EFFECTIVE MANUFACTURING THROUGH PROCESS OPTIMIZATION

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

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PROJECT CERTIFICATE

This is to certify that **Mr R Raja**, Final semester ME Mechanical Engg (Industrial Engg) student of Kumaraguru College of Technology, has successfully completed the project work in our organization.

Title of the Project	:	*EFFECTIVE MANUFACTURING THROUGH PROCESS* OPTIMIZATION
Period of the Project	:	*June 1999 to November 1999*
Department	:	*Manufacturing Engineering*

During this period his attendance and conduct were found to be **Good.**

We wish him the very best for a bright future.

ANTHONY THIAGARAJAN
DY.MANAGER - HRD

ISO 9001

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R. Raja

SYNOPSIS

To recognize and to anticipate changes taking place in any technology are part of the good management. Optimization of resources and improvement of productivity are the major works of a good management. Conventional machining process are used in practice, have many problems associated with time like.

1. Because of non standard and non optimized process parameters
2. Process parameters like speed, feed rate and depth of cut etc. affect the optimization.

In this project work, an attempt has been made to optimize (in this work minimization) the machining time of Internal grinding operation and milling operation in the critical components of Hand Taggle Press.

In this all the experiments are quantitative approach to find the optimum machining time as well as optimum process variables.

As per central composite Rotatable design of experiment. Internal grinding operation carried out in the critical component Ram of the handle taggle press. The variables such as speed, feed rate and software based on the trials conducted experimentally. The optimum process variables has been developed successfully for the above internal grinding operation.

In this project work, validation is achieved by means of arriving the percentage of error between the observed values and the predicted values.

Also in this project using Taguchi design of experiment, milling operations in the critical component body of Hand Taggle press are optimized.

CONTENTS

CHAPTER 1

INTRODUCTION

1.1. Optimization:

The exact dictionary meaning for optimization is "Extracting the best thing from the available choices". Here optimization is meant the most economical one. In general optimization is minimization. But depending upon our objective function optimization may be maximization also. If objective function is profit or accuracy, then optimization is maximization. If object objective function is time, cost etc. then optimization is minimization. The technical word optimize is more stronger than Improve or Enhance.

1.2. History for the Word Optimization:

[1] In the 18th century the famous philosopher cum mathematician Leibniz coined the word "Optimum". In Latin Optimus meaning "Best" Optimus contains the name of "ops", the sabine godness of agricultural abundance introduced into the Rame in the eighth century B.C. Wealth became the symbol of power. The rich aristocracy is known as "optimates". The same word used at Oxford University as a title for outstanding scholars.

1.3. Optimization As An Engineering Tool:

Optimization technique is very much useful for Engineers, Economist and Administrators. A good Engineer should have some economical sense and Administrative capabilities.

Optimization is one of the topic under Operation Research. Operation Research is a division of Mathematics which gives more practical solution to day to day problems as well as Engineering problems.

Optimization have various definitions some of the important definitions are

1) Optimization is "Improve upon the things, those we have chosen."
2) Optimization is "Maximizing profit (or) Minimizing Loss"
3) Optimization is "How to get more Profit with Minimum Effort."
4) Optimization is "Most economical one of all possible solutions."

1.4. Application Of Optimization In Engineering Fields:

1) Design of aircraft and aerospace structures for minimum weight.
2) Finding the optimal trajectories of space vehicles.
3) Design of civil engineering structures for minimum weight.
4) Selection of machining conditions in metal cutting process for minimum production cost.
5) Optimum design of electrical network.
6) Optimal PPC [Production Planning and Control.
7) Minimum weight design of structures for earthquake, wind and other types of loading.

... maximum benefit.

9) Optimal plastic design of structures.

10) Design of pumps, turbines and heat transfer equipment for maximum efficiency.

11) Optimum design of electrical networks.

12) Shortest route taken by a salesman visiting different cities during one hour.

13) Analysis of statistical data and building emprical models from experimental results to obtain the most accurate representation of the physical phenomenon.

14) Optimal design of chemical processing equipment and plants.

15) Design of optimum pipeline networks for process industries.

16) Selection of site for an industry.

17) Planning of maintenance and replacement of equipment to reduce operating costs.

18) Inventory control.

19) Allocation of resources or services among several activities to maximize the benefit.

20) Controlling the waiting and idle times and queing in production lines to reduce the costs.

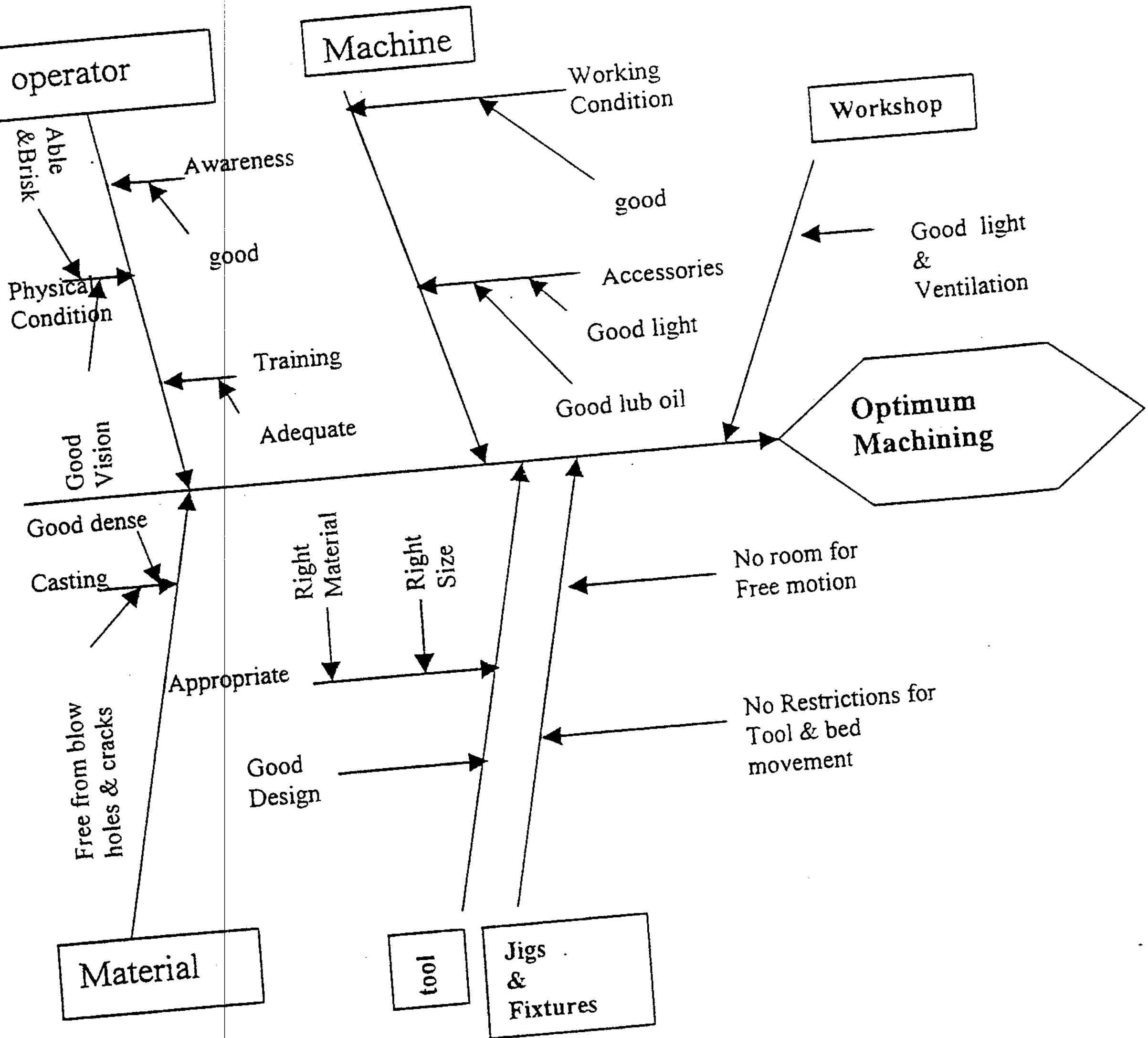
21) Planning the best strategy to obtain maximum benefit in the presence of competitor.

22) Optimum design of control systems.

1.5. Ishi – Kawa Diagram For Optimum Machining:

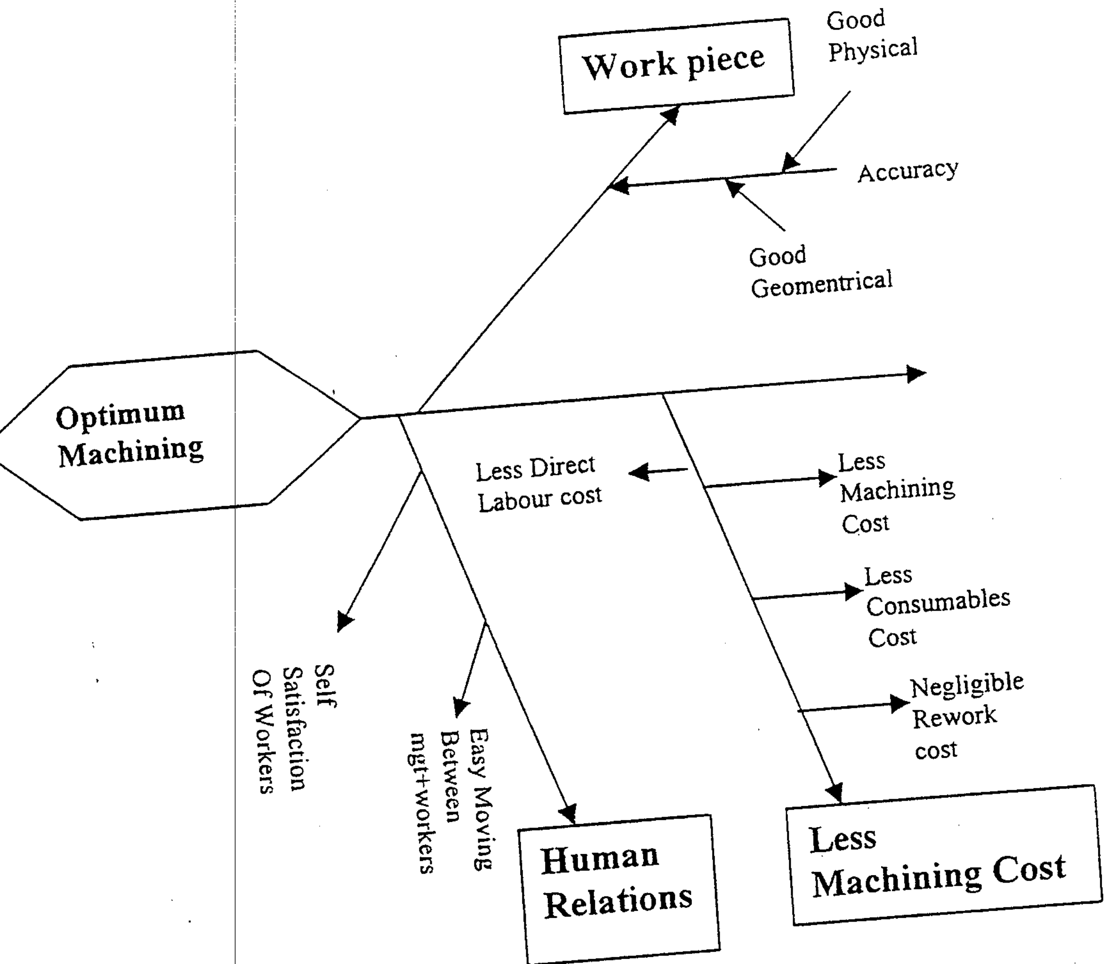
Ishi – Kawa diagram also known as fish-bone diagram or cause and effect diagram. This diagram is a graphical representation of ... f a particular event.

Ishi Kawa Diagram for Optimum Machining:



CAUSES

Ishi Kawa Diagram for Optimum Machining



EFFECTS

This project deals with conventional machining processes using conventional machines. So causes and effects are described as per the above things.

Event or the objective is put in the center Hexagon box. hexagon box is put in between the main centerline. In left side of the hexagon box causes are displayed. Main causes are in the rectangular boxes sub causes for each main cause are also displayed in the figures like the causes effects and subeffects are also displayed in the right side of the Hexagon Box. Arrow heads of Causes towards the Hexagon box and Arrow heads of Effects leaves the hexagon box. Optimum machining in the sense it should take less time without sacrificing the quality. In this diagram, various main causes and subcauses for each main causes as well as various main effects and sub effects for each main effect are also explained.

1.6. Introduction about the company

Pricol

Pricol's Inception:

Pricol stands for "Premier Instruments and Controls Limited".

Pricol was established in the year 1974 by Mr.Vijay Mohan. It was established to produce automotive instruments, within a short span of time, the company grew to the position of leadership in the field. Today, it maintains quality levels that match the best in the world.

Pricol's Products:

Today pricol is well enriched itself as a supplier to Industries which include textiles, process Industry, defence electronics and small machine tools.

In the earlier days pricol's main products are

1. Speedometers
2. RPM Meters
3. Fuel Gauges
4. Mechanical temperature gauges
5. Tank Units

apart from the above, pricol manufactures small machine tools like manual and pneumatic presses, coil winding machines, precision centreless grinders, screen printing machines and gear hobbing machines.

For the defence sector, Pricol supplies Instrumentation and sensors for 7.72 tanks. The company also makes industrial pressure gauges for the process Industry.

Electrical and Electronic Products from Pricol :

Besides the above products, Pricol manufacturing products such as

1. Electrical Pressure Gauges
2. Electronic Temperature Gauges
3. Electronic Tachometers
4. Electronic Tax – fare meters

Pricol's Manpower & Plants:

"Best people only can make the best things". Pricol has the talented, dedicated and hard working people.

Pricol have the strength of around 3650 employees, in which around 720 are clerical staff.

Pricol has four plants, as listed below.

Plant I - Situated at Periyanaikenpalayam, Coimbatore. It was established first it is also the big one.

Plant II - Situated at Gurageon New Delhi

Plant III - Situated at Chinmathampalayam

Plant IV - Situated at Karamadai

Pricol's corporate office is situated in Coimbatore city itself and it has offices in four metropolitan cities (New Delhi, Mumbai, Calcutta, Chennai) and it has representatives all over the country.

Pricol's Achievements:

Sustaining the vital edge at Pricol is its Research & Development Department [R & D] which cuts across the boundary of more technological commitment to satisfy the customer.

Pricol commitment to TQM [Total Quality Management] has own international acceptance. It was the first company in the automotive instrumentation industry to get the ISO 9001 certification in the year 1993.

Pricol has introduced the concept of Re-Engineering, a trend that gaining momentum world wide. Pricol also introduced TPM [Total Productive Manufacturing] concepts in the company.

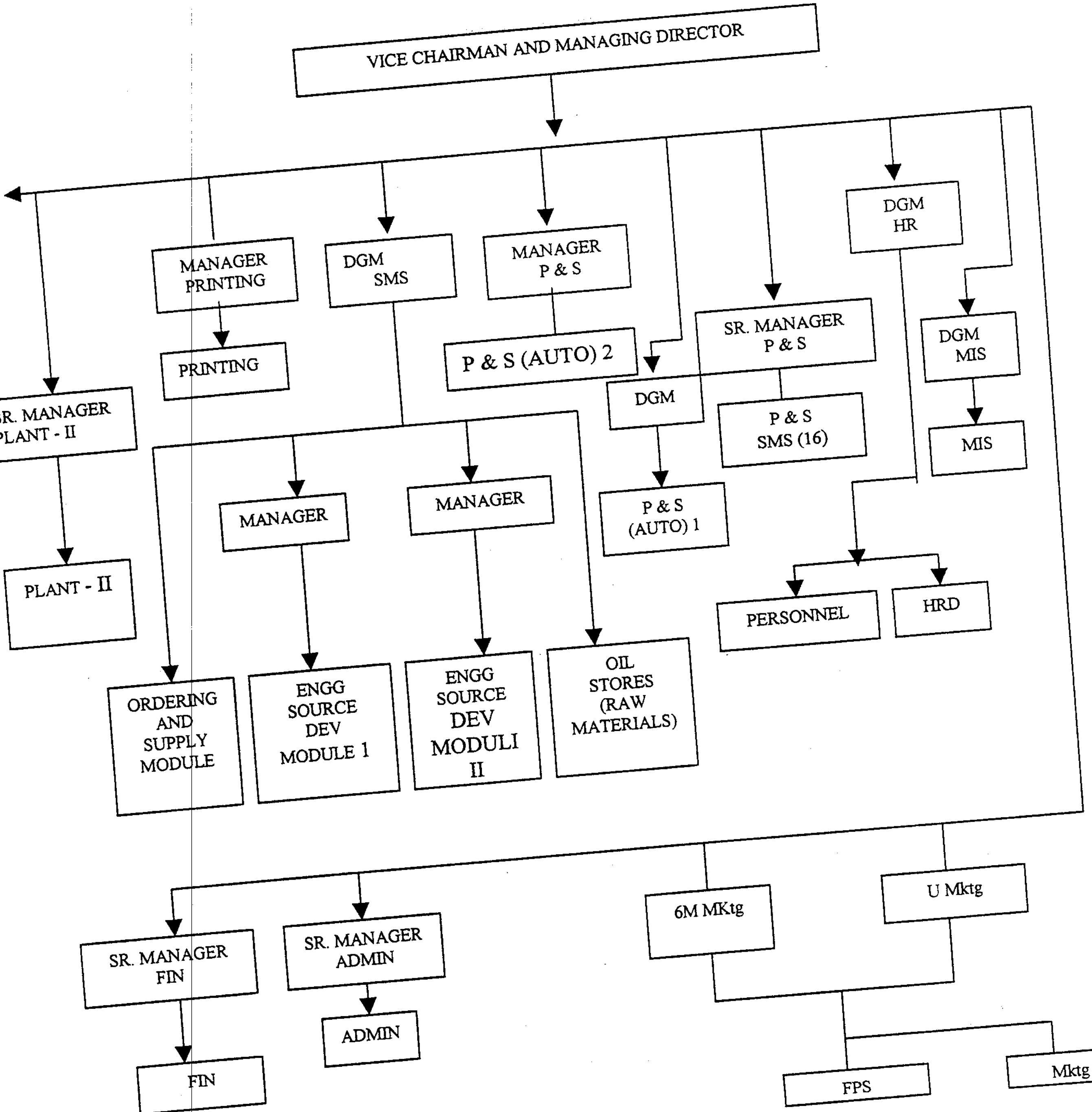
Pricol supplying its products to major Indian concerns like

1. Telco
2. Ashok Leyland
3. Mahindra and Mahindra
4. Maruthi

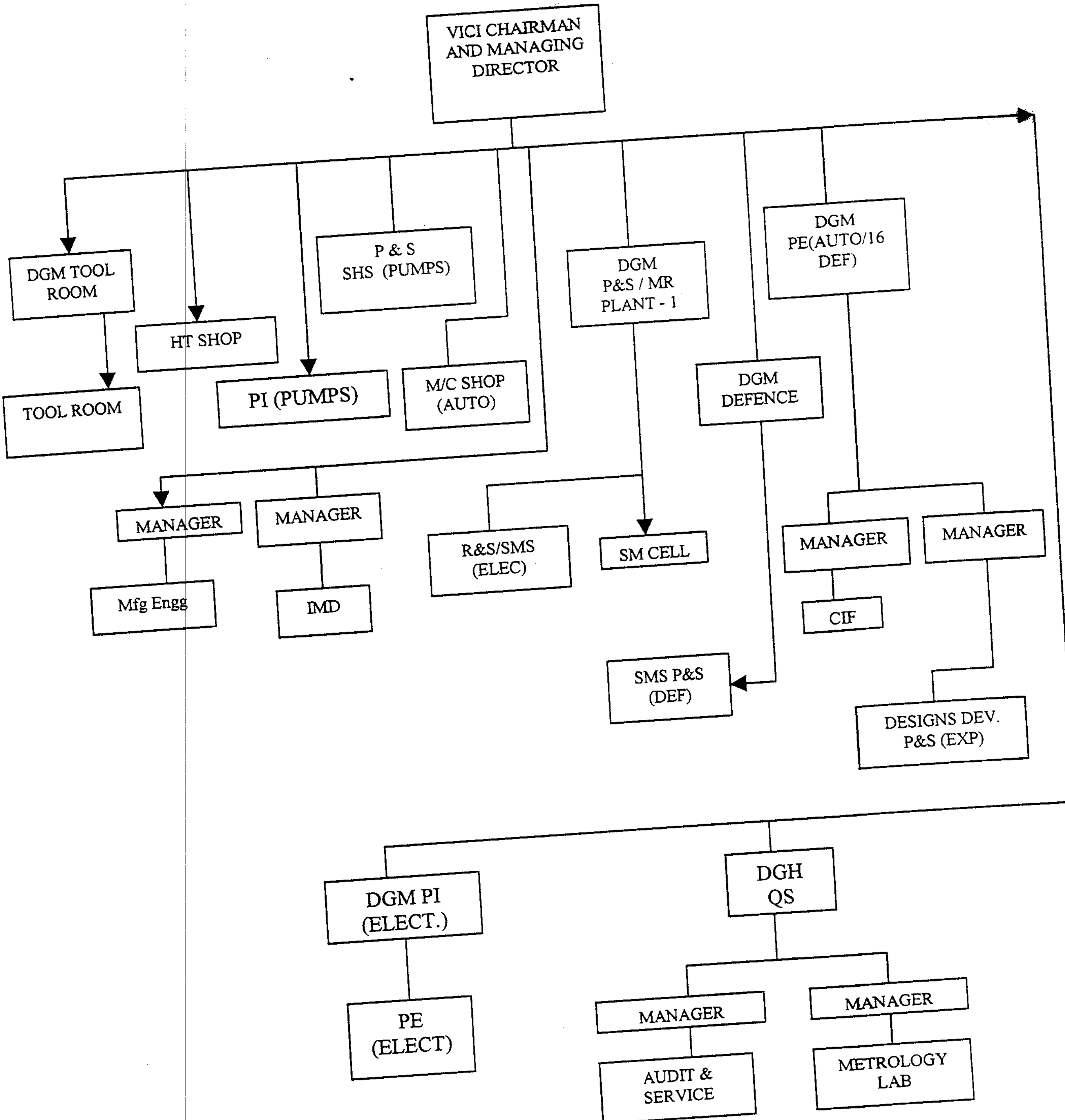
apart from the Pricol exporting the products to

1. USA [United States of America]
2. UK [United Kingdom]
3. Canada
4. Australia

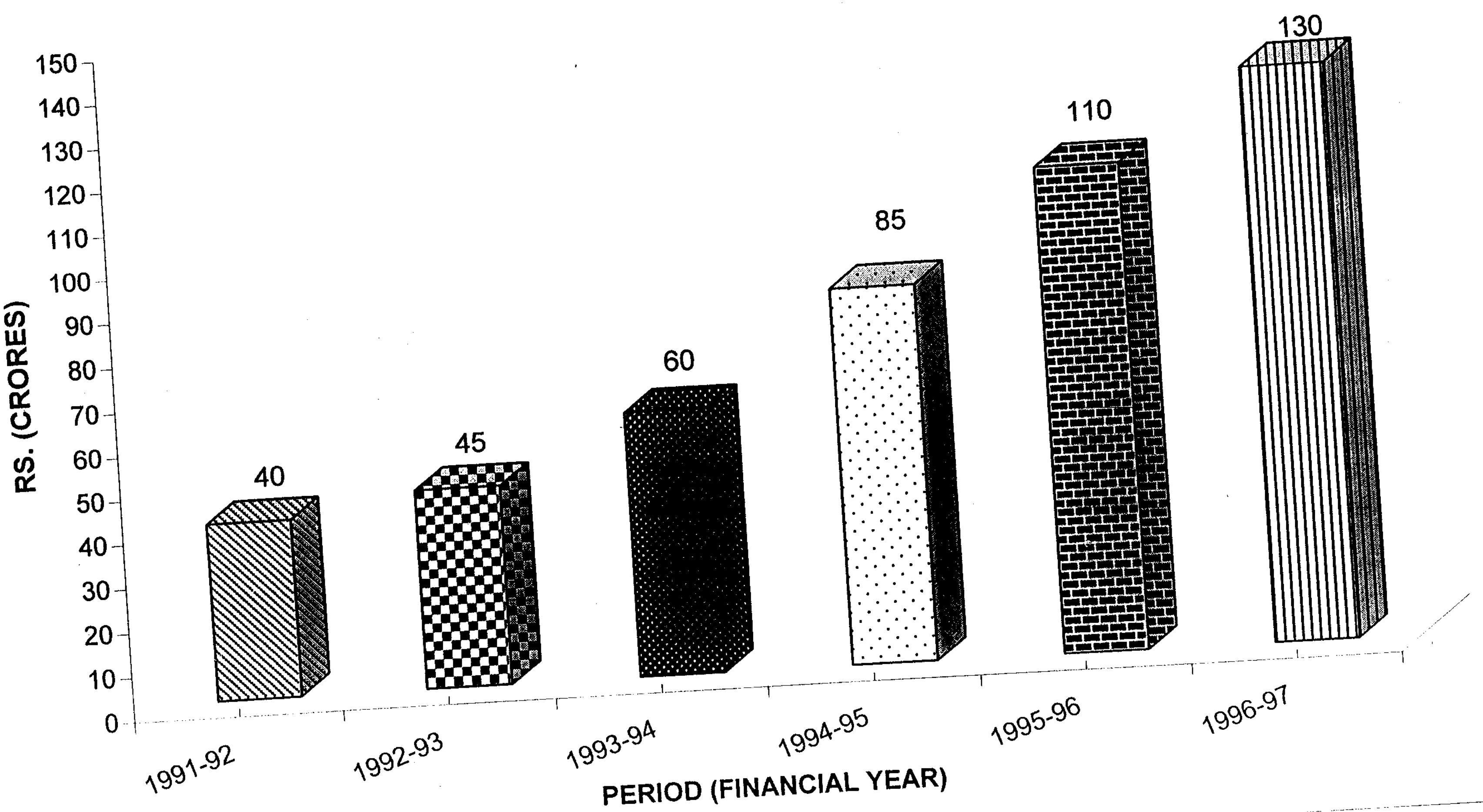
ORGANISATION CHART



ORGANISATION CHART



SALES TURNOVER
(Rs. In crores)



1.7. Introduction About The Project:

IE [Industrial Engineering] is concerned with increasing productivity of any concern. Productivity can be achieved in many ways, such as

1. Eliminating Ineffective time
2. Eliminating excess time in Total work content
3. Reducing the manufacturing cost

In this project, by means of machining process optimization [ie reducing machine time through selecting suitable process parameters like speed, feed rate and depth of cut] productivity is achieved. For some experiment number of trials and combination of process variables of each trial is selected as per the "composite Central Rotatable Design of Experiment" for some trial, the experiment conducted as per "Taguchi Design of Experiment" for the experiment using Central Rotatable Design of experiment through "MATLAB SOFTWARE" optimization has achieved.

1.8. Introduction About Software used in this Project MATLAB:

MATLAB is a high performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are

- Math and computation
- Algorithm development
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non interactive language such as C or Fortran.

The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state-of the-art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

The MATLAB System:

The MATLAB system consists of five main parts:

The MATLAB language. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs.

The MATLAB working environment:

This is the set of tools and facilities that you work with as the MATLAB user or programmer. It includes facilities for managing the ... and importing and exporting data. It also includes tools for developing, managing, debugging, and profiling M-files, MATLAB" applications.

Handle Graphics:

This is the MATLAB graphic system. It includes high-level commands for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level commands that allow you to fully customize the appearance of graphics as well as to build complete Graphical User Interfaces on your MATLAB applications.

The MATLAB mathematical function library:

This is vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigen values, Bessel functions, and fast Fourier transforms.

The MATLAB Application Program Interface (API):

This is a library that allows you to write C and Fortran programs that interact with MATLAB. It include facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for reading and writing MAT-files.

About Simulink:

Simulink, a companion program to MATLAB, is a interactive system for simulating nonlinear dynamic systems. It is a graphical mouse-driven program that allows you to model a system by drawing a block diagram on the screen and manipulating it dynamically. It can work with linear, nonlinear, continuos-time, discrete-time, multivariable, and multirate system.

Block sets are add-ins to Simulink that provide additional libraries of block for specialized applications like communications, signal processing, and power systems.

Real-time workshop is a program that allows you to generate C code from the block diagrams and to run it on a variety of real-time systems.

1.9. Introduction about the product:

Hand Taggle press:

It is used to press minimum thickness plate with a predetermined pressure. It can be operated by manpower or hydraulic force.

Construction of Hand Taggle press:

A body with base plate house all the components. in the hand portion of the body, slider is attached. Above the slider cylinder is attached. Ram is connected with the cylinder though some linkages via the slider. Air filter, lubricating oil chamber, pressure Gauge with control value and Electronic timer connected with this structure.

Working Mechanism:

In case of manual operation by simply moving the handle, the pressing can be achieved. In case of pneumatic force. From the external source, compressed air come to the air filter and the filtered air passes to cylinder. The air pressure can be controlled by control knob. Hence by controlling the knob the desired pressure is obtained. Forced air also take the lubricating oil into the cylinder. The time duration for the forward and return stroke of ram is set by the use of Electronic timer. The travel distance of ram can be adjusted according to the workpiece.

CHAPTER 2

OBJECTIVES AND PROBLEM DEFINITION

2.1 Literature Survey:

Conventional Machining Process:

The conventional machining process depends upon the workers intuition, experience skill and the overwhelming presence of a human element can sometimes lead to dangerous and erroneous results, in synthesis of simpler systems.

The conventional machining process can lead to uneconomical process and can involve job of calendar time. In the conventional machining process, first we are collecting the data to describe the processes which are involved in the particular component. Then the second step in the conventional machining process is estimate the initial process. That means finding the process which is going to do first.

The third step is analyzing the process. By analysing the process we can get more details about the process. After doing this one, next to checking at the performance criteria. In which we are knowing that the process is satisfactory (or) not suppose the process is satisfactory step it. If not, then change the process based on experience. Owing to the process is not satisfactory again goes to third step that means analyze the process.

For the conventional machining process, the industrial engineers should have more experience for giving the change values. So that it is uneconomical one. But this may not be that much sufficient.

Advantages:

1. Processing cost is less.
2. Power consumption rate for the process is less.

Optimum Machining Process :

The optimization process is more organized using trend information to make decision. However the optimization process can benefit substantially from the industrial engineers experiences and intution. The best approach would to be to have optimum machining process.

In the optimum machining process, we have to identify the machining Process variables

1. Cost function to be minimized
2. Constraints that must be satisfied

In the optimum machining process first three stages are as like as conventional Machining process. Then afterwards, in which doing check the constant. That means constraints which are used in

The decision making step is the next step which is does the design satisfy. Suppose the design is satisfied mean that stop it. If not, changed using optimization method.

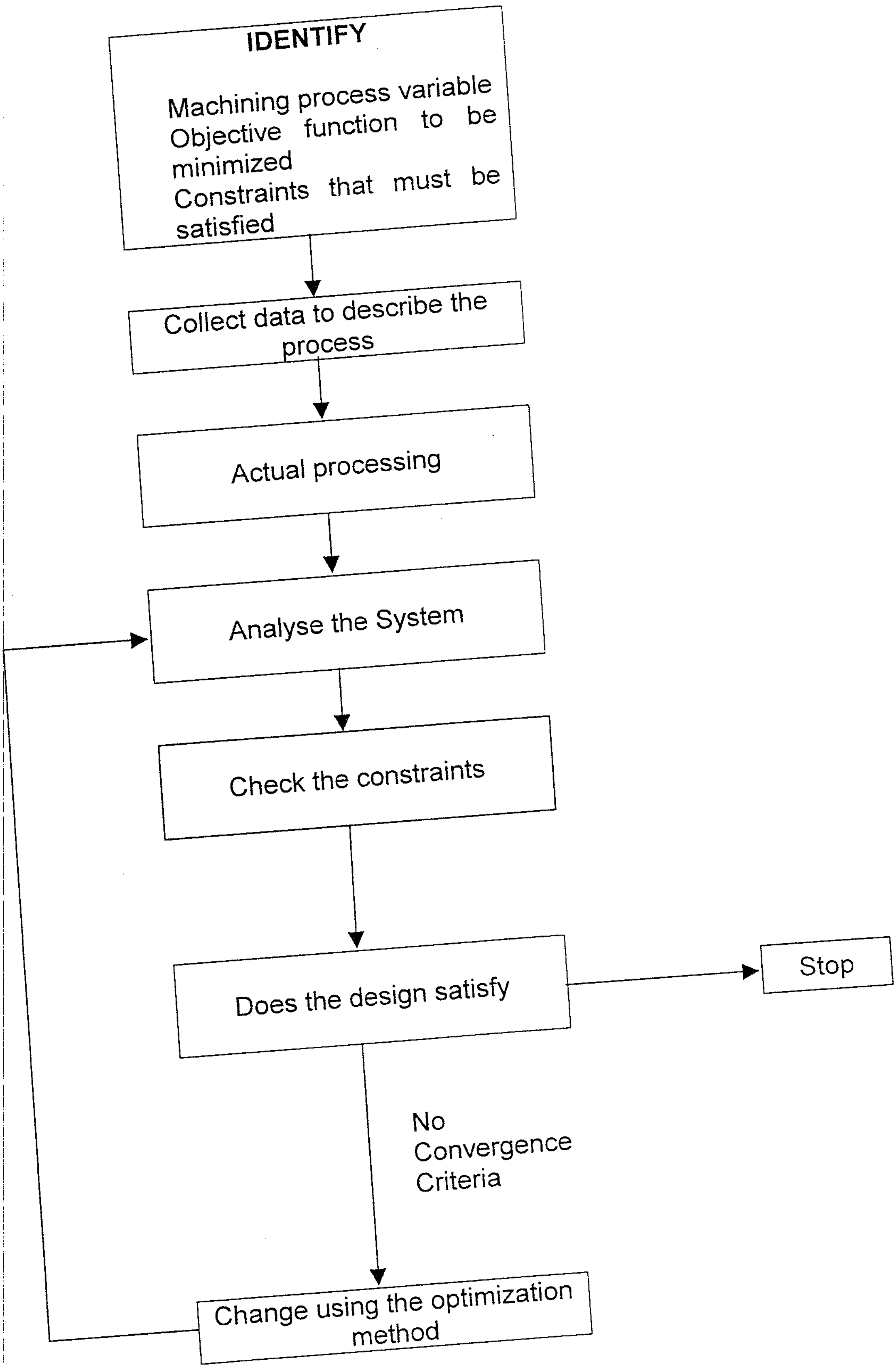
In the optimum machining process, the tool which is powerful for optimizing the process is MATLAB software it consists of optimization technique after changing the value using optimum method. It goes to analysing stage.

Objective:

The optimum machining process consists of number of objectives

1. The process time reduction lead to productive increase.
2. Effective utilisation of resources.

Optimum Machining Process



Advantages:

1. Productivity increases by getting variables at optimum levels
2. Process time reduction on each process

I Machine idle time is reduced

II Process time is reduced

III Production is increased

IV Production cost is reduced

Optimum machining process and optimum control :

The optimum control problem is to find feed rate back controllers for a process to produce the designed output. The process has active elements that sense fluctuation in the output process controls set automatically adjusted to correct the situation and optimize a measure of performance. The control problem are usually dynamic in nature.

In optimum process on the other hand we design the system and its elements to optimize an objective function. Formulation of optimum problem involves variable description of the problem into a well designed mathematical statement. The information process begins by identifying a set of variables to describe the system called process variables which are feed rate, speed, depth of cut.

All process are designed to perform within a given set of

eliminations on resources, materials failure response of the process. The constraints must be influenced by the process variables, because only then they can be imposed. If process satisfy all constraints, then have a feasible solution.

A criterion is needed to judge whether or not a given process than another. This criterion is called the objectives function.

A valid objective function must be influenced by the process variable problem (i.e.) it must be the function of the process variables.

Role of Computers in Optimizing The Machining Process:

The conventional machining process or optimum machining process is iterative process which requires some set of calculations repeatedly. So that, such repetitive calculations are ideally suited for computer implementations.

In addition, each process cycle may reactive substantial calculations. Therefore computers play an important role in the machining process.

It can be seen that the amount of data generated in the iterative comprehensive form. Graphical representation of data used for this process. Computer generated movies and animations combined with color-coded displays are highly digitilized for visualization of computer results. Many softwares having the optimization techniques.

Owing to iterative process, we can't able to have all the data in the mind and optimize. Computer which is having softwares using optimization technique can be used to optimize the iterative process.

Advantage :

It takes less time to optimize the process, when we are giving the input as objectives functions and constraints.

1. Flexibility is more.
2. It is better for more complicated process.

Disadvantages :

1. Capital cost is more
2. Processing cost is more
3. Maintenance cost is more
4. Power consumption rate is more.

Different Ways of process optimizations:

The main aim of the process optimization is to increase the productivity. So the process optimization can be achieved in different ways.

1. Automation method.
2. Methods to effectively use the resources.
3. Iterative method.

Automation Method:

The flexibility of automation varies from rigid or fixed automation to highly flexible automation by the use of the CNC machines. In most of the machine the job of the operator is reduced only to loading and unloading the machines. Therefore, multi-machine operations are preferred.

One operator is operating more than one machine depending upon the cycle time proportion of manual work involved in the total cycle time. So that, interference is unavoidable part in case of multimachine operations. Interferences can be classified into the following categories.

1) Interferences at the start and after every break taken by the operator.

3) Interferences due to inspection of jobs.

4) Interferences due to speed change in the machine.

5) Interferences due to change of machine and men other reasons are depending upon the method of working in an industry.

Iterative Method:

This is also of the way of process optimization. It has number of iterations. It can be seen that the amount of data generated in the iterative process can be enormous which must be presented in a comprehensive form.

So, this iterative method involve more number of calculations repeatedly using to the use of the computer is best for the iterative process optimization.

Higher productivity ways:

It should also be remembered that increase productivity is not solely achieved by worker's effort. Generally increased productivity can be achieved through simplification and standardization of products crumbling minimum number of counts by specialization and establishing the market.

Improved methods or simplifications for better planning and scheduling to minimize the bottle necks down time every better workplace layout, improved working condition like reduced temperature, less noise, less vibration, etc.

Cost reduction and optimization are highlighted in this. So reducing the time lead increase of the production.

Time Study:

Regarding the process the time taking for each and every process is important. For calculating the total manufacturing time stop watch time study is used.

Stop Watch Time Study:

It is one of the techniques of work measurement commonly used. Here we make use of a stop watch for measuring the time.

The various steps involved in the conduct of stop watch for measuring the time study are :

1. Select the work to be studied.
2. Record all the information about the job, operator and working condition.
3. Break down the operation into elements.
4. Examining each element.
5. Measuring using a stop watch, the time taken for each element to set the observed time.

7. Calculating the basic time.

8. Determining the allowance.

9. Compiling the standard time.

Selection of job :

(i) A new job, new component or new operation.

(ii) When new time standard is required.

(iii) To check all the correctness of the existing time standard.

(iv) When the cost of the operation is found to be high.

(v) Before introducing an incentive scheme.

Recording the specification:

The following information are recorded.

1. About the product, product number specification.

2. About the machine and equipment and tools

3. About the working condition – temperature-humidity –lighting- etc. These informations are used when deciding about the allowances.

4. About the operator name – experience, age, etc. This is needed for rating the operator.

Breaking Operation into elements:

Each operation is divided into a number of elements. This is done for easy observation and accurate measurement .The elements are grouped as constant element, variable element, occasional element, man element, machine element, etc.

Examining each element :

The element are examined to find out whether they are effective or wasteful elements are also examined whether they are done in correct method.

Measuring using a stop watch :

The time taken for each element is measured using a stop watch. The time measured from the stop watch is known as observed time. Time for various groups of elements should be recorded separately. This measurement has to be done for a number of items. The number of observation depends upon the type of operation, the accuracy required and time for one cycle.

Assessing the rating factor :

Rating is the measure of efficiency of a worker. The operators rating is found out by comparing his speed of work with standard of work with standard performances. The rating of an operator is needed by the work study man in consultation with the supervisor. The standard rating is taken as too. If the operator is found to be slow. His rating is less is less than two, says 126.

Calculating the basic time:

Basic time is calculated as follows by applying rating factor.

$$\text{Basic time} = \text{observed time} \times \frac{\text{Operator rating}}{\text{Standard rating}}$$

Determining the allowances:

A worker cannot work all the jobs continuously. He will require tie for rest, going for toilet, drinking water, etc. Unavoidable delays may occur because of tool breakages, etc., So some extra time is added to the basic time. This extra time is known as allowance.

Compiling the standard time:

The standard time is the sum of the basic time and allowances. The standard time is also known as allotted time.

Equipments Used In Stop Watch Time Study :

The standard time is the sum of the basic time and allowances. The standard time is also known as allotted time.

Equipments Used In Stop Watch Time Study:

The various equipments used in the conduct of stopwatch time study are

1. Stop watch
2. Study board
3. Time study sheets.
4. Pencil, calculators, reliable clock with seconds hand, measuring

Stop Watch:

Stop watch is a device used for measuring the time study. Generally a decimal minute stop watch is used in time study. We can read upto an accuracy of 0.01 minute in this stop watch. This stop watch has a big dial and a small dial.

The big dial is divided into two equal divisions. The big dial makes one complete revolution per minute. So each division of large dial represents 0.01 minute. The small dial has 30 divisions. The small hand makes one complete revolution in 30 minutes. So each division in the small dial represents one minute.

Starting and stopping of the watch are done by moving the slide A. We can stop the hand at any position by moving the slide when the knob is pressed down, both the hands return to zero. When the knob is released the hands will start moving. This stop watch can be used for measuring the time both in fly back method and continuous method.

Study Board:

This is made of plywood or plastic sheet. It is flat and light in weight. The board is made slightly larger than the size of the study sheet. A clip is provided to held the study sheets. There is an

...top watch rigidly at the right hand top corner.

Time study sheet:

The study sheet is a printed form. This is used to record the details about the study. The informations usually recorded in this forms are as follows.

1. Description of the operator, operation, machine, tool etc.,
2. Details about date, time and place of study.

There are columns for recording the description of elements and the stop watch read (WR). The rating is recorded for each element. The subtracted time and the basic time are calculated.

Other Equipments:

1. Calculator is required for doing calculations.
2. Steel rule is required for measuring distances.
3. Tachometer is required for finding the revolution per minute.
4. Clock is required in the study office to record elapsed time.

Objectives of the study:

1. Standardizing and optimizing the machining time for various process
2. optimizing the machining time through selection of optimum process variables
3. By optimizing the machining time optimizing the machine of its cost and thereby optimizing the production cost.
4. Increasing the productivity.
5. Reducing the process time.
6. Increasing the production.

2.3. Problem definition:

Study of the present system

Hand Taggle press is one of the job order production in Pricol from the overall study machining cost almost contributes 50% of total cost. Hand taggle press machined in various conventional machines.

Appendix Table 1 gives a clear idea about machining time as well as machining cost for the various components of the Hand taggle press.

2.4 The problem:

The problem lies with the machining time. The high machining

2.5 What way this project will help the concern:

In the project an attempt has been made to optimize the machining time of critical operations in the critical components.

Optimization machining time is achieved by selecting optimum process variable Adopting and maintaining the same optimized process variable will help the concern to reduce their production cost of the product hand taggle process.

CHAPTER 3

METHODOLOGY

Step by Step Procedure:

1. Selecting the Component which is critical
2. Selecting the critical process in the critical component
3. Finding the process variables for the process
4. Finding the working zone for each and every process
5. Then setting the limit values, using the working zone for doing the experiment.
6. Finding the responses for each and every iterative process in the experiment.
7. Forming the equation by using the calculation.
8. Then finding the optimum value for the process using the equations using MATLAB Software.
9. Confirmity test.

3.1. Selecting the critical component:

A product consists of various components from all the components. critical component should be identified. In this study, an attempt has been made to optimize the matching time of the product. Here critical component means.

"A Component which has more number of machining operations and also each machining operation in that component consumes more time"

In this project work, Ram is identified as one of the critical

3.2. Selecting the Critical process:

A critical component may have more number of operations. Among the operations, if one machining operation takes more time compare to other operations, then that particular operation identified as critical operation.

In this work, in the critical component Ram, Internal grinding operation taken as critical operation.

3.3. Finding the process variables for the process:

In a machining operation, there are so many factors contributes the machining time well as machining accuracy. Some of the factors are uncontrollable or difficult to control. So the controllable factors are taken as process variables. In this study speed (rpm), feed rate (mm/min), Depth of Cut (mm) are taken as process variables.

3.4. Finding the working Zone and Setting the limit values:

We can very the process variables within a working range while conducting the experiments. Working range means allowable limit. If the process variable varied or moved beyond the working range, accuracy cannot be achieved.

The working range for the three process variables in the internal

Speed (S)	:	40 rpm to 304 rpm
Feed rate (F)	:	0.8 mm /min to 1.2 mm / min
Depth of Cut(D)	:	0.048mm to 0.052mm

Finding the Responses:

As per the Composite rotatable design of experiment, the trials are conducted for each trial and the responses such as machining time, cylindricity, Bore diameter meter are taken and the same are tabulated.

3.6. Forming the equation:

Mathematical models can be developed from the results obtained in the experiment using some numerical formula.

3.7. Finding the optimum value:

Optimum value arrived by feed rating all the mathematical model in the MATLAB software. Entering the valves and Running the software is discussed in chapter 5.

3.8. Confirmity test:

After arriving the optimum process variables and optimum machining time confirmity test should be conducted. A trial with all optimum process variables was conducted and the result was checked with the experiment results.

CHAPTER 4

DESIGN OF EXPERIMENTS

4.1. Central Composite Rotatable Design Of Experiment:

[5] The rotatable designs most likely useful in practice belong to a series that are also called central composite design.

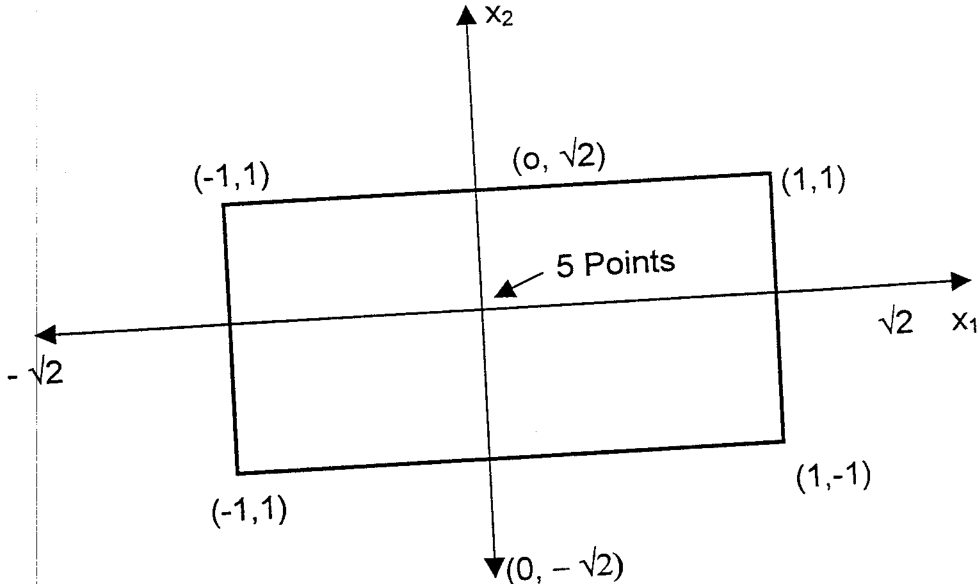


FIG.4.1.A.

Figure shows the design in two X variables, For two variable factorial points, star points and center points are calculated as shown below.

(i) The four points (-1, -1), (1, -1), (-1 1) and (1,1) constitute a 2^2 factorial points.

(ii) The four points (- 2, 0), (2,0), (0,-2), (0,2) are the extra points included to form a central composite design with 2 = 2. The figure formed by these points are called star points.

(iii) Five points are added at the center to give roughly equal precision for y within a circle of radius 1 Rotatable designs for any number K of X variable can be built up from these components. The value of 2 must be $2^{k/4}$ in order to make the design rotable. Table 6.1.A shows the number of trials or points

TABLE 4.1.B No. of Trials for Various number of process variables.

No. of x-variables	Number of points in			Total No. of Trials	Values of α
	2^k factorial	Star	Center		
3	8	6	6	20	1.682
4	16	8	7	31	2.000
5	16	10	6	32	2.000
6	32	12	9	53	2.378

Design for k= 3,4,5,6. Note that with 5 and 6 x-variables, the size of the experiment is reduced by using a half-replicate of the 2^k factorial. With a half-replicate, α becomes $2^{(k-1)/4}$.

Statistical Analysis:

The design for two x-variables is shown in the table. In a two variable experiment, the column threaded x_1 and x_2 which specify the actual combinations to be used, constitute the plan for experiment. Subsequent steps are as follows:

1. Complete the columns headed by x_o x_1^2 x_2^2 and $x_1 x_2$. The two-way array, with 6 columns and 13 rows, comprises the x matrix of the x variables. The corresponding values of the response y are placed on the right.

2. From the sum of products of each column in the x matrix with the column of values. These sum of products are denoted by (0y), (1y), (2y) and so on.

3. From the values of (0y), (1y) etc, the regression co-efficients are computed directly by the well developed equations. But the equations will be different for different number of process variables.

4. For a experiment, for all responses mathematical models should be developed. For optimizing certain response take the particular response as a objective and the other responses as its constraints. For example for optimizing the machining time, machining time can be considered as objective function and cylindricity and Bore diameter can be considered as constraint since cylindricity and Bore diameter should be maintained within a quality limit, while optimization of machining time took place. So these two considered as constraints.

Taguchi Design Of Experiment:

A manual procedure is available that quickly completes the calculation of effects from the orthogonally designed experimental observations. This method uses a special tabular format known as the

"Response table" for recording and manipulating the observed data. This method is illustrated with a 3 factor design example where the investigator uses only two treatments for each factor.

In the design example shown in the Table the investigation requires only eight experiment trials.

The effect of some factor A on the response y is the average change in the response it produces when the setting factor A goes from its low level (symbolically represented by "-1") to its high level "1". Suppose now that the factors A, B and C produced the response [4] in experiments run with the different treatments of A, B and C as shown in Table 4.2A. For each experiment (represented by a row in the table) the symbols "1" and "-1" show the particular coded combination of treatments used in that experiment.

TABLE 4.2.A.

THE ORTHOGONAL ARRAY

EXPERIMENT TRIAL NO.	TRIALS WITH PROCESS VARIABLES			OBSERVED RESPONSE
	A	B	C	
1	-1	-1	-1	Y_1
2	-1	-1	1	Y_2
3	-1	1	-1	Y_3
4	-1	1	1	Y_4
5	1	-1	-1	Y_5
6	1	-1	1	Y_6
7	1	1	-1	Y_1
8	1	1	1	Y_8

The response table method assumes additivity of factor effects at the outset. Hence in order to estimate the effect, for instance, of factor A on response y one would first add together the four responses at treatment "1" the "high". As shown in the ORTHOGONAL ARRAY. Because of orthogonally such summing (which produces $y_5 + y_6 + y_7 + y_8$) cancels out the effects of factors B and C and accumulates only the effect of setting at 1. Therefore, by dividing this sum by 4, one may find the average value of y, the response, at treatment for A = "1".

Let A bar$_1$ represent the average $[y_5 + y_6 + y_7 + y_8]/4$ similarly. Let
nt the average value of response y calculated for the

"row" treatment. "-1" . The effect of factor A on Y is then ($A\ bar_1 - A\ bar_2$) which is equal to $\frac{y_5 + y_6 + y_7 + y_8}{4} - \frac{y_1 + y_2 + y_3 + y_4}{4}$

Similarly, we find that

$$\text{Effect of B} = Bbar_1 - Bbar2 = \frac{y_3 + y_4 + y_7 + y_8}{4} - \frac{y_1 + y_2 + y_5 + y_6}{4}$$

The response table allows the above computations to be quickly completed, by hand. As one may observe, the layout of the response table 4.2B is quite straightforward. For most Orthogonal Arrays such a table may be constructed.

Note that the response table shown (Table 4.2B) include a "Random order" column. This column is the reminder to the investigator that he must randomize the experimental trials to minimize any biases in results that may develop if the trials are run in the systematic order. Such as Trial 1 to Trial 8 in a sequence. Such biases are due to uncontrolled factors. For example, the ambient temperature may rise as the experiments are run or that operator x runs the first few

Table 4.2 B

Table for the Estimated Main Effect

Random order	**Trial**	**Observed Response**	A		B		C	
			+1	**-1**	**+1**	**-1**	**+1**	**-1**
	1.	Y_1	Y_1	-	Y_1	-	Y_1	-
	2.	Y_2	Y_2	-	Y_2	-	-	Y_2
	3.	Y_3	Y_3	-	-	Y_3	Y_3	-
	4.	Y_4	Y_4	-	-	Y_4	-	Y_4
	5.	Y_5	-	Y_5	Y_5	-	Y_5	-
	6.	Y_6	-	Y_6	Y_6	-	-	Y_6
	7.	Y_7	-	Y_7	-	Y_7	Y_7	-
	8.	Y_8	-	Y_8	-	Y_8	-	Y_8
Total (Sum of All the observations in columns above goes here.								
No. of data values		8	4	4	4	4	4	4
Average		Ybar	Abar1	Abar2	Bbar1	Bbar2	Cbar1	Cbar2
Estimated Main Effect			Abar1 – Abar2		Bbar1 - Bbar2		Cbar1 - Cbar2	

Table shows the hand calculations done on a response Table. The calculations shown are for a process optimization investigation conducted with three process design factors F,S and D and a response called Yield. The bottom row of the response table shows main effects calculated.

The optimization can be achieved by the following. Consider in the above example if all the three factors. (A,B and C) –1 level has the high average and +1 level has the low average, then

$$Ymax = \bar{Y} + (Abar_{-1} - \bar{Y}) + Bbar_{-1} - \bar{Y}) + (Cbar_{-1} - \bar{Y})$$

$$Ymin = \bar{Y} + (Abar_{+1} - \bar{Y}) + Bbar_{+1} - \bar{Y}) + (Cbar_{+1} - \bar{Y})$$

Advantages of Taguchi design:

1. Compare to composite central rotatable design of experiment, the number of trials are minimum.
2. By using the formula, directly optimized responses are obtained.

Limitations of Taguchi design:

Simulating the trials apart from the real trial and getting responses are not possible.

CHAPTER 5

CONDUCTING OF EXPERIMENTS

5.1.1. Selection of Factors:

A smooth internal grinding operation even in general a good machining involves so many factors listed like below.

1. **Good Operator**
   a. Good Awareness
   b. Good Training
   c. Good Physical condition

2. **Good Machine**
   a. Good working condition
   b. Good accessories like lubricating oil and good light.

3. **Good Workshop:**
   a. Good light and ventilation

4. **Good Material:**
   a. Good Dense
   b. Free from blow holes

5. **Good Tool:**
   a. Good design
   b. Right material with right size

6. **Good Jigs And Fixtures:**

7. Good Process Variables:

Speed, Feed rate and depth of cut

Apart from the 7th factor all the other variables are difficult to control. So in this experiment only speed, feed rate and depth of cut is taken as process variables.

Selection Of Number Of Levels:

For each process variable (speed, feed rate and depth of cut) five levels or five steps are taken. Five levels have the code values as -1.682, -1, 0, 1, 1.682

Product : Hand Taggle Press

Critical Component : Ram

Critical Operation : Internal Grinding

Table 5.1

PROCESS PARAMETERS WITH THEIR LIMITS

Sl. No.	Parameter with units	Symbol	Limits				
			- 1.682	-1	0	1	+ 1.682
1	Speed (rpm)	S	40	90	144	222	304
2.	Feed rate (mm/min)	F	0.8	0.9	1.0	1.1	1.2
3.	Depth of out (mm)	D	0.048	0.049	0.050	0.051	0.052

For ease of calculation, code system is there coded value should have a relation with the real values. here the values are – 1.682,-1,0,1,+1.682. It is proportional to the values of cutting speed (feed rate) and depth of cut. But it is not proportional to the speed because it is a stepped variation. Stepped variation means within the working range, we can have only certain specific values by the design. In the above figure if you want to have the speed of fifty rpm, you couldn't get it. Because in the machine itself. After the 40 rpm, there is only 90 rpm, if it is not a stepped one, we can set any value for the five levels. For example in Pricol there is one conventional boring machine, it is having feed rate in the range of 1 mm/min to 1000 mm/min. If it is the condition, within the working range, we can set any values to our levels. so a code value can very well match with (proportional to) the real values of the factors.

TABLE 5.2 DESIGN MATRIX WITH ALL RESPONSES

Sl.No.	DESIGN MATRIX PROCESS VARIABLES			RESPONSES		
	Speed (S) (rpm)	Feed rate (F) (mm/min)	Depth of cut (D) (mm	Machining time Y1(min)	Cylindricity (μm) Y2	Boredia (mm) Y3
1.	-1	-1	-1	28.79	10	15.010
2.	1	-1	-1	28.68	13	15.010
3.	-1	1	-1	23.62	10	15.010
4.	1	1	-1	23.52	16	15.010
5.	-1	-1	1	28.94	9	15.022
6.	1	-1	1	28.84	17	15.022
7.	-1	1	1	23.82	10	15.022
8.	1	1	1	23.62	16	15.022
9	-1.682	0	0	26.90	6	15.015
10.	+ 1.682	0	0	26.10	30	15.016
11.	0	-1.682	0	32.63	13	15.015
12.	0	+1.682	0	21.63	14	15.016
13.	0	0	-1.682	26.60	13	15.005
14.	0	0	+1.682	26.60	13	15.028
15.	0	0	0	26.25	14	15.01
16.	0	0	0	26.25	13	15.02
17.	0	0	0	26.30	13	15.01
18.	0	0	0	26.25	14	15.01
19.	0	0	0	26.25	13	15.0
20.	0	0	0	26.25	15	15.0

TABLE 5.3 PROCESS VARIABLES WITH ALL RESPONSES

Sl.No.	PROCESS VARIABLES			RESPONSES		
	Speed (S) (rpm)	Feed rate (F) (mm/min)	Depth of cut (D) (mm)	Machining time Y1(min)	Cylindricity (time) Y2	Boredia (mm) Y3
1.	90	0.9	0.049	28.79	10	15.010
2.	144	0.9	0.049	28.68	13	15.010
3.	90	1.1	0.049	23.62	10	15.010
4.	222	1.1	0.049	23.52	16	15.010
5.	90	0.9	0.051	28.94	9	15.022
6.	222	0.9	0.051	28.84	17	15.022
7.	90	1-1	0.051	23.82	10	15.022
8.	222	1.1	0.051	23.62	16	15.022
9.	40	0.050	26.90	6	15.015	15.015
10.	304	1.0	0.050	26.10	30	15.016
11.	144	0.8	0.050	32.63	13	15.015
12.	144	1.2	0.050	21.63	14	15.016
13.	144	1.0	0.048	26.60	13	15.005
14.	144	1.0	0.052	26.50	14	15.02
15.	144	1.0	0.050	26.25	13	15.01
16.	144	1.0	0.050	26.35	13	15.02
17.	144	1.0	0.050	26.30	13	15.01
18.	144	1.0	0.050	26.25	14	15.0
19.	144	1.0	0.050	26.25	13	15.0
20.	144	1.0	0.050	26.25	14	15.0

TABLE 5.4 TRIALS (CODE VALUE) WITH SQUARE AND INTERACTION TERMS

Sl. No.	Speed S	feed rate F	Depth of Cut D	S^2	F^2	D^2	SF	SD	FD	Machining Time (min)	Cylindricity (μm)	Bore diameter (mm)
1.	-1	-1	-1	1	1	1	1	1	1	28.79	10	15.010
2.	1	-1	-1	1	1	1	-1	-1	1	28.68	13	15.010
3.	-1	1	-1	1	1	1	-1	1	-1	23.62	10	15.010
4.	1	1	-1	1	1	1	1	-1	-1	23.52	16	15.010
5.	-1	-1	1	1	1	1	1	-1	-1	28.94	9	15.022
6.	1	-1	1	1	1	1	-1	-1	1	23.84	17	15.022
7.	-1	1	1	1	1	1	-1	-1	1	23.82	10	15.022
8.	1	1	1	1	1	1	1	1	1	23.62	15	15.02
9.	-1.682	0	0	2.829	0	0	0	0	0	26.50	6	13.01
10.	+ 1.682	0	0	2.829	0	0	0	0	0	26.50	30	13.01
11.	0	-1.682	0	0	2.829	0	0	0	0	32.63	13	15,01
12.	0	+1.682	0	0	2.829	0	0	0	0	21.63	14	15.0
13.	0	0	-1.682	0	0	2.829	0	0	0	26.60	13	15.0
14.	0	0	+1.682	0	0	2.829	0	0	0	26.50	14	15.0
15.	0	0	0	0	0	0	0	0	0	26.25	13	15.0
16.	0	0	0	0	0	0	0	0	0	26.35	13	15.
17.	0	0	0	0	0	0	0	0	0	26.30	13	15.
18.	0	0	0	0	0	0	0	0	0	26.25	14	15
19.	0	0	0	0	0	0	0	0	0	26.35	13	15
20.	0	0	0	0	0	0	0	0	0	26.15	14	15
Σ	0	0	0	13.65	13.65	13.65	0	0	0	523.84	271	30

TABLE 5.5 TRIALS WITH SQUARE AND INTERACTION TERMS

Sl. No.	Speed (rpm) S	feed rate (mm / min) F	Depth of Cut (mm) D	S^2	F^2	D^2	SF	SD	FD	M.Time (min)	Cylindricity (µm)	Bore diameter (mm)
1.	90	0.9	0.049	8100	0.81	0.0024	81	0.0441	4.41	28.79	10	15.010
2.	144	0.9	0.049	20,736	0.81	0.0024	129.6	0.0441	7.056	28.68	13	15.010
3.	90	1.1	0.049	8,100	1.21	0.0024	99	0.0539	4.41	23.62	10	15.010
4.	222	1.1	0.049	49,284	1.21	0.0024	244.2	0.0539	10.88	23.52	16	15.010
5	90	0.9	0.051	8,100	0.81	0.0026	81	0.0441	4.59	28.94	9	15.022
6.	222	0.9	0.031	49,284	0.81	0.0026	199.8	0.0459	11.32	28.84	17	15.022
7.	90	1.1	0.051	8,100	1.21	0.0026	99	0.0561	4.59	23.82	10	15.02
8.	222	1.1	0.051	49,284	1.21	0.0026	244.2	0.0561	11.32	23.62	16	15.02
9.	40	1.0	0.050	1600	1	0.0025	40	0.050	2	26.90	6	15.01
10.	304	1.0	0.050	92,416	1	0.0025	304	0.050	2	26.10	30	15.01
11.	144	0.8	0.050	20,736	0.64	0.0025	115.2	0.04	15.2	32.63	13	15.01
12.	144	1.2	0.050	20,736	1.44	0.0025	172.8	0.06	72	21.63	14	15.0
13.	144	1.0	0.048	20,736	1	0.0023	144	0.048	7.2	26.60	13	15.0
14.	144	1.0	0.052	20,736	1	0.0027	144	0.052	6.91	26.50	14	15.0
15.	144	1.0	0.050	20,736	1	0.0025	144	0.050	7.49	26.25	13	15.0
16.	144	1.0	0.050	20,736	1	0.0025	144	0.050	7.49	26.35	13	15.0
17.	144	1.0	0.050	20,736	1	0.0025	144	0.050	7.49	26.30	13	15.
18.	144	1.0	0.050	20,736	1	0.0025	144	0.050	7.49	26.25	14	15.
19.	144	1.0	0.050	20,736	1	0.0025	144	0.050	7.49	26.25	13	15
20.	144	1.0	0.050	20,736	1	0.0025	144	0.050	7.49	26.25	14	15

TABLE 5.6 MEASURED VALUES FOR THE RESPONSE MACHINING TIME (Y1)

SL.NO	SY1	FY1	DY1	S^2Y1	F^2Y1	D^2Y1	SFY1	SDY1	FDY1
1.	-28.79	-28.79	-28.79	28.79	28.79	28.79	28.79	28.79	28.79
2.	28.68	-28.68	-28.68	28.68	28.68	28.68	-28.68	-28.68	28.68
3.	-23.62	23.62	-23.62	23.62	23.62	23.62	-23.62	23.62	-23.62
4.	23.52	23.52	-23.52	23.52	23.52	23.52	23.52	-23.52	-23.52
5.	-28.94	-28.94	28.94	28.94	28.94	28.94	-28.94	28.94	-28.94
6.	28.84	-28.94	28.94	28.94	28.94	28.94	-23.84	28.84	-28.84
7.	-23.82	23.82	23.82	23.82	23.82	23.82	23.82	23.82	23.82
8.	23.62	23.62	23.62	23.62	23.62	23.62	23.62	23.62	23.62
9.	-44.573	0	0	+74.97	0	0	0	0	0
10.	44.573	0	0	74.97	0	0	0	0	0
11.	0	-54.88	0	0	92.314	0	0	0	0
12.	0	36.33	0	0	61.19	0	0	0	0
13.	0	0	-44.74	0	0	75.25	0	0	0
14.	0	0	44.573	0	0	74.97	0	0	0
15.	0	0	0	0	0	0	0	0	0
16.	0	0	0	0	0	0	0	0	0
17.	0	0	0	0	0	0	0	0	0
18.	0	0	0	0	0	0	0	0	0
19.	0	0	0	0	0	0	0	0	0
20.	0	0	0	0	0	0	0	0	0
[illegible]					[illegible]	260.05	0	0	0

Table 5.7. MEASURED VALUES FOR THE RESPONSE CYLINDRICITY (Y2)

SL.NO.	Y2	SY2	FY2	DY2	S^2Y2	F^2Y2	D^2Y2	SFY2	SDY2	FDY2
1.	10	-10	-10	-10	10	10	10	10	10	10
2.	13	13	-13	-13	13	13	13	-13	-13	-13
3.	10	-10	10	-10	10	10	10	-10	+10	-10
4.	16	16	16	-16	16	16	16	16	-16	-16
5.	9	-9	-9	9	9	9	9	9	-9	-9
6.	17	17	-17	17	17	17	17	-17	17	-17
7.	10	-10	10	10	10	10	10	-10	-10	10
8.	16	16	16	16	16	16	16	16	16	16
9.	6	-10.092	0	0	16.974	0	0	0	0	0
10.	30	50.46	0	0	84.87	0	0	0	0	0
11.	13	0	-21.866	0	0	36.77	0	0	0	0
12.	14	0	23.548	0	0	39.60	0	0	0	0
13.	13	0	0	-21.866	0	0	36.77	0	0	0
14.	14	0	0	23.548	0	0	39.60	0	0	0
15.	13	0	0	0	0	0	0	0	0	0
16.	13	0	0	0	0	0	0	0	0	0
17.	13	0	0	0	0	0	0	0	0	0
18.	14	0	0	0	0	0	0	0	0	0
19.	13	0	0	0	0	0	0	0	0	0
20.	14	0	0	0	0	0	0	0	0	0
[illegible]	[illegible]	[illegible]	4.682	4.682	202.83	177.37	177.37	1	5	-3

Developing the Mathematical Model:

After finding the summation of square terms and interaction terms, Mathematical Model can be developed using the following formula.

$B_o = 0.166338\ (oy) - 0.056791\Sigma\ (iiy)$

$B_i = 0.073224\ (iy)$

$B_{ii} = 0.062500\ (iiy) + 0.006889\ \Sigma\ (iiy) - 0.056791\ (oy)$

$B_{ij} = 0.125000\ (iiy)$

In the experiment, the Responses are three namely

1. Machining time (y1)
2. Cylindricity (y2)
3. Bore diameter (Y3)

So for each Response mathematical model can be developed in the following way

$$Y1 = B_o + B_1 S + B_2 F + B_3 D + B_{ii} S^2 + B_{22} F^2 + B_{33} D^2 + B_{12} SF + B_{13} SD + B_{23} FD$$

$$Y2 = B_0 + B_1 S + B_2 F + B_3 D + B_{11} S^2 + B_{22} F^2 + B_{33} D^2 + B_{12} SF + B_{13} SD + B_{23} FD$$

$$Y3 = B_0 + B_1 S + B_2 F + B_2 D + B_{11} S^2 + B_{22} F^2 + B_{33} D^2 + B_{12} SF + B_{13} SD + B_{23} FD$$

By Using Central Composite Rotatable Design of experiment Developing a Mathematical Model for the Response Machining time (Y1)

[8] Bo = 0.166338(0Y) - 0.056791 (iiy)

= 0.166338 (0Y1) - 0.056791 ($S^2y_1 + F^2Y_1 + D^2 Y_1$)

= 0.166338 (523.84) – 0.056791 (359.77 + 362.34 + 360.05)

Bo = 25.62

B1 = 0.073224 (iy)

= 0.073224 (Sy1) = 0.073224 (-0.51)

B1 = -0.0373

B2 = 0.073224 (1y1)

= 0.073224 (Fy1)

B2 = -2.879

B3 = 0.073224 (Dy1)

B3 = -0.0324

Bii = 0.062500 (iiy) + 0.006889 Z (iiy) - 0.056791 ($0y_1$)

B11 = 0.062500 (S^2y1) + 0.00689 (S^2y1 + F^2y1+P^2Y1) – 0.056791 (0Y1)

B11 = -0.205

Similarly

$B22 = 0.062500 (F^2 y1) + 0.006889 (S^2 y1 + F^2 y1 + D^2 y1)$

$- 0.56791 (0y1)$

$\boxed{B22 = 0.758}$

$B33 = 0.062500 (D^2 y1) + 0.006889 (S^2 y_1 + F^2 y1 + D^2 y1)$

$\boxed{B33 = 0.553}$

$Bij = 0.125000 (iiy)$

$B12 = 0.125000 (SFY1)$

$B12 = 0.125000 (-0.09)$

$\boxed{B12 = -0.0113}$

$B13 = 0.125000 (SDY1)$

$\boxed{B13 = -00113}$

$B23 = 0.1250000 (FDY1)$

$\boxed{B23 = -0.00125}$

Machining time (y1) = $B0 + B1S + B2F + B3D + B11S^2 + B22F^2 + B33D^2 + B12SF + B13SD + B23FD$

Machining time (y1) = $25.62 - 0.0373S - 2.879F + 0.0324D + 0.205 S^2 + 0.758F^2 + 0.533 D^2 - 0.0113 SF - 0.0113 SD - 0.00125 FD$

Interpretation of Machining time [Y1] Mathematical model

1. Speed and feed rate have –ve sign in the mathematical model. So speed and feed rate inversely proportional to machining time.

2. Depth of cut has +ve sign in the mathematical model, Hence depth of cut directly proportional to machining time.

3. Magnitude of the co-efficient of the feed rate is more compare to speed and depth of cut. So feed rate has more influence on machining time.

4. Interaction effect of the process variables have –ve sign. So they are inversely proportional to machining time.

5. With this quantitative model, simulation of the response (machining time) for various combination of process variables is possible.

By central composite rotatable design of experiment developing a mathematical model for the response cylindricity (y2)

B0 = 0.166338 (0Y2) – 0.056791 Σ (iiy)

= 0.166338 (271) – 0.056791 (202.83 + 177.37 + 177.37)

B0 = 13.41

Bi = 0.073224 (1y2)

Bi = 0.073224 (1y2)

B1 = 0.073224 (sy2) = 0.07324 (63.36) = 4.63

B2 = 0.073224 (FY2) = 0.073224 (4.682) = 0.343

B3 = 0.073224 (DY2) = 0.073224 (4.682) = 0.343

Bii = 0.062500 (iiy) + 0.006889 Σ (iiy) – 0.056791 (0y)

B11 = 0.062500 (S^2Y2) + 0.006869 (S^2Y2 + F^2Y2 + D^2Y2)

– 0.056791 (0Y2)

= 0.062500 (202.83) + 0.006889 (202.83 + 177.37 + 177.37) – 0.056791 (271)

B11 = 1.128

B22 = 0.062500 (F^2Y2) + 0.006889 (S^2Y2 + F^2Y2 + D^2Y2)

– 0.056791 (0Y2)

= 11.085 + 3.84 – 15.3

B22 = -0.384

B33 = 0.062500 (D^2Y2) + 0.006889 (S^2Y2 + F^2Y2 + D^2Y2)

B33 = -0.384

Bii = 0.125000 (1SY)

B12 = 0.125000 (SFY2)

B12 = 0.125000 (SFY2)

B13 = 0.125000 (SDY2)

B13 = 0.625

B23 = 0.125000 (FDY2)

B23 = -0.375

$$\text{Cylindricity} = B0 + B1S + B2F + B3D + B11\,S^2 + B22F^2 + B33\,D^2 + B12\,SF + B13SD + B23FD$$

$$Y2 = 13.41 + 4.63S + 0.343F + 0.343D + 1.128S^2 - 0.384F^2 - 0.384D^2 + 0.125000\,(SF) + 0.625\,(SD) - 0.375\,(FD)$$

Interpretation of Cylindricity (Y2) mathematical Model

1. All the three process variable have +ve sign. So all the variables are directly proportional to machining time.
2. The magnitude of the co-efficient of speed is more. So speed has more influence over the response cylindricity.
3. The interaction effect speed and feed rate and the interaction effect speed and depth of cut is inversely proportional to machining time.
4. The interaction effect of feed rate and depth of cut directly proportional to machining time.
5. All the interaction effects in the mathematical have very minimum effect

By Central Composite Rotatable Design of Experiment developing a Mathematical model for the response Bore diameter (Y3)

Bo = 0.166338 (OY) – 0.056791 Σ (iiY)

= 0.166338 (300 326) – 0.056791 (34.94)

= 49.95 – 34.94

B0 = 15.015

Bi = 0.73224 (iY)

B1 = 0.073224 (SY3) = 0.073224 (0.01)

B1 = 0.00073

B1 = 0.001

B2 = 0.073224 (FY3) = 0.0732243 (0.01)

B2 = 0.001

B3 = 0.073224(SY3) = 0.073224 (0.05)

B3 = 0.0036

B3 = 0.004

Bii = 0.062500 (iiY) + 0.006889 Σ (iiY) – 0.056791 (OY)

B11 = 0.062500 (S^2Y3) + 0.006889 (S^2Y3 + F^2Y3 + D^2Y3) - 0.056791 (0Y3)

= 0.062500 (205.050) + 0.006889 (205.250 + 205.250 + 205.250) - 0.056791 (300.326)

B11 = 12.828 + 4.242 – 17.06 = 0.014

B22 = 0.062500 (F^2Y3) + 0.006889 ($S^2Y3 + F^2Y3 + D^2Y3$)

- 0.056791 (0Y3)

B22 = 0.062500 (205.250) + 0.006889 [205.250 + 205.250 +

205.250] - 0.05679 [300.326]

B22 = 0.014

B33 = 0.062500 (D^2Y3) + 0.006889 ($S^2Y3 + F^2Y3 + D^2Y3$)

- 0.056791 (0Y3)

B33 = 0.062500 (205.250) + 0.006889 [205.250 + 205.250 +

205.250] - 0.056791 (0Y3)

B33 = 0.014

Biy = 0.125000 (ijy)

B12 = 0.125000 (SFY3) = 0.125000 (0)

B12 = 0

B13 = 0.125000 (SDY3) = 0.125000 (0)

B13 = 0

B23 = 0.125000 (FDY3) = 0.125000 (0)

B13 = 0

Mathematical Model

Y = B0 + B1S + B2F + B3D + $B_{11}S^2$ + $B22F^2$ + B33 D^2

+ B12 SF + B13 SD + B23 FD

Y3 = 15.015 + 0.001 (S) + 0.001 (F) + 0.004 (D) +0.014 (S^2) +

0.014 ((F^2) + 0.014 (D^2) + 0 + 0 + 0

Interpretation of Bore diameter (y3) Mathematical Model

1. All the process variables speed (s) feed rate (f), Depth of cut (D) are directly proportional to the response bored.
2. All the variables have very minimum influence over the response.
3. Interaction effects of all the process variables are negligible.

PROCEDURE FOR OPTIMIZATION:

Machining time = $Y = 25.62 - 0.0373S - 2.879\ F + 0.0324\ D + 0.205S^2 + 0.758\ F^2 + 0.0553D^2 - 01113SF\ 0.0113\ SD - 0.00125FD$

Cylindricity = $Y = 13.41 + 4.63\ S + 0.343\ F + 1.128\ S^2 - 0.384\ F^2 - 0.384D^2 + 0.125000\ (SF) + 0.625\ (SD) - 0.375\ FD$

Bore diameter $Y3 = 15.015+0.001F+0.004D+0.014S^2+0.014F^2+0.014\ D^2$

Optimization :

One mathematical model should be taken as objective function and other two mathematical model can be considered as constraints. In this experiment objective is to minimize the machining time, so the first response (y1) (ie. machining time) can be considered as [illegible] responses cylinder city (y2) and

Bore diameter (Y3) considered as constraints. Cylindercity and Bore diameter should be within a limit. So they are considered as constraints.

The objective function selected for optimization was total machining time of the machining process the working zone in which solution for the objective function has decreases as the number of constraints increases. Hence only important parameter like cylindricity and Bore diameter is taken as constraints. The process variables and the notations used in the machining process for optimization using MATLAB software are given below.

X (1) = Speed

X (2) = Feed rate

X (3) = Depth of cut

Optimization of the objective function:

The main objective of this study is to minimize the total time of the manufacturing process with other important process parameters with their limits as constraints. The model is a non linear equation with constraints. The step by step procedure of minimization of total manufacturing time using the optimization model available in the tool box of the MATLAB version 4.26 software package is given below. The Constrained minimum of a scalar function of Several variables of an initial estimate which is referred as constraints non linear ... mathematically stated as Minimize f(x) subject to G (x1, x2, x 3 ... XN) Where F(X) and G (X) represents the objective function and constraint function. Optimization, the value of the constraints should be less than Zen to satisfy this condition, upper limits of each of the constraint equation. So that each of the constraints is kept below or equal to the limit. The limits of the constraints (ie. cylindricity, Bore diameter) were fixed based on the data obtained from the past experience with a view that they should provide a good machining process with a feasible solution to the objective function. Also the constraints were given in the form of equation with constraints.

Step 1 Using M File:

Function (f,g) = f (x)

f(x) = 25.62 – 0.037* x (1) - 2.879* x (2) + 0.032 * x (3) + 0.205 * x (1)^ 2 + 0.758 * x (2)^2+ 0.055 * x (3)^2 - 0.0113 * x (1) * x (2) -0.0113 * x (1) * x(3) - 0.001 * x (2) * x (3)

G(1) = 13.41 + 4.63 * x (1) + 0.343 * x (2) + 0.343 * x (3) + 1.128 * (1)^ 2 - 0.384 * x (2)^ 2 - 0.384 * x (3)^2 + 0.125 * x (1) * x (2) + 0.625 * x (1) * x (3)

G(2) = 15.015 + 0.001 * x (1) + 0.001 * x (2) + 0.004 * x (3) + 0.014 * x (1)^2 + 0.014 * x (2)^2 + 0.014 * x (3)^ 2 – 15.030

Step 2 Invoke an optimization Routine (R.file):

Xo	=	(-1, -1, 1, 1) (guess of initial solution)
Options (14)	=	1000 (Change in the details of setting)
V lb	=	(-1.682, - 1.682, - 1.682)
		Lower boundaries of the variable.
Vub	=	(1.682, 1.682, 1.682)
		Upper boundaries of the variable.

Step 3:

After invoking the R file, the optimum value of the objective function (i.e. machining time) is arrived by running the program. The optimum process variables values are also arrived. All the above values in the code form, we can get the real values from the code values.

Code values are

x	=	0.0018	0.3240	-0.0183
f(g)	=	mie (x)		
	=	24.7657		

Here mie is the programme name. All the optimum process variables have the code value which is very near to the mid point. (code value = 0). So the optimum process variables are

Speed (S)	=	144 rpm (Code Value 0)
Feed rate (F)	=	1.0 mm/ min (Code Value 0)
Depth of cut (D)	=	0.050 mm (Code Value 0)

Confirmity test:

With the optimized valves, the experiment is again conducted and the same results are achieved as below.

Machining time	=	24.73 min
Process Variables		
Speed	=	144 rpm
Feed rate	=	1.0 mm / min
Depth of cut	=	0.050 mm

Validation of Model:

In this composite Central Rotatable design of experiment 3 (Y1, Y2, Y3) mathematical models are developed. Validation of models can be achieved in two ways.

1. Percentage of Error
2. Scatter diagram.

(a) Percentage of Error:

$$\text{Percentage of Error} = \frac{OV - PV}{PV} \times 100$$

OV = Observed Value

PV = Predicted Value

Observed Value :

value which is obtained during the trial of

Predicted Value :

It is the value obtained through substuting the code values in the developed mathematical model.

If the percentage of error is minimum (say below 10%) the model is a valid. If the model has percentage of error is 10% then the acceptance level is 90%.

Percentage of Acceptance = 100~ Percentage of Error

Scatter diagram:

1) Scatter diagram is graph plotted between the observed value and the predicted value.

2) In the scatter diagram, if most of the points lies in the same trend line then the mathematical model is valid.

Validation through systat software:

For validating the methodology and the result, one of the mathematical model cylindricity is fed into the systat software. The output result of systat software is very close to the mathematical model.

DEP VAR: CYL N: 20 MULTIPLE R:0.892 SQUARED MULTIPLE R: 0.796
ADJUSTED SQUARED MULTIPLE R: .613 STANDARD ERROR OR ESTIMATE: 2.902

VARIABLE	COEFFI CIENT	STD ERROR	STD CODE	TOLERANCE	T	P(2 TAIL)
CONSTANT	13.413	1.184	0.000	.	11.333	0.000
X1	4.640	0.785	0.844	1.000	5.909	0.000
X2	0.343	0.785	0.062	1.000	0.437	0.672
X3	0.343	0.785	0.062	1.000	0.437	0.672
X1*X1	1.127	0.764	0.213	0.982	1.475	0.171
X2*X2	-0.463	0.764	-0.087	0.982	-0.606	0.558
X1*X2	0.125	1.026	0.017	1.000	0.122	0.905
X1*X3	0.625	1.026	0.087	1.000	0.609	0.556
X2*X3	-0.375	1.026	-0.052	1.000	-0.366	0.722

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F.RATIO	P
REGRESSION	328.745	9	36.527	4.338	0.016
RESIDUAL	84.205	10	8.421		

Variables which have more influence

DEP VAR: CYL N: 20 MULTIPLE R:0.874 SQUARED MULTIPLE R: 0.764
ADJUSTED SQUARED MULTIPLE R: .736 STANDARD ERROR OR ESTIMATE: 2.394

VARIABLE	COEFFI CIENT	STD ERROR	STD CODE	TOLERANCE	T	P(2 TAIL)
CONSTANT	12.723	0.685	0.000	.	18.586	0.000
X1	4.640	0.648	0.844	1.000	7.163	0.000
X1*X1	1.211	0.625	0.228	1.000	1.938	0.069

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F.RATIO	P
REGRESSION	315.530	2	157.765	27.530	0.000
RESIDUAL	97.420	17	5.731		

TABLE 5.9. VALIDATION FOR THE MATHEMATICAL MODEL MACHINING TIME [Y1]

No Trial No	Observed valued	Predicted Value	% of Error Value	% of Validation
1	28.79	29.79	-4.0%	96
2	28.68	29.96	-4.2%	9508
3	23.62	24.25	-2.5%	97.5
4	23.52	24.18	-2.7	97.3
5	28.84	30.01	-3.5	96.5
6	28.84	30.01	-3.8	96.6
7	23.82	24.38	-2.2	97.8
8	23.62	24.23	2.5	97.5
9	26.90	26.26	2.4	97.6
10	26.10	26.26	-0.6	99.4
11	32.63	30.643	6.48	93.52
12	21.63	22.92	-5.62	94.38
13	26.60	27.12	-1.91	98.09
14	26.50	27.23	-2.6	97.4
15	26.25	25.62	2.5	97.5
16	26.35	25.62	2.8	97.2
17	22.30	25.62	-2.6	97.4
18	26.25	25.62	2.4	97.6
19	26.35	25.62	2.8	91.2
20	26.15	25.62	2.0	98

TABLE 5.10. VALIDATION FOR THE MATHEMATICAL MODEL CYLINDRICITY [Y2]

Trial No	Observed Value (ov)	Predicted Value (pv)	Percentage of error $\frac{Ov-Pv}{Pv}$ x100	Percentage of Validation
1	10	8.94	11.85	88.15
2	13	12.70	2.36	97.64
3	10	9.26	8	92.00
4	16	17.26	- 7.3	92.70
5	9	10.26	- 12.28	87.72
6	17	18.26	- 6.9	93.10
7	10	10.64	- 6.0	94
8	16	16.88	- 5.22	94.78
9	6	6.5	- 7.70	92.30
10	30	28.71	4.49	95.51
11	13	12.57	3.92	96.08
12	14	13.51	3.63	96.37
13	13	12.75	- 3.78	96.22
14	14	13.51	- 3.77	96.23
15	13	13.41	- 3.78	96.22
16	13	13.41	- 3.78	96.22
17	13	13.41	- 3.78	96.22
18	14	13.41	- 3.78	96.22
19	13	13.41	- 3.78	96.22
		13.41	- 3.78	96.22

TABLE 5.11. VALIDATION FOR THE MATHEMATICAL MODEL BORE – DIA [Y3]

Trial No	Observed value (OV)	Predicted Value (PV)	Percentage Error $\frac{Ov-Pv}{Pv}$ x100	Percentage of Validation
1	15.010	15.059	- 0.33	99.67
2	15.010	15.061	- 0.33	99.66
3	15.010	15.061	- 0.33	99.66
4	15.010	15.063	- 0.35	99.65
5	15.022	15.067	- 0.29	99.70
6	15.022	15.069	-0.31	99.70
7	15.022	15.071	- 0.325	99.67
8	15.022	15.063	-0.27	99.72
9	15.015	15.021	- 0.01	99.97
10	15.016	15.016	- 0.03	99.97
11	15.010	15.016	- 0.04	99.96
12	15.016	15.021	- 0.03	99.97
13	15.005	15.021	- 0.09	99.90
14	15.028	15.033	- 0.03	99.97
15	15.015	15.015	0	100
16	15.026	15.015	0.07	99.93
17	15.016	15.015	0.01	99.99
18	15.016	15.015	0.01	99.99
19	15.015	15.015	0	100
20	15.015	15.015	0	100

Product : Hand Taggle Press

Component : Body

Operation : Milling of the Arm of the body

TABLE 5.12. TAGUCHI DESIGN FOR THREE VARIABLE (EACH VARIABLE CONTAINS 2 LEVELS)

Trial No	Process Variables			Responses		
	Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	Machining time (min. 1/100 min)	Paralality (mm)	Width (mm)
1	1	1	1	Y_1	Y_A	Y_i
2	1	1	2	Y_2	Y_B	Y_{ii}
3	1	2	1	Y_3	Y_C	Y_{iii}
4	1	2	2	Y_4	Y_D	Y_{iv}
5	2	1	1	Y_5	Y_E	Y_v
6	2	1	2	Y_6	Y_F	Y_{vi}
7	2	2	1	Y_7	Y_G	Y_{vii}
8	2	2	2	Y_8	Y_H	Y_{viii}

TABLE 5.12.B PROCESS VARIABLES WITH THEIR LIMITS

Speed (rpm)		Feed rate (mm/min)		Depth of cut (mm)	
180	222	80	125	0.7	1.2

Table 5.12 C PROCESS VARIABLES WITH THEIR RESPONSES

S.NO	Process Variables			Responses		
	Speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	Machining time (min. 1/100 min)	Paralality mm	Width mm
1.	180	80	0.7	19.00	0.01	60.01
2.	180	80	1.2	18.50	0.02	60.02
3.	180	125	0.7	15.10	0.03	60.03
4.	180	125	1.2	15.20	0.03	60.02
5.	222	80	0.7	18.20	0.01	60.02
6.	222	80	1.2	18.50	0.02	60.03
7.	222	125	0.7	14.60	0.02	60.03
8.	222	125	1.2	14.90	0.03	60.02

Table 5.12D. TABLE FOR THE ESTIMATED MAIN EFFECT

Trial No	Observed Response Mahining Time	Speed (rpm) [S]		Feed rate (mm/min) [F]		Depth of out (mm) [D]	
		1	2	1	2	1	2
1.	19.00	19.00	--	19.00	--	19.00	--
2.	18.50	18.50	--	18.50	--	--	18.50
3.	15.10	15.10	--	--	15.10	15.10	--
4.	15.20	15.20	--	--	15.20	--	15.20
5.	18.20	--	18.20	18.20	--	18.20	--
6.	18.50	--	18.50	18.50	--	--	18.50
7.	14.60	--	14.60	--	14.60	14.60	--
8.	14.90	--	14.90	--	14.90	--	14.90
Total	134	67.8	66.2	74.2	59.8	66.9	67.1
No.of Observed	8	4	4	4	4	4	4
Average	16.75	16.95 Max	16.55 Min	18.55 Max	14.95 Min	16.73 Min	16.77 Max
Estimated Main Effect		- 0.4		- 3.6		0.04	

$$\text{Ymin} = \bar{Y} + (\overline{S2} - \bar{Y}) + (\overline{F2} - \bar{Y}) + (\overline{D1} - \bar{Y})$$

$$= 16.75 + (16.55 - 16.75) + (14.95 - 16.75) + (16.73 - 16.75)$$

$$= 16.75 - 0.2 - 1.8 - 0.02$$

$$\text{Ymin} = \underline{\underline{14.73}}$$

After the computation, the optimum response is 14.73. It is close to real value 14.60. the corresponding process variables are the optimum process variables.

Optimum process variables are

Speed	=	222 rpm
Feed rate	=	125 mm/min
Depth of cut	=	0.7 mm

Product : Hand Taggle Press

Component : Body

Operation : Milling of Bottom of the surface

Machine : MB 01

For the operation two bodies are fixed and machining operations are carried out in a continuous manner. So the observed machining time divided by two to get the machining time for 1 Body. In this operation no care taker for dimensional accuracy. This operation meant for smooth sealing of the body.

Initial setting time for 2 Body	=	6 min
Initial setting time for 1 Body	=	3 min
Time for loading and unloading 2 Body	=	3 min
Time for loading and unloading 1 Body	=	1.5 min

Therefore Told time for setting and loading unloading for one body = 4.5 min

TABLE 5.13 PROCESS VARIABLES WITH THEIR LIMITS

Speed (rpm)		Feed rate (mm/min)	
1	1	1	2
90	125	100	125

TABLE 5.13A. PROCESS VARIABLES WITH THEIR RESPONSE

Sl. No.	Process Variables		Response
	Speed rpm	Feed rate (mm/min)	Machining time for (min.1/100 min)
1.	90	100	4.48
2.	125	100	4.28
3.	90	125	3.64
4.	125	125	3.44

Table 5.13 B TABLE FOR THE ESTIMATED MAIN EFFECT

Random No.	Trial No.	Observed Response Time	Speed (rpm) S		Feed rate (mm/min) F	
			1	2	1	2
			90	125	100	125
1	1	4.28	4.48	--	4.48	--
3	2	3.64	3.64	--	--	3.64
2	3	4.48	--	4.28	4.28	--
4	4	3.44	--	3.44	--	3.44
Total		15.84	8.12	7.72	8.76	7.08
No. of Observation		4	2	2	2	2
Average		3.96	4.06	3.86	4.38	3.54
Estimated Main Effect			- 0.2		- 0.84	

$$\overline{Ymin} = \bar{Y} + (\overline{S2} - \bar{Y}) + (\overline{F2} - \bar{Y})$$

$$= 3.96 + (3.86 - 3.96) + 3.54 - 3.96)$$

$$= 3.96 - 0.1 - 0.42$$

$$= \underline{3.44}$$

The minimum machining time is 3.44 min., fourth trial has the same minimum value of the optimum machining time. Hence the optimum process variables are

Speed	:	125 rpm
Feed rate	:	125 mm/min

Validation for Taguchi design:

Validation of Taguchi Design is achieved through confirmity test. Calculating the percentage of error is not possible here because here all the values are real no predicted values.

CHAPTER 6

RESULTS AND ANALYSIS

Results and analysis:

The results of the optimization is Total facing time is 24.77 min.

Cylindricity	15 µm
Boredia	15.015 mm

Analysis of results:

1. Total machining time reduced from 28.94 min to 24.77 min when the speed rised from 90 rpm to 144 rpm.

2. Total machining time reduced from 28.94 min to 24.77 min when the feed rate rised from 0.9 mm/min to 1.0 mm/min.

3. The above reduction is achieved also by decrease of 0.05 mm depth of cut to 0.050 mm depth of cut.

4. Direct effect of speed and Direct effect of depth of cut is minimum compared to direct effect of feed rate (Direct effect of feed rate is move).

5. Interaction effect speed and feed rate is comparatively more.

6. Optimum process variables for this internal grinding operation.

Speed	=	144 rpm
Feed rate	=	1.0 mm/min
Depth of cut	=	0.050 mm

7. Direct effect of all the variables on all the responses are obtained and plotted in the graphs.

8. Interaction effect of predominant process variables such as speed and feed rate on machine time also calculated and plotted in the graphs.

9. Direct effect of a variable on a response is obtained by substituting the code value of the particular variable at the particular trial on the corresponding mathematical model. While doing the above all the other variables should be in their mid point (code values are zero).

10. Interaction effect also calculated in the same way of direct effect, instead of substituting one value here two values are substituted in the mathematical model. While doing the above the third variable should be in its mid point (Code value is zero).

Direct effect of feedrate on Machining Time

Machining time [Y1] mathematical model is

$$Y1 = 25.62 - 0.0373S - 2.879F + 0.0324D + 0.205S^2 + 0.758F^2 + 0.533D^2 - 0.0113SF - 0.0113SD - 0.00125FD$$

By substituting the code value (O) of the mid points of the other process variables, mathematical model is reduced to direct effect model like below.

$$Y1 = 25.62 - 2.879F + 0.758F^2$$

In the above model, direct effect of feed rate obtained by substituting the code value of the corresponding feed rate.

For example

For Direct effect of feed rate 90 rpm (code value –1)

$$Y1 = 25.62 - 2.879F + 0.758F^2$$

$$Y1 = 25.62 - 2.879(-1) + 0.758(-1)^2 = 29.26$$

Similar all other variables are obtained as listed below

Feed Rate (mm/min)	Code Value	Machining Time Min. 1/100 min
0.8	-1.682	32.60
0.9	-1	29.26
1.0	0	25.62
1.1	1	23.5
1.2	1.682	22.92

The same procedure is repeated for obtaining direct effect of various variables on various responses.

Interaction effect of speed and feed rate on Machining time

In the machining time mathematical model speed (S), feed rate (F) have more influence. So Interaction effect of the above variables on Machining time is calculated.

Machining time mathematical model is

$$Y = 25.62 - 0.0373S - 2.879F + 0.0324\,D + 0.205S^2 + 0.758\,F^2 + 0.533\,D^2 - 0.0113SF - 0.0113\,SD - 0.00123FD$$

By substituting code value (0) of the mid point of the third variable (Depth of cut), mathematical model reduced interaction effect model like below.

$$Y = 25.62 - 0.0373S - 2.879F + 0.205\,S^2 + 0.758F^2 - 0.0113\,SF$$

In the above model, interaction effect of speed and feed rate can be obtained by substituting the code value of the corresponding variables.

For speed 144 rpm (Code value = 0)

Feed rate 1.2mm / min (Code value = 1.682)

$$Y1 = 25.62 - 0.0373S - 2.879F + 0.205S^2 + 0.758F^2 - 0.0113SF$$

$$= 25.62 - 0.0373\ [0] - 2.879\ [1.682] + 6.205(0)^2 + 0.758\ [1682]^2 - 0.0113\ (0)\ (1.682)$$

$$Y1 = 23.5 \text{ min}$$

	40	90	144	222	304
0.8	33.71	33.41	33.18	32.71	32.41
0.9	30.50	26.50	25.62	25.52	25.42
1.0	26.80	26.50	25.62	25.52	25.42
1.1	24.80	24.62	24.07	23.60	23.30
1.2	23.97	23.72	23.5	22.81	22.72

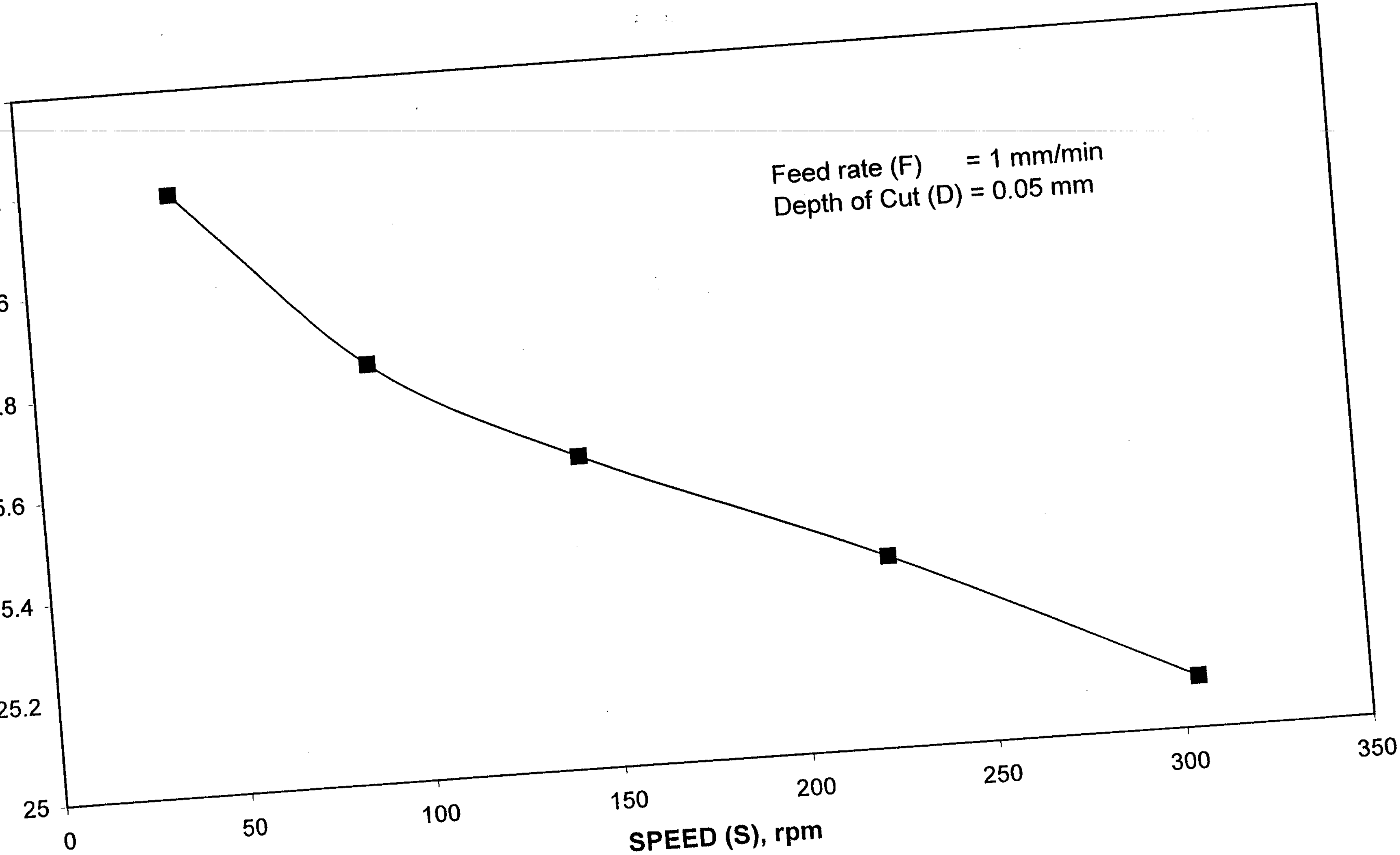


FIG.1 DIRECT EFFECT OF SPEED ON MACHINING TIME

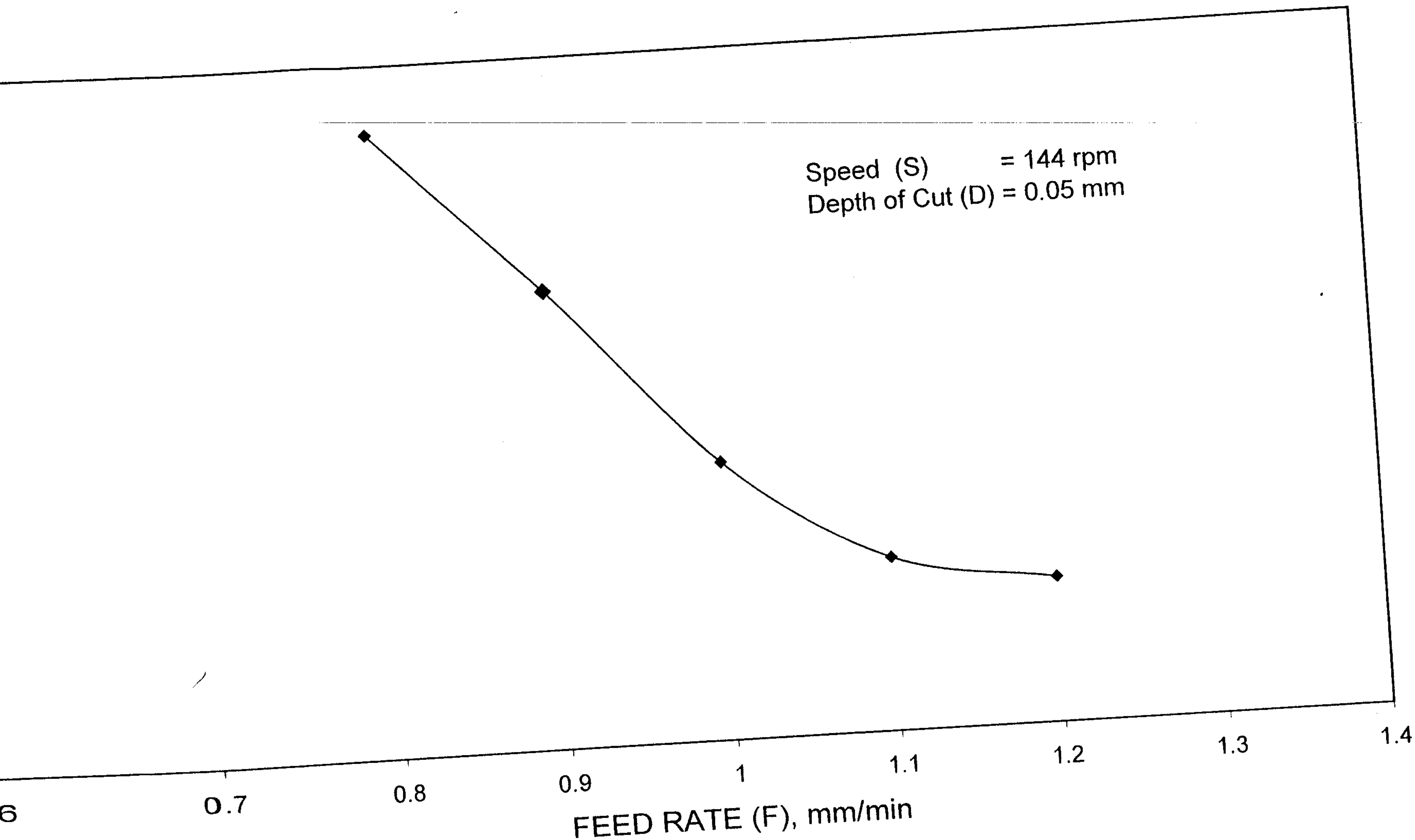


FIG. 2 DIRECT EFFECT OF FEED RATE ON MACHINING TIME

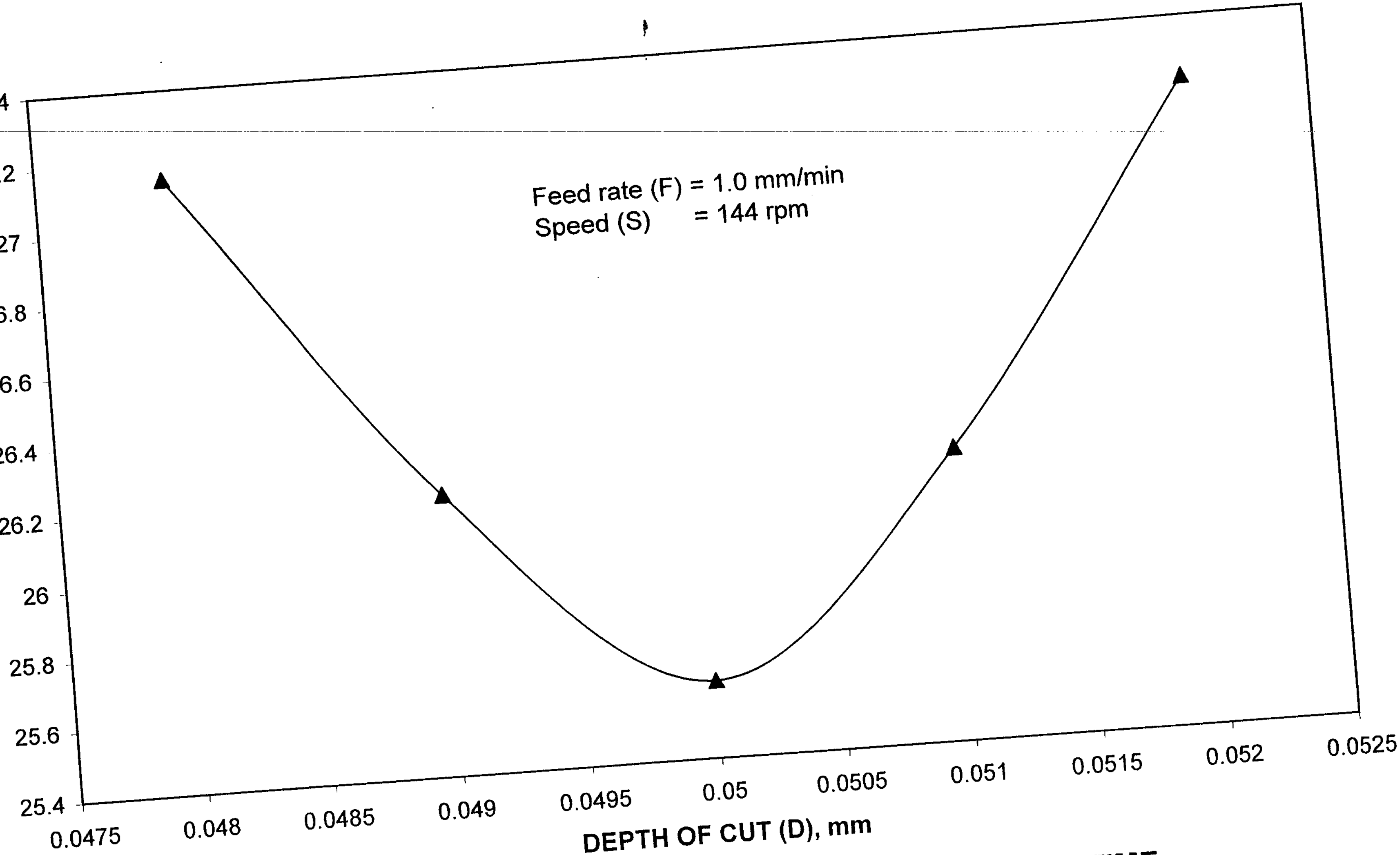


FIG. 3 DIRECT EFFECT OF DEPTH OF CUT ON MACHINING TIME

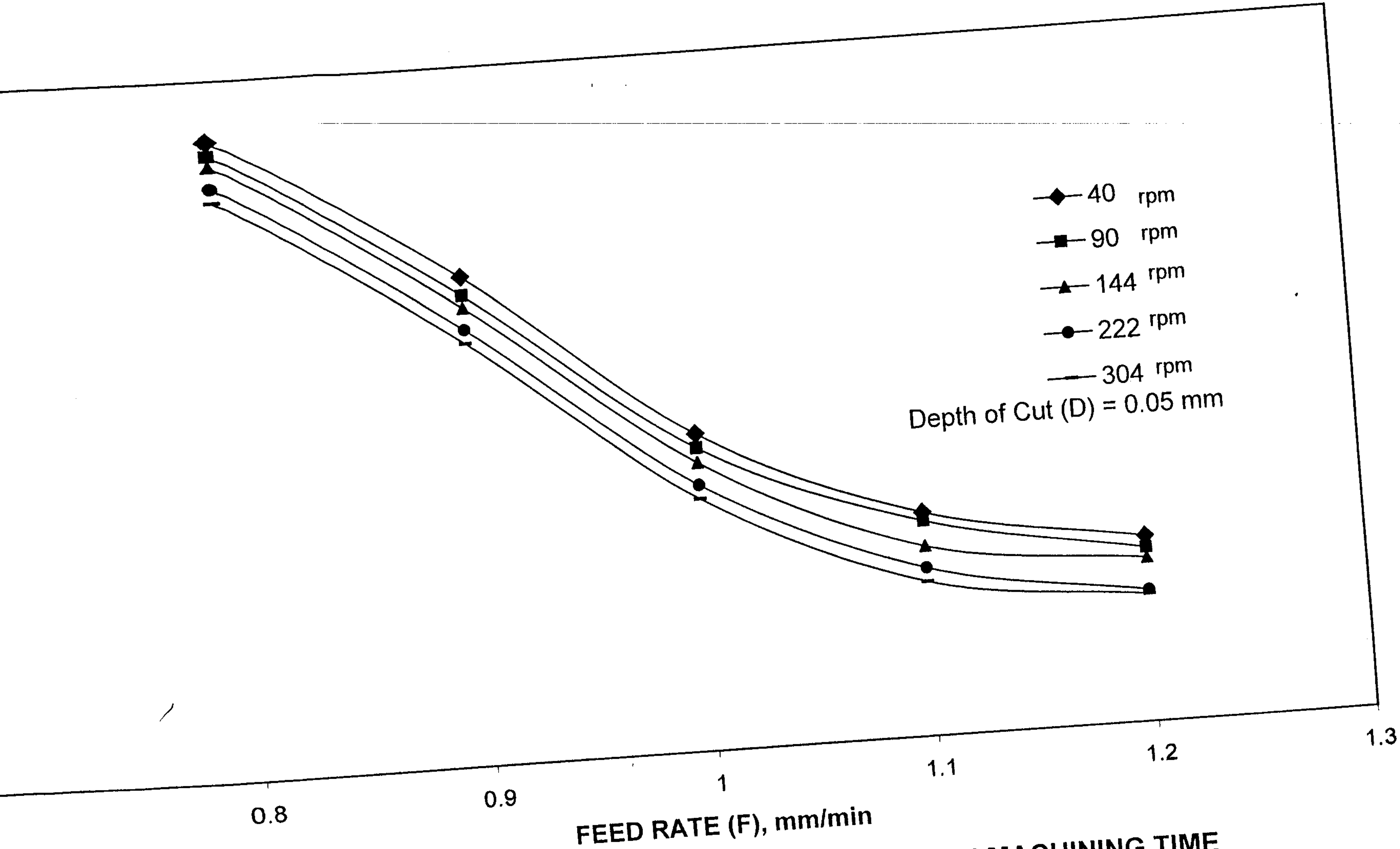


FIG. 4 INTERACTION EFFECT OF SPEED AND FEED RATE ON MACHINING TIME

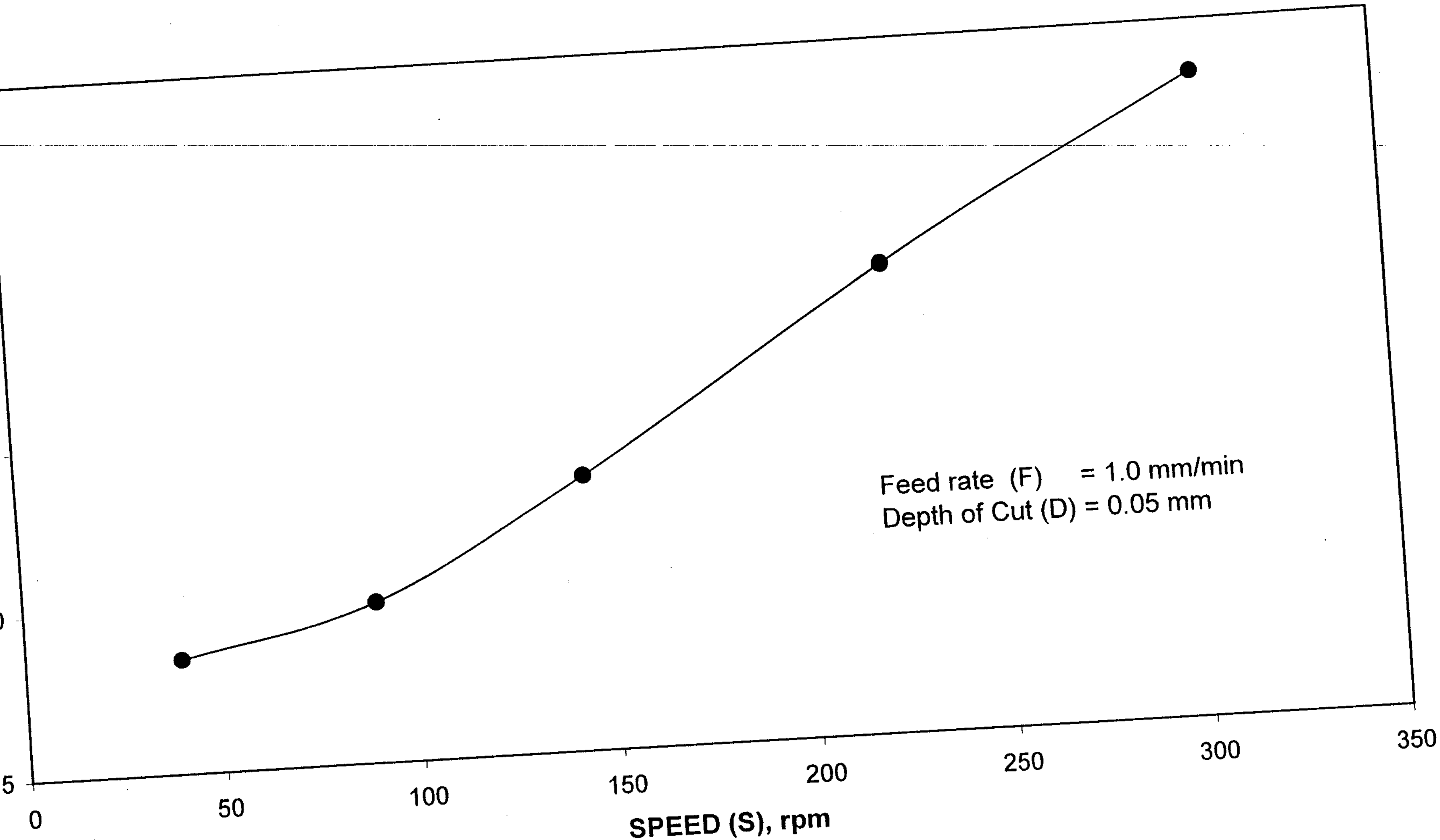


FIG. 5 DIRECT EFFECT OF SPEED ON CYLINDRICITY

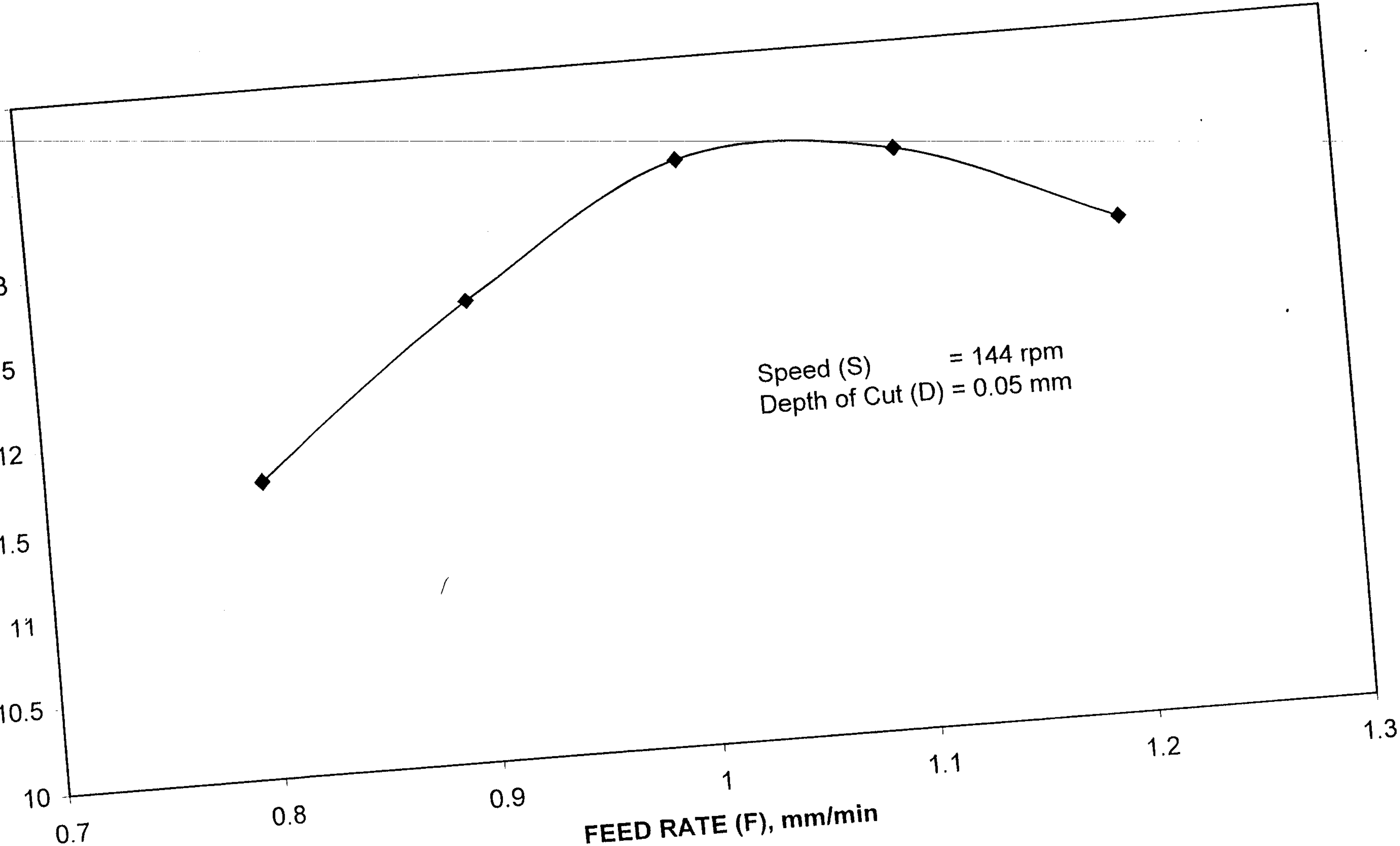


FIG. 6 DIRECT EFFECT OF FEED RATE ON CYLINDRICITY

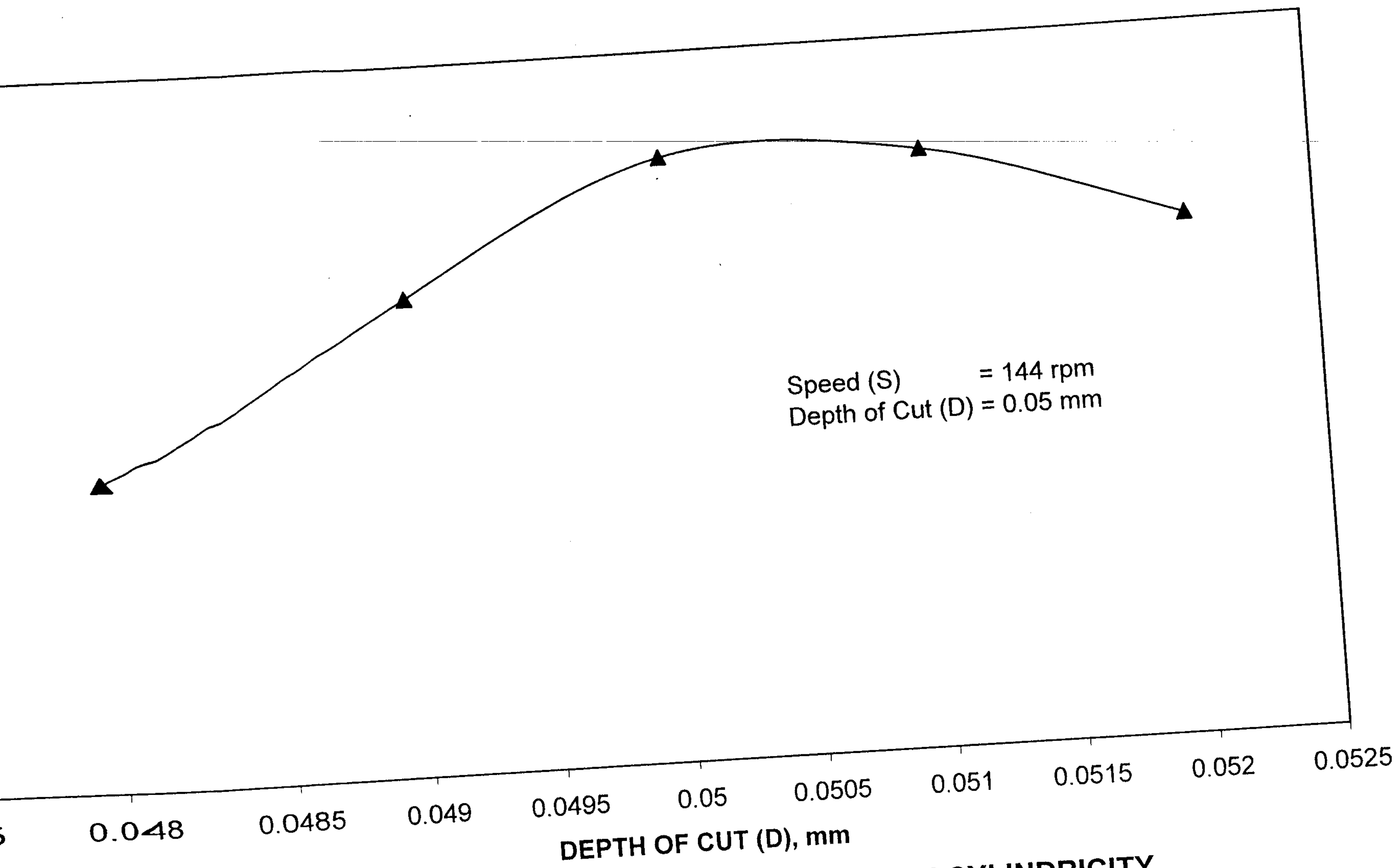


FIG. 7 DIRECT EFFECT OF DEPTH OF CUT ON CYLINDRICITY

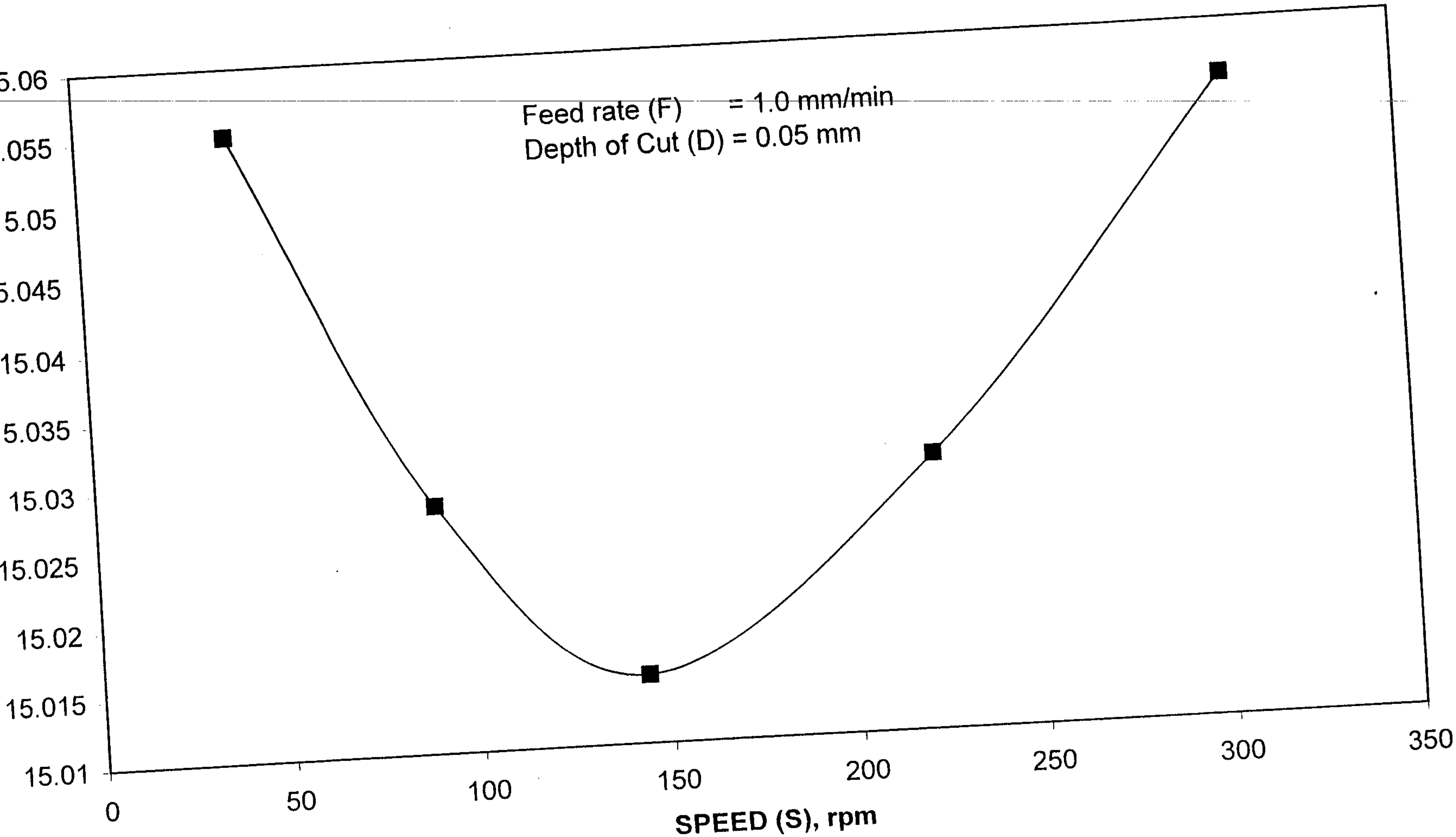


FIG. 8 DIRECT EFFECT OF SPEED ON BORE DIAMETER

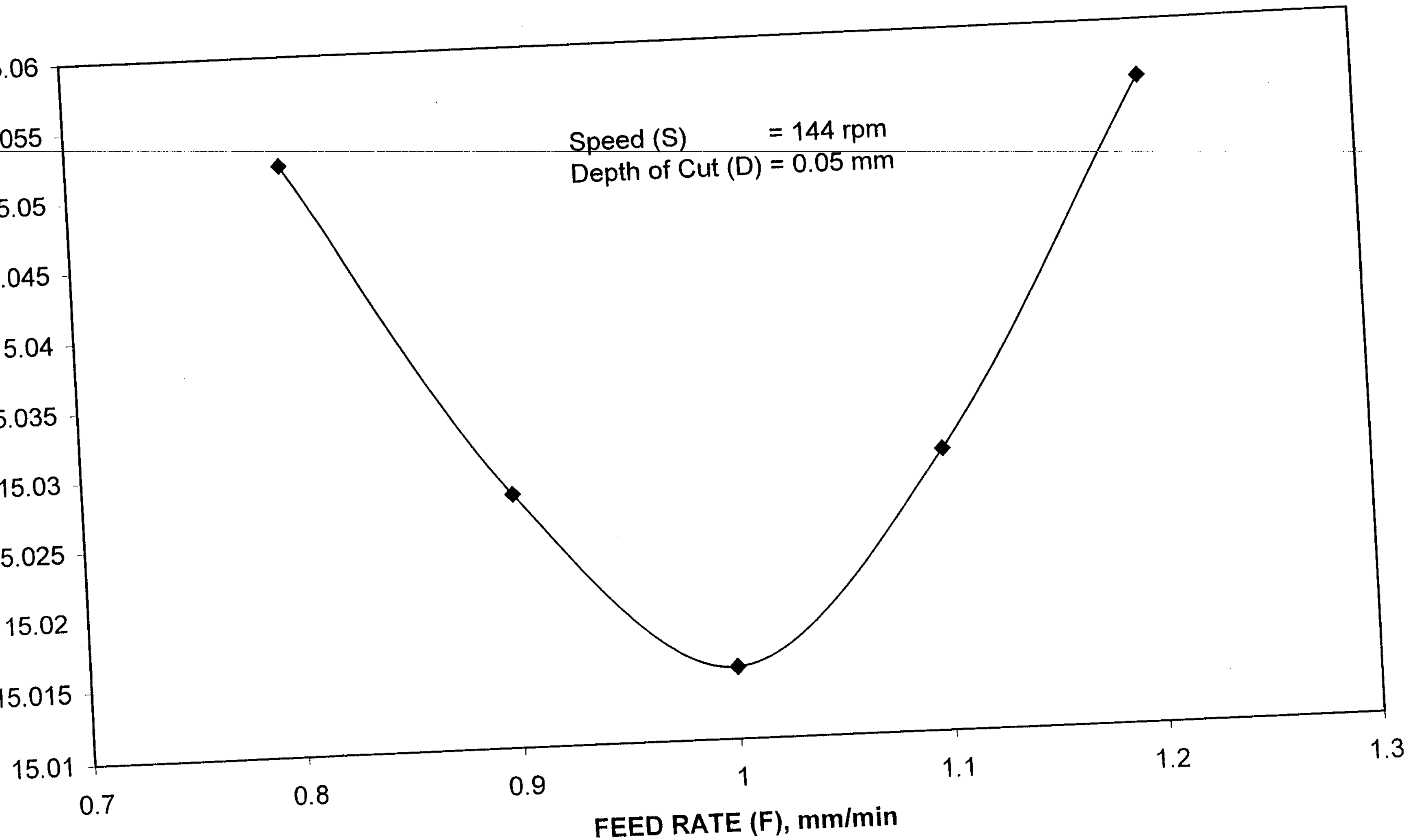


FIG. 9 DIRECT EFFECT OF FEED RATE ON BORE DIAMETER

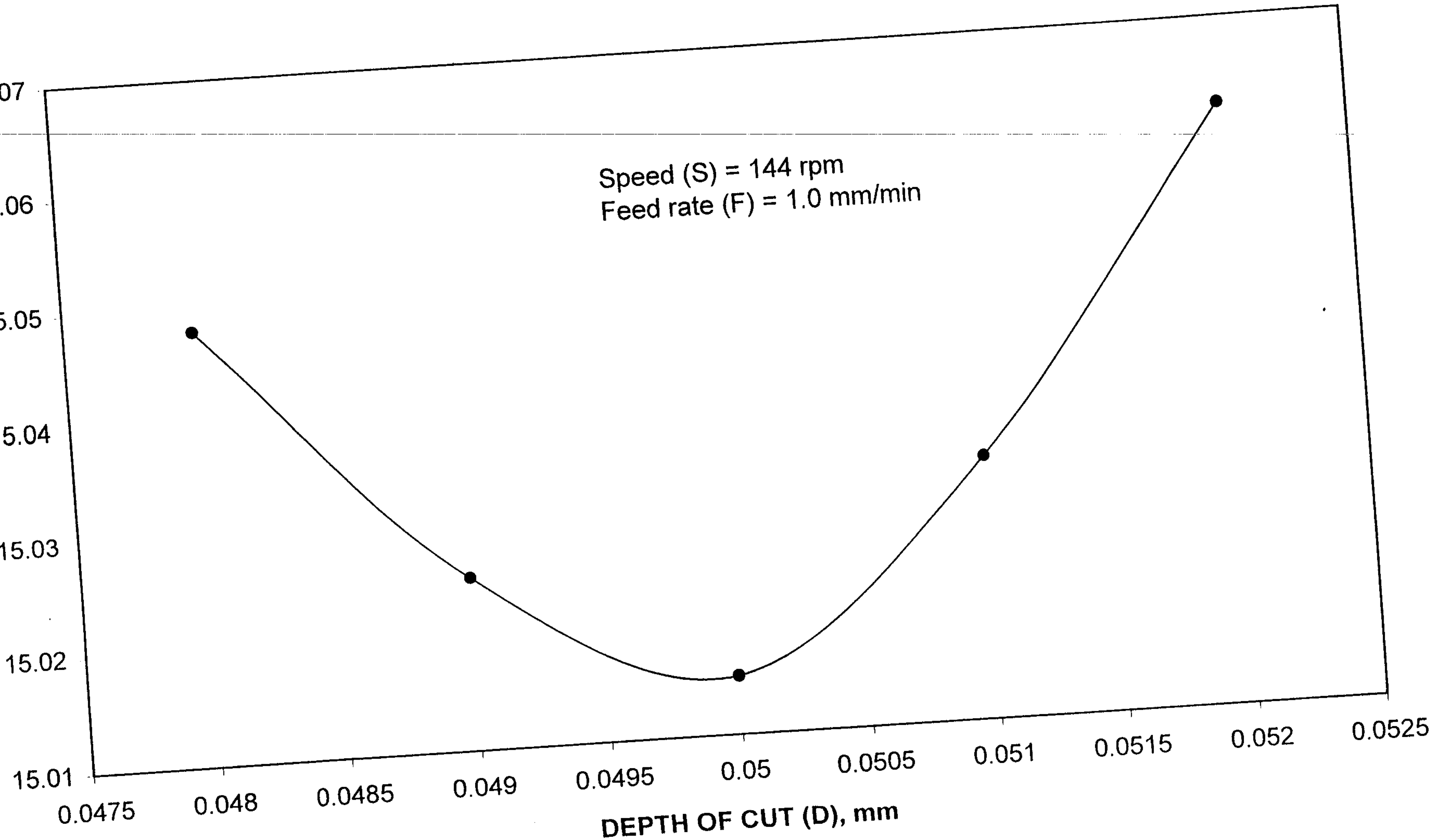


FIG. 10 DIRECT EFFECT OF DEPTH OF CUT ON BORE DIAMETER

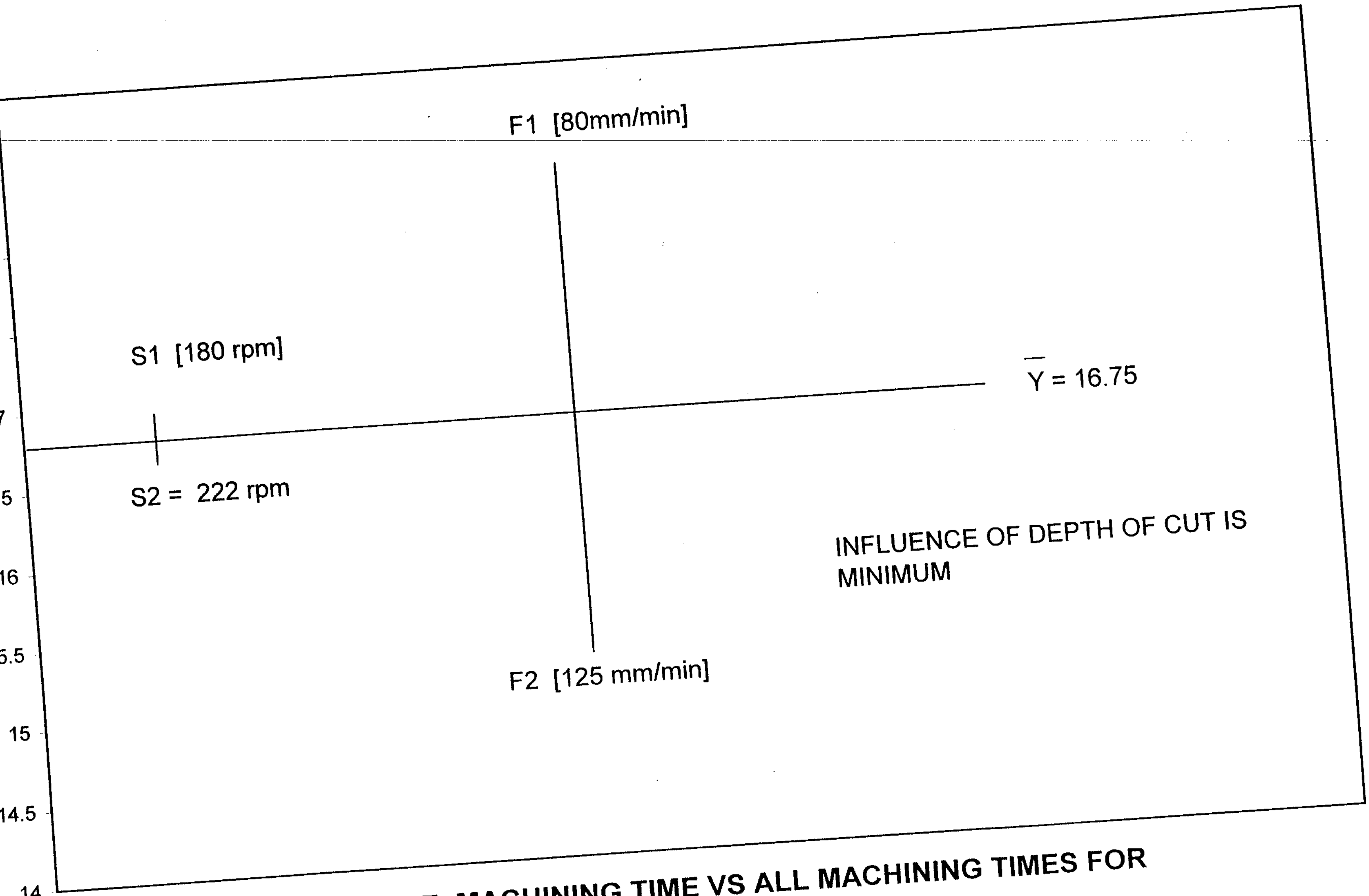


FIG. 11 AVE. MACHINING TIME VS ALL MACHINING TIMES FOR TAGUCHI DESIGN - 1

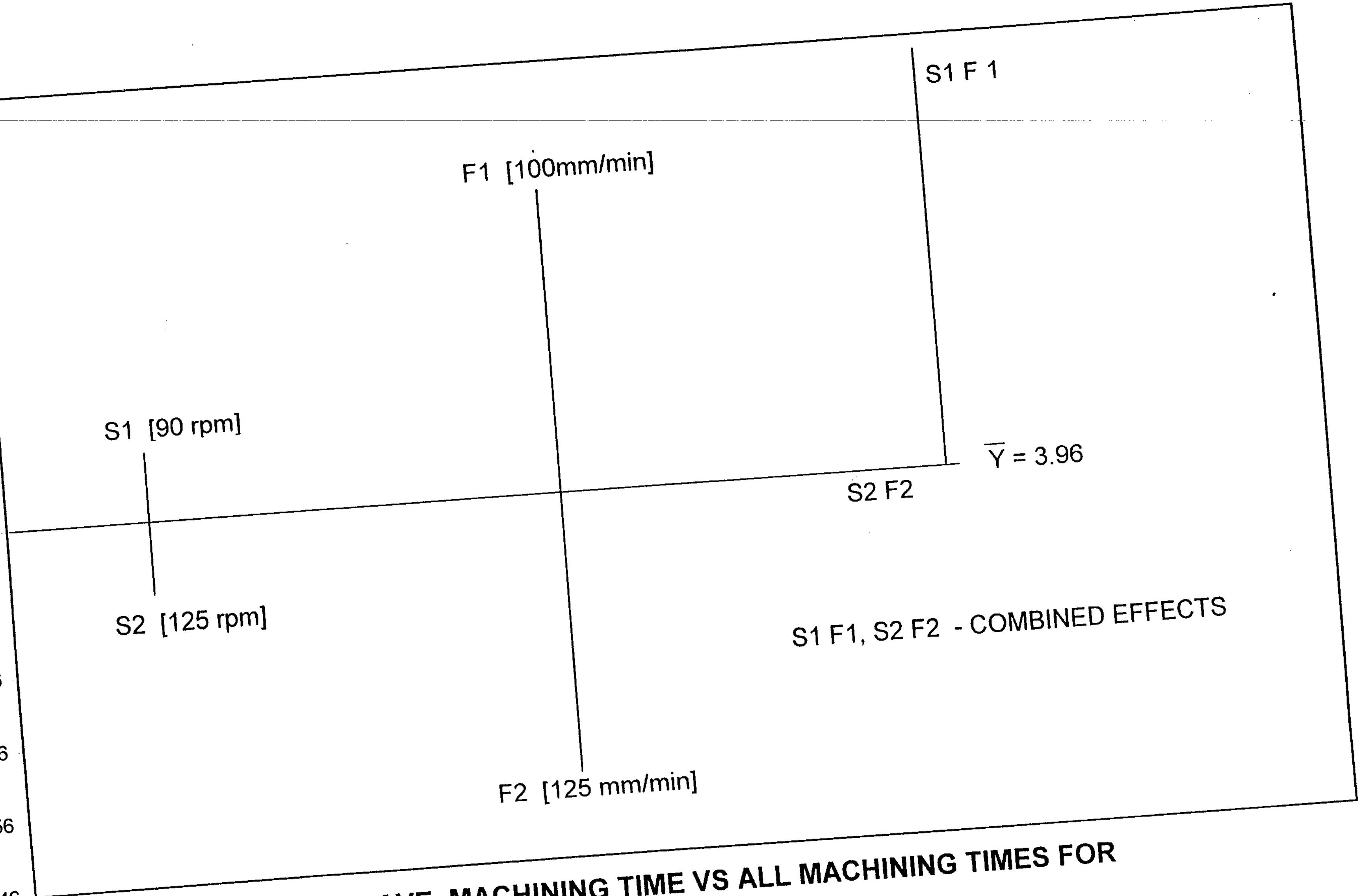


FIG. 12 AVE. MACHINING TIME VS ALL MACHINING TIMES FOR TAGUCHI DESIGN - 2

CHAPTER 7

CONCLUSIONS AND SCOPE

Conclusions

The above project work, have not been implemented in the concern Pricol, after realising the merits of the methodology and the proven results , they are going to implement the optimum process.

The following conclusions with **quantitative figures** obtained from this project.

1. Machining time steadily decreases when the feed rate increases.
2. Machining time steadily decreases when the speed increases.
3. Machining time increases when the depth of cut increases.
4. Comparatively Influence of feed rate on machining time is very high and influence of speed on machining time is high and Influence of depth of cut on machining time is low.
5. Optimum machining time need not be a lowest one but at a particular trial it should consume less time and also it should satisfy the quality requirements.

SCOPE

1. **Automating the process:**

The same process can be subjected to automation and then the performance of the process can be calculated. The results can be compared with conventional machining process and its advantages can be highlighted.

2. **Modification with Jigs and fixtures:**

For each process with improved work holding devices jigs and fixtures the same procedure can be repeated with the variation in values.

3. **Critical Analysis:**

By critically Analysing each mathematical model, changing can be done on suitable process variables only. It reduces the risk of changing all the variables.

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APPENDIX

Appendix Table I (Continued)

Abbreviations used in Appendix Table I

RM wt	- Raw material weight
RM cost	- Raw material cost
RM cost per pc	- Raw material cost per piece
T	- Turning
S	- Shaping
M	- Milling
D	- Drilling
SG	- Surface grinding
CG	- Centreless grinding
CYG	- Cylindrical grinding
GC	- Gear cutting
HT	- Heat Treatment
FA	- Fabrication
B / out cost	- Boughtout cost
Total CC	- Total cost