z = 0$, stop

(The best possible solution has been obtained)

4.3. SOLVING FOR THIRD CELL :

Table 18: Part Type Details For 3rd Cell

Part Type (i)		No.of Process plan (s_i)	No.of Operations (O_{is})	Operation sequence (Operation type) j = 1	2	3	4	5	6	7	8	9
1	1^{I}	2	6	3	6	1	10	2	3			
			4	3	1	6	2					
2	2^{I}	1	2	3	1							
3	3^{I}	2	5	3	1	6	10	2				
			6	3	1	6	10	3	2			
4	5^{I}	2	9	4	5	1	8	7	10	1	2	3
			9	4	1	5	11	8	7	1	2	10
5	6^{I}	2	8	4	1	5	11	7	1	2	10	
			8	4	1	5	11	1	2	7	10	
6	7^{I}	2	5	3	1	7	3	2				
			4	3	1	2	7					
7	8^{I}	2	5	3	1	7	3	2				
			4	3	1	2	7					
8	11^{I}	2	4	4	5	6	1					
			5	4	6	5	1	5				
9	13^{I}	2	4	4	5	6	1					
			5	4	6	5	1	5				
10	15^{I}	2	6	5	9	4	1	6	10			
			6	4	5	9	1	6	10			
11	16^{I}	2	6	5	9	4	1	6	10			
			6	4	5	9	1	6	10			
12	17^{I}	1	5	4	5	1	6	2				
13	1^{II}	2	6	3	6	1	10	2	3			
			4	3	1	6	2					
14	2^{II}	1	4	3	5	1	10					
15	3^{II}	1	4	5	3	10	1					

16	4II	2	5 6	3 1 6 10 2 3 1 6 10 3 2
17	6II	2	9 9	4 5 1 8 7 10 1 2 3 4 1 5 11 8 7 1 2 10
18	7II	2	8 8	4 1 5 11 7 1 2 10 4 1 5 11 1 2 7 10
19	8II	2	5 4	3 1 7 3 2 3 1 2 7
20	9II	2	5 4	3 1 7 3 2 3 1 2 7
21	12II	2	4 5	4 5 6 1 4 6 5 1 5
22	14II	2	4 5	4 5 6 1 4 6 5 1 5
23	16II	2	6 6	5 9 4 1 6 10 4 5 9 1 6 10
24	17II	2	6 6	5 9 4 1 6 10 4 5 9 1 6 10
25	18II	1	5	4 5 1 6 2
26	1III	2	6 4	3 6 1 10 2 3 3 1 6 2
27	2III	2	5 6	3 1 6 10 2 3 1 6 10 3 2
28	4III	1	4	4 5 10 2
29	8III	1	4	3 10 1 2
30	11III	2	9 9	4 5 1 8 7 10 1 2 3 4 1 5 11 8 7 1 2 10
31	12III	2	5 4	3 1 7 3 2 3 1 2 7
32	17III	2	6 6	5 9 4 1 6 10 4 5 9 1 6 10
33	18III	1	6	4 5 9 1 6 2

Operation type for 3rd cell:

Number of operation	Operation Type (q)
1	Drilling
2	Tapping
3	Shaping
4	Facing
5	Turning
6	Boring
7	Threading
8	Grooving
9	Knurling
10	Milling
11	Tapper turning

Tool Type for 3rd cell:

Number of Tools	Tool Type (t)
1	Drilling bit (5mm, 10mm, 20mm)
2	Tapping Tool
3	Shaping Tool
4	Facing Tool
5	Turning Tool
6	Boring Tool
7	Threading Tool
8	Grooving Tool
9	Knurling Tool
10	Milling Cutter (10mm, 30mm)
11	Turning Tool

Machine Type for 3rd cell:

Number of machine	Machine Type (m)
1	Vertical Machining center
2	Shaping machine
3	CNC Lathe

Table 19: Tool Types Details for 3rd cell:-

Tool Type (t)	Slots required (h_t)	Tool copies Available (c_t)	Set of operation types for tool type 't' (Q_t)
1	2	2	(1)
2	4	2	(2)
3	1	1	(3)
4	4	3	(4)
5	4	1	(5)
6	2	2	(6)
7	2	1	(7)
8	2	1	(8)
9	2	1	(9)
10	3	2	(10)
11	2	1	(5, 11)

Table 20: Machine Details for 3rd cell:

Machine (m)	Tool magaZine capacity (b_m)	Process capability										
		1	2	3	4	5	6	7	8	9	10	11
1	64	√	√	X	√	X	√	X	X	X	√	X
2	1	X	X	√	√	X	X	X	X	X	X	X
3	12	√	X	X	√	√	X	√	√	√	X	√

√ : Operation possible

X : Operation not possible

Stepwise Solution for 3rd cell:

Step I: $Z = -\infty$

Iteration 1 of two-stage heuristic:

Step II:

The list of neighbouring operation types for all the operation types for the 3rd cell as obtained from Tables 18,19 and 20 is shown in Table:21

Table 21: Neighbouring operation types

Operation Type (q)	Set of Neigbouring operation types (j_q)	Set of machines (m_q)
1	2,3,4,5,6,7,9,10	1,3
2	1,6,7,10	1
3	1,5,10	Φ
4	1,5	1,3
5	1,3,4,6,9,10,11	3
6	1,2,5,10	1
7	1,2,8,11	3
8	7,11	3
9	1,5	3
10	1,2,3,5,6	1
11	5,7,8	3

I Objective of the model (ANOP) is

<u>LINDO PACKAGE:</u>

<u>INPUT:</u>

```
Max =  u11+u13+u21+0u32+u41+0u42+0u43+u53+u61+u73
       +u83+u93+u101+u11+0w311+0w12+0w13+0w14+0w15
       +0w16+0w17+0w18+0w19+0w110+0w111+0w21+0w22
       +0w23+0w24+0w25+0w26+0w27+0w28+0w29+0w210
       +0w211+0w31+0w32+0w33+ 0w34+0w35+0w36+0w37+0w38
       +0w39+0w310+0w311
      subject to

2w11+4w12+3w13+4w14+4w15+2w16+2w17+2w18+2w19+3w110
+2w111<=64
2w21+4w22+3w23+4w24+4w25+2w26+2w27+2w28+2w29+3w210
+2w211<=2
2w31+4w32+3w33+4w34+4w35+2w36+2w37+2w38+2w39+3w310
+2w311<=12
      w11+w21+w31<=2
      w12+w22+w32<=2
      w13+w23+w33<=1
      w14+w24+w34<=3
      w15+w25+w35<=1
      w16+w26+w36<=2
      w17+w27+w37<=1
      w18+w28+w38<=1
      w19+w29+w39<=1
      w110+w210+w310<=2
      w111+w211+w311<=1
      u11-w11<=0
      u13-w31<=0
```

u21-w12<=0
u32-w23<=0
u41-w14<=0
u42-w24<=0
u43-w34<=0
u53-w35-w311<=0
u61-w16<=0
u73-w37<=0
u83-w38<=0
u93-w39<=0
u101-w110<=0
u113-w311<=0
u11+u13>=1
u21>=1
u32>=1
u41+u42+u43>=1
u53>=1
u61>=1
u73>=1
u83>=1
u93>=1
u101>=1
u113>=1
u11<=1
u13<=1
u21<=1
u32<=1
u41<=1
u42<=1
u43<=1
u53<=1
u61<=1
u73<=1
u83<=1
u93<=1
u101<=1
u113<=1
w11>=0
w31>=0
w12>=0
w23>=0

```
w14>=0
w24>=0
w34>=0
w35>=0
w16>=0
w37>=0
w38>=0
w39>=0
w110>=0
w311>=0
w11<=1
w31<=1
w12<=1
w23<=1
w14<=1
w24<=1
w34<=1
w35<=1
w16<=1
w37<=1
w38<=1
w39<=1
w110<=1
w311<=1
u11>=0
u13>=0
u21>=0
u32>=0
u41>=0
u43>=0
u42>=0
u53>=0
u61>=0
u73>=0
u83>=0
u93>=0
u101>=0
u113>=0
END
gin u11
gin u13
```

gin u21
gin u32
gin u41
gin u42
gin u43
gin u53
gin u61
gin u73
gin u83
gin u93
gin u101
gin u113
gin w11
gin w12
gin w13
gin w14
gin w15
gin w16
gin w17
gin w18
gin w19
gin w110
gin w111
gin w21
gin w22
gin w23
gin w24
gin w25
gin w26
gin w27
gin w28
gin w29
gin w210
gin w211
gin w31
gin w32
gin w33
gin w34
gin w35
gin w36
gin w37

gin w38
gin w39
gin w310
gin w311

OUTPUT:

VARIABLE	VALUE
U11	1.000000
U13	1.000000
U21	1.000000
U32	1.000000
U41	1.000000
U42	1.000000
U43	.000000
U53	1.000000
U61	1.000000
U73	1.000000
U83	1.000000
U93	1.000000
U101	1.000000
U113	1.000000
W11	1.000000
W12	1.000000
W13	.000000
W14	1.000000
W15	.000000
W16	1.000000
W17	.000000
W18	.000000
W19	.000000
W110	1.000000
W111	.000000
W21	.000000
W22	.000000
W23	1.000000
W24	1.000000
W25	.000000
W26	.000000

W27	.000000
W28	.000000
W29	.000000
W210	.000000
W211	.000000
W31	1.000000
W32	.000000
W33	.000000
W34	.000000
W35	.000000
W36	.000000
W37	1.000000
W38	1.000000
W39	1.000000
W310	.000000
W311	1.000000

The machine – tool type and machine – operation type assignments are shown in Table:22 as obtained through LINDO

Table 22: Solution for model ANOP

Operation Type (q)	Machines $m^{\varphi(i,s,j)}$		
1	1,3		
2	1		
3	2		
4	1,2		
5	3		
6	1		
7	3		
8	3		
9	3		
10	1		
11	3		
Machine	1	2	3
Tool Types	1,2,4,6,10	3,4	1,7,8,9,10

Step III:

The solution for $(PMM)_i$ is presented below using the suggested procedure

Step 0: Set $Z_{11} = Z_{131} = Z_{261} = 1$,

$Z_{12} = Z_{132} = Z_{262} = 0$

Iteration 1 for $(PMM)_1$, $(PMM)_{13}$, $(PMM)_{26}$:-

Step 1: Process plan (1) = (3-6-1-10-2-3)

Each pair of Successive operation	Set of common m/c's
3-6	φ
6-1	1
1-10	1
10-2	1
2-3	Φ

Step 2: Frequency of m/c '1', f1 = 3

Step 3: Fmax = fs = f_1 = 3

Step 4: Set $Z_{12} = Z_{132} = Z_{262} = 1$,

$Z_{11} = Z_{131} = Z_{261} = 0$ and go to Step:1

Iteration 2 for $(PMM)_{11}$ $(PMM)_{13}$, $(PMM)_{26}$:-

Step 1: Process plan (2) = 3-1-6-2

Each pair of Successive operation	Set of common m/c's
3-1	φ
1-6	1
6-2	1

Step 2: Frequency of m/c '1', f_1 = 1

Step 3: Fmax = fs = f_1 =2

Step 4: Since the list of process plan is empty, we proceed to next step.

Step 5: Objective valve for process plan (1) = (6-1-3=2)

Process plan (2) = (4-1-2-1)

We select the process plan(2) which has got the minimum objective value

- (PMM)1 = (PMM)13 = (PMM)26 = 1

Step 6: Operations (1,2,6) can assigned to m/c '1'.

Operation (3) can not assigned to m/c '1'.

Step 7: Hence the next highes frequency is = 0

- Ie. Of m/c '2' where operation (3) can be allocated.
- Same procedure for the other parts
- Therefore the objective value for
- $(PMM)_2 = 1$
- $(PMM)_3 = (PMM)_{16} = (PMM)_{27} = 1$
- $(PMM)_4 = (PMM)_{17} = (PMM)_{30} = 2$

- $(PMM)_5 = (PMM)_{18} = 2$
- $(PMM)6 = (PMM)7 = (PMM)_{19} = (PMM)_{20} = (PMM)_{31} = 2$
- $(PMM)_8 = (PMM)_9 = (PMM)_{21} = (PMM)_{22} = 2$
- $(PMM)_{10} = (PMM)_{11} = (PMM)_{23} = (PMM)_{24} = (PMM)_{32} = 3$
- $(PMM)_{12} = (PMM)_{25} = 2$
- $(PMM)_{14} = 2$
- $(PMM)_{15} = 2$
- $(PMM)_{28} = 2$
- $(PMM)_{29} = 1$
- $(PMM)_{33} = 3$

Table 23: Solution for all $(PMM)_i$

Part type(i)	Process plan selected	Operation (j) – machine(m) Assignment (j/m)
1	2	3/2-1/1-6/1-2/1
2	1	3/2-1/3
3	1	3/2-1/1-6/1-10/1-2/1
4	2	4/1-1/1-5/3-11/3-8/3-7/3-1/1-2/1-10/1
5	1	4/1-1/1-5/3-11/3-7/3-1/1-2/1-10/1
6	2	3/2-1/1-2/1-7/3
7	2	3/2-1/1-2/1-7/3
8	1	4/2-5/3-6/1-1/1
9	1	4/2-5/3-6/1-1/1
10	2	4/2-5/3-9/3-1/3-6/1-10/1
11	2	4/2-5/3-9/3-1/3-6/1-10/1

12	1	4/2-5/3-1/3-6/1-2/1
13	2	3/2-1/1-6/1-2/1
14	1	3/1-5/3-1/1-10/1
15	1	5/3-3/2-10/1-1/1
16	1	3/2-1/1-6/1-10/1-2/1
17	2	4/1-1/1-5/3-11/3-8/3-7/3-1/1-2/1-10/1
18	1	4/1-1/1-5/3-11/3-7/3-1/1-2/1-10/1
19	2	3/2-1/1-2/1-7/3
20	2	3/2-1/1-2/1-7/3
21	1	4/2-5/3-6/1-1/1
22	1	4/2-5/3-6/1-1/1
23	2	4/2-5/3-9/3-1/3-6/1-10/1
24	2	4/2-5-3-9/3-1/3-6/1-10/1
25	1	4/2-5/3-1/3-6/1-2/1
26	2	3/2-1/1-6/1-2/1
27	1	3/2-1/1-6/1-10/1-2/1
28	1	4/2-5/3-10/1-2/1
29	1	3/2-10/1-1/1-2/1
30	2	4/1-1/1-5/3-11/3-8/3-7/3-1/1-2/1-10/1
31	2	3/2-1/1-2/1-7/3
32	2	4/2-5/3-9/3-1/3-6/1-10/1
33	1	4/2-5/3-9/3-1/3-6/1-2/1

Therefore

Z_1= [-1-1-1-2-2-2-2-2-2-3-3-2-1-2-2-1-2-2-2-2-2-2-3-3-2-1-1-2-1-2-2-3-3]

= - 64

-Since $Z_1 > Z$ we save the current solution update $Z=Z_1= - 64$, Z_1 # 0

Step IV:

- Operation type (3,5) each causes two movement

  and operation types (1,4,6,7,10) each causes one movement.

- Operation type (3,5 and 1) can not be selected because it is already assigned to m/c '1' m/c '3' and no alternate machine is left.

- Select operation type '4' and set **U42 = 0** Go to step II

Iteration 2 of two – stage heuristic:

Step II: The model (ANOP) remains same as in the previous iteration but with the additional constraint **U42 = 0**

II Objective of the model (ANOP) is

LINDO PACKAGE:

INPUT:

Max = u11+u13+u21+0u32+u41+0u42+u43+u53+u61+u73+u83+u93
+u101+u113+0w11+0w12+0w13+0w14+0w15+0w16+0w17+0w18
+0w19+0w110+0w111+0w21+0w22+ w23+0w24+0w25+0w26
+0w27+0w28+0w29+0w210+0w211+0w31+0w32+0w33+ 0w34
+0w35+0w36+0w37+0w38+0w39+0w310+0w311

subject to

2w11+4w12+3w13+4w14+4w15+2w16+2w17+2w18+2w19+3w110
+2w111<=64
2w21+4w22+3w23+4w24+4w25+2w26+2w27+2w28+2w29+3w210
+2w211<=2
2w31+4w32+3w33+4w34+4w35+2w36+2w37+2w38+2w39+3w310
+2w311<=12
w11+w21+w31<=2
w12+w22+w32<=2
w13+w23+w33<=1
w14+w24+w34<=3
w15+w25+w35<=1
w16+w26+w36<=2
w17+w27+w37<=1
w18+w28+w38<=1

w19+w29+w39<=1
w110+w210+w310<=2
w111+w211+w311<=1
u11-w11<=0
u13-w31<=0
u21-w12<=0
u32-w23<=0
u41-w14<=0
u42-w24<=0
u43-w34<=0
u53-w35-w311<=0
u61-w16<=0
u73-w37<=0
u83-w38<=0
u93-w39<=0
u101-w110<=0
u113-w311<=0
u11+u13>=1
u21>=1
u32>=1
u41+u42+u43>=1
u53>=1
u61>=1
u73>=1
u83>=1
u93>=1
u101>=1
u113>=1
u11<=1
u13<=1
u21<=1
u32<=1
u41<=1
u42<=1
u43<=1
u53<=1
u61<=1
u73<=1
u83<=1
u93<=1
u101<=1

u113<=1
w11>=0
w31>=0
w12>=0
w23>=0
w14>=0
w24>=0
w34>=0
w35>=0
w16>=0
w37>=0
w38>=0
w39>=0
w110>=0
w311>=0
w11<=1
w31<=1
w12<=1
w23<=1
w14<=1
w24<=1
w34<=1
w35<=1
w16<=1
w37<=1
w38<=1
w39<=1
w110<=1
w311<=1
u11>=0
u13>=0
u21>=0
u32>=0
u41>=0
u43>=0
u42>=0
u53>=0
u61>=0
u73>=0
u83>=0
u93>=0

```
u101>=0
u113>=0
u42=0
END
gin u11
gin u13
gin u21
gin u32
gin u41
gin u42
gin u43
gin u53
gin u61
gin u73
gin u83
gin u93
gin u101
gin u113
gin w11
gin w12
gin w13
gin w14
gin w15
gin w16
gin w17
gin w18
gin w19
gin w110
gin w111
gin w21
gin w22
gin w23
gin w24
gin w25
gin w26
gin w27
gin w28
gin w29
gin w210
gin w211
```

```
gin w31
gin w32
gin w33
gin w34
gin w35
gin w36
gin w37
gin w38
gin w39
gin w310
gin w311
```

OUTPUT:

VARIABLE	VALUE
U11	1.000000
U13	1.000000
U21	1.000000
U32	1.000000
U41	1.000000
U42	.000000
U43	1.000000
U53	1.000000
U61	1.000000
U73	1.000000
U83	1.000000
U93	1.000000
U101	1.000000
U113	1.000000
W11	1.000000
W12	1.000000
W13	.000000
W14	1.000000
W15	.000000
W16	1.000000
W17	.000000
W18	.000000
W19	.000000

W110	1.000000
W111	.000000
W21	.000000
W22	.000000
W23	1.000000
W24	.000000
W25	.000000
W26	.000000
W27	.000000
W28	.000000
W29	.000000
W210	.000000
W211	.000000
W31	1.000000
W32	.000000
W33	.000000
W34	1.000000
W35	.000000
W36	.000000
W37	1.000000
W38	1.000000
W39	1.000000
W310	.000000
W311	1.000000

The machine – tool type and machine – operation type assignments are shown in Table:24 as obtained through LINDO

Table 24: Solution for model ANOP

Operation Type (q)		Machines $m^{\varphi(i,s,j)}$	
1		1,3	
2		1	
3		2	
4		1,3	
5		3	
6		1	
7		3	
8		3	
9		3	
10		1	
11		3	
Machine	1	2	3
Tool Types	1,2,4,6,10	3	1,4,7,8,9,11

Step III: The solution for $(PMM)_i$ is presented below using the suggested procedure.

- Objective value for all parts type

- $(PMM)_1 = (PMM)_{13} = (PMM)_{26} = 1$
- $(PMM)_2 = 1$
- $(PMM)_3 = (PMM)_{16} = (PMM)_{27} = 1$
- $(PMM)_4 = (PMM)_{17} = (PMM)_{30} = 1$
- $(PMM)_5 = (PMM)_{18} = 1$
- $(PMM)_6 = (PMM)_7 = (PMM)_{19} = (PMM)_{20} = (PMM)_{31} = 2$
- $(PMM)_8 = (PMM)_9 = (PMM)_{21} = (PMM)_{22} = 1$
- $(PMM)_{10} = (PMM)_{11} = (PMM)_{23} = (PMM)_{24} = (PMM)_{32} = 2$
- $(PMM)_{12} = (PMM)_{25} = 1$
- $(PMM)_{14} = 2$
- $(PMM)_{15} = 2$
- $(PMM)_{28} = 1$
- $(PMM)_{29} = 2$
- $(PMM)_{33} = 2$

Table 25: Solute for all $(PMM)_I$

Part type(i)	Process plan selected	Operation (j) – machine(m) Assignment (j/m)
1	2	3/2-1/1-6/2-2/1
2	1	3/2-1/3
3	1	3/2-1/1-6/1-10/1-2/1
4	2	4/3-1/3-5/3-11/3-8/3-7/3-1/1-2/1-10/1
5	1	4/3-1/3-5/3-11/3-7/3-1/1-2/1-10/1
6	2	3/2-1/1-2/1-7/3
7	2	3/2-1/1-2/1-7/3
8	1	4/3-5/3-6/1-1/1
9	1	4/3-5/3-6/1-1/1
10	2	4/3-5/3-9/3-1/3-6/1-10/1
11	2	4/3-5/3-9/3-1/3-6/1-10/1
12	1	4/3-5/3-1/3-6/1-2/1
13	2	3/2-1/1-6/1-2/1
14	1	3/2-5/3-1/1-10/1
15	1	5/3-3/2-10/1-1/1
16	1	3/2-1/1-6/1-10/1-2/1
17	2	4/3-1/3-5/3-11/3-8/3-7/3-1/1-2/1-10/1
18	1	4/3-1/3-5/3-11/3-7/3-1/1-2/1-10/1
19	2	3/2-1/1-2/1-7/3
20	2	3/2-1/1-2/1-7/3
21	1	4/3-5/3-6/1-1/1
22	1	4/3-5/3-6/1-1/1
23	2	4/3-5/3-9/3-1/3-6/1-10/1
24	2	4/3-5/3-9/3-1/3-6/1-10/1
25	1	4/3-5/3-1/3-6/1-2/1
26	2	3/2-1/1-6/1-2/1
27	1	3/2-1/1-6/1-10/1
28	1	4/3-5/3-10/1-2/1
29	1	3/2-10/1-1/1-2/1
30	2	4/3-1/3-5/3-11/3-8/3-7/3-1/1-2/1-10/1
31	2	3/2-1/1-2/1-7/3
32	2	4/3-5/3-9/3-1/3-6/1-10/1
33	1	4/2-5/3-9/3-1/3-6/1-2/1

Therefore

$$Z_2 = [-1-1-1-1-1-2-2-1-1-2-2-1-1-2-2-1-1-1-2-2-1-1-2-2-1-1-1-1-2-1$$
$$-2-2-2]$$

$$Z_2 = -47$$

- Since $Z_2 > Z_1$ we save the current solution update $Z = Z_2 = -47$,
- $Z_2 \# 0$

Step IV:

- Operation types (3,5) each causes two movement

  and operation types (6,7,10) each causes one movement.

- All the operation can not be selected because no alternate machine is left.

- This gives the final solution.

CHAPTER - 5

Results

The following results have been obtained after using the algorithm for the loading problem for FMS on the data obtained from the company. The same objective value and assignments were obtained by LINDO computer package.

5.1. Solution for first cell

Table 26: Optimal part type – process plan – operation – Tool type – machine – Assignment

Part type (i)	Process plan selected	Operation (j) – machine (m)-Tool type(t) Assignment (j,m,t)
1	1	(1,3,5), (2,3,1), (3,2,6)
2	1	(1,3,4) (2,3,5), (3,3,1), (4,1,7),(5,1,2), (6,1,6)
3	1	(1,3,4), (2,3,5), (3,3,1), (4,1,7), (5,1,2), (6,1,6)
4	1	(1,3,4), (2,3,5), (3,3,1), (4,1,7), (5,1,2), (6,1,6)
5	1	(1,3,5), (2,3,1), (3,2,6)
6	1	(1,3,5), (2,3,1), (3,2,6)
7	1	(1,3,5), (2,3,1), (3,2,6)
8	1	(1,3,4), (2,3,5), (3,3,1), (4,1,7), (5,1,2), (6,1,6)
9	1	(1,3,4), (2,3,5), (3,3,1), (4,1,7), (5,1,2), (6,1,6)
10	1	(1,3,4), (2,3,5), (3,3,1), (4,1,7), (5,1,2), (6,1,6)
11	1	(1,3,5), (2,3,1), (3,2,6)
12	1	(1,3,5), (2,3,1), (3,2,6)
13	2	(1,3,4), (2,3,5), (3,3,1), (4,2,6), (5,2,6)
14	1	(1,3,4), (2,3,5), (3,3,1)
15	1	(1,3,5), (2,3,1), (3,2,6)
16	1	(1,3,4), (2,3,5), (3,1,7),(4,3,1)
17	1	(1,3,4), (2,3,5), (3,3,1),(4,1,7),(5,1,2),(6,1,6)
18	1	(1,3,4), (2,3,5), (3,3,1),(4,1,7),(5,1,2),(6,1,6)

The optimal objective function value for the first cell is = -22

i.e., 22 pair of successive operation is not assigned together.

5.2. Solution for second cell

Table 27: Optimal part type – process plan – operation – Tool type – machine –Assignment for second cell:-

Part type (i)	Process plan selected	Operation (j) – machine (m)-Tool type(t) Assignment (j,m,t)
1	2	(1,2,6), (2,2,1), (3,2,6)
2	2	(1,2,4) (2,2,6), (3,2,1), (4,2,6)
3	1	(1,3,4), (2,3,5)
4	1	(1,3,4), (2,3,5)
5	2	(1,2,6), (2,2,1), (3,2,6)
6	2	(1,2,4), (2,2,6), (3,2,1), (4,2,6)
7	1	(1,3,4), (2,3,5)
8	1	(1,3,4), (2,3,5)
9	1	(1,3,4), (2,3,5)
10	1	(1,1,3), (2,1,4), (3,1,6)
11	1	(1,3,4), (2,3,1), (3,3,5)
12	2	(1,2,6), (2,2,1), (3,2,6)
13	2	(1,2,4), (2,2,6), (3,2,1), (4,2,6)
14	1	(1,3,4), (2,3,5)

- The optimal objective function value is = 0
  - i.e., **All pair of successive operation is assigned together**.

5.3. Solution for thread cell

Table 28: Optimal part type – process plan – operation – Tool type – machine – assignment for 3rd cell

Part type (i)	Process plan selected	Operation (j) – machine (m)-Tool type(t) Assignment (j,m,t)
1	2	(1,2,3), (2,1,1), (3,1,6),(4,1,2)
2	1	(1,2,3) (2,3,1)
3	1	(1,2,3), (2,1,1), (3,1,6), (4,1,10), (5,1,2)
4	2	(1,3,4),(2,3,1),(3,3,11),(4,3,11),(5,3,8),(6,3,7),(7,1,1),(8,1,2),(9,1,10)
5	1	(1,3,4), (2,3,1), (3,3,11),(4,3,11),(5,3,7),(6,1,1),(7,1,2),(8,1,10)
6	2	(1,2,3), (2,1,1), (3,1,2), (4,3,7)
7	2	(1,2,3), (2,1,1),(3,1,2),(4,3,7)
8	1	(1,3,4), (2,3,11),(3,1,6),(4,1,1)
9	1	(1,3,4), (2,3,11),(3,1,6),(4,1,1)
10	2	(1,3,4), (2,3,11), (3,3,9),(4,3,1),(5,1,6),(6,1,10)
11	2	(1,3,4), (2,3,11), (3,3,9),(4,3,1),(5,1,6),(6,1,10)
12	1	(1,3,4), (2,3,11), (3,3,1),(4,1,6),(5,1,2)
13	2	(1,2,3), (2,1,1), (3,1,6), (4,1,2)
14	1	(1,2,3), (2,3,11),(3,1,1),(4,1,10)
15	1	(1,3,11),(2,2,3),(3,1,10),(4,1,1)
16	1	(1,2,3),(2,1,1),(3,1,6),(4,1,10),(5,1,2)
17	2	(1,3,4),(2,3,1),(3,3,11),(4,3,11),(5,3,8),(6,3,7),(7,1,1)(8,1,2)(9,1,10)
18	1	(1,3,4),(2,3,1),(3,3,11),(4,3,11),(5,3,7),(6,1,1),(7,1,2),(8,1,10)
19	2	(1,2,3),(2,1,1),(3,1,2),(4,3,7)
20	2	(1,23),(2,1,1),(3,1,2),(4,3,7)
21	1	(1,3,4),(2,3,11),(3,1,6),(4,1,1)
22	1	(1,3,4),(2,3,11),(3,1,6),(4,1,1)
23	2	(1,3,4),(2,3,11),(3,3,9),(4,3,1),(5,1,6),(6,1,10)
24	2	(1,3,4),(2,3,11),(3,3,9),(4,3,1),(5,1,6),(6,1,10)
25	1	(1,3,4),(2,3,11),(3,3,1),(4,1,6),(5,1,2)
26	2	(1,2,3),(2,1,1),(3,1,6),(4,1,2)
27	1	(1,2,3),(2,1,1),(3,1,6),(4,1,10)

28	1	(1,3,4),(2,3,11),(3,1,10),(4,1,2)
29	1	(1,2,3),(2,1,10),(3,1,1),(4,1,2)
30	2	(1,3,4),(2,1,1),(3,3,11),(4,3,11),(5,3,8),(6,3,7),(8,1,2),(9,1,10)
31	2	(1,2,3),(2,1,1),(3,1,2),(4,3,70
32	2	(1,3,4),(2,3,11),(3,3,9),(4,3,1),(5,1,6),(6,1,10)
33	1	(1,3,4),(2,3,11),(3,3,9),(4,3,1),(5,1,6),(6,1,2)

- The optimal objective function value for the 3rd cell is = - 47

- i.e., **47 pair of successive operation is not assigned together.**

CHAPTER - 6

Conclusion and Scope

6.1 Conclusion

The number of Flexible manufacturing systems in the manufacturing world is increasing in order. The varieties of Problems are solved in the design and use of such FMSs. An attempt has been made in this thesis to study a specific loading and part movement minimisation of an FMS [17].

The objective function for loading and part movement minimisation problem for the FMS has been identified and formulated. The constraints have been made after thoroughly analysing the problem environment. The assumptions on which the formulations made, are clearly indicated. This problem has been made as a case study problem for a company manufacturing milling attachments to drilling machines.

A two stage heuristic procedure is adopted to solve the problem. The ANOP and PMM are used. The machines and machine tool types are assigned against the operation type using ANOP model. The problem is solved with help of LINDO computer package. The optimal process plan is selected with reference to the solution obtained from ANOP. Using PMM the results are tabulated in the Tables 26,27,28 for the three different cells.

Thus, the solutions would certainly minimize the resources utilized for manufacturing the milling attachments as the parts movement is minimized.

6.2 Future scope :

The results embodied in thesis is not the unique solution. And, the sequencing problems could be combined with the loading in future in order to avoid the complexities in sequencing.

Further, quest and promodel like software's could be used to study the performance of the FMSs with the results obtained.

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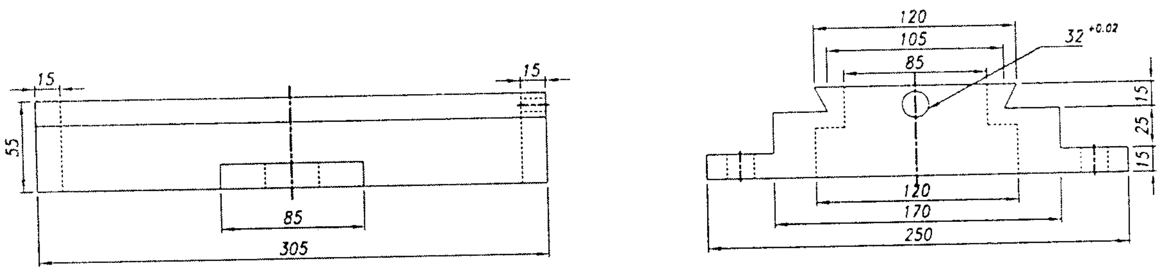
APPENDIX

Appendix: (A)

Components for milling attachment (Type 1) of the drilling machine

PART-I



SCALE 1:2.5
All dimension are in mm.

FIG 4.1.1: CROSS FEED BED

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Shaping	1.	Shaping
2.	Boring	2.	Drilling
3.	Drilling	3.	Boring
4.	Milling	4.	Tapping
5.	Tapping		
6.	Shaping		

PART: 2

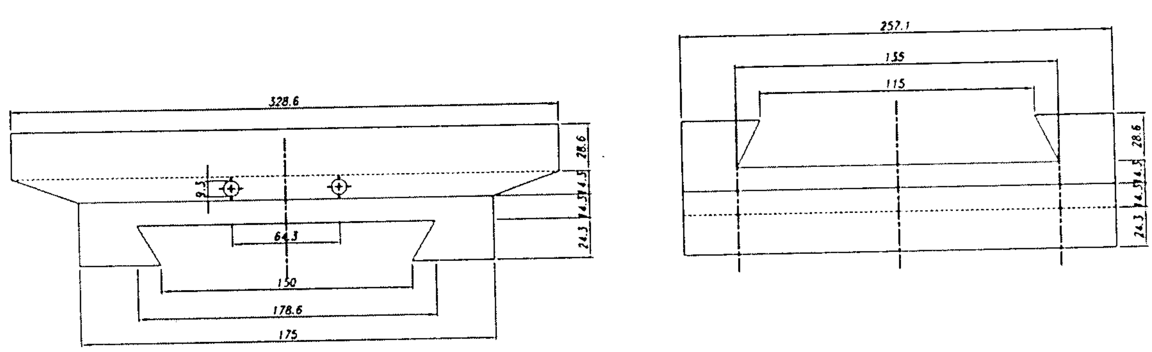
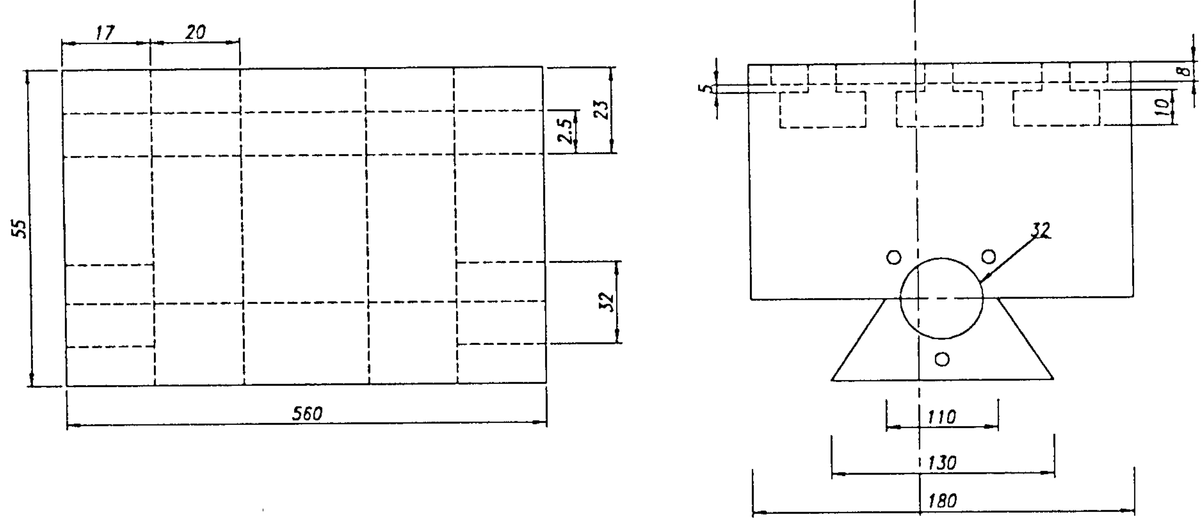


FIG 4.1.2 FIXING BRACKET

SCALE 1:2.5
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	
1.	Shaping
2.	Drilling

PART:3



SCALE : N.T.S
All dimension are in mm.

FIG 4.1.3.TABLE

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Shaping	1.	Shaping
2.	Drilling	2.	Drilling
3.	Boring	3.	Boring
4.	Milling	4.	Milling
5.	Tapping	5.	Shaping
		6.	Tapping

PART:4,21,22

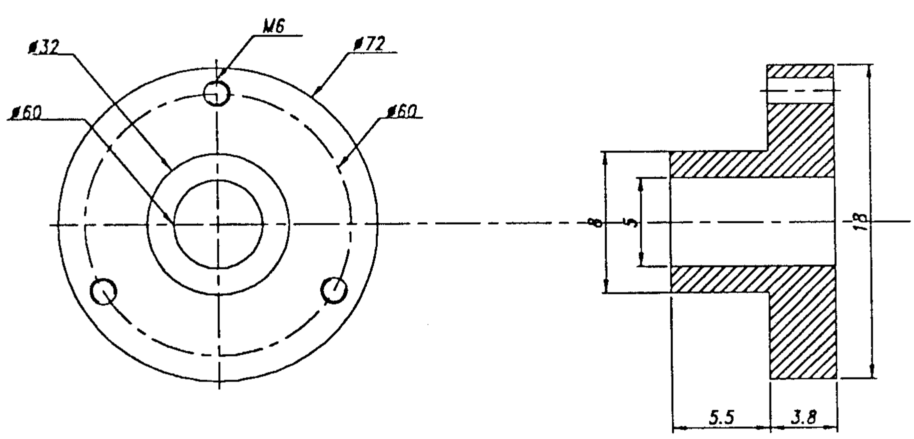
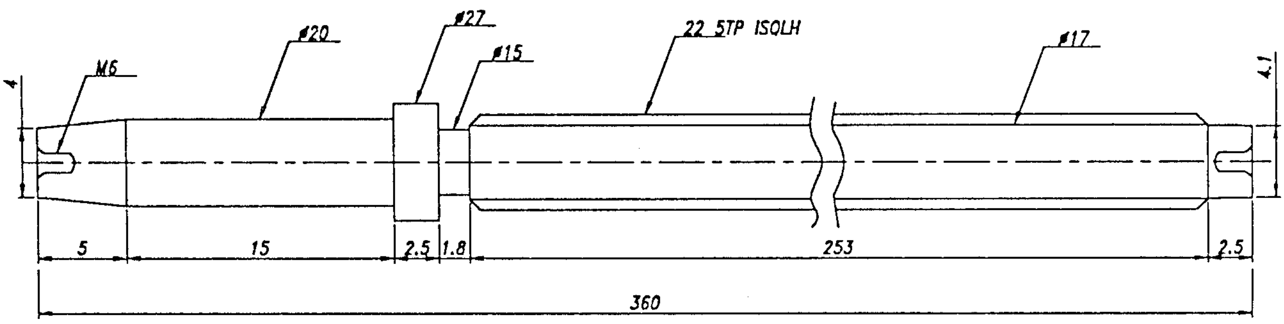


FIG 4.1.4 SCREW ROD COLLAR

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Turning 2. Drilling 3. Tapping

PART:5

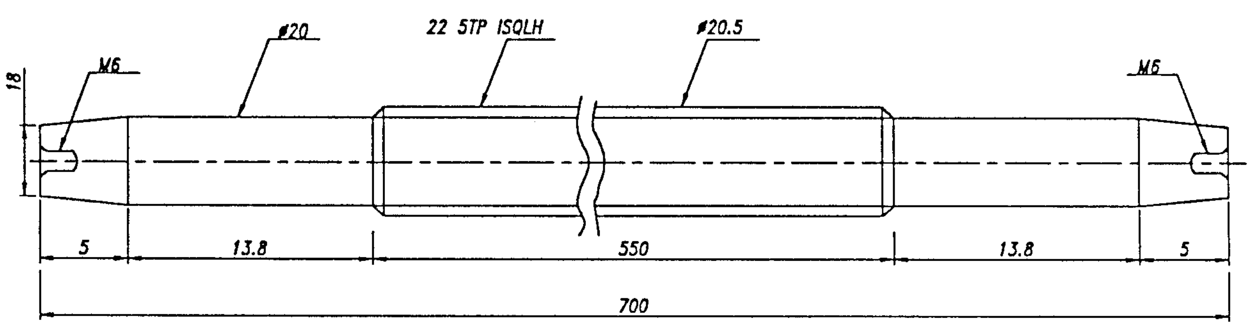


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Turning	2.	Drilling
3.	Drilling	3.	Turning
4.	Grooving	4.	Taper turning
5.	Threading	5.	Grooving
6.	Milling	6.	Threading
7.	Drilling	7.	Drilling
8.	Tapping	8.	Tapping
9.	Shaping	9.	Milling

FIG 4.1.5 CROSS FEED SCREW ROD

PART:6

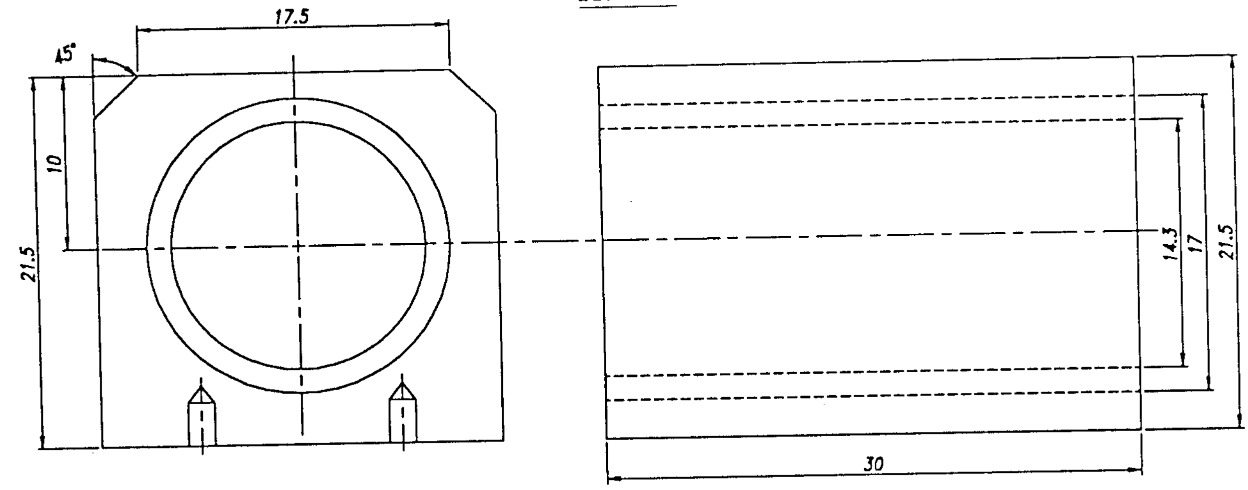


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Drilling	2.	Drilling
3.	Turning	3.	Turning
4.	Taper turning	4.	Taper turning
5.	Threading	5.	Drilling
6.	Drilling	6.	Tapping
7.	Tapping	7.	Threading
8.	Milling	8.	Tapping

FIG 4.1.6 TABLE MOVEMENT SCREW ROD

PART:7

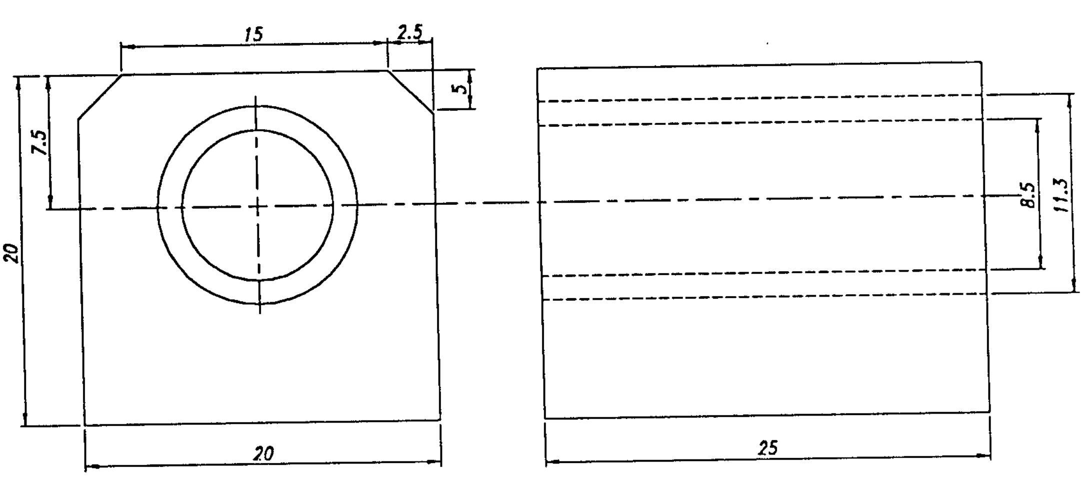


SCALE 1:2
All dimension are in mm.

FIG 4.1.7 CROSS FEED SCREW ROD NUT

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Shaping 2. Drilling 3. Threading 4. Shaping 5. Tapping	1. Shaping 2. Drilling 3. Tapping 4. Threading

PART:8

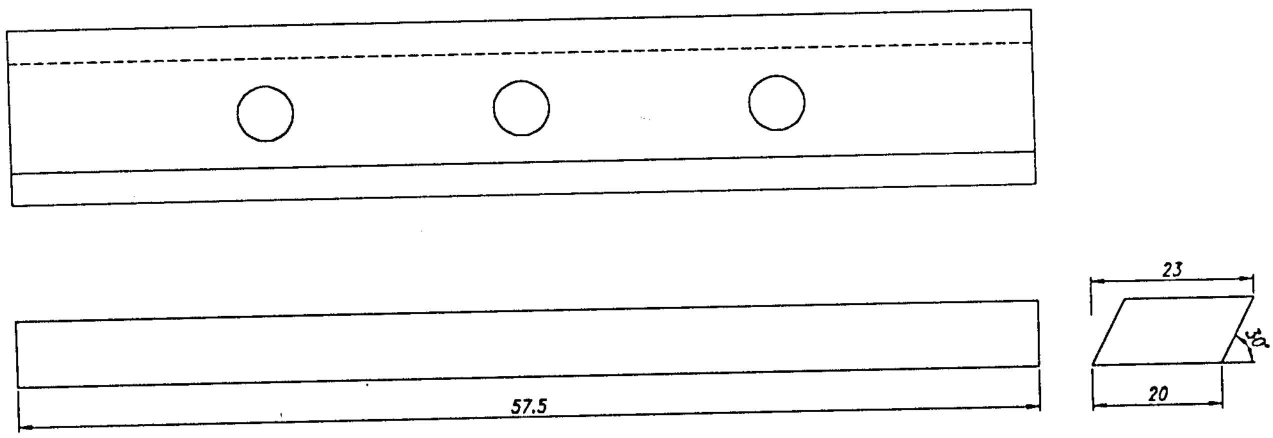


SCALE 1:2
All dimension are in mm.

FIG 4.1.8 TABLE MOVEMENT SCREW ROD NUT

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Shaping 2. Drilling 3. Threading 4. Shaping 5. Tapping	1. Shaping 2. Drilling 3. Tapping 4. Threading

PART:9

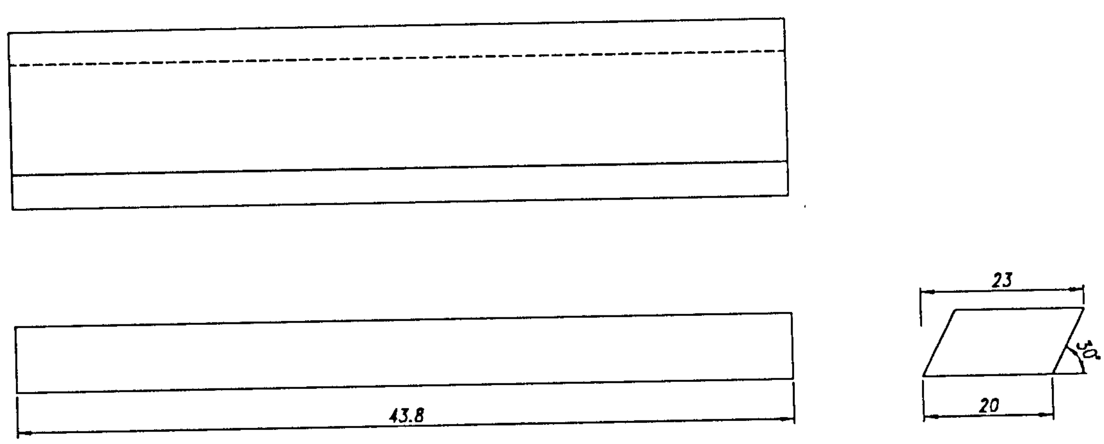


SCALE 1:1
All dimension are in mm.

FIG 4.1.9 TABLE MOVEMENT ZIP

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Milling
2.	Milling	2.	Drilling
3.	Slotting	3.	Slotting
4.	Drilling		

PART:10



SCALE 1:1
All dimension are in mm.

FIG 4.1.10 CROSS FEED MOVEMENT ZIP

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Facing
2.	Milling	2.	Milling
3.	Slotting	3.	Drilling
4.	Drilling	4.	Slotting

PART:11

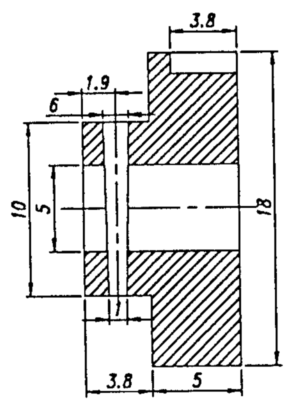


FIG 4.1.11 CROSS FEED MOVEMENT DIAL READING COLLAR

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Facing 2. Turning 3. Boring 4. Drilling	1. Facing 2. Boring 3. Turning 4. Drilling 5. Turning

PART:12 & 14

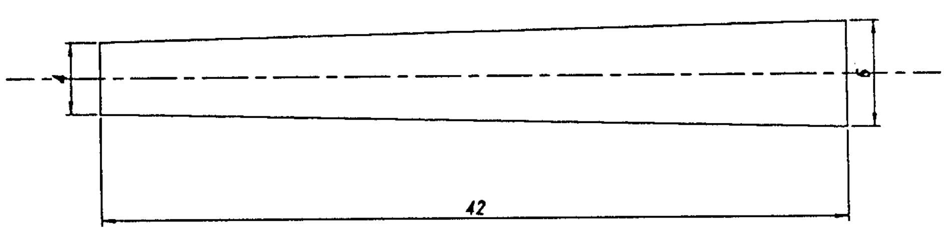
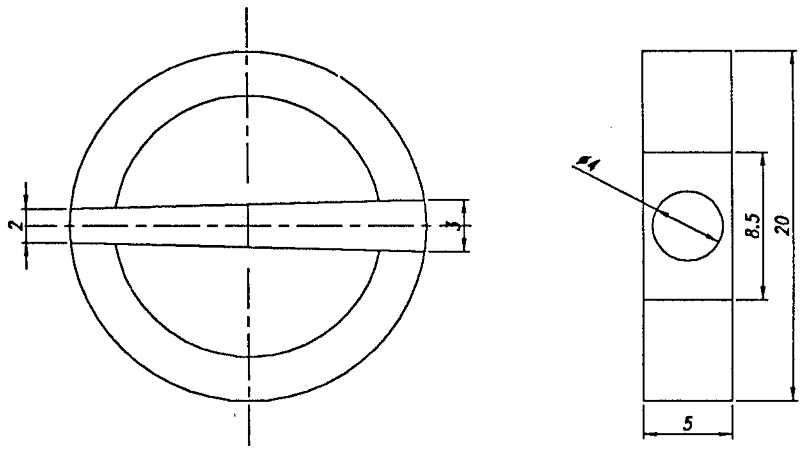


FIG 4.1.12 STEADY PIN

SCALE 1:4
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	
1.	Facing
2.	Turning

PART-13

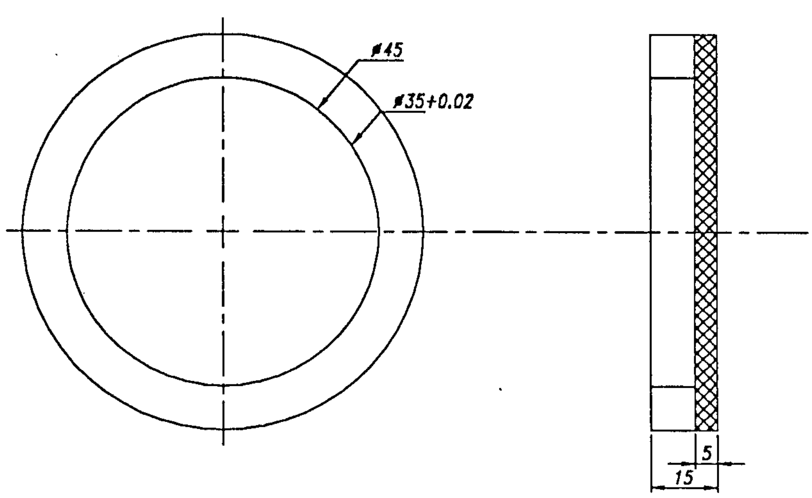


SCALE 1:2
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Turning	2.	Boring
3.	Boring	3.	Turning
4.	Drilling	4.	Drilling
		5.	Turning

FIG 4.1.13TABLE SCREW ROD LOCKING COLLAR

PART:15

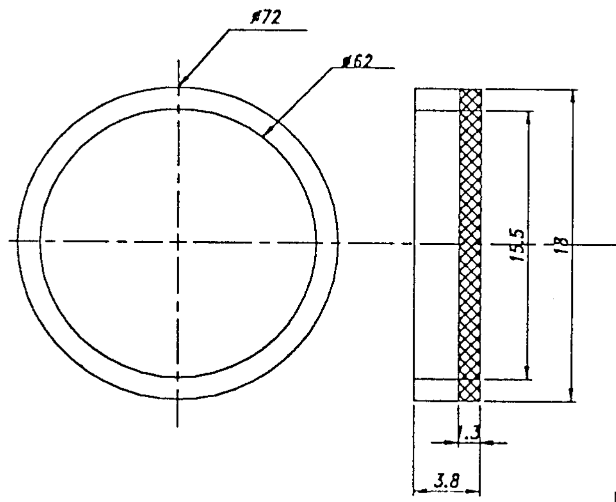


SCALE 2:1
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Turning	1. Facing
2. Knurling	2. Turning
3. Facing	3. Knurling
4. Drilling	4. Drilling
5. Boring	4. Boring
6. Milling	6. Milling

FIG 4.1.14 TABLE MOVEMENT READING DIAL

PART:16

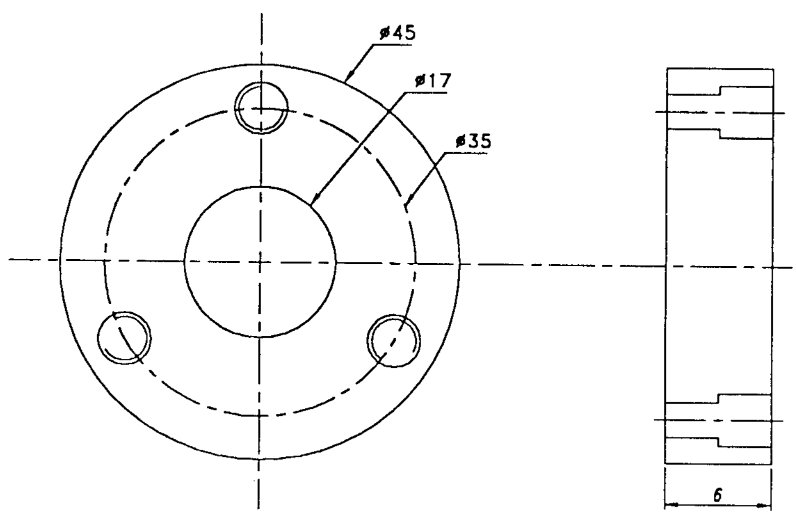


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Turning 2. Knurling 3. Facing 4. Drilling 5. Boring 6. Milling	1. Facing 2. Turning 3. Knurling 4. Drilling 5. Boring 6. Milling

FIG 4.1.15 CROSS FEED MOVEMENT READING DIAL

PART:17

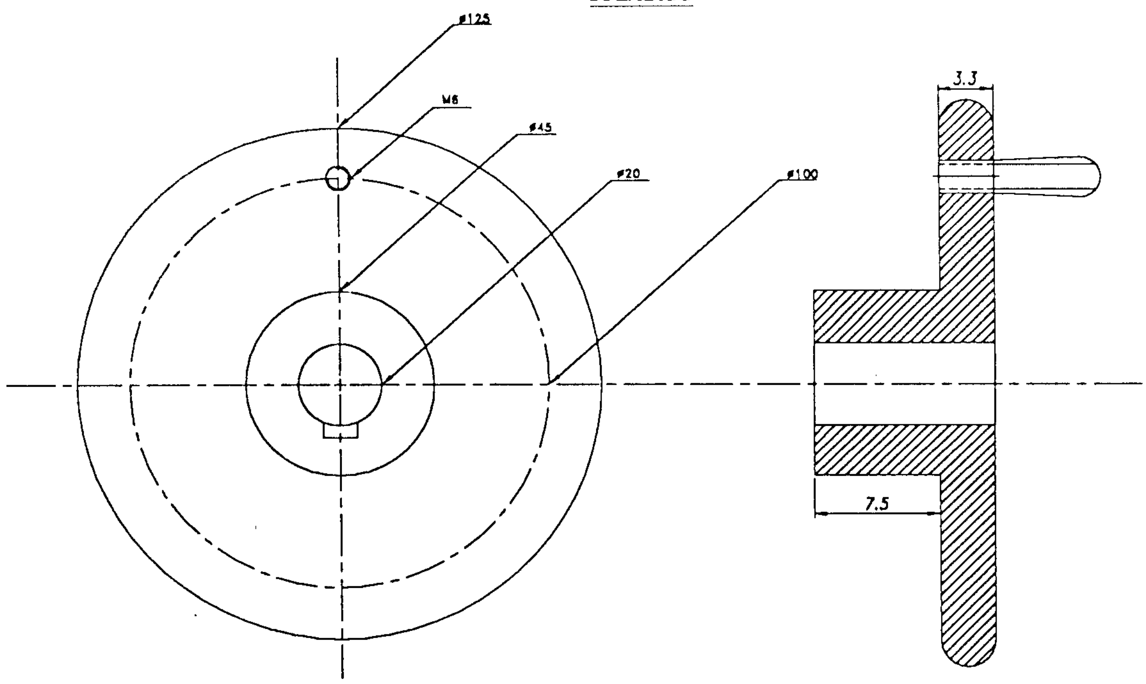


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Facing 2. Turning 3. Drilling 4. Boring 5. Tapping

FIG 4.1.16 DIAL GUAGE SPACER

PART:18

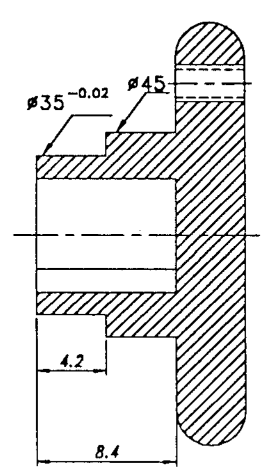


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Facing	1.	Facing
2.	Turning	2.	Drilling
3.	Drilling	3.	Boring
4.	Boring	4.	Tapping
5.	Tapping	5.	Turning
6.	Slotting	6.	Slotting

FIG 4.1.17 FEEDING HANDLE FOR TABLE AND CROSS FEED

PART:19 & 20



SCALE 1:1
All dimension are in mm.

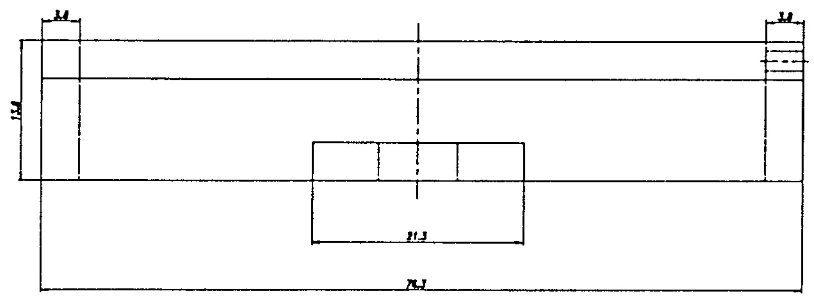
OPERATION SEQUENCE FOR	
Process plan–I	Process plan–II
1. Facing	1. Facing
2. Turning	2. Drilling
3. Drilling	3. Boring
4. Boring	4. Tapping
5. Tapping	5. Turning
6. Slotting	6. Slotting

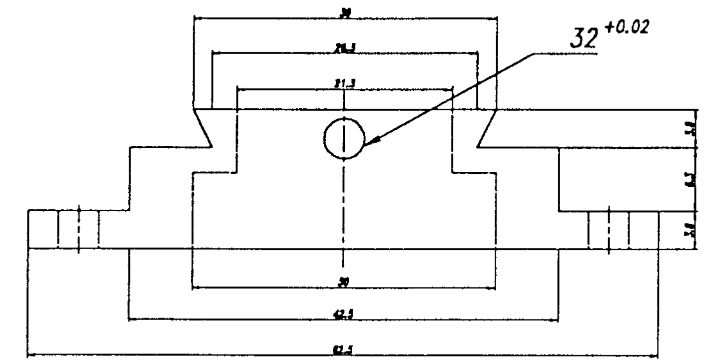
FIG 4.1.18 FEEDING HANDLE FOR TABLE FEED IN DIAL FIXING SIDE:-

Appendix: (B)

Components for milling attachment (Type 2) of the drilling machine

PART-I





SCALE 1:2.5
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Shaping
2.	Boring	2.	Drilling
3.	Drilling	3.	Boring
4.	Milling	4.	Tapping
5.	Tapping		
6.	Shaping		

FIG 4.2.1: CROSS FEED BED

PART:2

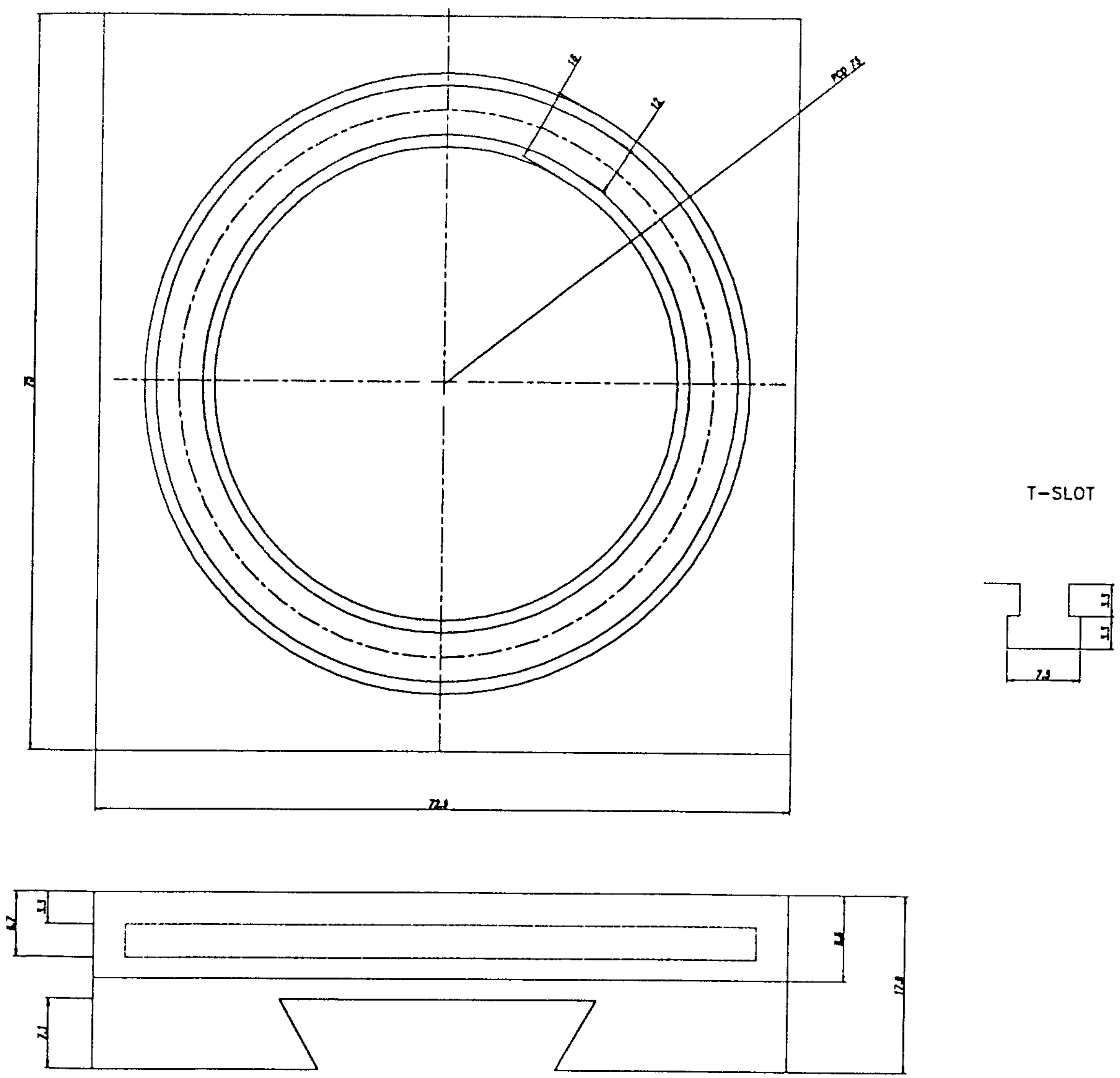


FIG 4.2.2 BOTTOM FIXING BRACKET

SCALE 1:1.5

All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	**Process plan-II**
1. Shaping	1. Shaping
2. Boring	2. Drilling
3. Drilling	3. Boring
4. Milling	4. Tapping
5. Tapping	
6. Shaping	

PART:3

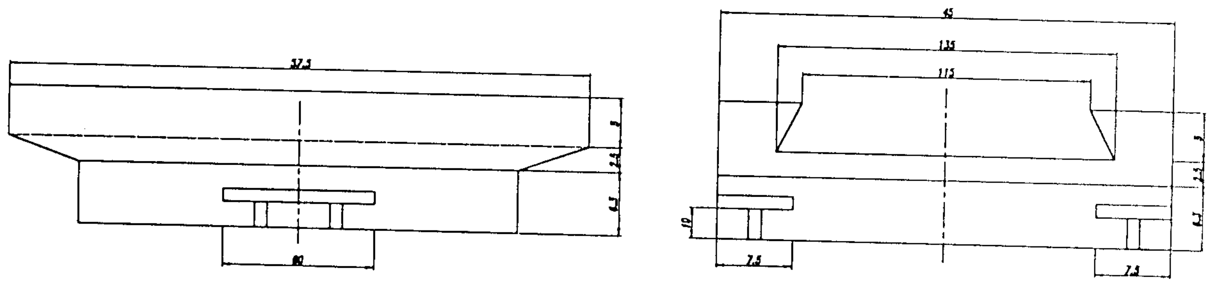


FIG 4.2.3 TOP FIXING BRACKET

SCALE 1:2.5
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	
1.	Turning
2.	Shaping
3.	Milling
4.	Drilling

PART:4

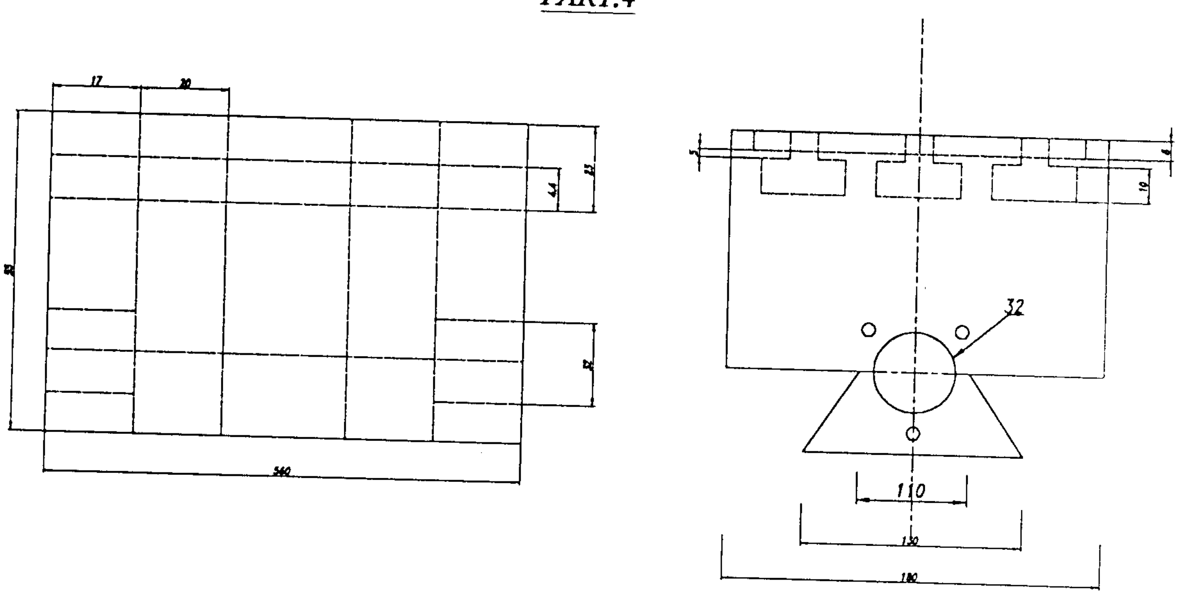


FIG 4.2.4.TABLE

SCALE : N.T.S
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Shaping	1.	Shaping
2.	Drilling	2.	Drilling
3.	Boring	3.	Boring
4.	Milling	4.	Milling
5.	Tapping	5.	Shaping
		6.	Tapping

PART:5,22,23

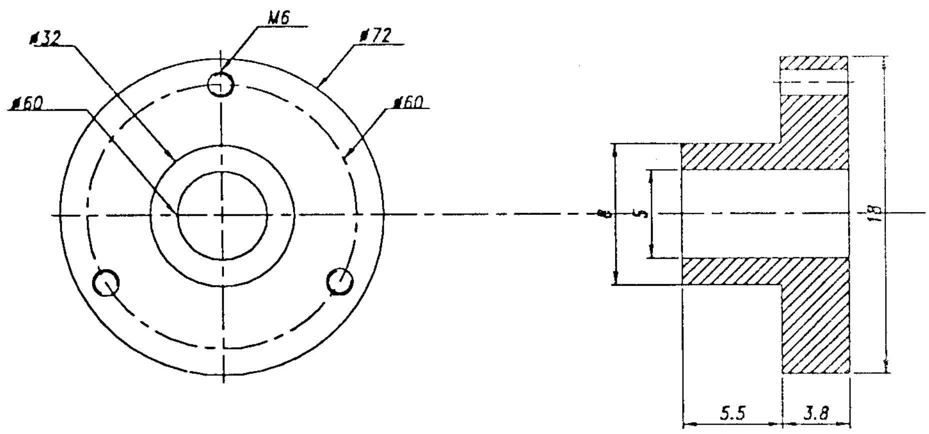


FIG 4.2.5 SCREW ROD COLLAR

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Turning 2. Drilling 3. Tapping

PART:6

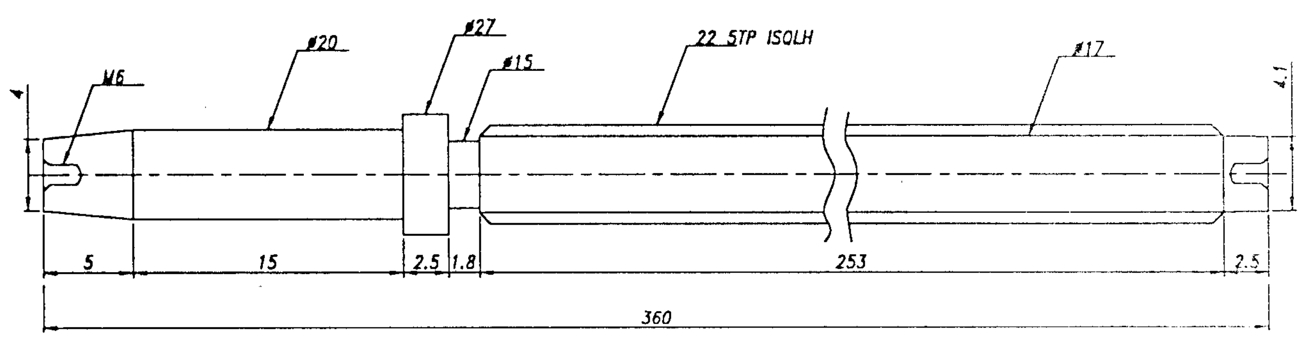
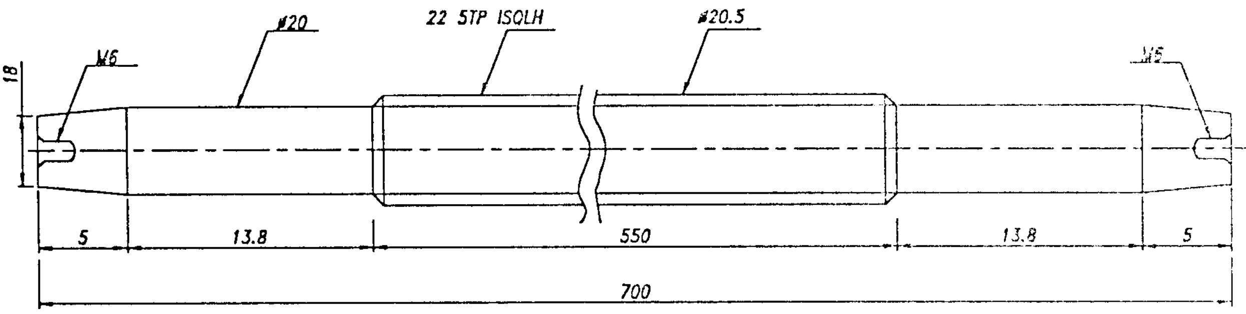


FIG 4.2.6 CROSS FEED SCREW ROD

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Turning	2.	Drilling
3.	Drilling	3.	Turning
4.	Grooving	4.	Taper turning
5.	Threading	5.	Grooving
6.	Milling	6.	Threading
7.	Drilling	7.	Drilling
8.	Tapping	8.	Tapping
9.	Shaping	9.	Milling

PART:7

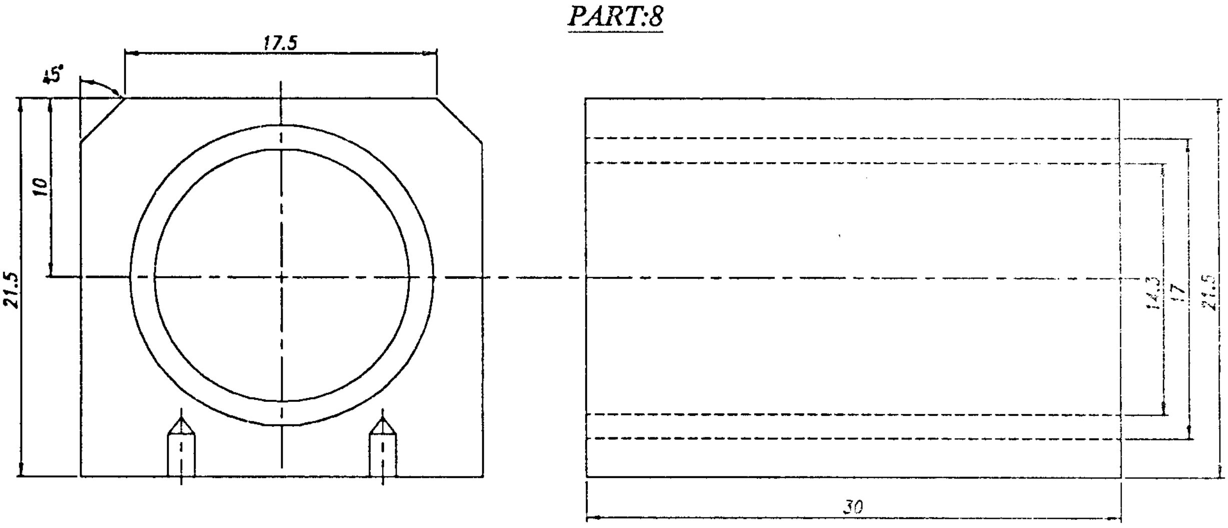


SCALE 1:1
All dimension are in mm.

FIG 4.2.7 TABLE MOVEMENT SCREW ROD

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Facing	1.	Facing
2.	Drilling	2.	Drilling
3.	Turning	3.	Turning
4.	Taper turning	4.	Taper turning
5.	Threading	5.	Drilling
6.	Drilling	6.	Tapping
7.	Tapping	7.	Threading
8.	Milling	8.	Tapping

PART:8

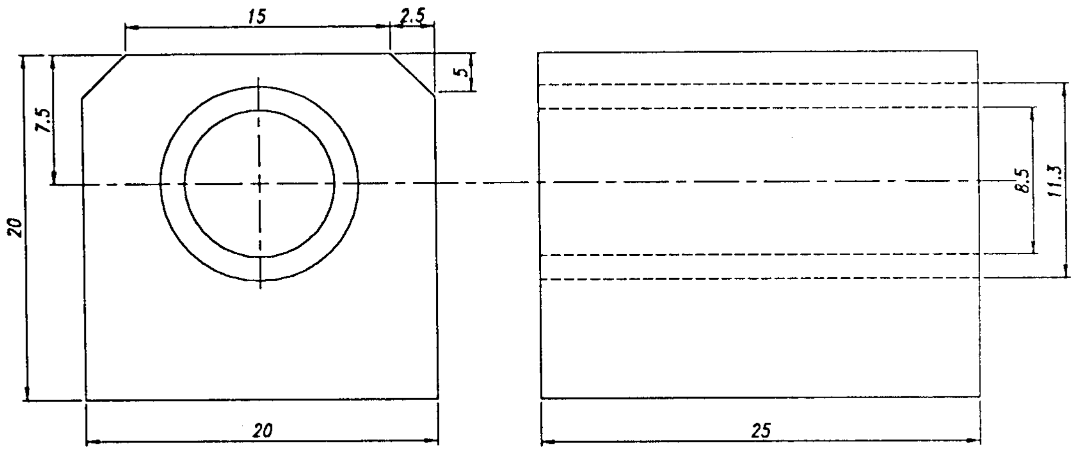


SCALE 1:2
All dimension are in mm.

FIG 4.2.8 CROSS FEED SCREW ROD NUT

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Shaping
2.	Drilling	2.	Drilling
3.	Threading	3.	Tapping
4.	Shaping	4.	Threading
5.	Tapping		

PART:9

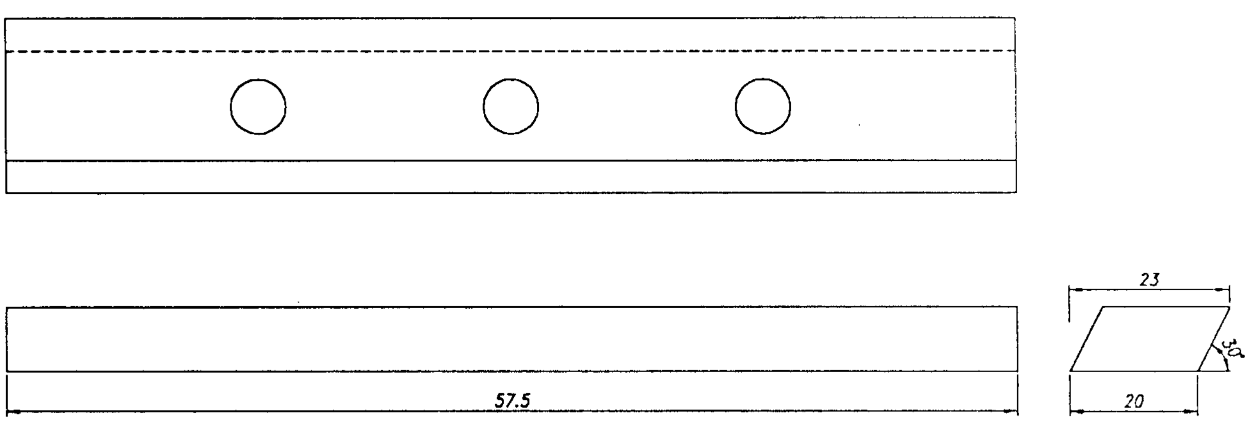


SCALE 1:2
All dimension are in mm.

FIG 4.2.9 TABLE MOVEMENT SCREW ROD NUT

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Shaping
2.	Drilling	2.	Drilling
3.	Threading	3.	Tapping
4.	Shaping	4.	Threading
5.	Tapping		

PART:10

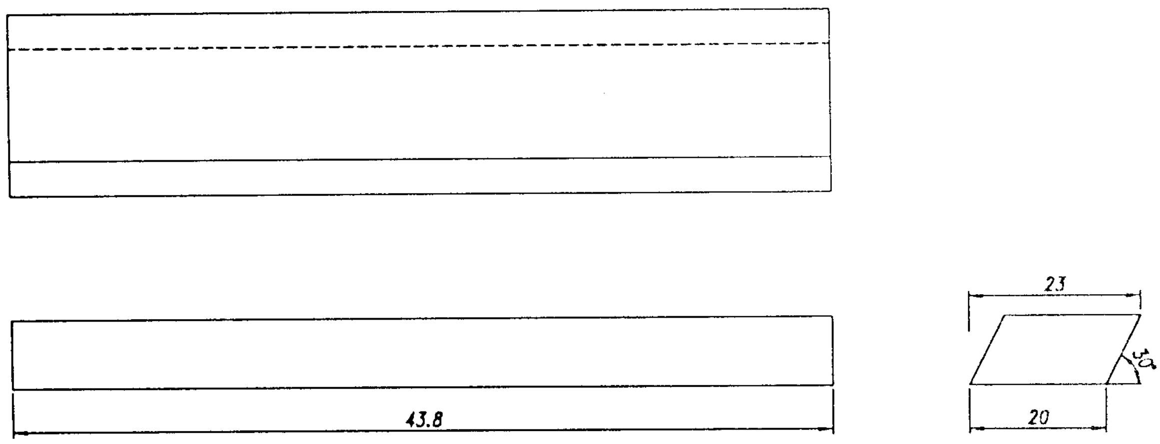


SCALE 1:1
All dimension are in mm.

FIG 4.2.10 TABLE MOVEMENT ZIP

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Milling
2.	Milling	2.	Drilling
3.	Slotting	3.	Slotting
4.	Drilling		

PART:11

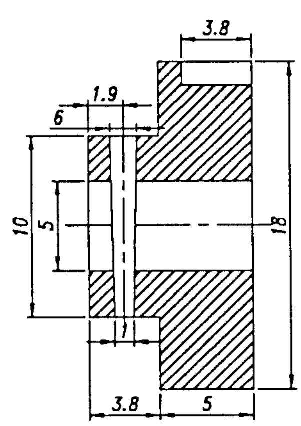


SCALE 1:1
All dimension are in mm.

FIG 4.2.11 CROSS FEED MOVEMENT ZIP

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Facing
2.	Milling	2.	Milling
3.	Slotting	3.	Drilling
4.	Drilling	4.	Slotting

PART:12



SCALE 1:1
All dimension are in mm.

FIG 4.2.12 CROSS FEED MOVEMENT DIAL READING COLLAR

OPERATION SEQUENCE FOR	
Process plan–I	Process plan–II
1. Facing	1. Facing
2. Turning	2. Boring
3. Boring	3. Turning
4. Drilling	4. Drilling
	5. Turning

PART:13 & 15

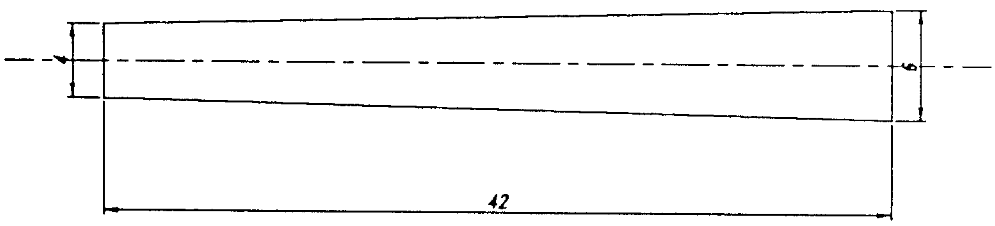


FIG 4.2.13 STEADY PIN

SCALE 1:4
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	
1.	Facing
2.	Turning

PART-14

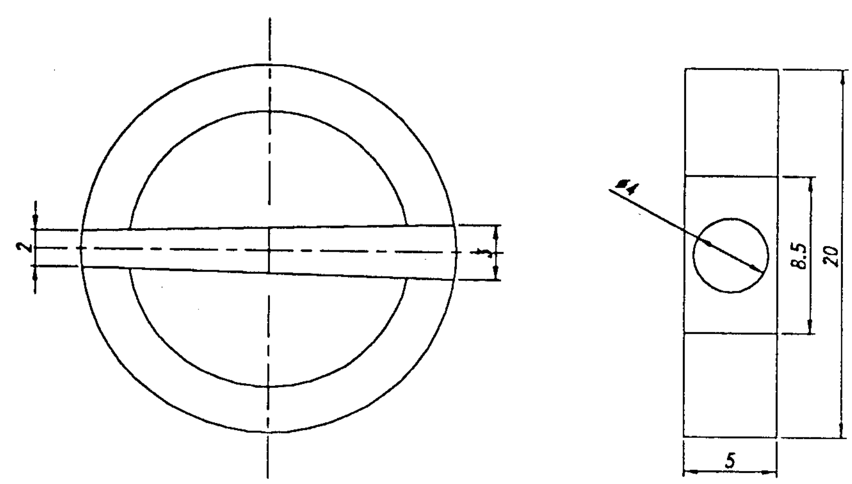
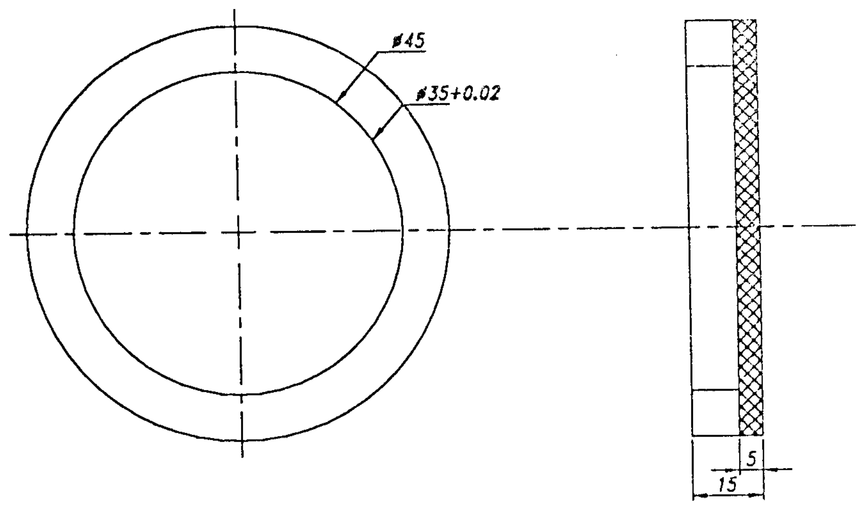


FIG 4.2.14TABLE SCREW ROD LOCKING COLLAR

SCALE 1:2
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Turning	2.	Boring
3.	Boring	3.	Turning
4.	Drilling	4.	Drilling
		5.	Turning

PART:16



SCALE 2:1
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Turning 2. Knurling 3. Facing 4. Drilling 5. Boring 6. Milling	1. Facing 2. Turning 3. Knurling 4. Drilling 4. Boring 6. Milling

FIG 4.2.15 TABLE MOVEMENT READING DIAL

PART:17

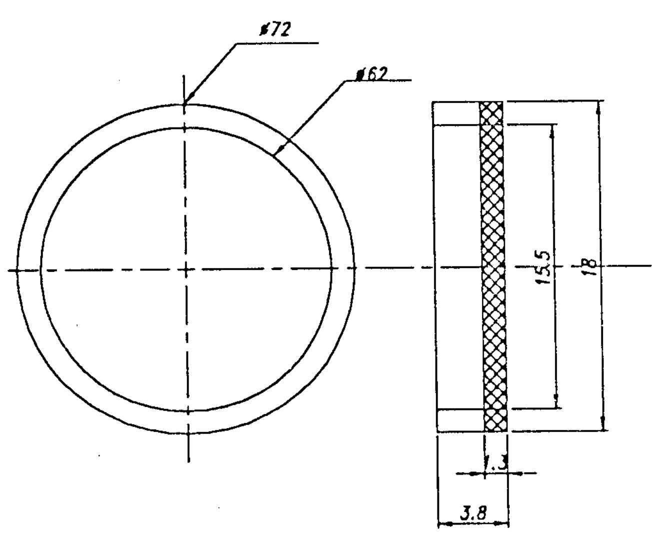
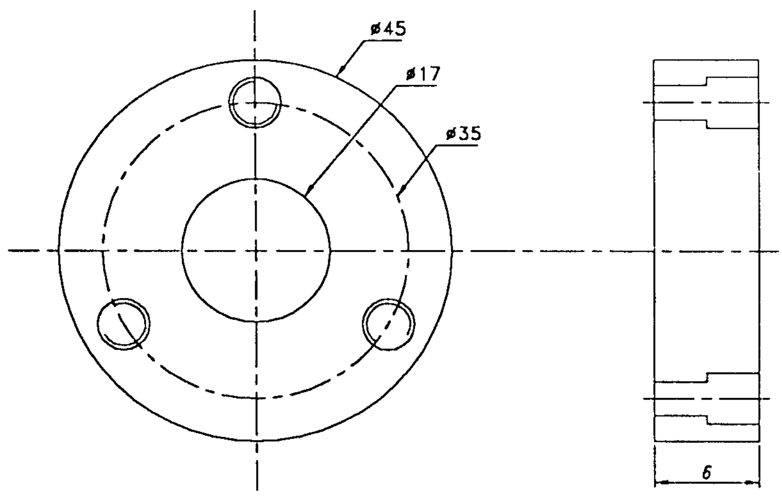


FIG 4.2.16 CROSS FEED MOVEMENT READING DIAL

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Turning 2. Knurling 3. Facing 4. Drilling 5. Boring 6. Milling	1. Facing 2. Turning 3. Knurling 4. Drilling 5. Boring 6. Milling

PART:18

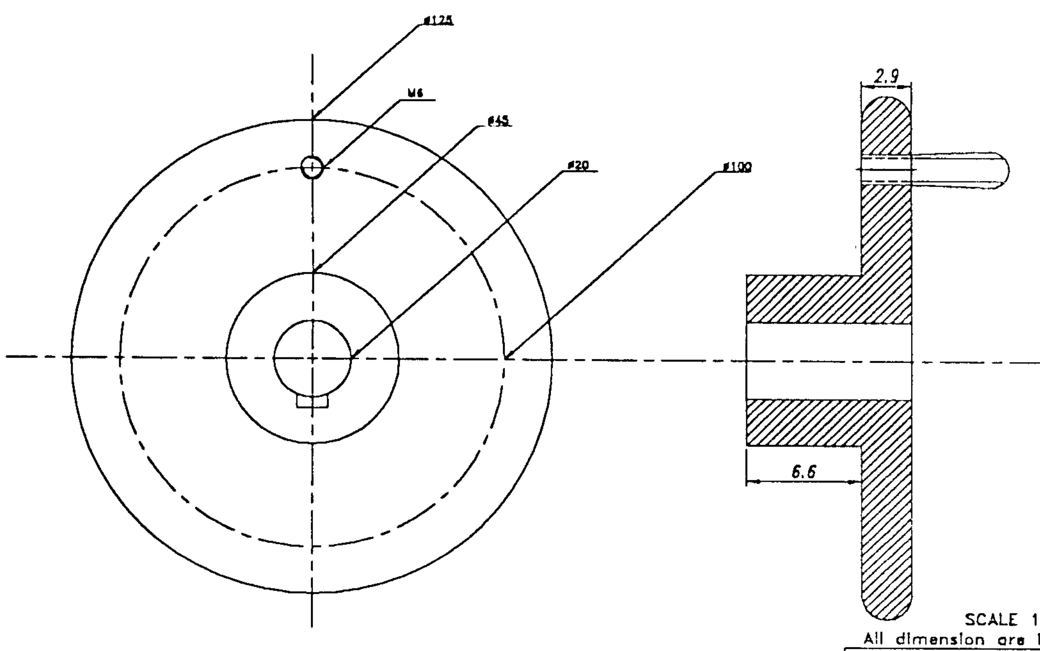


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Facing 2. Turning 3. Drilling 4. Boring 5. Tapping

FIG 4.2.17 DIAL GUAGE SPACER

PART:19 & 21

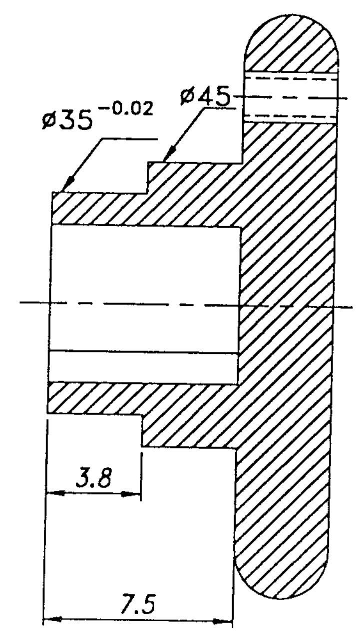


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Turning	2.	Drilling
3.	Drilling	3.	Boring
4.	Boring	4.	Tapping
5.	Tapping	5.	Turning
6.	Slotting	6.	Slotting

FIG 4.2.18 FEEDING HANDLE FOR TABLE AND CROSS FEED

PART: 20



SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan–I	Process plan–II
1. Facing	1. Facing
2. Turning	2. Drilling
3. Drilling	3. Boring
4. Boring	4. Tapping
5. Tapping	5. Turning
6. Slotting	6. Slotting

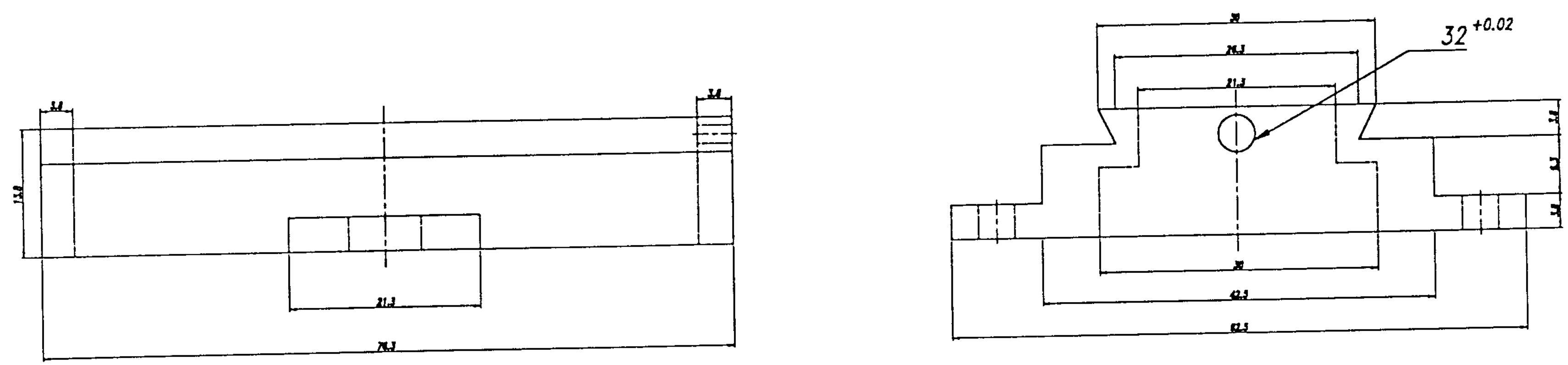
FIG 4.2.19 FEEDING HANDLE FOR TABLE

FEED IN DIAL FIXING SIDE:-

Appendix: (C)

Components for milling attachment (Type 3) of the drilling machine

PART-I



SCALE 1:2.5
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Shaping	1.	Shaping
2.	Boring	2.	Drilling
3.	Drilling	3.	Boring
4.	Milling	4.	Tapping
5.	Tapping		
6.	Shaping		

FIG 4.3.1: CROSS FEED BED

PART:2

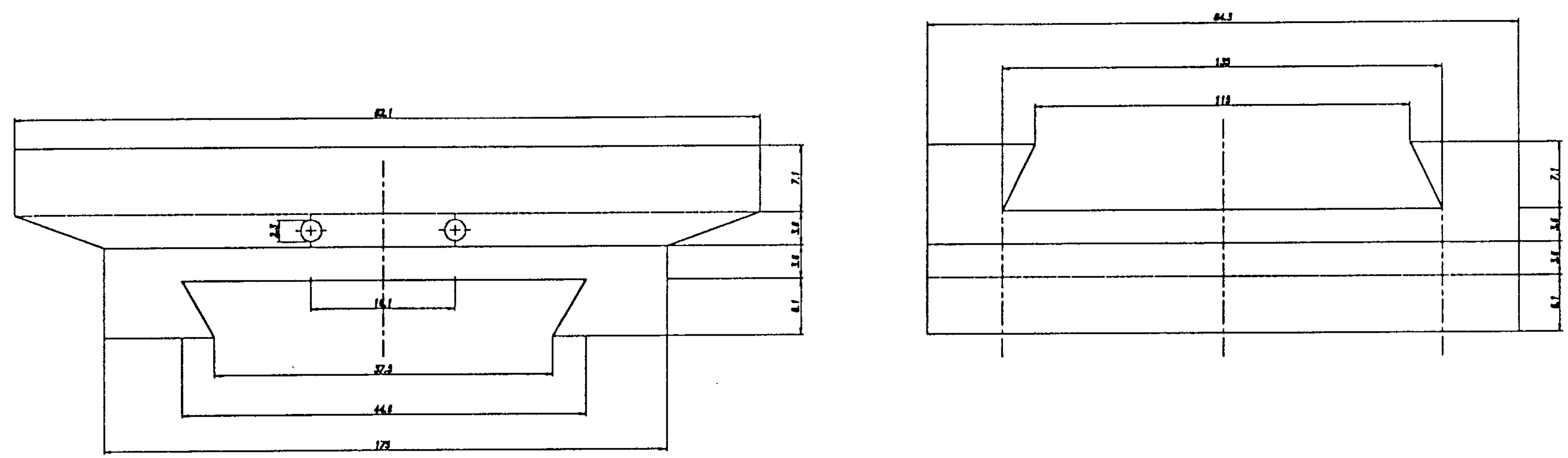
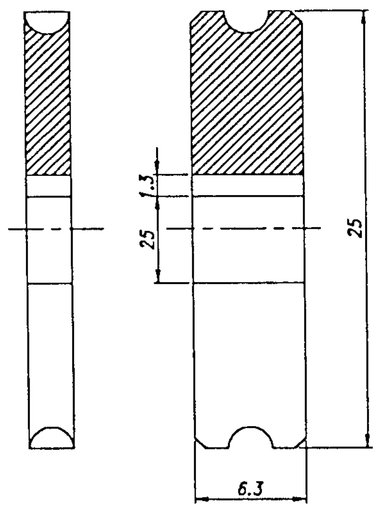


FIG 4.3.2 FIXING BRACKET

SCALE 1:2.5
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan–I	
1.	Shaping
2.	Drilling

PART:3



SCALE 1:1
All dimension are in mm.

FIG 4.3.3 GEAR WHEEL

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Drilling	2.	Drilling
3.	Turning	3.	Turning
4.	Shaping	4.	Slotting
5.	Slotting	5.	Shaping

PART:4

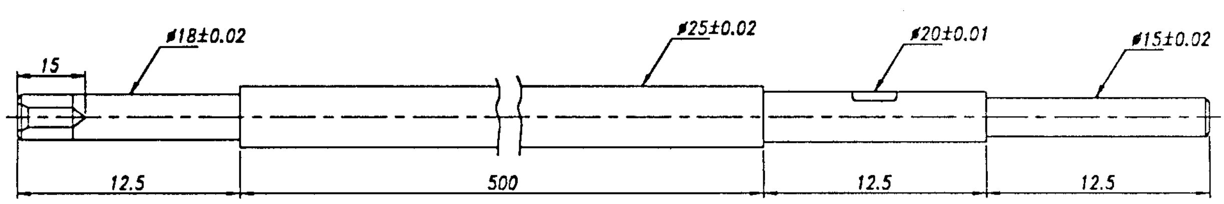


FIG 4.3.4 SHAFT

SCALE:NTS
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Facing 2. Turning 3. Milling 4. Drilling 5. Tapping

PART:5

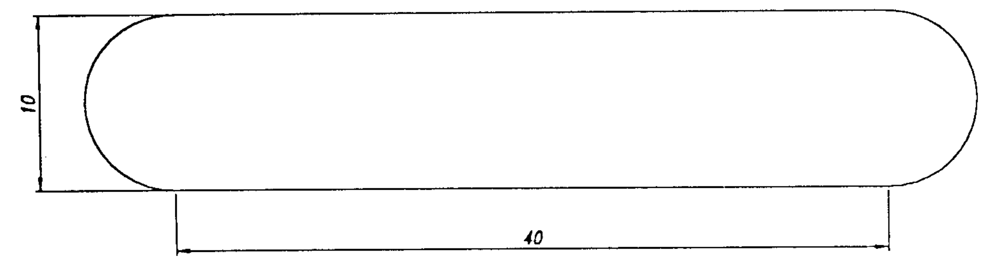


FIG 4.3.5 KEY

SCALE 4:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Facing 2. Turning

PART:6

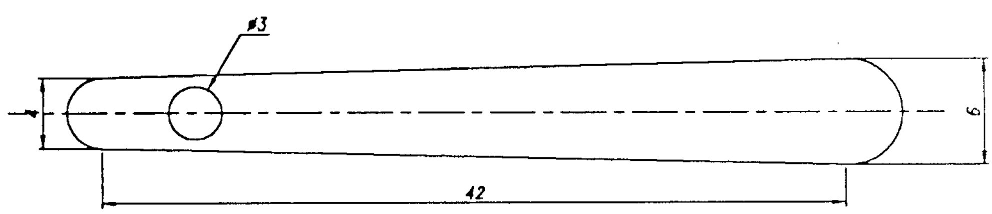


FIG 4.3.6 LOCKING PIN

SCALE 4:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Facing 2. Turning 3. Drilling

PART:7

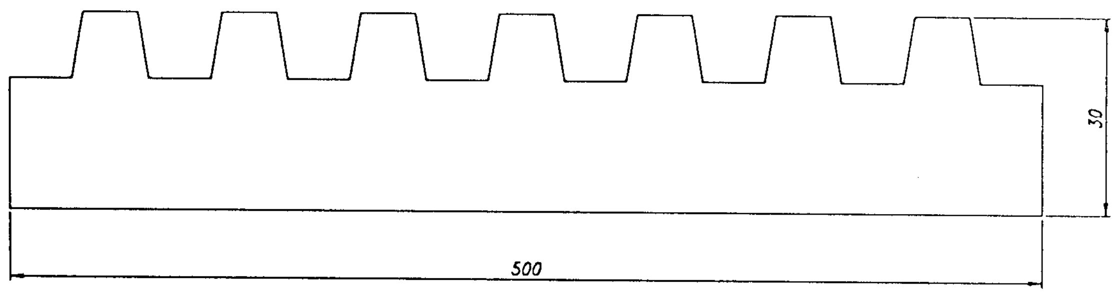
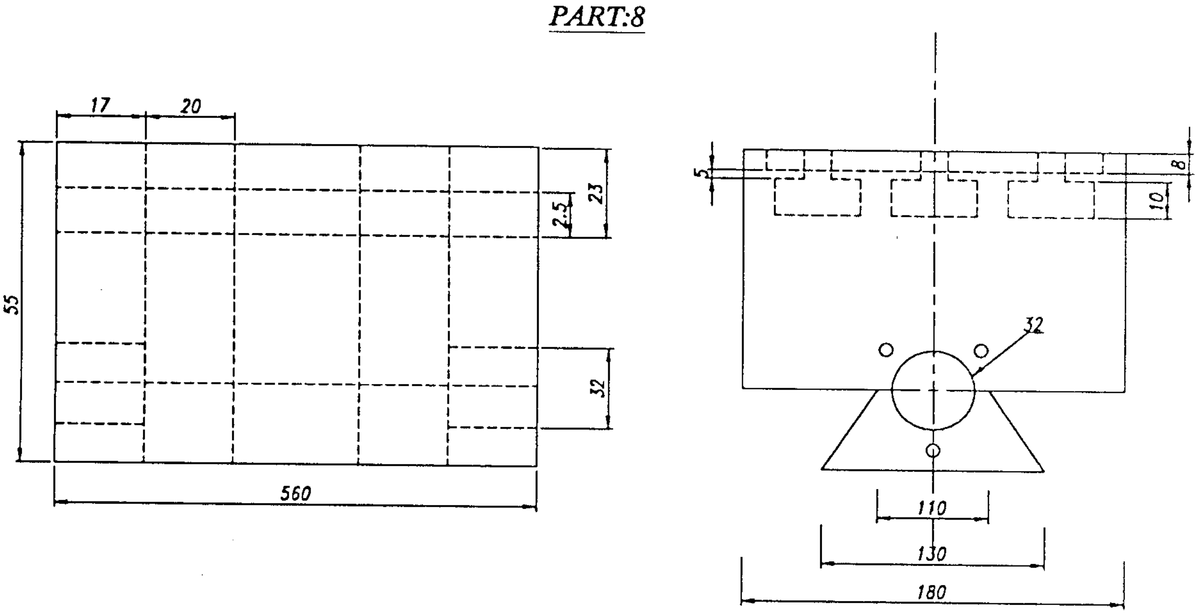


FIG 4.3.7 RACK

SCALE:NTS
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan–I
1. Shaping 2. Facing 3. Milling

PART:8



SCALE : N.T.S
All dimension are in mm.

FIG 4.3.8.TABLE

OPERATION SEQUENCE FOR	
Process plan–I	Process plan–II
1. Shaping	1. Shaping
2. Drilling	2. Drilling
3. Boring	3. Boring
4. Milling	4. Milling
5. Tapping	5. Shaping
	6. Tapping

PART:9

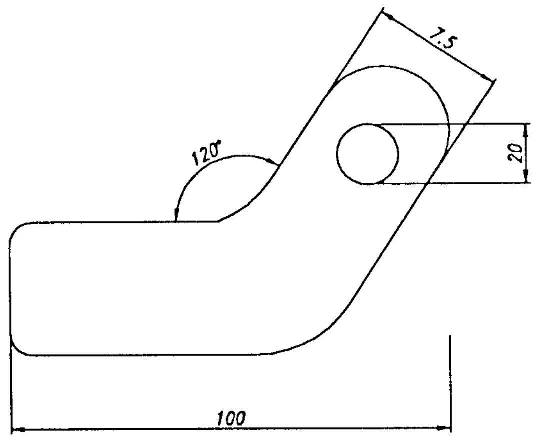


FIG 4.3.9 STROKE ADJUSTING LEVER

SCALE:NTS
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Facing 2. Drilling 3. Turning

PART:10

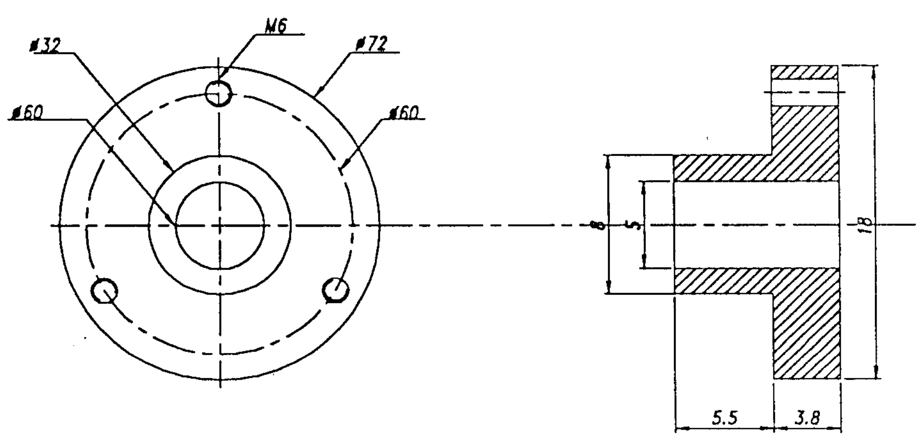
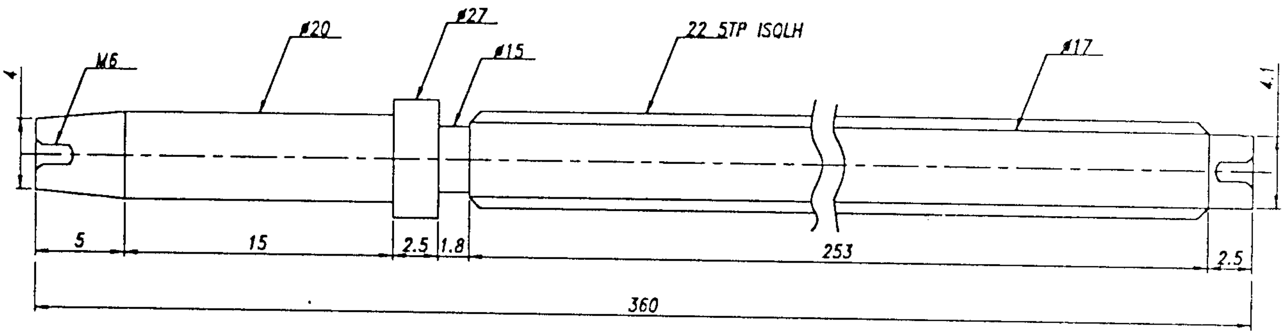


FIG 4.3.10 SCREW ROD COLLAR

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Turning 2. Drilling 3. Tapping

PART:11

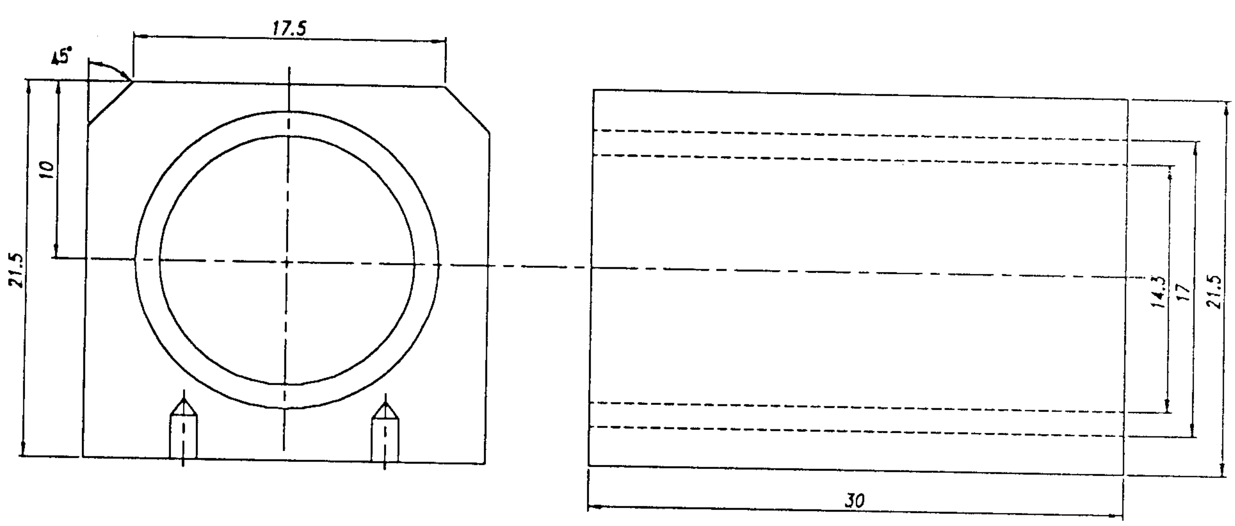


SCALE 1:1
All dimension are in mm.

FIG 4.3.11 CROSS FEED SCREW ROD

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Facing	1.	Facing
2.	Turning	2.	Drilling
3.	Drilling	3.	Turning
4.	Grooving	4.	Taper turning
5.	Threading	5.	Grooving
6.	Milling	6.	Threading
7.	Drilling	7.	Drilling
8.	Tapping	8.	Tapping
9.	Shaping	9.	Milling

PART:12

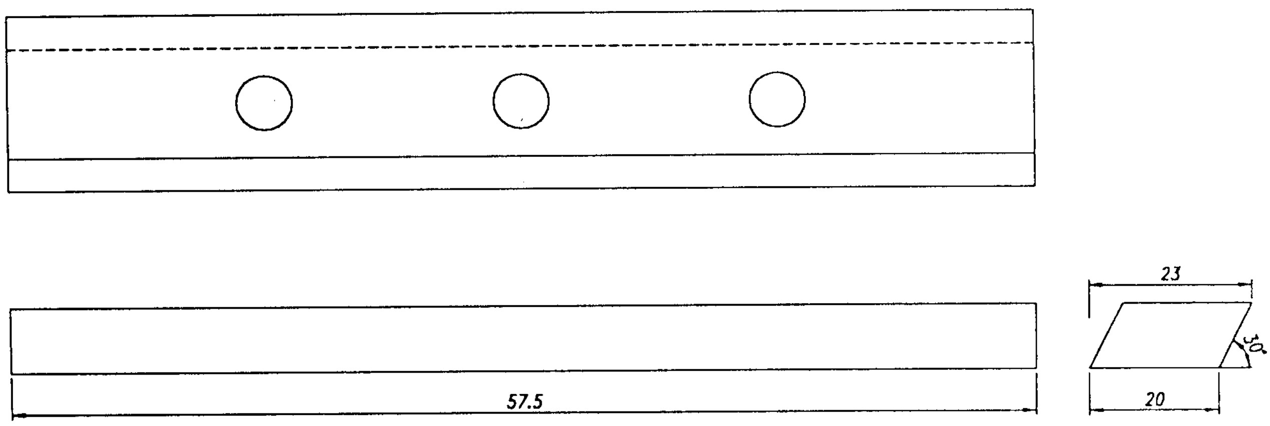


SCALE 1:2
All dimension are in mm.

FIG 4.3.12 CROSS FEED SCREW ROD NUT

OPERATION SEQUENCE FOR			
Process plan-I		Process plan-II	
1.	Shaping	1.	Shaping
2.	Drilling	2.	Drilling
3.	Threading	3.	Tapping
4.	Shaping	4.	Threading
5.	Tapping		

PART:13

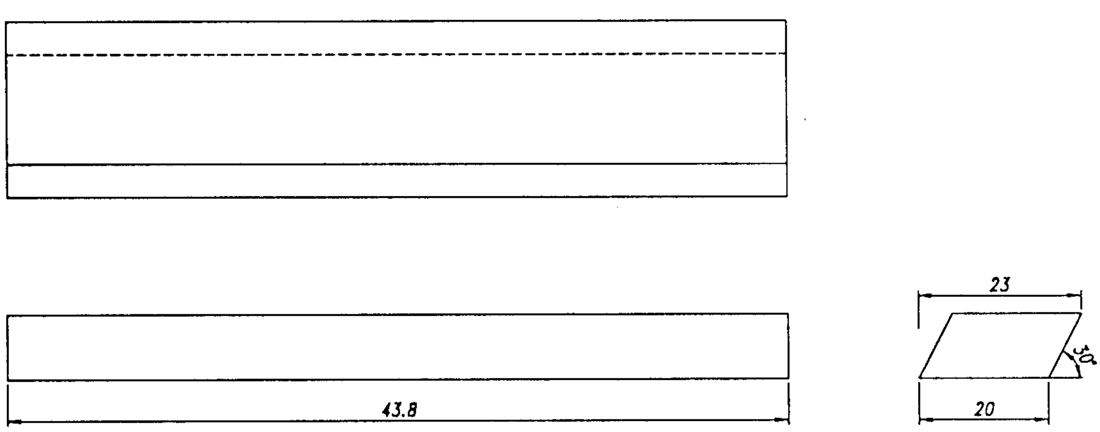


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Milling
2.	Milling	2.	Drilling
3.	Slotting	3.	Slotting
4.	Drilling		

FIG 4.3.13 TABLE MOVEMENT ZIP

PART:14

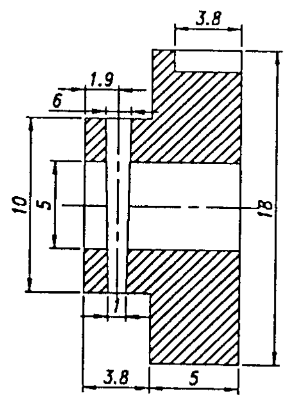


SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR			
Process plan–I		Process plan–II	
1.	Shaping	1.	Facing
2.	Milling	2.	Milling
3.	Slotting	3.	Drilling
4.	Drilling	4.	Slotting

FIG 4.3.14 CROSS FEED MOVEMENT ZIP

PART:15



SCALE 1:1
All dimension are in mm.

FIG 4.3.15 CROSS FEED MOVEMENT DIAL READING COLLAR

OPERATION SEQUENCE FOR	
Process plan–I	Process plan–II
1. Facing 2. Turning 3. Boring 4. Drilling	1. Facing 2. Boring 3. Turning 4. Drilling 5. Turning

PART:16

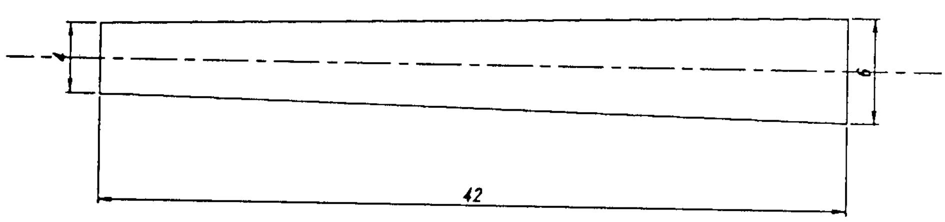


FIG 4.3.16 STEADY PIN

SCALE 1:4
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan–I	
1.	Facing
2.	Turning

PART:17

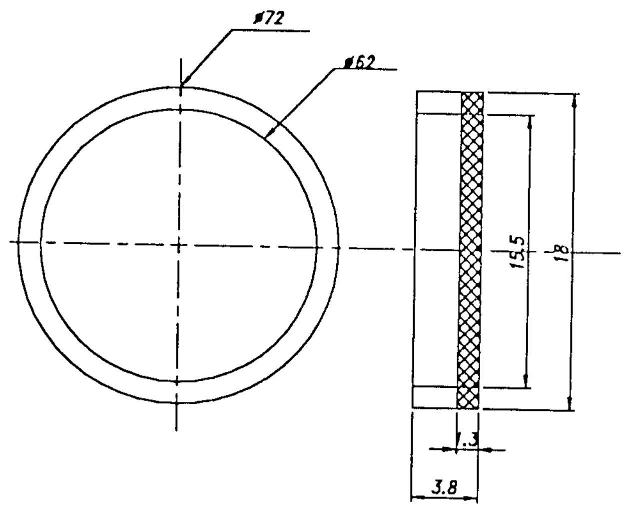


FIG 4.3.17 CROSS FEED MOVEMENT READING DIAL

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Turning 2. Knurling 3. Facing 4. Drilling 5. Boring 6. Milling	1. Facing 2. Turning 3. Knurling 4. Drilling 5. Boring 6. Milling

PART:18

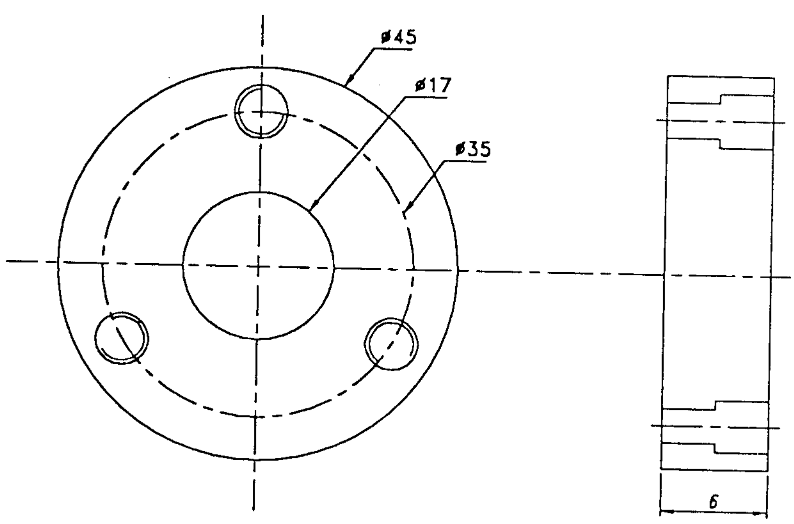


FIG 4.3.18 DIAL GUAGE SPACER

SCALE 1:1
All dimension are in mm.

OPERATION SEQUENCE FOR
Process plan-I
1. Facing 2. Turning 3. Drilling 4. Boring 5. Tapping

PART:19 & 20

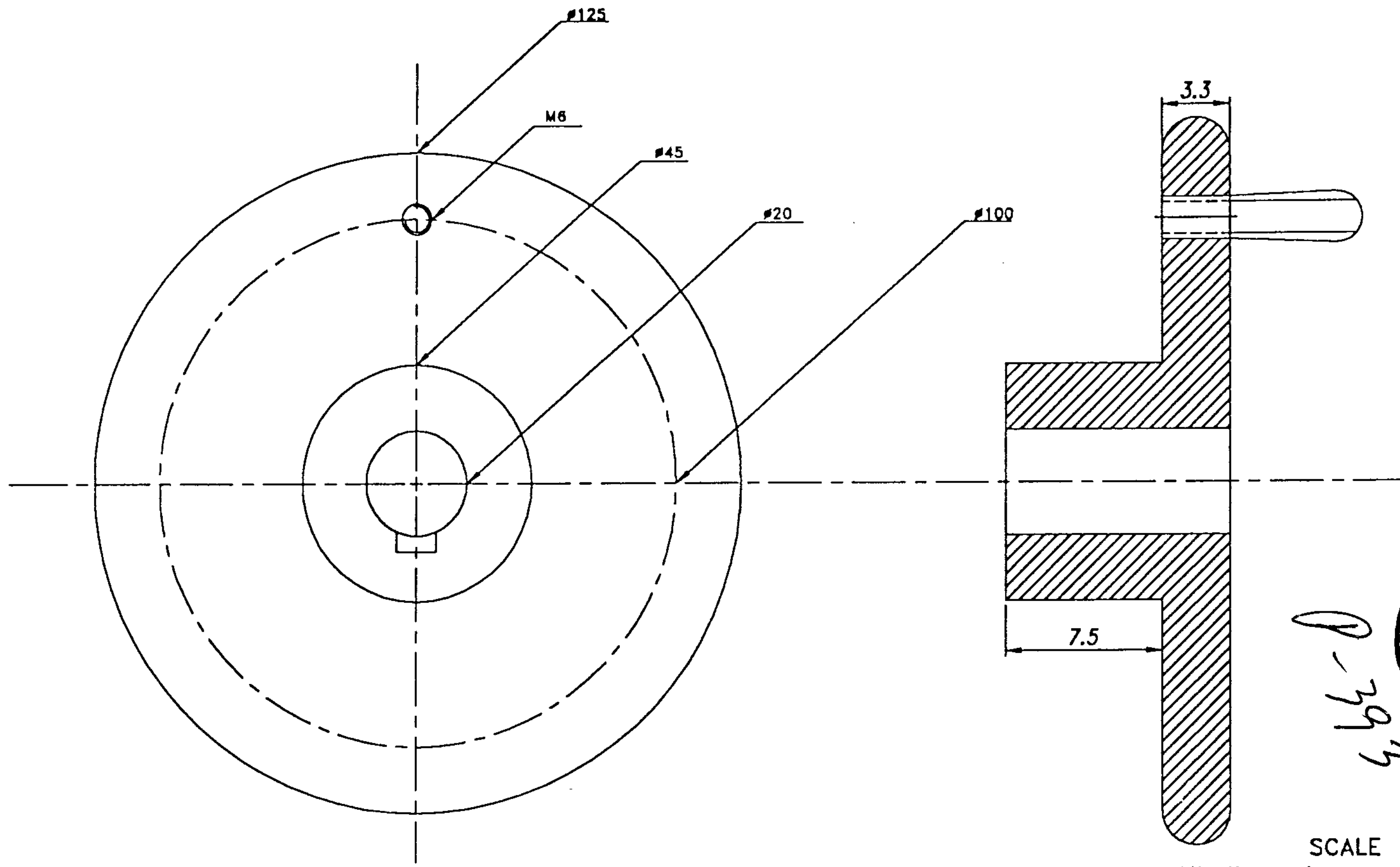


FIG 4.3.19 FEEDING HANDLE FOR TABLE AND CROSS FEED

SCALE 1:1

All dimension are in mm.

OPERATION SEQUENCE FOR	
Process plan-I	Process plan-II
1. Facing	1. Facing
2. Turning	2. Drilling
3. Drilling	3. Boring
4. Boring	4. Tapping
5. Tapping	5. Turning
6. Slotting	6. Slotting