COMPUTER AIDED PROCESS PLANNING FOR EDM PRODUCTS

THESIS

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Dedicated to my Parents

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ABSTRACT

Computer aided process planning has started gaining more and more acceptability in the industrial scenario in this country. A review of literature survey indicates that considerable research work have already been initiated but all these are basically limited in the area of conventional metal cutting and metal forming based products but a logical approach to process planning in Electric Discharge machining does not appear to exist.

As a first step towards the automation in EDM process planning the present work attempts to develop a systematic mathodology for generation of computerised process plan.

The input module takes the information about the raw material, features to be machined and available machine tool.

The planning module combines the features in a logical fashion to achieve economics of tooling and machine tool capability. The application of proposed methodology will reduce time, efforts and costs involved in development of the process plans for EDM.

The present work can be divided into two parts :

1. Input Module 2. Planning Module.

In the Input module necessary input information are collected. The necessary input information are blank dimension, finished part dimension, shape, surfare roughness, material and machinability requirement. Blank dimension are used during the stage of the preliminary selection of the machine tool. Machinability refers to the case of metal removal. A material is said to have good machinability if it can machined with less tool wear.

The planning module first select the machine available on the basis of conditions of the machines available (i.e. busy, idle, breakdown) time. Machining areas are determined from the drawing of the component and by applying geometrical formulas. Volume of material to be removed are calculated from machining areas and depth of cut.

After this the Operation are sequenced and various process parameters such as current, voltage, metal removal rate etc. are determined. The mathematical model for Metal Removal Rate (MRR) for different electrode with different W/P material has been developed by using Regression/Co-relation analysis with the parameter surface roughness and Intensity level for EDM and W/P thickness and Intensity Level for WEDM.

The process sheet generated both for EDM and WEDM will highlight the following output informations

* M/C number selected
* Type of M/C
* Machining Speed
* Machining Time
* S.R. of Finished Job
* Direction of Flush
* Operating M/C Current
* Metal Removal Rate

In the last part of the present work an attempt to optimise the lead time and cost by Hungerian Method are developed.

Based on the experience already available in the domain on the mechanism of the EDM processes its optimisation and also on the techniques of computer aided process planning as applied to metal cutting based process, the present work reports a portion of attempts to synthesize both set of knowledge and provide a logical analysis of the decisions of process planning activities including the aspects of

- Selection of machine tool
- Sequencing the operation
- Deciding the operating parameters
- Calculation of overall time required for machining both for EDM & Wire EDM
- Generation of process sheet both for EDM & Wire EDM

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CHAPTER - I

GENERAL INTRODUCTION

CHAPTER-I

GENERAL INTRODUCTION

There has been a rapid growth in the development of harder. and difficult to machine and high strength temperature resistance *(HSTR)* materials during the last three and half decades. Modern Metallurgical engineering and material science & technology based skills and knowledge have been continuously presenting newer and larger spectrum of material having wide ranging diverse properties including increasingly higher strength - a trend distinctly departing from conventional materials with well known manageable characteristics and properties particularly in the realm of manufacturing strategy selection.

In fact, with the development of such new high strength material. it becomes imperative to develop further improved materials for manufacturing of cutting tools necessary for machining those developed materials by applying the conventional metal cutting based manufacturing technologies. Although different types of carbon steel were the only tool materials used till 1870. tremendous developments have taken place in the field of machining technology based manufacturing process, initiated primarily by F W Tayler leading to the development and use of High Speed Steel. cemented carbides, coated carbides and ceramics which are now used extensively in industries all over the world including ours.

But even with such a versatile and potential range of tool materials effective machining technology based manufacturing for some of the newly developed materials. which are already extensively used for the purpose of increasing life and reliability of equipment and components intended to be used and or operated in severe adverse environmental conditions. are still out of reach. The singularly significant reason being the fact that the conventional metal cutting process demands that the tool conditions previling during such machining operations. Congrauence with such requirement would necessiate using a better *(in the aspects already mentioned)* material. Such a condition implies participation in a never ending race in which as soon as any new material is developed and used, a better material must be developed to enable cutting tools being manufactured and so on.

Therefore it is evident that some new strategies of machining must be developed and adopted in order to overcome the problems created by the development and use of the high strength temparature - resistant and hard-to-machine alloys. Consequently a set of machining strategies commonly termed as '*non-traditional machining*' processes have been developed using some scientific principle already establised. Such processes were also found to be effective in producing complex profiles on hard to machine and brittle material. These technologies are also known as New Technology. Table 1.1 (page-4) gives a classification of the machining processes based on the type of energy used, the mechanism of metal removal, the source of energy requirements etc.

These nontraditional manufacturing processes can be classified into various groups according to the following basic charecteristics :

i) Types of energy required. namely, mechanical. electrical. chemical etc.

ii) Basic mechanism involved in the processes, like erosin, ionic disolution, vaporisation etc.

iii) Source of energy required for material removal, namely, hydrostatic pressure, high current density, high voltage etc.

iv) Medium of transfer of these energies like high velocity particles, electrolyte, electron, hot gases etc.

To cope with fast changing machining technology and the difficulties caused by the development of hard-to-machine and high-strength-temperature resistant alloys, one of the various non-traditional techniques of machining is Electrical Discharge Machining.

TABLE 1.1

CLASSIFICATION OF MODERN MACHINING PROCESSES

Type of energy	Mechanism of metal removal	Transfer media	Energy source	Processes
Mechanical	Erosion	High velocity particles	Peneumatic/ hydraulic pressure	AJM, USM, WJM.
	Shear	Physical contact	Cutting tool	Convention-al machining
Electro chimical	Ion displacement	Electrolyte	High current	ECM, ECG
Chemical	Ablative relation	Reactive enviornment	Corrosive agent	CHM
Thermoelectric	Fusion	Hot gasses	Ionized material	IBM, PAM
		* Electrons	* High voltage	* EDM
	Vapourisation	Radiation	Amplified light	LBM
		Ion stream	Ionized material	PAM

NOTE

AJM-	Abrasive Jet Machining
USM-	Ultrasonic Machining
WJM-	Water Jet Machining
ECM-	Electro-chemical Machining
ECG-	Electro-chemical Grinding
CHM-	Chemical Machining
IBM-	Ion Beam Machining
PAM-	Plasma Arc Machining
EDM-	Electric Discharge Machining
LBM-	Laser Beam Machining

CHAPTER - II

THE STUDY OF THE EXISTING LITERATURE AND THE STATE-OF-THE-ART.

CHAPTER-II

THE STUDY OF THE EXISTING LITERATURE AND THE STATE-OF-THE ART

2.1 INTRODUCTION

Although, the non-traditional machining process have created a revoliution in the field of machining technology but the development of the ideas of the various processes were initiated as early as in 1920 in the *USSR* by Gusser. A method of machining adopting chemical and mechanical means in combination was suggested by him.

B. R. Lazarenko and N. I. Lazarenko are credited with the development of *EDM* process for the first time in the *USSR*. During early 1943 they first developed the idea of spark-erosion machining, advancement also took place almost simultaneously in *Europe* and *USA* since then developments have been taking place very rapidly in the theory and technology of the process and still continuing.

The idea of Ultrasonic Machining *(USM)* was invented by Balamuth in the year 1942 at the time of investigating dispersion of solids in liquids with the help of a vibrating magnetostrictive nickel tube.

In the early nineteen-sixties, the idea of ultrasonic machining began to develop widely in the *USSR*.

The basis of laser been machining was established by the processes which were developed by *Basov*, *Prokhrov* and *Fabrikant* in the *USSR* IN 1950. The laser methods which have been developed in the early 1960's, simultaneously in the *USA* and the *USSR*, are an application of quantum radio electronics and electron optics. The first application of laser beam machining had been for the combined welding and cutting of components used in the electronic industry and also for drilling small holes.

Electrochemical Grinding process has practically been developed in about 1950 and in the early nineteen-sixties the concept of Whirling Jet machining was innovated.

Many of these new techniques of machining have been developed in the last decade to meet the challenges put forward by the rapid development of the hard-to-machine and high-strength-temperature-resistant *(HSTR)* alloys. It is anticipated that in the near future, these new technologies will find an ever increasing application in all branches of mechnical engineering industry.

2.1.1 BRIEF INTRODUCTION TO VARIOUS PROCESSES

i) Abrasive Jet Machining *(AJM)*

AJM differs from usual sand blasting in the size of the abrasive and control. Material removal takes place by impact and erosive action.

ii) Ultrasonic Machining (USM)

The idea of *USM* was invented by Balamuth in 1942 while investigating dispersion of soilds in liquids with the help of a vibrating magnetostrictive nickel table. However, initial work on developing it as a process was done by Resenberg. Material removal in *USM* is through brittle fracture of work material at the sites where the abra sive grains are hammered down by the vibrating tool. So the process is most suitable for brittle materials.

iii) Electrochemical Machining *(ECM)*

Towards the end of 1920 Gussev suggested a method of machining by the combination of chemical and mechanical means and in 1940 he laid down the basis of *ECM* processes. Parallel research had also been made by an american, Burgess and in 1941 he had demostrated the possibilities of *ECM*. In *ECM* material is removed through electrochemical action and hence, it is independent of the mechanical properties. This is one of the most important nontraditional proc esses. When electrochemical action is coupled with normal abrasive action during grinding the process is called electrochemical grinding (*ECG*).

iv) Chemical machining (*CHM*)

Chemical machining is basically a process of material removal by an etchant. The etchant may be either in liquid or in gaseous from.

v) Electric Discharge Machining (*EDM*)

EDM was originally developed by B. R. and N. L. Lazarenko in 1943. Subsequently advancement parallely took place in Europe and USA. In *EDM*, material removal takes place by a combined process of fusion, vaporization, mechnical shock and dielectric circulation. Recently a modification of the process, known as wire *EDM* is coming up as very versatile and powerful method.

vi) Electron Beam Machining (*EBM*)

In *EBM* material is removed by heating and vaporization of the work material where the electron beam impinges on it. A fine control of heating rate is possible by controlling the accelerating voltage.

vii) Laser Beam Machining (*LBM*)

The basic method of material removal is quite similar to that in *EBM*. In case of *LBM* the advantage is that the process need not be conducted in high vacuum. The initial application of *LBM* had been for the combined welding and cutting of components used in electronic industry.

2.2 PROCESS PLANNING

The task of process planning is to translate design data to work instruction to produce a part or a product most effectively. This implies that process planning should interact directly manufacturing process and sequencing based on the information presented on the work piece drawing and the bill of materials. This interface can be achieved with the aid of the computer using a common data base leading ultimately to a completely integrated manufacturing system.

Process Planning is that set of function withen a manufacturing facility that indentifies the specific machining processes along with their relevant parameters duly determined which are to be used to convert a piece part from its inital form to a final form most effectively.

Alternatives, process planning could be defined as the act of preparing detailed work instructions required to produce a part. The initial material required to be used can be of a number of forms, the most common of which being bar stock, plate, castings, forgings or may be just a slab *(of any geometry)* of metal.

With the raw meterial as a base, the process planner prepares a list of processes needed to convert such material into a predetermined final shape specified by attributes like dimensions and accuracies.

The process plan is freequently called an operation sheet, route sheet, operation planning summary or another similar name. The detailed plan usually contains the route, processes, process parameters, and machine and tool selections. In a more general sense, a process is called an operation. The process plan provides the instructions for production of the part. These instructions dictate the cost, quality and rate of productions. Therefore process plan is of utmost importance to the production system.

2.3 INPUT TO PROCESS-PLANNING

The Principal inputs required for effective process planning can be broadly classified as shown below:

i) Part Design and Description
ii) Machine Tools
iii) Tools
iv) Jigs and Fixtures
v) Standard time and costs.

In addition to above parameters, process planning function requires the following procedure and related methodoligies:

i) Design identification and part classification
ii) Process Selection
iii) Jigs and Fixtures selection
iv) Parameter optimisation
v) Cutter path generation
vi) Material selection
vii) Machine selection
viii) Tool selection
ix) Process sequencing
x) Intermediate surface generation.

2.3.1 OUTPUT TO PROCESS-PLANNING

The most important out put of process planning function is process plan. In addition process plans provide pertinant input information for bringing out various statistics related to machine tool utilisation, tool utilisation, meterial utilisation etc.

2.4 PROCESS PLANNING FUNCTION

The first step is to select the raw part, which may be a slab, a blank, a rough forging or a rod. It is necessary to determine the required oversize of the part to assure a flawless surface after machining. The weight of the raw part also has to be calculated. This however excludes situations where processing are to be done on an already preprocessd work piece.

In the next phase, the individual operations to produce the part are determined. The possible operational sequences are maintained in a sequence file.

The next activity is the selection of the machine tools. For this purpose, the system must contain a machine tool matrix files. It holds information on the functions of the machine tools and their physical restrictions. To determine auxiliary functions, the system has to contain fixtures, tool and measuring instrument matrix file. In addition, a file containing manufacturing specificatications must be provided. In a succeeding step the manufacturing times are calculated. This includes determination of feed, speed and set up, lead and porcessing times. Information on these activities may be obtained from look up tables or with the help of quantitative expressions.

2.5 COMPUTER AIDES PROCESS PLANNING

Conventional Process Planning exercises carried out by manually system makes the planner to rely heavily on personal manufacturing experiences and handbook. The acquired knolwdge of the planner includes possible machining operations and sequences to produce a part and available cutting tool, machine tool to be followed and measuring instruments. In addition tables and handbooks are often required to be used by the planner to determine depth of cut, speed for machining, feed etc. and the tolerances and surface finish that would be achieved through adoption of identified cutting condition.

In the light of above an automated process planning system derived with the aid of computers should have the following features:

i) It should operate as an integrated planning aid that obtains input data through direct interaction automatically from engineering function to generate a complete set of process plans to be used in production planning activities.

ii) The design of the module should be of generalized nature to ensure a sufficient level of varsatality in terms of types or nature of products that can be handled.

iii) It should posses an on-line interactive system to exploit the potential of the computer further by becomming able to take care of changes that may be required to be accomodated.

iv) It should be user firendly and provide operator guidance so that it can achieve ready acceptance from a wide range of technical professional.

v) Like all other production equipment, it should be cost justified.

Computer aided process planning can be catagorized in three major areas based on the difference of approaches; viz (i) Variant process planning, where library retrieval procedures are applied to find standard plans for similar components which have already been implemented, (ii) generative process planning, where plans are generated automatically for now components, (iii) Hybrid of semigenerative i.e. synthesis of variant and generative approach. Generative approach is the most desirable as well as the most complex way of performing computer aided process planning with maximum effectiveness. Current "*CAPP*" systems commercially available range from simple editors for manual planning to fully atormated systems for planning a range of products. Some benefits of such *CAPP* are as follows:

i) Improved Productivity
ii) Lower Production Cost
iii) Consistency
iv) Time savings
v) Rapid integration of new production capabilities.

2.6 DIFFERENT APPROACH TO PROCESS PLANNING

VARIANT APPROACH

The variant approach to the process planning is comparable with the traditional manual approach where a process plan for a new part is created by recalling, identifying, and retrieving an existing plan for a similar part, and making necessary modifications to accommodate the amended features of the new part. In this system the parts are classified unambigously into a number of discreate part families, characterized by similarities in manufacturing methods. For each part family a standard process plan, which includes all possible operations that may be required for all the member of the family is stored in the system.

Through classification and coding, a code is built up, these codes are often used to identify the part family and the associated standard plan.

The standard plan is retrieved and edited to match exactly the manufacturing requirements for the new part.

This approach is still popular due to lower investiment, short development time, lower hardware and development cost.

The significant disadvantage of this approach is that the quality of process plan depends upon the knowledge background of process planner and quality as well as the coverage of data base.

GENERATIVE APPROACH

An ideal generative process planning system relies primarily on information pertaining to the design of the part and generates the process plan. Such process plans include processes to be adopted on sequence and documents them without human intervention. The generative approach is based on defining the process planning logic using methods like:

- Decision trees
- Decision tables
- Artificial intelligence-based approach

Generative process planning systems are to be rapid and consistent in generating process plans. They should posses the ability to create process plans for entirely now components. Generative process planning attempts to initiate the process planner's thinking by applying the planner's decision making logic. It uses *"built-in"* decision logic which checks condition requirements of the component.

The rules of manufacturing and equipment capabilities are stored in a data base in a computer system. A specific process plan for a specific part can be generated without any involvment of human process planner using such system. This delinks the effectiveness of the system from the skill, experience & knowledge of the planner. The input requirements are either provided in the form of text input requirements are either porvided in the form of text input (*i.e. interactive input*) or the form of graphic input where the part data is transfered from a *CAD* module (*i.e. interface input*).

The process plan generalised by this approach are fully automated but the initial investment is high primarily because of more demand on the nature of hardware capabilities.

SEMI-GENERATIVE / HYBRID APPROACH

The term semi-generative approach may be defined as a aynthesis of generative and variant approach. A pre-process plan is required to be developed and modified before the plan can be utilized in a real production environment. This approach is an interim approach and is still in its infancy. The decision logic, formulae and technological algorithms as well as geometry based coding scheme for translating physical features of the job are built into the system. At the first sight, the system working steps are the same as generative approach, but the final process plan has to be examined and errors corrected if it does not fit the real production environment. The modification in the process plan is small as compared to variant approach.

The main advantage of this approach are speedy automatic generation reduced process planner's participation and ensured quality of the process plan.

2.7 EARLY RESEARCH ON CAPP

WYSK R. A. & BARASH M. M.[1] described the outlines of the responsibilities and finctions carried out by the process planner, particularly in the context of products to be processed through machining centers.

The report also presents an overview of the two approaches to automated process planning, namely the variant and the generative process planning. A variant process planning system uses the simmilarity among components to retrieve existing process plans where as a generative process planning can be defined as a system that synthesizes process information in order to create a process plan for a new component automatically. Process plans are created from information avilable in a manufacturing data base without human intervention.

They also presented a methodology for selecting some optimum machining parameters such as speed, feed and depth of cut. Side by side the input requirements for process planning were also discussed.

EVERSHEIM. W. et al [2] illustrated possibilities and experiences of using computer systems for process planning problems. They presented a method by which an entire process plan could be automatically generated with the help of cutting data and with the information regarding machine tool.

S. ZHANG & W. D. GAO [3] introduced *"TOJICAP"* which is an interactive computer aided process planning system for rotational parts.

TOJICAP is Written in *MS-BASIC* designed to run on a *VICTOR 9000* micro-computer. It *is claimed* that the *TOJICAP* system combines the merits of variant as well as generative process planning, in the sense that although the standard process sequence is retrieved through the part family classification and code, the details of each operation are generated automatically from the data base.

ESKICIOGLU H & DAVIES B. J.[4] introduced a feature oriented process planning system known as *'ICAPP'*. The system using both the variant planning via the part family concept and the generative planning, can plan machining operation interactively so that appropriate task could be shared by the computer and the planner to improve the overall system performance. The system was also reported to be capable of processing basic machning processes.

WEILL R, SUPR G & EVERSHEIM W [5] presented the prevailing state of art in the field of computer aided process planning system and on the basis of a typical example they carried out a methodical analysis of the process planning function. Besides, a systematic review of typical existing system had also been presented with an effort to classify the differentsystem according to their basis characteristics.

Van't ERVE. A. H & KALS. H. J. J. [6] presented the concept of *XPLANE*, a generative computer aided process planning system for part manufacturing.

Ths system would automatically select tools, machining operations and their sequence and would provide the facility to specify dimensions, positions and tolerances of the produce.

PANDE S. S. & PALSULE N. H. [7] presented the design and implementation of a computer assisted process planning system for turned components. The system incorporated modules for component geometry representation, automatic selection and sequencing of machining operations, process parameter selection, machine and tool selection, time and cost calculation and finally report generation with an aim to provide a quick and efficient method of generating consistent process plans.

The lead time in preparing process sheets had also been reported to have been considerably reduced as a result.

GURUSAN, BATRA J. L & JAIN V. K. [8] presented a systematic methodology for the generation of computerized process plan for electrochemically machined components produced on standard sinking machine.

The system is divided into two modules viz, input moduleand planning module. The imput module collects and accept information on available machine tool, anode material, electrolyte property and the geometric feature to be machined on the work-piece, while the planning module combines features for simultaneous machining, their optimal sequencing and determining the optimal machining parameters.

These procedures when repeated for each machine tool could indentify the most economical machine tool for performing all the operations. This system helped the planner to generate logical and optimal process plans in the non-traditional machining area where *CAPP* efforts have not been rather signigicant.

CHAPTER - III

SYSTEM ANALYSIS AND DESIGN

CHAPTER - III

SYSTEM ANALYSIS AND DESIGN

3.1 PROCESS SELECTION

To make efficient use of non-traditional machining processes, it is necessary to know the exact features of the machining task. It is to be understood that a particular machining method found suitable a set of given conditions may not be equally efficient under other conditions. Therefore a judicious selection of the process for a given machining task is essential.

The following perspective features are to be given due consideration to ensure judicious selection procedure :

i] Physical parameters

ii] Properties of the work material and the profile to be machined

iii] Process Capability

iv] Economic considerations

A matrix of physical parameters of processes and the processes themselves have been presented in Table 1.2 (page-19). It is evident from such representation that both *EDM* and *USM* require approximately the same power, whereas *ECM* consumes roughly forty times more power than *EDM*. applications of modern machining processes have been presented in Table 1.3 (page- 20). It can be seen here that although *ECM* consumes much greater power, it is an excellent method for drilling long holes with length/dia ratio > 20 mm.

Material application of the various machining methods are summarized in Table 1.4 (Page- 21). It can be observed that for the machining of electrically non-conducting materials both *ECM* and *EDM* can not be used straight way, whereas the machanical methods can achieve the desired results. Process capability have been presented in Table 1.5 (Page- 22).

It is further observed from this table that although *ECM* results in excellent surface finish, it can be accompanied by extensive surface damage as compared to *AJM* or *USM*. Effects on equipments and toolings have been presented in Table 1.6 (page-23). It can be commented from this table that *ECM* has another advantage of a very low tool wear ratio. A comparison of the process economy and their relative efficiencies are given in Table 1.7 (Page-24) and Fig 1.1 respectively.

3.2 ELECTRIC DISCHARGE MACHINING (EDM)

In 1970 the English scientist, Priestly, first observed and detected the erosive effect of electrical discharges on metals. Later on during research the soviet scientists Lazarenko B R and Lazarenko N I, decided to exploit the destructive effect of an electrical discharge. Subsequently they develop a controlled method of metal machining utilising the erosiv effect of electrical discharge. In 1943 they reported the developement and construction of the first spark erosion machine. The spark generator used in 1943, known as the Lazarenko circuit has been employed over many years in power supplies for *EDM* mcahines and an improved form is being used in many current application.

Table 1.2

Physical Parameters of the Modern Machining Processes

Parameter	USM	AJM	ECM	CHM	EDM	EBM	LBM	PAM
Potential (V)	220	220	10	–	45	150,000	4500	100
Current (Amp)	12 (A.C)	1.0	10,000 (D.C)	–	50 (Pulsed D.C)	.001 (Pulsed D.C)	2 (agerage 200 peak)	500 (DC)
Power (W)	2400	220	100,000	–	2700	150 (average 200 peak)	–	50,000
Gap (mm)	0.25	0.75	0.20	–	0.025	100	150	7.5
Medium	Abrasive in water	Abrasive in gas	Electrolyte	Liqued chemical	Liqued dielectric	Vaccum	Air	Argon or hydrogen

Table 1.3

Shape Applications of Modern Machining Processes

Process	Holes: Precision small holes, Dia <.025 mm	Holes: Precision small holes, Dia >.025 mm	Holes: Standard, Length <20 Dia	Holes: Standard, Length >20 Dia	Through cavities: Precision	Through cavities: Standard	Surfaceing: Doubles contouring	Surfaceing: Surfaces of revolution	Through cutting: Shallow	Through cutting: Deep
USM	—	—	G	P	G	G	P	—	P	—
AJM	—	—	F	P	P	F	—	—	G	—
ECM	—	—	G	G	F	G	G	F	G	G
CHM	F	F	—	—	P	F	—	—	G	—
EDM	—	—	G	F	G	G	F	—	P	—
LBM	G	G	F	P	P	P	—	—	G	F
PAM	—	—	F	—	P	P	—	P	G	G

NOTE G Good F Fair P Poor

Table 1.4

Materials Application

Process	Material							
	Aluminium	Steel	Super alloys	Titanium	Refractories	Plastics	Ceramics	Glass
USM	P	F	P	F	G	F	G	G
AJM	F	F	G	F	G	F	G	G
ECM	F	G	G	F	F	N	NP	N
CHM	G	G	F	F	P	P	P	F
EDM	F	G	G	G	G	N	N	N
EBM	F	F	F	F	G	F	G	F
LBM	F	F	F	F	P	F	G	F
PAM	G	G	G	F	P	P	N	N

NOTE **G** Good Application **F** Fair **P** Poor **N** Not applicable

Table 1.5

Process Capability

Process	Metal removal rate mm3/min	Tolerance μ	Surface finish CLA μ	Surface damage depth μ	Corner radii mm
USM	300	7.5	0.2-0.5	25	0.025
AJM	0.8	50	0.5-1.2	2.5	0.100
ECM	01500	50	0.1-2.5	5.0	0.025
CHM	15.0	50	0.4-2.5	50	0.125
EDM	800	15	0.2-12.5	125	0.025
EBM	1.6	25	0.4-2.5	250	2.50
LBM	0.1	25	0.4-1.25	125	2.50
PAM	75000	125	Rough	500	—
Conventional milling of steel	50000	50	0.4-5.0	25	0.050

Table 1.6

Effects on Equipments and Tooling

Process	Tool wear ratio	Machining medium contamination	Safety	Toxity
USM	10	NRP	NP	NP
AJM	—	NRP	NRP	NP
ECM	0	CP	NRP	NP
EDM	6.6	NRP	NRP	NRP
EBM	—	NRP	NRP	NP
LBM	—	NP	NRP	NP
PAM	—	NP	NP	NP
Tool Wear Ratio	—	volume of work material removed/volume of tool electrode removed		

NOTE

NP No Problem **NRP** Normal Problem **CP** Critical Problem

Table 1.7

Process Economy

Process	Capital investment	Tooling and fixtures	Power requirement	Efficiency	Tool consumption
USM	L	L	L	H	M
AJM	VL	L	L	H	L
ECM	VH	M	M	L	VL
CHM	M	L	H	M	VL
EDM	M	H	L	H	H
EBM	H	L	L	VA	VL
LBM	M	L	VL	VH	VL
PAM	VL	L	VL	VL	VL
Conventional machining	L	L	L	VL	L

NOTE

VL Very Low Cost **B** Low **M** Medium **H** High **VH** Very High

In *EDM* a suitable shaped tool electrode, with a precision controlled feed movement is employed in place of cutting tool as in the case of conventional cutting process. The cutting energy is provided by means of short duration electrical impulses.

The *EDM* process has the added advantage of being capable of machining complicated components.

The popularity of *EDM* process is due to the following advantages:

i) During machining, the work piece is not subjected to mechanical de formation as there is no physical contact between the tool and the work. This makes the process more varsatile.

ii) The process can readily be applied to electrically conductive materials. Physical and metallurgical properties of the work material, such as strength, toughness, micro structure no longer acts as barrier to its application.

iii) The matal removal in *EDM* is due to thormal effects but there is no heating in the bulk of the material.

iv) Complicated die contours in hard materials can be produced to a high degree of accuracy and surface finish.

v) The surface produced by *EDM* consists of a multitude of small craters.

This helps in oil retention and better lubrication, specially for component where lubrication is a porblem.

SPARK EROSION MACHINING PROCESSES

Electric Discharge Machining (*EDM*) is the removal of matericals conducting electricity by electrical discharges between two electrodes *(W/P electrode and tool electrode)*, a dielectric fluid being used in the process. The aim of the process is controlled removal of material from the work piece. *Fig. 1.1* (page-27) shows a classification of the speark erosion machining processes.

SINKING BY EDM

Material removal in sinking operation is affected by non stationary electrical discharges which are seperated from each other both spatially and temporarily. This process includes those *EDM* operations in which the avarage relative speed between the tool and work piece is coincident with the penetration speed in the work piece *(Fig. 1.2)* (page- 28).

CUTTING BY EDM

It includes those machining operations where the work piece is cut off. *Fig. 1.3* to *Fig 1.6* (page- 29-32)demostrate various *EDM* cutting operations.

GRINDING BY EDM

Spark erosion grinding embraces the machining processes made with

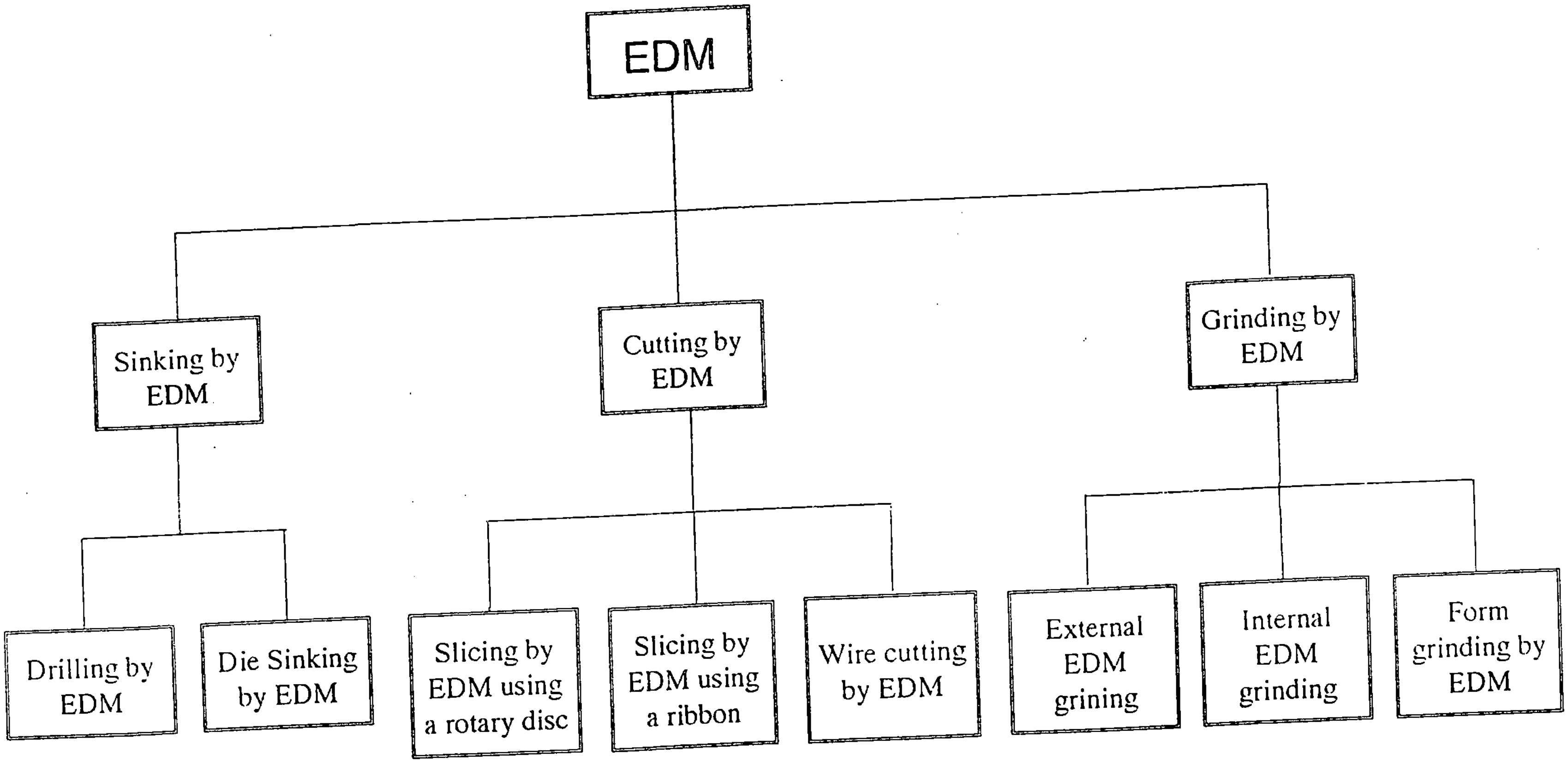


Fig 1.1 Classification of Spark Erosion Machining Processes

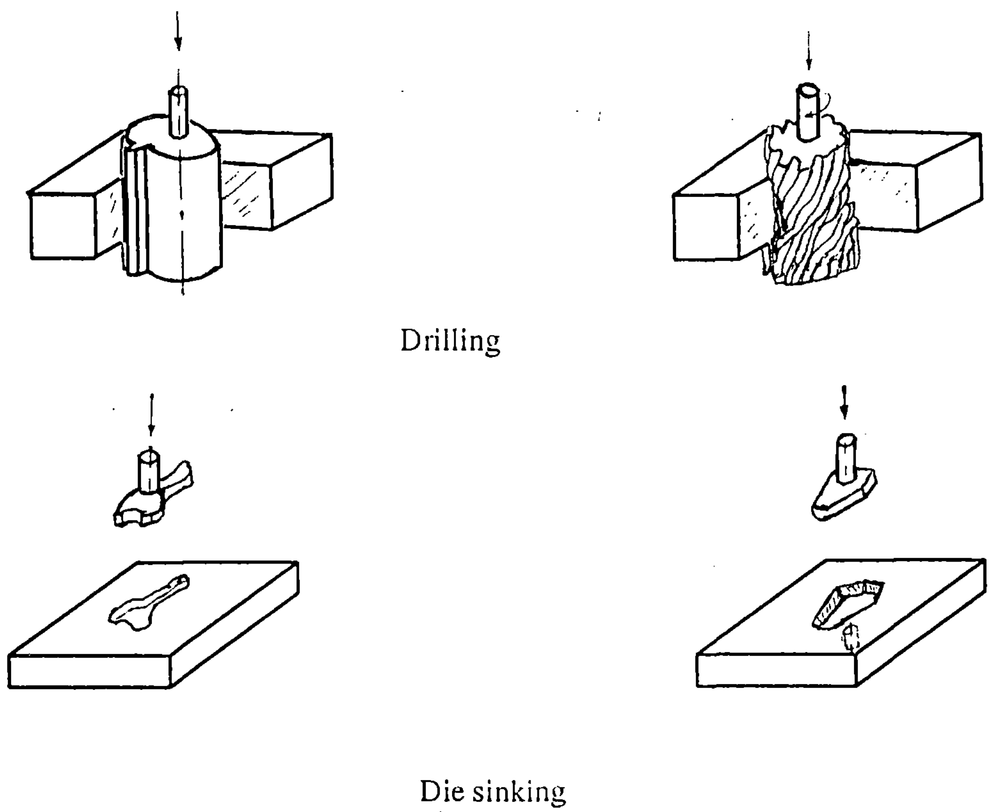


Fig 1.2 Sinking by EDM.

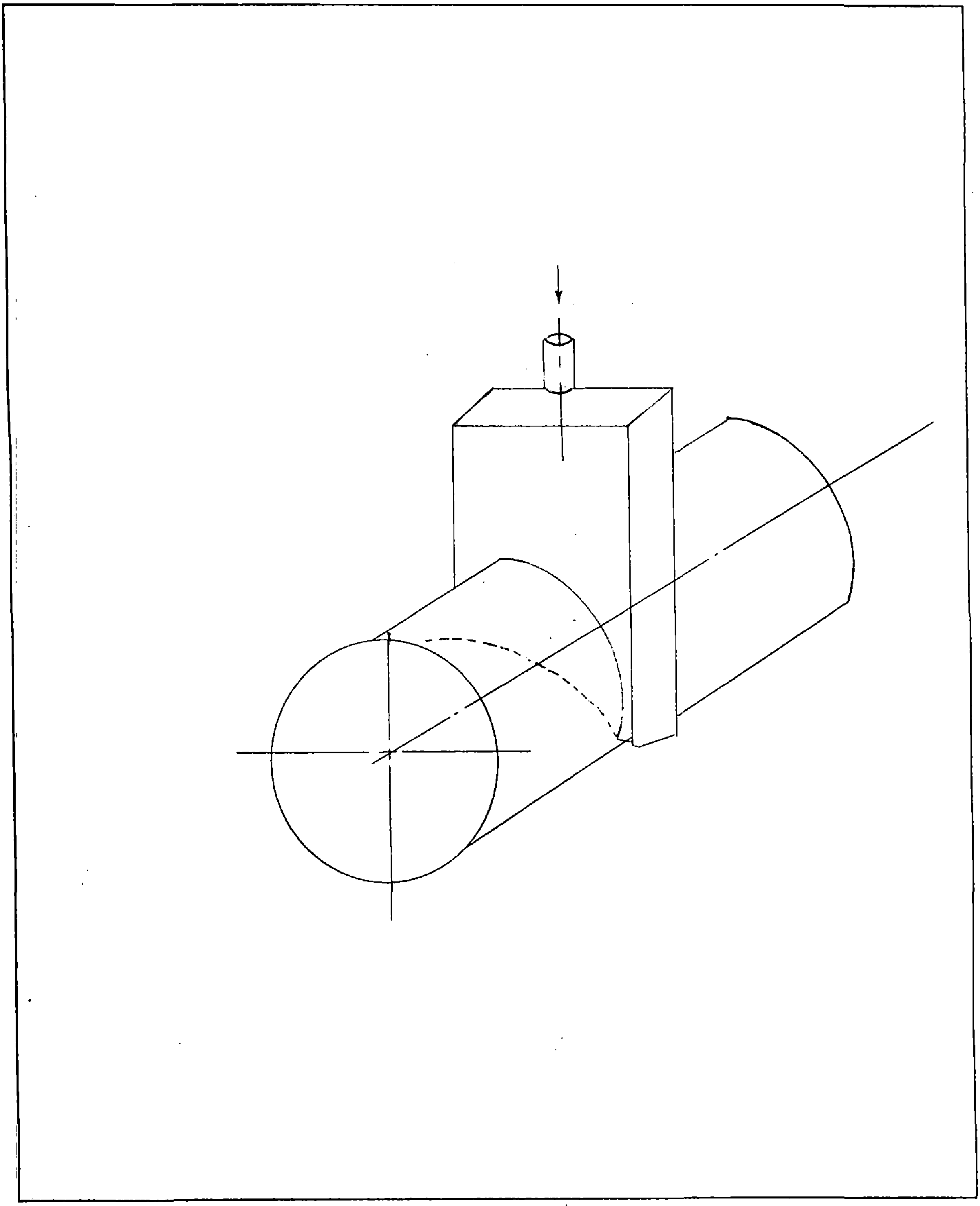


Fig 1.3 Spark Erosion cutting with a blade.

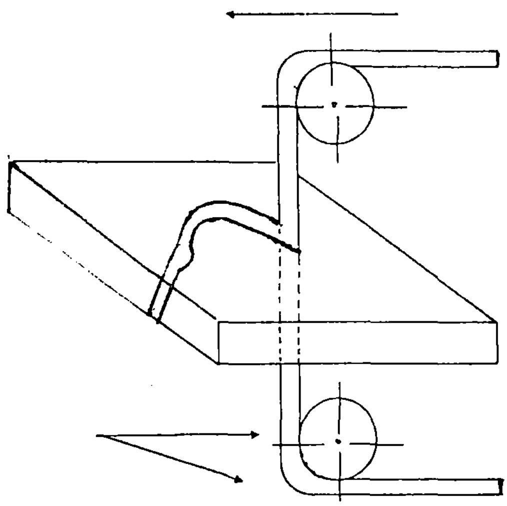


Fig 1.4 Spark Errosion cutting with a wire.

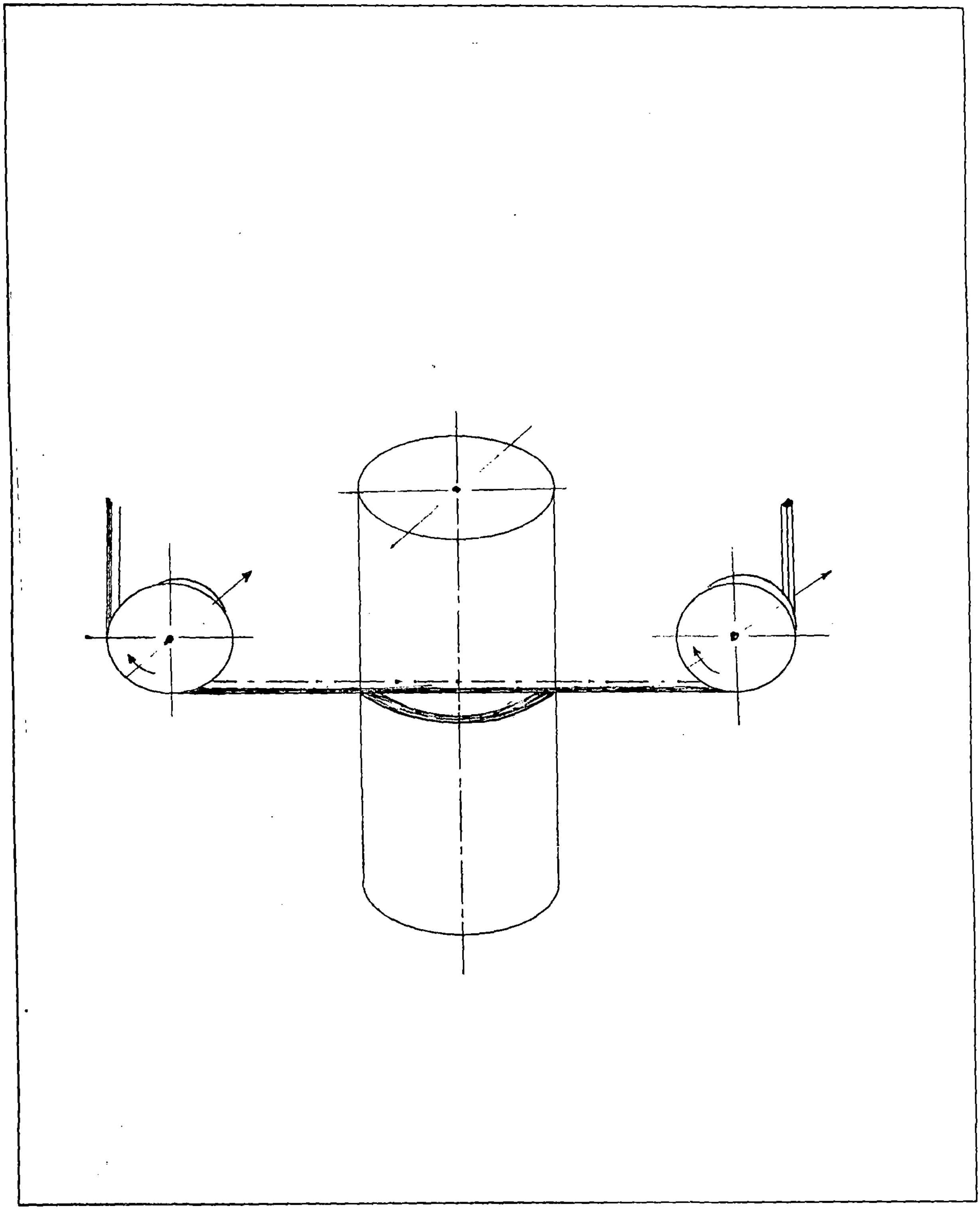


Fig 1.5 Spark Errosion cutting with a Ribbon.

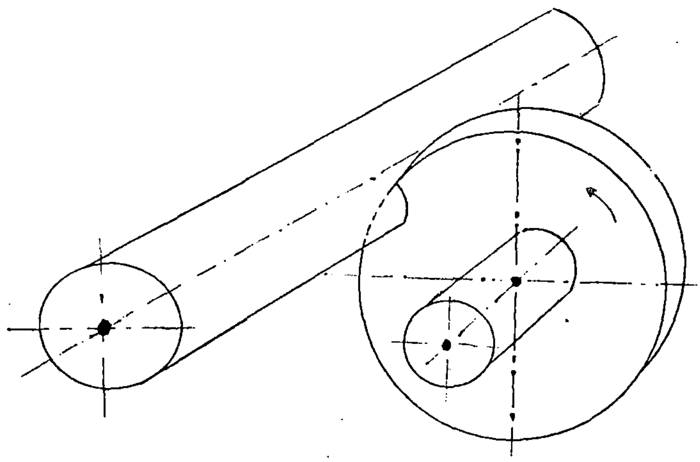


Fig 1.6 Spark Errosion Cutting with a rotating disc.

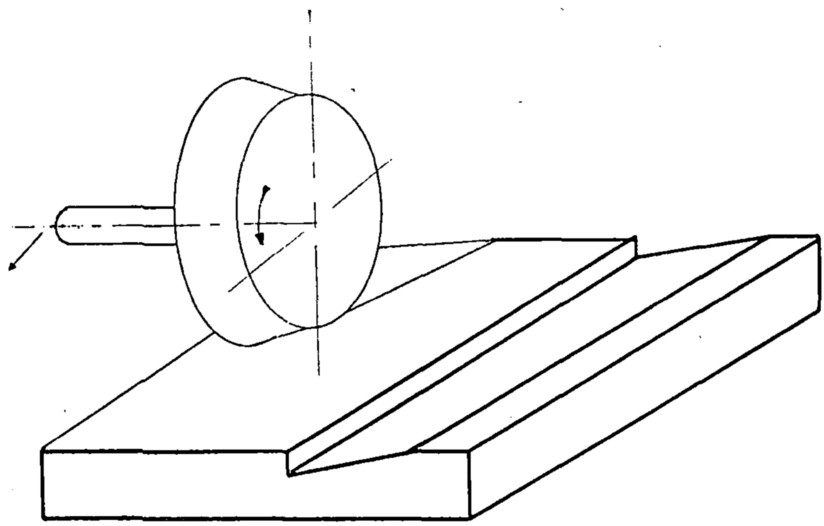


Fig 1.7 Spark - Errosion Flat Grinding with profile.

an electrode rotating around an axis in addition to normal electrode feed. The forms and arrangement are shown in *Fig. 1.7* (page- 33).

3.3 MECHANISM OF METAL REMOVAL

The basic scheme as enunciated earlier ensures a discharge between two electrodes (tool cathode and work anode) through a liqued midium.

As soon as a suitable voltage is built up across the tool *(or chathode)* and the work piece (or anode), seperated by a properly chosen spark gap filled with the dielectric fluid, The breakdown of the dielectric medium takes place owing to the development of a strong electrostatic field between the electrodes. The field thus created causes a cold emission of electrons from the cathode surface towards the anode initiated from the micro-irregularities on either electrode yielding shortest flow parhs. Thus a free electron, liberated from the cathode surface, gets accelerated towards the anode by the electric field clready established and acquires a high velocity on being accelerated by the effect of the electrical field. The short mean free path between molecules in the dielectric fluid leads to the collission between the free electrons and the dielectric fluid molecules, as the former moves through the dielectric medium.

The dielectric fluid molecule decomposes into electrons (negative) and positive ions (proton) as shown in Fig. 1.8 (a) & (b) (page- 36) provided the free electron carries sufficient energy at the time of collision. The electrons so produced also accelerate and may ultimately dislodge the other electrons from the dielectric fluid molecules.

The continuing ionization phenomenon results in the formation of a narrow channel of continious conductivity. A considerable amount of electrons flow along the channel, thus created, to the anode. These flow electrons cause a momentary current impulse or discharge. This impulsive current enables liberation of energy which leads to the generation of extremly high temp appx. 10000°c localised over a micro area and causing fusion by the partial vapourisation of the meterial as well as the dielectric fluid at the point of discharge.

Since the momentum with the positive ions strikes the cathode surface is much less than the momentum with which the electron stream impinges on the anode surface, comparatively less marerial is eroded from the cathode then the anode.

Consequent upon this happening, the gap between the electrodes at A increases and nolonger represents the shortest path. Another path of irregularity location some where else serves as the location of the second discharge channel. in such way the cycle is repeated, with the sparks wandering all over the electrode surface and, ultimately the process results in a uniform gap so, depending on the negative electrode shape, an impression is created on the other electrode.

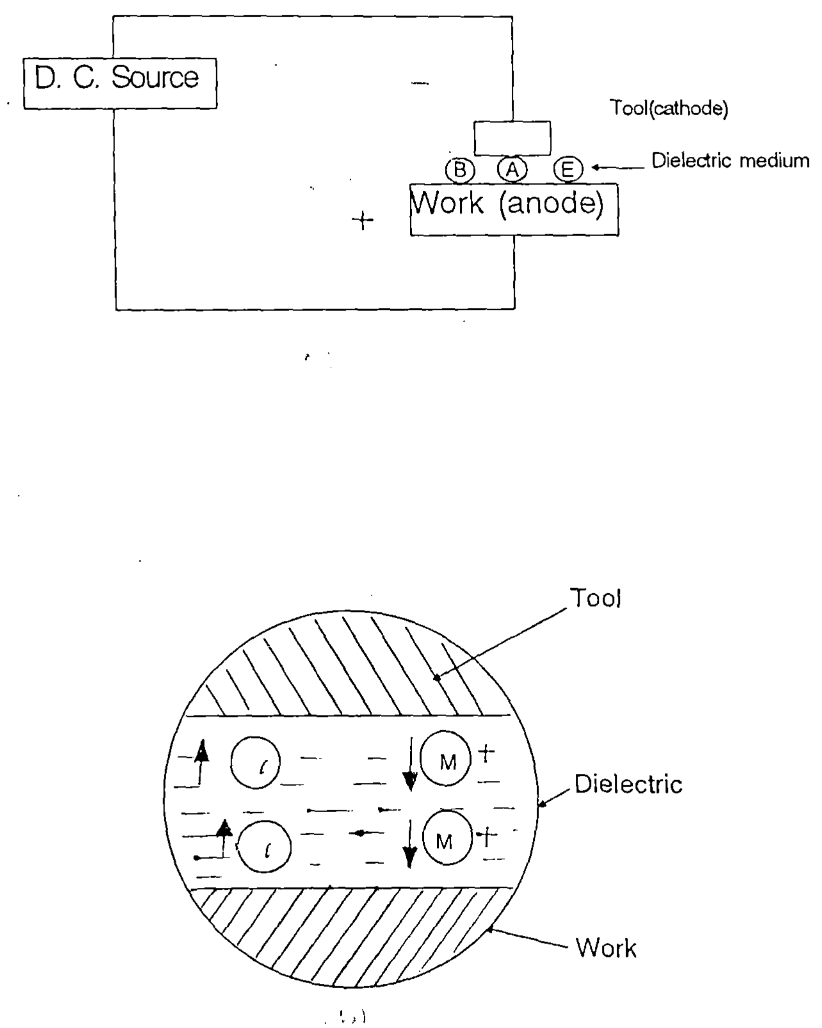


Fig 1.8 (a) & (b) Basic Principle of EDM.

3.4 WIRE EDM

The latest developments have brought about systems / form of *EDM* operation - *EDM* by wire cutting using a thin copper, brass, tungsten wire which acts as the tool with deionised water as dielectric fluid. Instead of using expensive shaped electrodes, it uses expondable wire to vapourize metal as it moves through the work piece.

The main requirement for machining by wire *EDM* are that work piece be electrically conductive and essentially flat and that all cuts be through type machining - no blind cavities can be cut. There are no limitations interms of its applicability while operating on high-strength-temp-resistance alloys *(HSTR)* or even diffcult to machine alloys such as wasp alloy or molybdenum which are rather readily machined by this process.

Conventional *EDM* has got certain shortcomings which can be easily overcome by *EDM* wire cutting sacrificing the accuracy and the surface finish at economical cost. Shortcomings of conventional *EDM* are as follow:

i) The wear of the working electrode inevitable affects the accuracy of machining, one tool electrode can, therefor produce only a limited number of parts, sometimes only 2 or 3.

ii) A working electrode can only produce a part of definite shape and dimensions, for another work piece, regardless of how much it differs from the former, a new tool electrode is required.

iii) The consumption of Labour and material in manfacturing the electrodes is realatively high.

The pilot hole in the workpiece is first drilled by conventional machining before heat treatment. The wire is unwounded from thr feeding spool by a drive at a constant speed, passes through a tension mechanism and through the work piece. The expanded wire is rewound on the take up spool. This system creates a situation in which a new electrode *(wire)* is being continiously presented to the machining zone.

Deionised Water is used as a dielectric fluid, rather than oil or kerosine *(as in the case of conventional EDM)* because it affords better flushing and cooling.

Both the work piece and the wire are eroded in the process, but the erosion of the wire does not affect the accuracy of the cut because the wire passes through the work only once. The size of the overcut depends on the spark gap and the depth of the crater produced by the single discharge.

The width of cut `b' depends on the wire diameter `d', the spark gap 'l' and the depth of the crater produced by a single discharge` δ'

$$b = d + 2l + 2\delta$$

$$= d + 2\theta$$

where $\therefore \theta = l + \delta =$ overcut also $\therefore \delta = K. Wp^{1/3}$ where $Wp \rightarrow$ pulse energy = $1/2\ cv^2$

$$\therefore \theta = l + K (1/2\ cv^2)^{1/3}$$

3.5 APPLICATIONS OF EDM/WEDM

Spark machining is used for the manufacture of internal profiles having complicated geometry and for a number of other components with relatively simpler profiles but involving difficult to machine materials. Spark erosion provides an economic advantage particularly for making metal forming tools & dies like stamping tools, wire drawing and extrusion dies, header dies, forging dies, intricate mould cavities etc. Besides, it has been extensively used for machining of exotic materials used in aero-space industries, refractory metals, hard carbides and hardenable steels.

EDM by wire cutting is extensively used in tool and die making industries. All the die shaving through type cavities can be machined by it, e.g. extrusion dies, progressive dies and punches, piercing, compound dies etc.

Moreover this process is already heavily relied upon to make cam wheels, special gears, stators for stepping motors and similar intricate parts.

The initial models of wire cut *EDM* system incorporating travelling wire *EDM* could cut openings of any shape so long as they had straight walls. Now-a-days a number of attachments or models are available that make it easier and possible to orient the wire in other positions than being perpendicular to the X and Y axes.

To mention as an example Mitsubisni of *JAPAN* achieves 3 dimensional machining as a travelling wire machine with an attachment that introduces two additional axes, known as U and V. This attachment is basically a set of drive motors displaces the upper wire guide to the right or left side of the machine. The other pushes the upper wire gùide to the front or back of the machine. The lower guide remains stationary in relation to the upper guide. The drive motors are linked with the Computer Numerical Control *(CNC)* and are controlled by programmed commands. The wire can be tilted any amout up to $\pm$ 10° as it travels in the X and Y axes.

In our country the following industries and organisation are extensively using *EDM/ wire EDM* for their convenience. Indian Fine Blank, General Electric Company, Voltas India Ltd, Hindustan Aeronanties Ltd, Hindustan Machine Tools, CTTC etc. are the examples

3.6 N/C EDM

Fig (1.9) (page- 43) is a graphic representation of the basic Numerically Controlled *EDM* process. The strength of Numerical Controlled *EDM* lies in the basic makeup of the Process.

The general advantages of EDM includes the ability to erode hardened-tool-steels, tungsten carbide, and some of the exotic materials with good finish and tolerance control. The fixturing reqirements is minimal and as such cutting forces are negligible.

While the job is running the EDM operator usually gets sufficient in-cycle free time. In case of numerically controlled EDM, new jobs can be set up and run with only minor changes (usually only tool changes), job runs may be stopped and started at specific program locations as desired. After a first piece is approved, repeatability and accuracy are consistent unless the operator intervenes or program changes are made since the machine tool functions are controlled by the numerical unit which as well can make processing of any job possible with only minimal operator attention and or intervention.

The combination of features from numerical control technique and spark erosion process result in a process that will machine almost any material which is electrically conductive. The process will produce 2 dimensional shapes that are limited in profile complexity only by programming capabilities, and certain restrictions imposed by workpiece size. The former limitations are minimal if state-of-the-art programming languages are employed. Once setup, a job may be left unattended during the erosion cycle already mentioned.

Pressworking tools are excellent examples of ideal workload for numerical controlled *EDM*. The making of these tools is highly desirable because fabrication by any other alternate method would require a significantly higher labor cost.

Numerically Controlled EDM process have the capabilities of generating sharp corners and fillets, good surface finish at relatively fast speed of machining.

"Impossible" jobs such as square internal corners, narrow slot machining in tunssten carbide or hardened steel, erosion of conventional *EDM* electrodes, with allowance for roughing and finishing generated from the same numerical control programme are typical applications.

Numerical Control EDM have shown significant savings in direct labor for production of parts and tools.

One of the important advantages of numerically controlled EDM is the minimization of operator error since the effect of operator's capability, skill are limited to the activities of setting of the job.

If the numerical control programme setup and operating parameters are aceptable, results will be acceptable and insensitive to the construct job queries and other error - producing factors which might influence a machine tool operator resulting in a costly and untimely error.

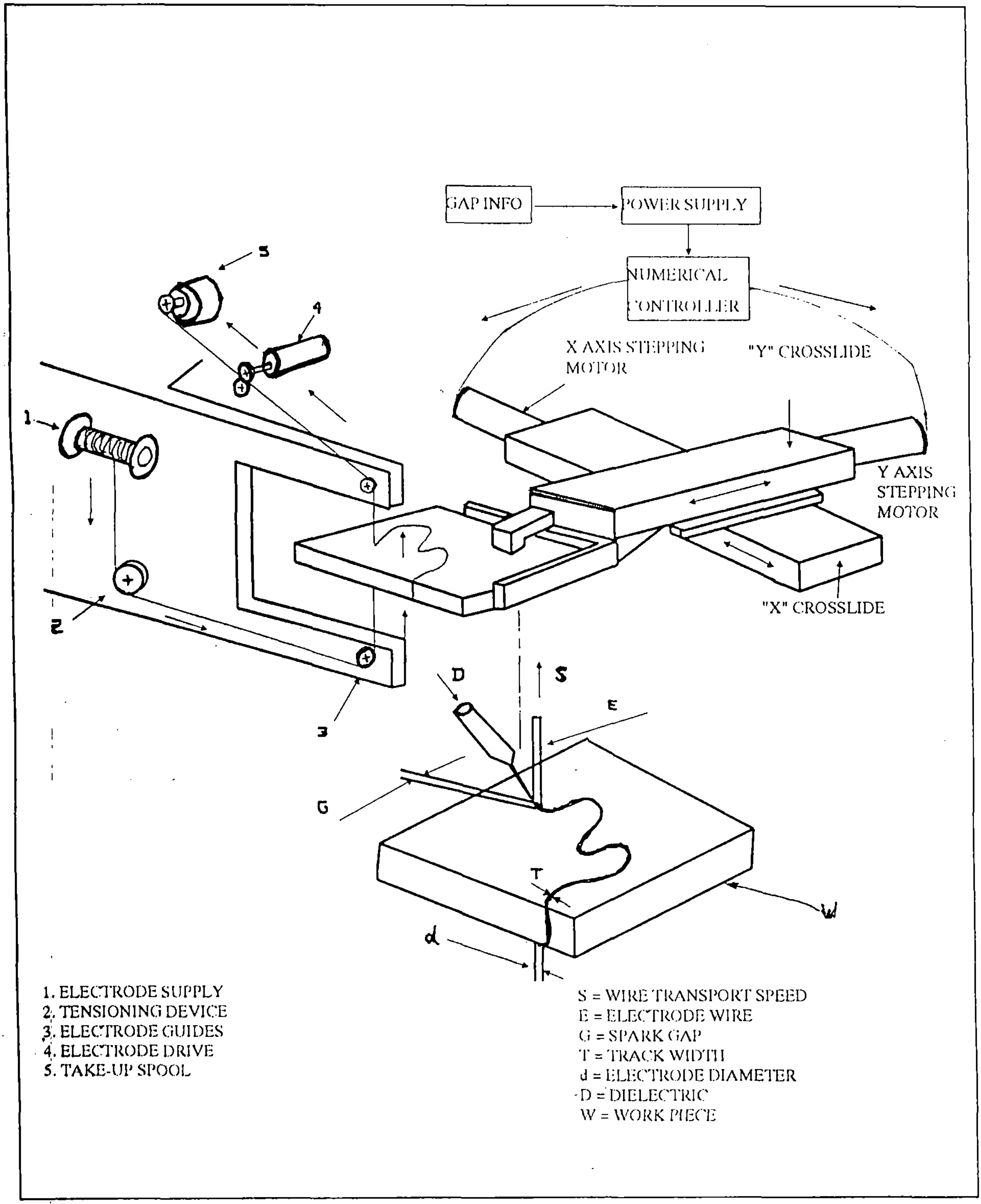


Fig 1.9 The basic N/C EDM Process.

CHAPTER - IV

SYSTEM IMPELEMENTATION

4.1 DECISION REGARDING NO. OF CUTS

For Completing any job three different modes of material removals namely Roughing, semi-finishing & finishing can be made use of.

The ultimate choice is primarily guided by the desired surface finish.

If the target surface roughness is between 0.4 μm to 1.4 μm three machining operation modes Roughining, Semi-finishing & Finishing are to be adopted except for small holes where two operation mode only will be necessary.

If the surface roughness required is between 1.4 μm to 2.2 μm two or three machining operation depends comparing the manufacturing cost of a third electrode to the again resulting from the reduction of time by a medium machining stage i.e. semi-finishing.

If the surface roughness required is above 2.2 μm in theory, two operation mode i.e. One Rough cut and one Finish cut will be sufficient. Surface roughness required more than 10 μm can be done by a single cut operation.

The difference between the various surface roughness values of the selected settings will be smaller between finishing and semi-finishing than between semifinishing & roughing.

BASIC FORMULA TO CALCUALTE MACHINING TIME FOR EDM OPERATION

$$\text{Machining Time} = \frac{\text{Material Valume to be removed in } mm^3}{\text{Material Removal rate in } mm^3/min. \text{ (MRR)}}$$

$$= \frac{V\ mm^3}{M\ mm^3/min}$$

Where V representes material volume to be removed in mm^3 and M represent Material removal rate in mm^3/min.

A mathmatical model for Material Removal rate for different electrode with work piece material as steel is shown in table 3 (page-51) which has been developed by using Regression analysis in form which Machining time for spark erosion machine is easily calculated.

Similarly a mathmatical model for different work piece material with electrode as Brass is shown in table 4 (page-52) which has been develoo `ped by using Requression Analysis with the original datas obtained from General Electric Company, Calcutta, from which machining time for wire out machines is easily calculated.

Cost of wirecut of EDM machinies is Rs. 500 / hr. where as cost of spark erosion EDM machines is Rs. 300 / hr. approximatly.

Material wolume to be removed ($V\ mm^3$) = Frontal area x Machining Depth.

Distance between the electrode and workpiece not at right angle to the axis of electrode penetration is known as Frontal gap. The area generated by this gap is known as Frontal area.

Material reomval rate ($M\ mm^3 / min$) are the maximum values which can be obtained only when the Frontal area is enough to accept maximum current.

FOR ROUGHING OPERATION

Frantal area = Total Frontal area - pre machining Frontal area.

FOR FINISHING OPERATION

$$\text{Frontal are} = \left(\frac{\text{Safety cut}}{2}\right) +$$

$$\left(\frac{\text{Dia. limit sparking dist - Dia mean sparking dist}}{2}\right)$$

x Perimeter of Machined Hole.

DIA LIMIT SPEARKING DISTANCE

The difference between the dimension of the electrode and dimension of the cavity, measured at bottom of the oraters.

DIA MEAN SPARKING DIST

The difference between the dimension of the electrode and dimension of the cavity, measured on the median line of creater is known as dia. mean sparking distance.

4.2 INTENSITY LEVEL

Different intensity levels can be selected with generator (Ref. Charmlles D-10 Model). Intesity level allows a mean current of 25A maximum to pass between electrode and Workpiece. Intensity level $^1/_2$, $^1/_4$, $^1/_8$, $^1/_{16}$, $^1/_{32}$ correspondintly represents a mean current of 12.5, 6.25, 3.1, 1.5 and 0.75 amp maxm. to pass between electrode and work piece. The Frontal area between electrode and workpiece is used as a guide in selectiog intensity level as shown in Table 2 (page-50). Recommended intensity level with electrode having different frontal area bas been represented as shown in Table 1 (page-49).

4.3 POLARITY

Machining polarity is always defined by the polarity to which the electrode in connected.

The influence of ploarity depends upon the electrode and work piece material being used.

4.4 SAFETY MARGIN OR SAFETY CUT

An increase in the under-sizing of roughing and semifinishing elictrodes calculated according to the technology to take into account any possible error between axis and shapes of roughing, semi-finishing and finishing electrodes.

4.5 INJECTION / SUCTION, FLUSHING

Circulation of dieelectric fluid in the gap due to a pressure higher than the atmospheric pressure is known as Injection Flushing.

Circulation of dicleetic fluid in the gap due to a pressure lower than the atmospheric presure is known as suction flushing.

TABLE - 1

Frantal area	Recommended intensity level with Electrode	
	Gr + Gr -	Cu + Cu -
0 to 0.1 cm²	1/8 to 1/4	1/8 to 1/4
0.1 to 0.25 cm²	1/4 to 1/2	1/4 to 1/2
0.25 to 1 cm²	1/2 to 1	1/2 to 1
1 to 4 cm²	1 to 2	1/2 to 2
4 to 16 cm²	2 to 4	1 to 2
16 to 64cm²	4 to 8	1 to 2
64 cm² and above	8	1 to 2

TABLE - 2

Intcnsity Level	Maximum Current
1/8	3.10 amp
1/4	6.25 amp
1/2	12.50 amp
1	25.00 amp
2	50.00 amp
4	100.00 amp
8	200.00 amp
16	400.00 amp

TABLE - 3

Electrode	Work pice material	Material Remuval rate (mm^3 / min)
Graphite (+ve)	Steel	$X_1 = 295 (X_2)^{0.89} . (X_3)^{0.6}$
Graphite (-ve)	Steel	$X_1 = 295 (X_2)^{.83} . (X_3)^{0.8}$
Cupper (+ve)	Steel	$X_1 = 2089 (X_2)^{1.17} . (X_3)^{1.02}$
Cupper (-ve)	Steel	$X_1 = 0.158 (X_2)^{0.26} . (X_3)^{1.82}$

X_1 ⇨ Material Removal rate
X_2 ⇨ Surface Roughness required in mm
X_3 ⇨ Maxm current in amp.

TABLE - 4

Electrode	Work piece material	Machining speed. (mm^3 / min)
Brass	High Carbon High Cromium (HCHCR)	$X_1 = 2.23 - .027 (X_2)$
Brass	Brass	$X_1 = 3.83 - .041 (X_2)$
Brass	Tungsten Carbide.	$X_1 = 0.41 - .002 (X_2)$
Brass	Steel	$X_1 = 0.45 - .005 (X_2)$

X_1 ⇨ Machining speed

X_2 ⇨ Profile Depth in mm.

$$\text{Machining Time} = \frac{\text{Perimeter of the job to be profiled}}{\text{Machining Speed}}$$

CHAPTER - V

CASE STUDY FOR AN OPEN THROUGH JOB

CASE STUDY FOR AN OPEN THROUGH JOB (Ref. Fig. page-60)

5.1 NORMAL EDM

i] Workpiece material - High carbon High chromium steel

Surface finish required - 2 μm.

Taper : 0.01 mm maxm.

No. of Parts - 1.

Part preparation - a 10 mm dia. hole is drilled prior to heat treatment.

ii] Number of machine setting and their values for normal *EDM*.

According to discussion as mentioned "Decision regarding No. of cuts" (chap-iv) two or three diff. settings can be chosen. In this example two settings is enough since the machining depth is below 20 mm and the saving of machining time by including a semi-finishing operation is less than the manf. cost of a third electrode.

Finishing : Surface roughness 2 μm.

Roughing : Surface roughness between 4 μm and 9 μm.

iii] Selection of electrode material for normal *EDM*

For machining steel *(st.)* tungsten carbide *(cw)* and various other material following electrode materials are available.

- Copper *(cu)*
- Copper tungsten *(cuw)*
- Graphite *(gr)*
- Copper graphite *(cu gr)*

For this simple application, we eliminate both copper tungsten *(Cuw)* and CuGr (copper graphite) since both are bery expensive. Therefore choice of electrode material is restricted between coper and graphite in this example.

iv] Electrode Material for normal EDM

a) Roughing : From the machining characteristics description available, surface finish between 4 μm and 9 μm can be obtained either by *Cu* or *Gr* electrodes. Graphite gives high removal rates with negative palarity. The electrode wear is, of course, high, but this is not so important with cylindrical hole machining.

In this case graphite will be chosen, since it is easier to machine than copper.

b) Finishing : In the same reason as in Roughing, graphite will be chosen for this operation also.

v) Basic Setting Parameters for normal EDM

a) Polarity : for roughing as well as finishing the machining characteristics description available shows that (-)ve polarity is faster.

b) Intensity level

Frontal area for

Roughing Operation = Total Frontal area - Premachining Frontal area

$$= 50 \times 25 - \frac{\lambda \times 10^2}{4}$$

$$= 1250 - 78.5$$

$$= 1171.50 \text{ mm}^2$$

$$= 11.72 \text{ cm}^2$$

ROUGHING

The Frontal area of the through hole being 11.72 cm^2 the chioce between intensity levels is 2 and 4 (Ref Table 1). Being closer to the lower limit, intensity level 2 will be slected for roughing operation.

FINISHING

From the machining charcteristics description availabe only intensity level 1/4 can be used to obtain a surface finish 2 μm for finishing operation.

vi) **Suction Flushing :**

Suction flushing avoids the taper effect due to sparking via parti cles along the sides of the electrode. The hole obtained is thus practically cylindrical.

INJECTION FLUSHING :

Components machined using injection flushing are always slightly tapped, even when using an electrode with a constant profile. The taper effect is due to particles being forced up the sides of the electrode, producing lateral discharge. As a result, this flushing methods is often used when machining press tools, where a slight taper clearence is required. In this case taper of 0.01 *mm* *(negligible)* can be obtained by suction.

vii) Data summary (Refer page-61)

viii) CALCULATION OF MACHINING TIME

ROUGHING

$$\text{Frantal are} = 50 \times 25 - \frac{\lambda \times 10^2}{4} = 1171.5\ mm^2$$

$$\text{Material volume to be removed } (V) = 1171.5 \times 15$$

$$= 17{,}572.5\ mm^3$$

From the machining characteristics description available Maxm. material removal rate *(M)* for surface finish required 4 - 9 μm with Int. level 2 is 550 mm^3/min. (Refer table-3, page- 51)

$$\therefore \text{Machining time for Roughing} = \frac{V}{M} = \frac{17,572.5}{550} \, min.$$

$$= 31.9 \, min.$$

FINISHING

$$\text{Frantal area} = \left(\frac{0.4}{2} + \frac{0.32 - 0.170}{2}\right) \times \text{Perimeter of Machined hole}$$

$$= \left(\frac{0.4}{2} + \frac{0.32 - 0.170}{2}\right) \times 150 \, mm^2$$

$$= 40.65 \, mm^2$$

Material volume to be removed (V) = 40.65 x 15

= 609.75 mm^3

From the machining characteristics description available maximum material removal rate *(M)* for this stage i.e. at intensity level 1/4 and surface finish requird 2 µm is 20 mm^3/min. (Refer table-3, page-51)

$$\therefore \text{Machining time for Roughing} = \frac{V}{M} = \frac{600.75}{20} \, min.$$

$$= 30.48 \, min$$

$\therefore$ Total Machining time = Roughing Time + Finishing Time

= 31.9 + 30.48 min

= 62.38 min.

= about one hour

$\therefore$ Total Cost = Appx. Rs. 300/-

(The cost of normal EDM is Rs. 300/- Hr. for charmilles model)

5.2 WIRE-CUT EDM

With the help of wire cut *EDM* we can achieve required surface roughness values of about .4µm to 1.4µm by a single cut operation mode instead of 2 or 3 operation mode as in normal *EDM*. Machining for all workpiece material such as tungsten carbide and other non-ferrous material like Brass, Aluminium, Copper can be done by a single cut operation except for High carbon High chromium steel where sometimes 2 operation modes i.e. one Rough and one Finishing are necessary depending on the very low surface roughness value required.

For this present example as surface roughness required is 2 µm single cut operation will be chosen.

Perimeter of the machined surface = 2 (50 + 25) - 10λ

= 150 - 31.4 = 118.6 *mm*

From the machining characteristics description available for wire cut EDM, machining speed (Low) for High carbon High chromium steel 15 mm thick work piece material at finish cut is 1.6 mm/min.(Refer table-4, page-52)

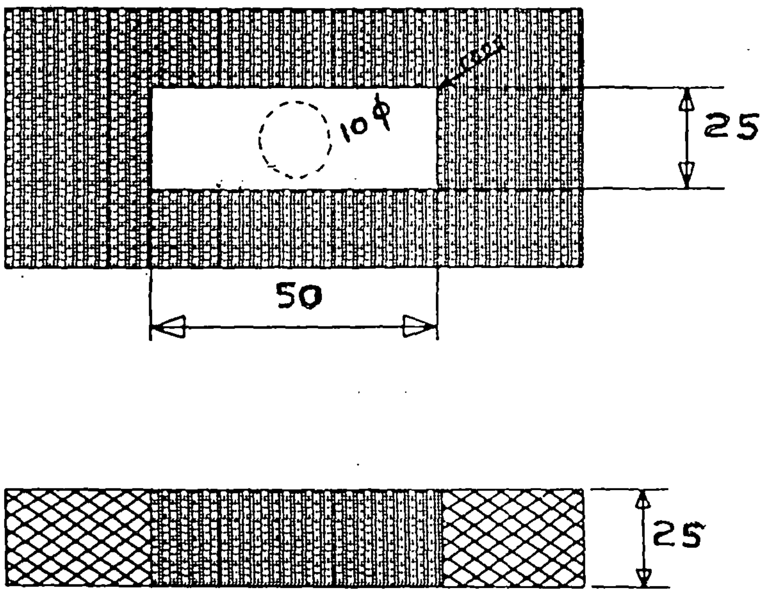
$$\text{Machining time for Finishing} = \frac{\text{Perimeter}}{\text{Machining speed}} = \frac{118.6}{1.6} = 74 \text{ min}$$

$\therefore$ Total machining time = 74 min

$\therefore$ Total cost = Appx 625/-

(The cost of wire EDM is Rs. 500/- /Hr. for AGIE Model)

5.3 PART DRAWING OF DIFFERENT COMPONENTS



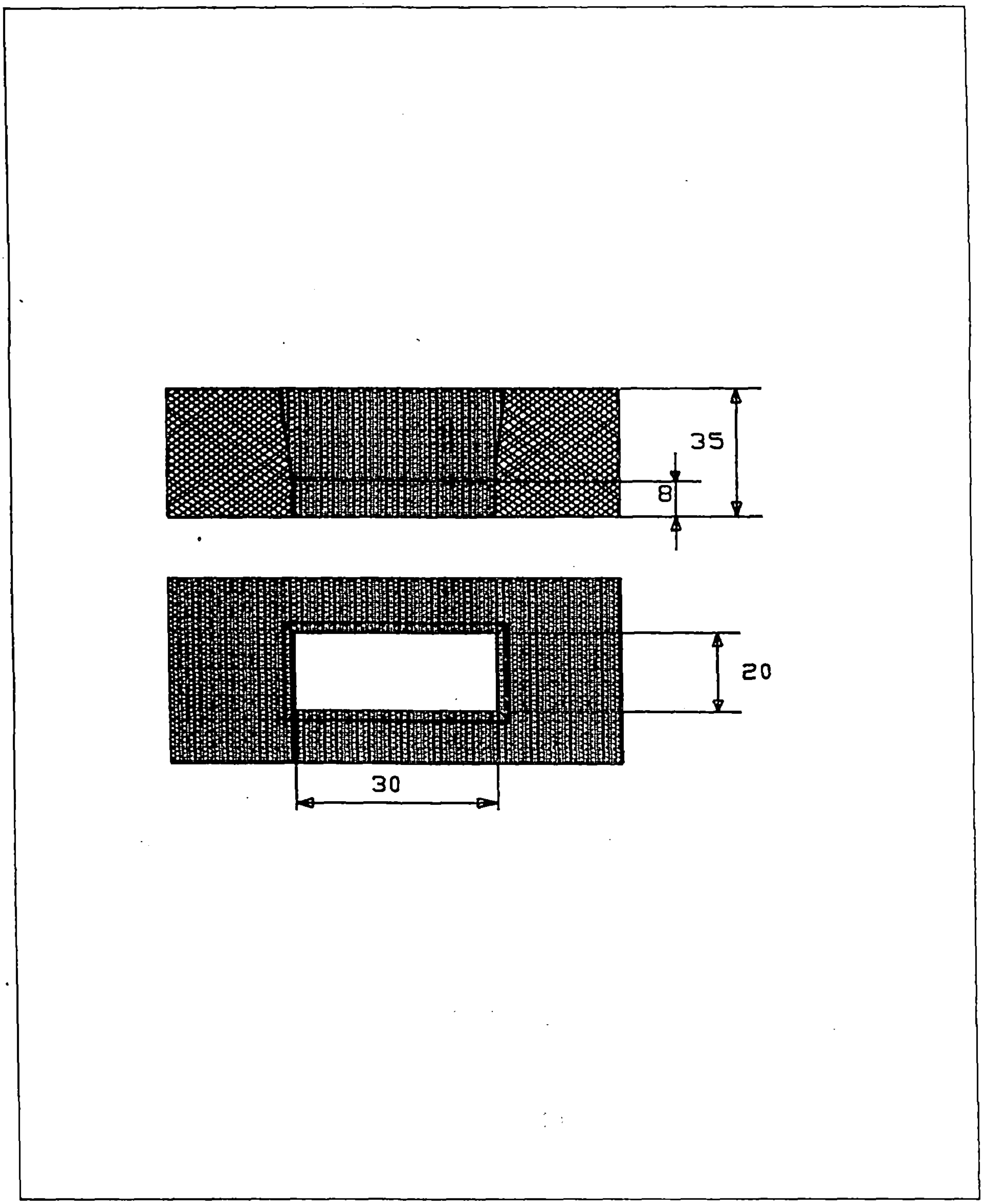
Cutting of Rectangular hole in wire EDM / EDM.

DATA SUMMARY

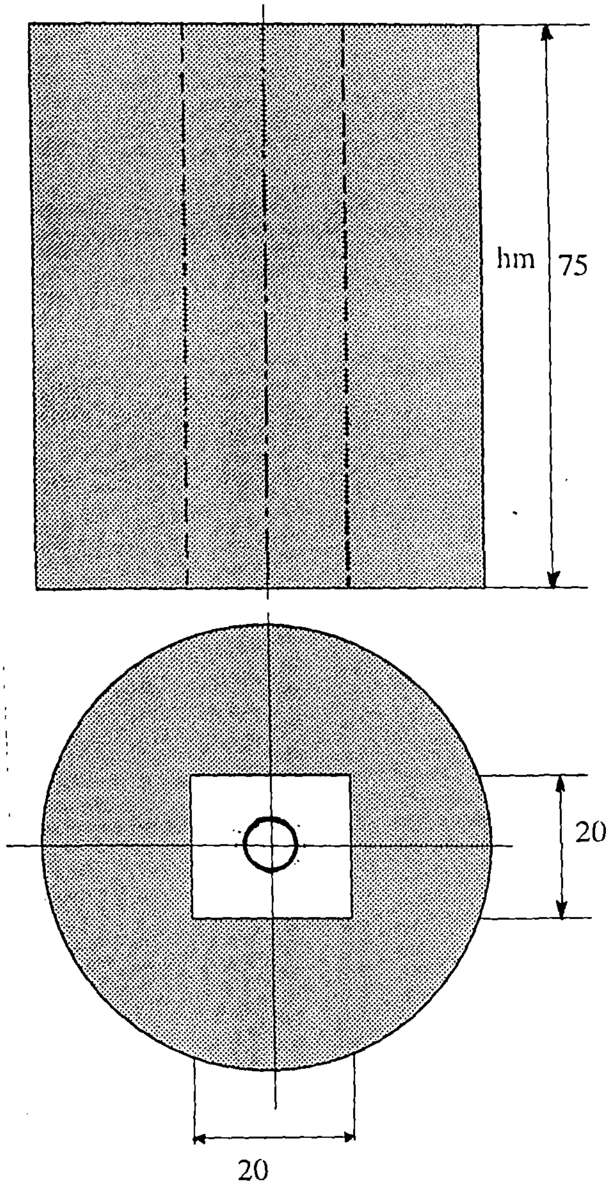
OPERATION	ELECTRODE MATERIALS	REQUIRED SURFACE FINISH	BASIC PARAMETERS			CALCULATION OF ELECTRODES			MATERIAL REMOVAL	
			POLARITY	INTENSITY LEVEL	FLUSHING	DIAM MEAN SPARKING DIST	DIAM LIMIT SPARKING DISTANCE	SAFETY CUT	mm^3/ min	Relative volumetric Electrode wear %
R	Gr	4 — 9 μm	(—) ve	2	suction	.178 mm	0.32 mm	.4	550	15
F	Gr	2 μm	(—) ve	$^1/_4$	"	.04	—	—	20	31

DATA SUMMARY

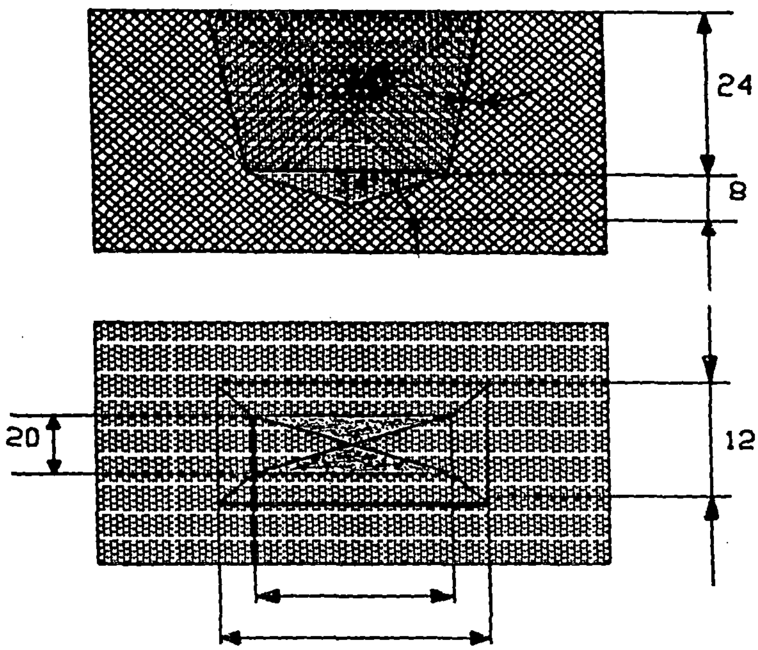
OPERATION	ELECTRODE MATERIALS	REQUIRED SURFACE FINISH	BASIC PARAMETERS			CALCULATION OF ELECTRODES			MATERIAL REMOVAL	
			POLARITY	INTENSITY LEVEL	FLUSHING	DIAM MEAN SPARKING DIST	DIAM LIMIT SPARKING DISTANCE	SAFETY CUT	mm^3/ min	Relative volumetric Electrode wear %
R	Gr	4 — 9 µm	(—) ve	2	suction	.178 mm	0.32 mm	.4	550	15
F	Gr	2 µm	(—) ve	$^1/_4$	"	.04	—	—	20	31



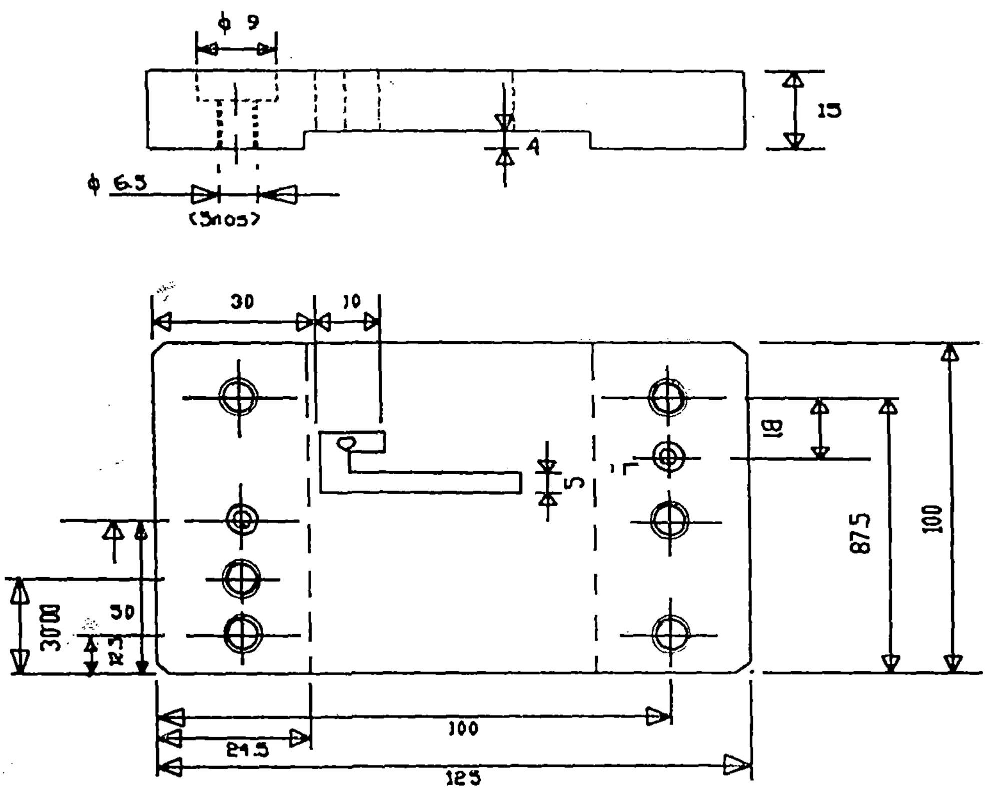
Cutting of Die block by wire EDM / EDM.



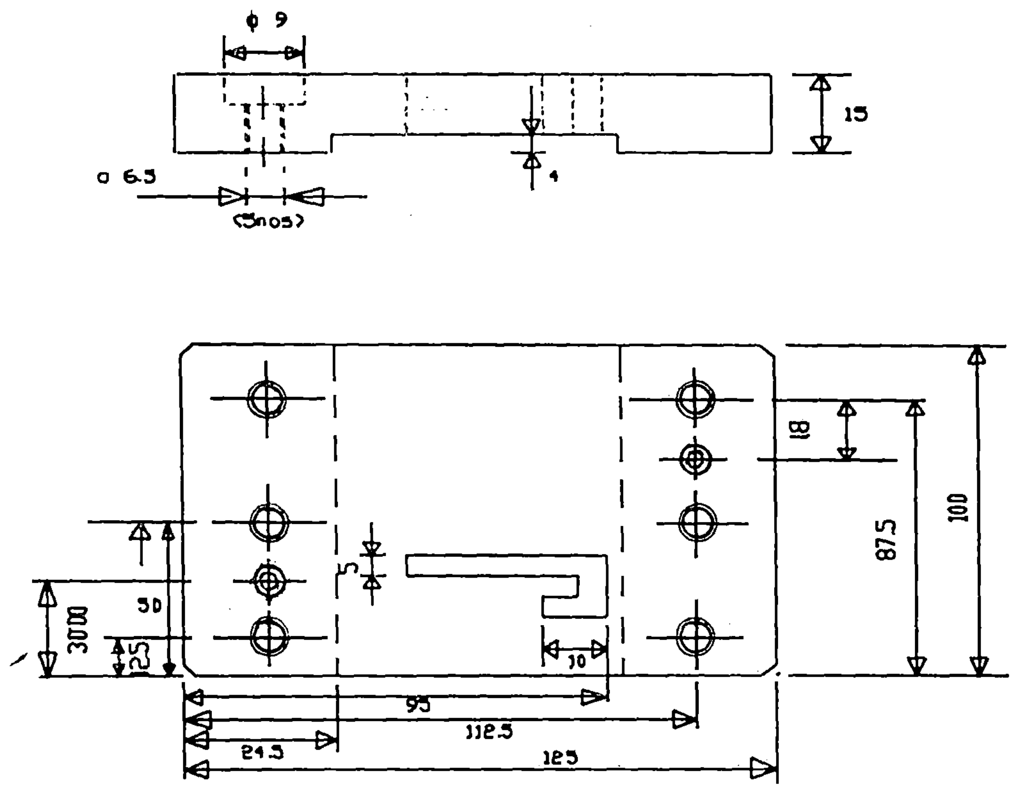
Cutting of Square hole in a round job by EDM.



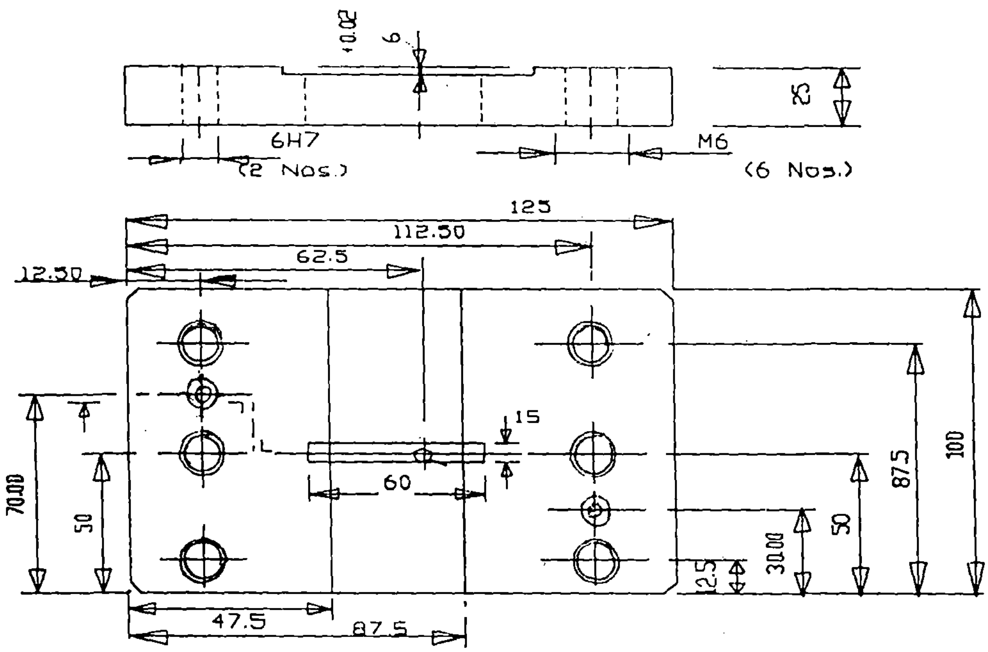
Rectangular taper hole by EDM.



Lamination Die.

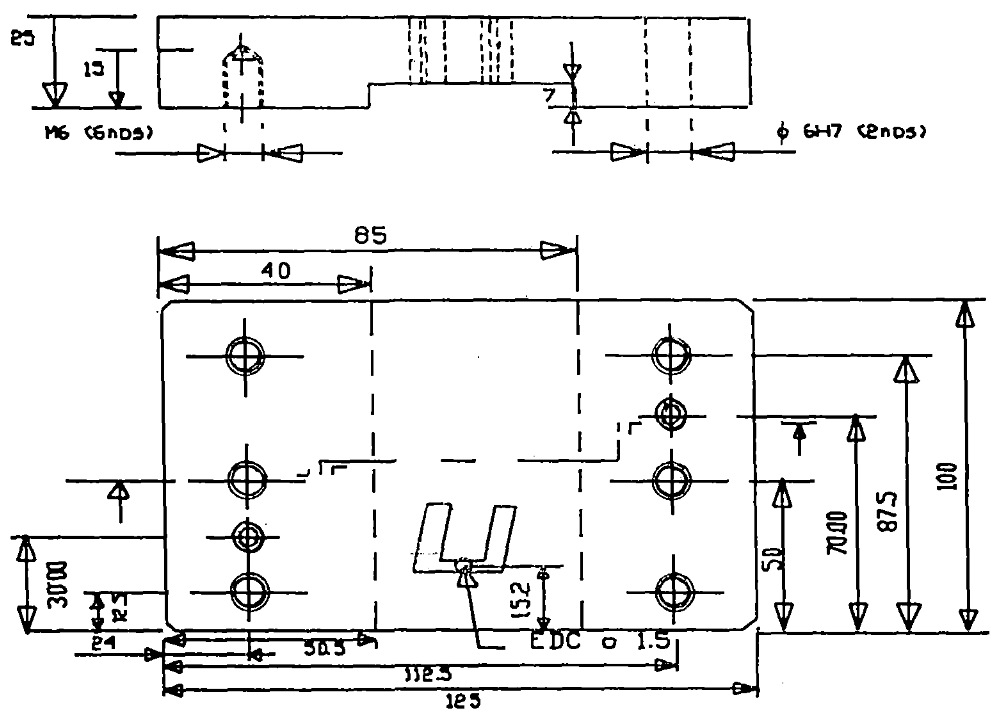


Stipper plate.

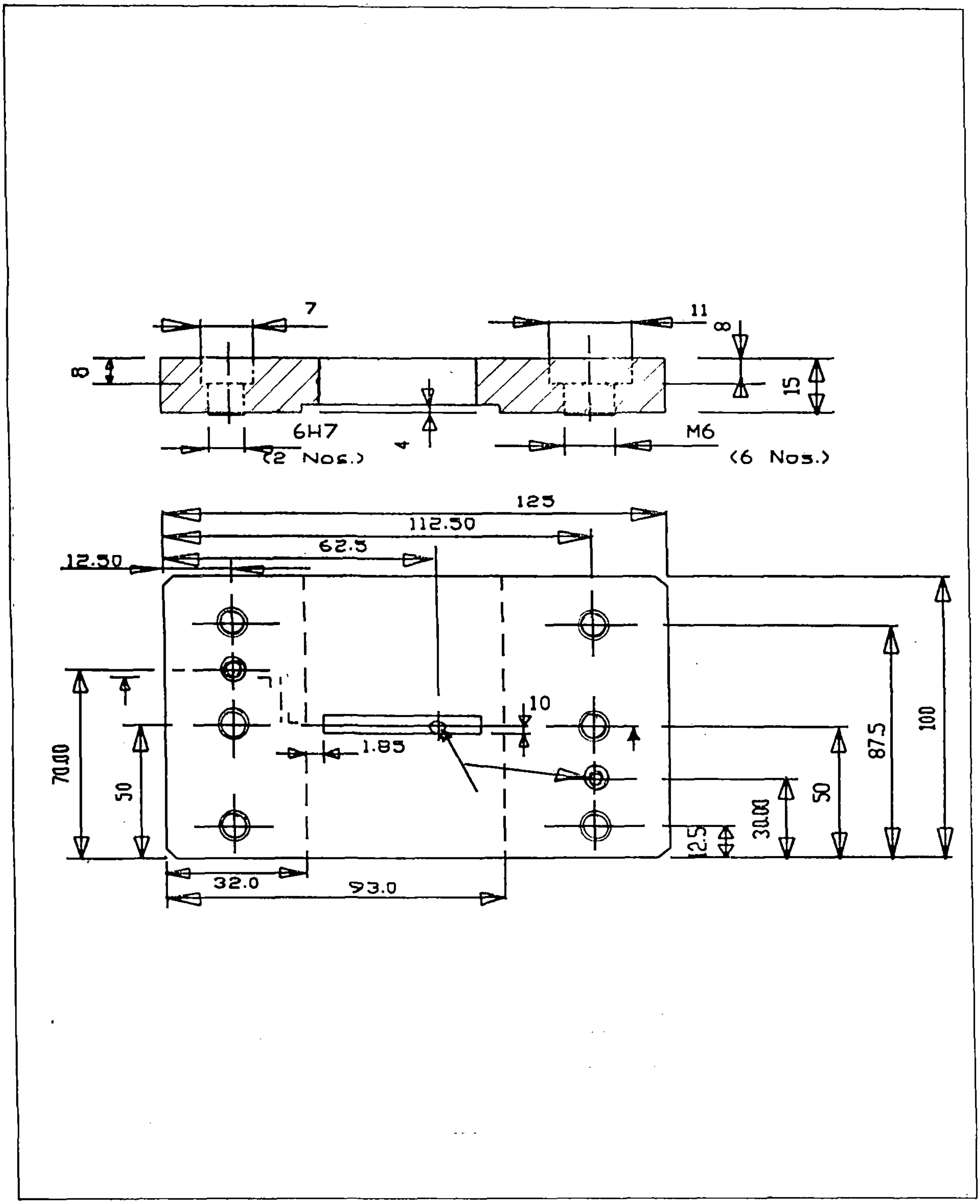


±0.02
6
25
6H7
(2 Nos.)
M6
(6 Nos.)
125
112.50
62.5
12.50
15
60
70.00
50
12.5
30.00
50
87.5
100
47.5
87.5

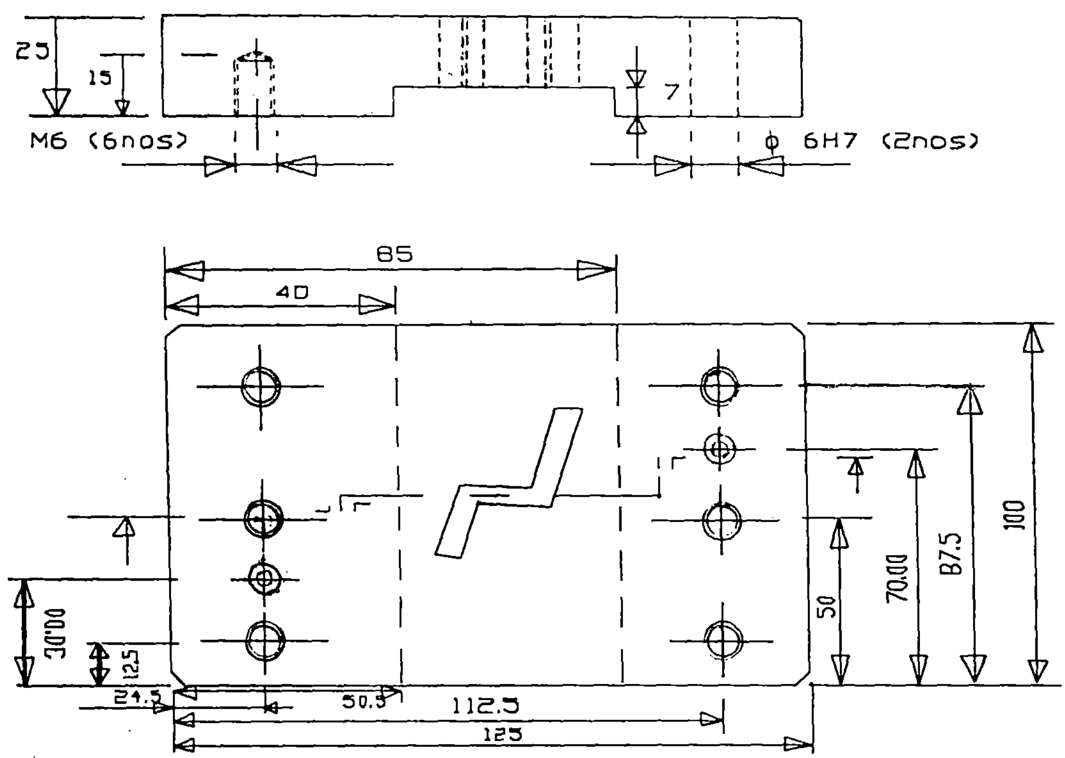
Die cavity


25
15
M6 (6nos)
7
φ 6H7 (2nos)
85
40
100
87.5
70.00
50
30.00
12.5
24
50.5
112.5
125
15.2
EDC ø 1.5

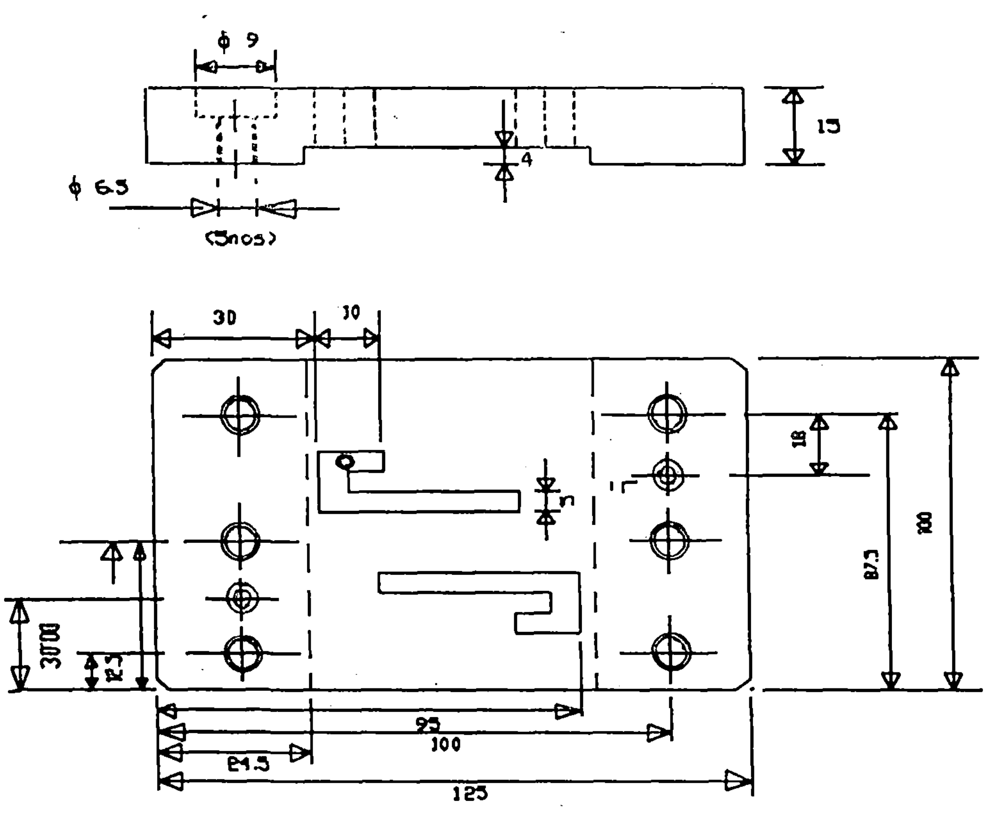
Die cavity



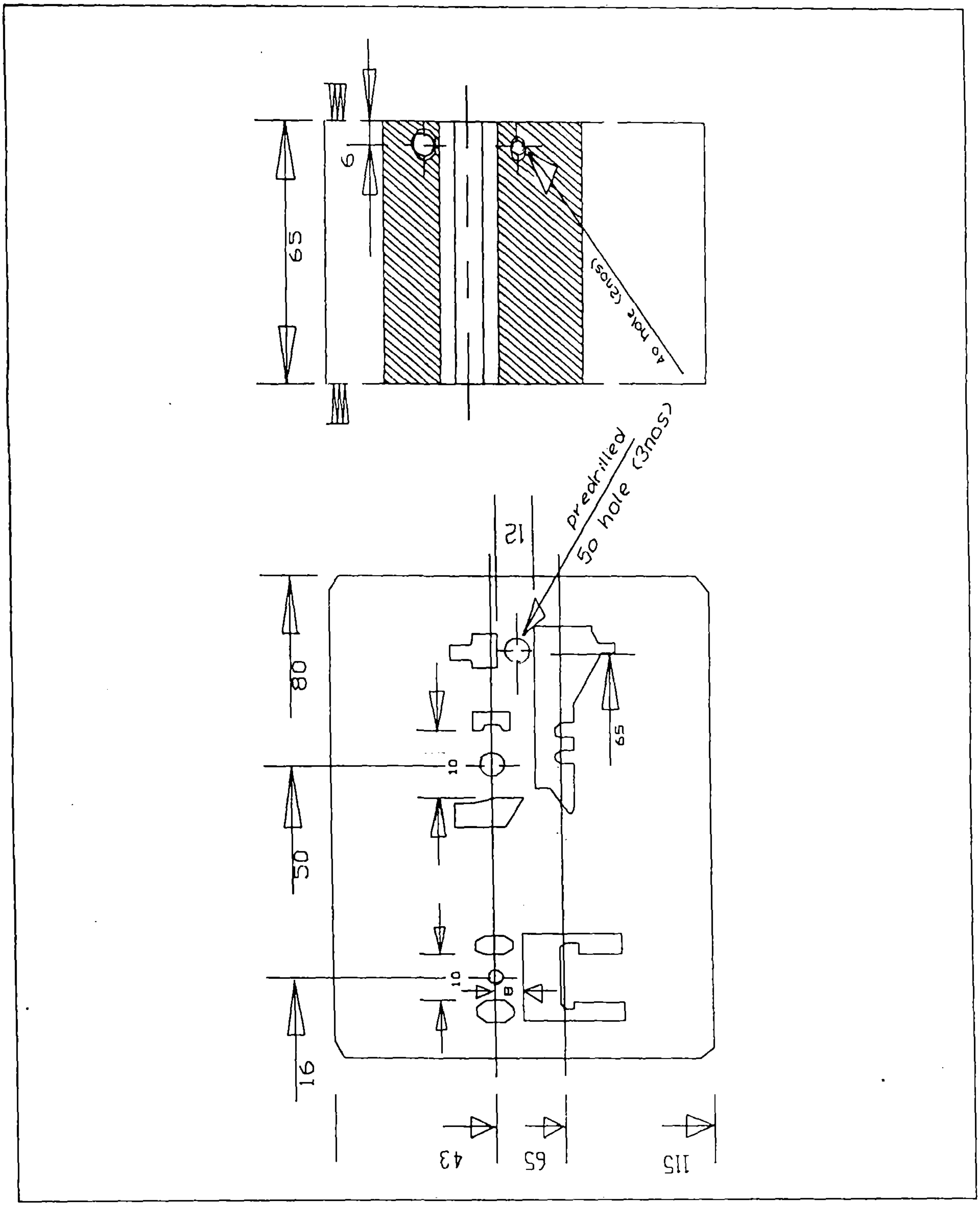
Stipper plate



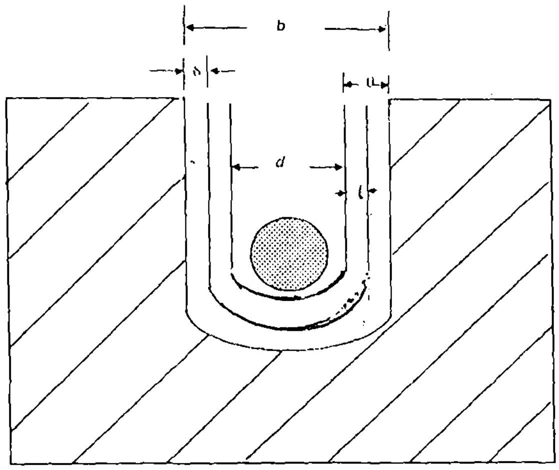
Die for Press tool.



Lamination Die



A multi EDM operation in a single plate used for Electronic circuit board.



d — Diameter of wire
l — Spark gap
0 — Overcut
δ — Average depth of crater

Groove Produced by Wire EDM.

CHAPTER - VI

CONCLUSION AND SCOPE OF FURTHER WORK

CHAPTER - VI

CONCLUSION AND SCOPE OF FURTHER WORK

Based on the experience already available in the domain on the mechanism of the EDM processes its optimisation and also on the techniques of computer aided process planning as applied to metal cutting based process, the present work reports a portion of attempts to synthesize both set of knowledge and provide a logical analysis of the decision of process planning activities including the aspects of selection of m/c tool and sequencing the operation and also to decide the operating parameter and calculation of overall time required.

Generation of process sheet both for EDM and wire EDM could be presented neatly if some more datas regarding clamping, polarity and flushing were available from the different companies who are in touch with EDM products.

In normal practice injection flushing and for slight taperness of the product always machine flushing is preferred by most of the companies. Positive polarity means electrode or wire is connected to positive voltage pole (for fast cutting) and simmilarly negative polarity means electrole or wire is connected to negative voltage pole.

The validatian of the entire work has been compared and tested with the well known authenticated results and works of the leading scientists of the field.

A new modified software could be developed after having all the incorporations mentioned above which would really help the process planner of EDM products.

APPENDIX

PROGRAMMING LOGIC FOR THE OPTIMIZATION MODEL

I. INPUT VARIABLES

1. No. of machines to be in operation and designation of the machines

   i.e. READ $M_{(i)}$ for $i = 1, N$

   (Where N = no. of machines and M_i is the designation of the i -th machine)

2. Maximum job size that can be accomodated by each machine in X, Y and Z directions.

   i.e. READ $JX_{(i)}$, $JY_{(i)}$, $JZ_{(i)}$ for each individual m/cs.

   (Where, $JX_{(i)}$, $JY_{(i)}$ & $JZ_{(i)}$ are the maximum Job size in X, Y, Z directions respectively for i -th machine)

3. Maximum weight of job (W) that can be accomodated by each individual machine

   i.e. READ $W_{(i)}$ for $i = 1, N$

4. Maximum current (I) that can be provided by each individual machine

   i.e. READ I_i for $i = 1, N$

5. Diameter of wire (D) for only wirecut machines

i.e. READ $D_{(i)}$ for $i = N_1, N_2$

(Where N_1 and N_2 are the initial and final number of wirecut machine). For the present problem, $N_1 = 13$, $N_2 = 18$

6. No. of jobs to be done and designation of the jobs

i.e. READ JOB_j for $j = 1, X$

(Where, X = No. of jobs to be done and JOB_j is the designation of $_j$ the job)

7. Job shape and necessary linear dimensions for each job.

i.e. READ Shape $JX_{(j)}$, $JY_{(j)}$, $JZ_{(j)}$ for $_j = 1, X$

(Where, Shape J designates the shape of the j th job like circle, Rectangle, Square etc.; JX_j JY_j and JZ_j are the corresponding appropriate dimensions for the particular shape of the job under consideration.)

8. Job Material (JM) and Corresponding valid electrode materual (EM)

i.e. READ JM_j, EM_j for $j = 1, X$

9. Surface roughness (SR) of the job required for each individual job.

i.e. READ SR_j for $j = 1, X$

10. Product Profile (PP) to be generated with requisite shape and liner dimensions.

i.e. READ PP_j, PX_j, PY_j, PZ_j for $j = 1. X$

(Where PP_j is the product profile to be generated like circle, Rectangle, Square etc. for j th job; PX_j, PY_j, PZ_j are the corresponding dimensions for the appropirate shape of the product profile under consideration)

11. Depth of cut or, profile height or, thickness as appropriate for the job concerned (MZ)

i.e. READ MZ_j for $j = 1, X$

12. Hourly cost (Rs./hr) for each concerned machine

i.e. READ C_i for $i = 1, N$

II. CONSTRAINS & FEATURES

1. For machine Nos. 1 to 12 (i.e. for $i = 1, 12$)

   a) job material can be only steel

   b) Electrode material may be Gr(-), Gr(+), Cu(+), Cu(-)

2. For machine nos. 13 to 18 (i.e. for i = 13, 18)

   a) job material may be HCHCR (High Carbon High Chromium), Brass, T/Carbide, Steel

   b) Electrode material can only be Brass

   c) JZ_j must be equal to MZ_j (if $JZ_j \neq MZ_j$ then only spark erosion machines are available)

III SELECTION OF ALL POSSIBLE COMBINATION OF JOBS TO BE DONE BY RESPECTIVE MACHINE

This decision for selection is done by the computer programme by comparing the input variable with constraints.

IV CALCULATION

Frantal area or profile area by considering geometry of profile of the job to be done.

Equation

(i) $FA_j = \pi D^2/4$

(If profile is circular with diameter 'D')

(ii) $FA_j = L \times B$

(If profile is rectangular with length 'L' and breadth 'B') and so on.)

2. Intensity level for different electrode malerial having positive or negative polarity is the function of Frontal / Profile area.

$$IL_j = f\ (FA_j)$$

Refer table 1 page- 49

3. Maximum current in amp. is the function of intensity level.

$$I_j = f\ (IL_j)$$

Refer table 2 page- 50

4. Material remoral rate for spark erosion machine (MRR) is the function of Surface Roughness required, Maxim. current available and electrode material selected.

Refer table 3 page- 51

5. Machining speed for wire cut machines (MS_j) is the function of profile Depth (MZ_j) i.e. depth of cut.

$$MS_j = f\ (MZ_j)$$

Refer table 4 page- 52

6. Volume of material to be removed (V mm^3) from profile geometry is the product of frontal area and Depth of cut.

$$VM_j = FA_j \times MZ_j$$

7. Perimeter of the profile from profile geometry.

(i) Perimeter $(PM_j) = \pi D$

(if profile is circular with diameter 'D')

(ii) Perimeter $(PM_j) = 2(L + B)$

(if profile is Rectangular with length L and breadth B an so on.)

8. Machining Time for S. E. machines

$$MT_j = \frac{MRR}{VM_j}$$

9. Machining Time for wire cut machines

$$MT_j = \frac{PM_j}{MS_j}$$

10. Cost Investment is the function of time only.

$C_j = f\ (MT_j)$

V OPTIMIZATION

Optimise the set of Combination of the jobs done by different machines based on.

- Minimum Cost.
- Minimum Time.
- Maximum Profit.

APPENDIX-B

MATHEMATICAL MUDELS DEVELOPED USING REGRESSION / CO-RELATION ANALYSIS

X_1 => Material Removal Rate in mm^3/min.
X_2 => Surface finish required in mm.
X_3 => Maxm. current in amp.

X_1	X_2	X_3	$\log X_1$	$\log X_2$	$\log X_3$	X_1X_2	X_1X_3	X_2X_3	X_1^2	X_2^2	X_3^2
20	.00158	6.30	1.3	-2.8	.8	-3.64	1.04	-2.24	1.69	7.84	.64
24	.0020	6.30	1.38	-2.7	.8	-3.73	1.11	-2.16	1.9	7.29	.64
28	.0025	6.3	1.45	-2.6	.8	-3.77	1.16	-2.08	2.10	6.76	.64
31	.0035	6.3	1.49	-2.46	.8	-3.67	1.19	-1.97	2.72	6.05	.64
34	.0050	6.3	1.53	-2.3	.8	-3.52	1.22	-1.84	2.34	5.29	.64
34	.005	12.5	0.53	-2.7	1.10	-4.13	1.68	-2.97	2.34	7.29	1.21
59	.005	12.5	1.77	-2.6	1.10	-4.6	1.95	-2.86	3.13	6.76	1.21
100	.0039	12.5	2	-2.4	1.10	-4.8	2.20	-2.64	4.00	5.76	1.21
129	.0056	12.5	2.11	-2.25	1.10	-4.75	2.32	-2.48	4.45	5.06	1.21
150	.007	12.5	2.18	-2.15	1.10	-4.69	2.40	-2.37	4.75	4.62	1.21
60	.002	25	1.78	-2.7	1.4	-4.8	2.49	-3.78	3.17	7.29	1.96
80	.0025	25	1.90	-2.6	1.4	-4.94	2.66	-3.64	3.61	6.76	1.96

X_1	X_2	X_3	$\log X_1$	$\log X_2$	$\log X_3$	X_1X_2	X_1X_3	X_2X_3	X_1^2	X_2^2	X_3^2
135	.0035	25	2.13	-2.46	1.4	-5.24	2.98	-3.45	4.54	6.05	1.96
195	.0045	25	2.29	-2.35	1.40	-5.38	3.21	-3.29	5.24	5.52	1.96
280	.0063	25	2.45	-2.2	1.40	-5.39	3.43	-3.08	6.00	4.84	1.96
68	.0025	50	1.83	-2.6	1.7	-4.76	3.11	-4.42	3.35	6.76	2.89
125	.0032	50	2.10	-2.49	1.7	-5.23	3.57	-4.23	-4.41	6.20	2.89
275	.0040	50	2.44	-2.4	1.7	-5.86	4.15	-4.08	5.95	5.76	2.89
427	.0056	50	2.63	-2.25	1.7	-5.92	4.47	-3.83	6.92	5.06	2.89
180	.0035	50	2.26	-2.46	1.7	-5.56	3.84	-4.18	5.10	6.05	2.89
			Σ38.52	Σ-49.47	Σ25	Σ-94.38	Σ50.18	Σ-61.59	Σ77.21	Σ123.01	Σ33.5

$$\underline{X}_1 = \frac{\Sigma X_1}{n} = \frac{38.52}{20} = 1.93$$

$$\underline{X}_2 = \frac{\Sigma X_2}{n} = -\frac{49.47}{20} = -2.47$$

$$\underline{X}_3 = \frac{\Sigma X_3}{n} = \frac{25}{20} = 1.25$$

$\Sigma X_1^2 = \Sigma X_1^2 - n(\underline{X}_1)^2 = 77.21 - 20\ (1.93)^2 = 2.71$

$\Sigma X_2^2 = \Sigma X_2^2 - n(\underline{X}_2)^2 = 123.01 - 20(-2.47)^2 = 1$

$\Sigma X_3^2 = \Sigma X_3^2 - n(\underline{X}_3)^2 = 33.5 - 20\ (1.25)^2 = 2.25$

$\Sigma X_1 X_2 = \Sigma X_1 X_2 - n\, \underline{X}_1\, \underline{X}_2 = -94.38 - 20\ (1.93)\ (-2.47) = 0.96$

$\Sigma X_1 X_3 = \Sigma X_1 X_3 - n\, \underline{X}_1\, \underline{X}_3 = 50.18 - 20\ (1.93)\ (1.25) = 1.93$

$\Sigma X_2 X_3 = \Sigma X_2 X_3 - n\, \underline{X}_2\, \underline{X}_3 = -61.59 - 20(-2.47)\ (1.25) = -61.59 + 61.75 =$
0.16

The least square equations are

$$\Sigma X^2_2\, b_{12.3} + \Sigma X_2 X_3\, b_{13.2} = \Sigma X_1 X_2$$

$$\Sigma X_2 X_3\, b_{12.3} + \Sigma X^2_3\, b_{13.2} = \Sigma X_1 X_3$$

From this least square equation we form two sets of auxiliary equ.

$$C_{22}\, \Sigma X^2_2 + C_{23}\, \Sigma X_2 X_3 = 1 \qquad \text{--- (a)}$$

$$C_{22}\, \Sigma X_2 X_3 + C_{23}\, \Sigma X^2_3 = 0 \qquad \text{--- (b)}$$

and

$$C_{23}\, \Sigma X^2_2 + C_{33}\, \Sigma X_2 X_3 = 0 \qquad \text{--- (c)}$$

$$C_{23}\,\Sigma X_2 X_3 + C_{33}\,\Sigma X_3^2 = 1 \quad --- \quad (d)$$

Putting values of X_2 , X_3 and $X_2 X_3$ in equ. (a) & (b) we get,

$$C_{22} + 0.16\, C_{23} = 1 \quad --- \quad (1)$$

$$0.16\, C_{22} + 2.25\, C_{23} = 0 \quad --- \quad (2)$$

or, $0.16\, C_{22} + 0.25\, C_{23} = 0.16$ [Multiplying both sides of equ. (1) by 0.16]

$$0.16\, C_{22} + 2.25\, C_{23} = 0 \quad --- \quad (2)$$

Substrating, $-\,2.225\, C_{23} = 0.16$

$$C_{23} = -\,.0719$$

Putting value of C_{23} in equation (1)

$$C_{22} = 1 - (0.16)(-.0719)$$

$$= 1 + .01 = 1.01 \qquad [C_{22} = 1.01]$$

Again putting the values of X_2, X_3 and $X_2 X_3$ in equ. (c) and (d) we get

$$C_{23} + 0.16\, C_{33} = 0$$

$$0.16\, C_{23} + 2.25\, C_{33} = 1$$

or, $0.16\, C_{23} + .025\, C_{33} = 0$ --- (3) [Multiplying both sides of 1st equ. by 0.16]

$$0.16\, C_{23} + 2.25\, C_{33} = 1 \quad --- \quad (4)$$

Substracting, $-2.225\, C_{33} = -1$

$$C_{33} = 1/2.225 = 0.45$$

Putting value of C_{33} in equation (3)

$$0.16\, C_{23} + .025(0.45) = 0$$

$$[C_{23} = -\,.07]$$

We find the b's from the relationship

$$b_{12.3} = C_{22} \Sigma X_1 X_2 + C_{23} \Sigma X_1 X_3$$

$$b_{13.2} = C_{23} \Sigma X_1 X_2 + C_{33} \Sigma X_1 X_3$$

b12.3 = 1.01 (0.96) - .07 (1.93) = 0.834

b13.2 = -.07 (0.96) + 0.95 (1.93) = 0.801

$$\Sigma V^2_{1.23} = \Sigma X^2_1 - b_{12.3} \Sigma X_1 X_2 - b_{13.2} \Sigma X_1 X_3$$

$$= 2.71 - (0.83)(0.96) - (0.80)(1.93)$$

$$= 0.37$$

Co-relation co-efficient between the three variables

$$\hat{R}^2_{1.23} = 1 - \frac{(n-1)\Sigma V^2_{1.23}}{(n-3)\Sigma X_1^2} = 1 - \frac{19\ (0.37)}{17\ (2.71)} = 1 - \frac{7.03}{46.07} = 1 - 0.15 = 0.85$$

85% of the variation in MRR is accounted for the S.R and intensity level

$$a_{1.23} = \bar{X}_1 - b_{12.3} \bar{X}_2 - b_{13.2} \bar{X}_3$$

$$= 1.93 - (0.83)(-2.47) - (0.80)(1.25)$$

$$= 2.98$$

Antilog of 2.98 = 954

∴ The equation can be written

$$X_1 = 954\ (X_2)^{0.83}\ (X_3)^{0.80}$$

M.R.R for electrode graphite (polarity negative) for W/P material steel MST 65 RC

$$MRR = 954\ (X_2)^{0.83}\ (X_3)^{0.80}$$

Where X_2 = S.R required and X_3 = current required

For X_2 = .0016 mm and X_3 = 6.25 amp.

MRR = 19.41 mm^3/min (given value 20 in the charmilles table)

The datas for Regression/co-relation analysis are taken from the practical guide book of ATELIERS DES CHARMILLES S-A, Geneva, Switzerland. from where all the mathematical models for diff. electrode with diff. W/P material are developed as shown in table 3 and table 4 of page no 51 and 52.

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