CHAPTER 1
INTRODUCTION

1.1 OPTIMIZATION OF MACHINING PROCESS AND MACHINING ECONOMICS

In a manufacturing industry, machining process is to shape the metal parts by removing unwanted material. During the machining process of any part to follow given quality specifications such as surface finish, accuracy with minimum production cost or machining time, tool wear are to be considered. To satisfy these objectives, an optimal solutions of properly formulated mathematical models with combination of machining parameters including cutting speed, feed rate, depth of cut and the number of passes are need to be determined by seeking the machining processes. Subject to various constraints from given quality specifications and machining conditions the mathematical models are developed for optimal production cost, production time and to maximize the profit.

The availability and affordability of high-speed computers, optimization algorithms are becoming increasingly popular in engineering activities. They are extensively used in those engineering problems where the emphasis is on maximizing or minimizing of a certain goal. For example, optimization algorithms are routinely used in aerospace designs to minimize the overall weight of the aircraft, Production engineers are interested in designing optimum schedules of various machining operations to minimize the idle time of machines and the overall completion time.

Civil engineers are involved in designing buildings, dams and other structures in order to achieve minimum overall cost or maximum safety or both. Like Mechanical engineers, Electrical and Electronics engineers are
interested in their field to minimize the design and simplify the network communication system. The aim of the optimization is to improve an existing process that meets the given requirements and satisfies all the constraints placed on it. This is called the optimum process.

1.2 PLAN OF RESEARCH

Flow chart shown in the Figure 1.1 explains the various chapters involved in this research work. Literature survey is carried out in the areas of objective functions formulated for the work and various literatures are depicted with respect to the following areas:

- For minimum production cost and time
- For single and multipass turning operation
- For surface finish aspects
- For any of the above mathematical models optimization attempts using various evolutionary algorithms also called as Meta heuristics.
- Also about Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithms which were considered in this work as optimization technique.

Using CNC machine, the machining process is carried out. The results of stochastic mathematical models’ simulations and that of real time CNC machining process were compared.

Finally a conclusion is substantiated based on the results and discussion. The scope for further research is also suggested at the end. The following Figure 1.1 illustrates various modules of the research work planned.
1.3 THE OPTIMIZATION OF MACHINING AND PARAMETER SELECTION

The machining parameters are selected traditionally based on machinist’s experiences and industrial handbooks. The given work piece to get the required shape the machining parameters such as speed, feed and depth of cut play a vital role in machining. These have a major impact on the quantity of production, cost of production and production rate etc., The selected machining parameters should yield desired quality on the machined surface while utilizing the machining resources such as machine tool and cutting tool to the fullest extent possible, consistent with the constraints on these resources.
Presently, the industries use both conventional and NC machines on their shop floor, hence it becomes necessary to go for automated methods to select the optimal machining parameters that suit the demands. Computer Numerical Control (CNC) machines have been found reliable for their fastness, accuracy and consistency in the automated selection of machining parameters compared to their manual counterparts. For a particular machining operation various optimization techniques can be used to find the optimal machining parameters.

The advances in the manufacturing engineering and developments in the areas of computer aided design and computer aided manufacturing give a high level of automation in the present competitive environment. With this, attempts have also been made to automate the selection of machining parameters. The traditional methods have been replaced by reliable computer aided procedures in the selection of machining parameters.

Figure 1.2 CNC Machine
The optimization of machining parameters usually consists of two steps, one is to formulate a mathematical optimization model based on certain economic criteria for machining conditions with various realistic constraints, the second step is to design a suitable solution procedure to seek the optimal or near optimal solutions. The optimizations of machining parameters have been addressed using two basic approaches: 1) single-pass machining operations and 2) multi-pass machining operations. A single-pass operation removes the total desired depth of cut in just one pass. In practice, however, this rarely happens. Therefore, a multi-pass approach has to be considered for the determination of the machining parameters.

Consideration of machining parameter optimization research has increased since the 1950's. High initial investment and operation cost plays a great demand to optimize the machining parameters for economic yield. It is important to know how to establish a machining optimization turning parameter with high quality material that will be produced in order to increase the profit. By understanding the concepts, it will be easy to develop and implement the suitable optimization procedures and algorithm for a wide variety of problem in the area of designing and manufacturing.

Due to the high cost of the Computer Numerical Control (CNC) turning machines, particularly for operating the machining parameters, optimization has significant practical importance, an economic analysis needs to be performed to operate them as effectively as possible in order to obtain the required return on investment. The operating parameters in this context are cutting speed, feed rate, depth of cut, and so on that do not violate any of the constraints that may apply to the process and satisfy the objective criterion, such as minimum time, minimum production cost and minimum tool wear.
1.4 OPTIMIZATION CRITERIA

1.4.1 Minimum production cost

This criterion minimizes the production cost per piece, and coincides with the maximum profit criterion if the unit revenue is constant. The minimum cost per component criterion (along with maximum production rate criterion) was first proposed by Gilbert in his "Economics of Machining" in 1950. This criterion will lead to a low production rate and therefore is the criterion to be adopted when there is ample time for production. Minimum cost per piece criterion is so far the most frequently used optimization criterion, adopted by many researchers in both single and multiple pass machining analysis.

Machining models are required to determine the optimum machining parameters including cutting speed, feed rate and depth of cut, in order to minimize unit production cost. Unit production cost can be divided into four basic cost elements:

- Cutting cost by actual cut in time
- Machine idle cost due to loading and unloading operation and idling tool motion cost
- Tool replacement cost
- Tool cost

For the optimization of unit production cost, practical constraints which present the state of machining processes need to be considered.
The constraints imposed during machining operations are:

- Parameter constraint – Ranges of cutting speed, feed rate and depth of cut.
- Operating constraint – Maximum allowable cutting force, power available on machine tool and surface finish requirement.

1.4.2 Minimum operation time

To estimate the cost of any product involving machining operations, the machining time is required to be estimated before the total cost of the product/component can be computed. In addition to actual time taken for operation to be carried out, time is spent on certain other elements of work. The total time required to perform an operation consists of the following elements:

1. Set –up time
2. Machining time
3. Tear down time
4. Time required to exchange a tool
5. Machining idle time

Set-up time

This is the time taken to prepare the machine for operation. The set-up time includes the time taken to:

(i) Study the blue print (component drawing)
(ii) Draw tools from tool crib
(iii) Install and adjust the tools, jigs and fixtures on the machine
The time above the unit standard time to produce a first few pieces is also taken in set-up time. We can say set-up time is the overall preparation time less than the standard time for the units produced during the process of preparation.

The set-up time occurs only once for a batch or lot being taken up for production. Standard data are available for set-up time for various machine tools.

**Tool sharpening/Change time**

The time taken by the operator to get the tool changed or to reshape the tool when it becomes dull. This time varies from machine to machine and depends upon the type of tool being used.

**Machining time**

It is the time during which the machine works on the component, i.e. from the time when the tool touches the work, till it leaves the component after completion. The machining time depends on the type and extent of machining required, material being machined, speed, feed, depth of cut and number of cuts required.

**Unit operation time**

The sum of handling time and machining time for a job is called operation time. It is the duration of time that elapses between outputs of two consecutive units of production. It is also called cycle time.

**Machine idle time**

It is the time taken by the operator in preparing a part for machining and the time for loading and unloading the components on machine, tool changing time, etc.
Estimation of machining time

Estimation of machining time means to calculate the time required to complete the operations to make the components as per the drawing. Machining time is the time for which the machine works on the component.

1.4.3 Minimum tool wear

During machining process, the tool is subjected to three important factors such as force, temperature and sliding action due to relative motion between tool and work piece. In foresaid factors, the tool will be giving unsatisfactory performance after sometime. This results in loss of dimensional accuracy, increased surface roughness and increased power requirements etc. The unsatisfactory performance results of the tool wear due to its continuous use. Therefore, the tool requires periodical reconditioning or replacement. This will result in loss of production and also the cost of replacing or reconditioning. Hence, the study of tool wear is important.

The tool wear is generally classified as follows.

i) Flank wear or Crater wear.

ii) Face wear

iii) Nose wear

![Figure 1.3 Tool wear](image)
Flank wear

This is also called “edge wear”. Friction, abrasion, adhesions are the main causes for this type of wear. Flank wear is a flat worn out portion behind the cutting edge. The worn out region of the flank is known as wear land. This wear takes place when machining brittle material like cast iron. It also occurs when the feed is less than 0.15mm/revolution. When the wear land increases, the frictional wear will cause excessive temperature of the tool at the cutting edge thereby decreasing its hardness rapidly and hence catastrophic failure of the tool will occur. Flank wear results in a rough machined surface.

Crater wear

The face of the tool is always contacted with the chip. The chip slides over the face of the tool. Due to the pressure of the sliding chip, the tool face wears out gradually. A cavity is formed on the tool face. The cavity is called crater. This type of wear is known as crater wear. The major tendency of this type of wear is abrasion between the chip and the face of the tool. When cratering becomes excessive, the cutting edge of the tool may break.

Cratering is commonly occurred when machining a ductile material which produces continuous chips. Diffusion of metal may be one of the causes of this type wear. The maximum depth of the crater is usually a measure of the amount of the crater wear. The tool life due to crater wear can be determined by fixing the ratio of width of crater to its depth.

Nose wear

This is similar to flank wear in certain operations. The wear occurs on the nose radius of the tool. When the nose of the tool is rough, abrasion and friction between the tool and work piece will be high. Due to this type of wear, more heat will be generated. Also more cutting force will act on the tool. This type of wear is more prominent than flank wear.
1.5 MATHEMATICAL MODEL APPROACH

In this model, the problem is converted into mathematical models based on certain criteria. The criteria differ for different problems. In case of automated machining parameters selection, mathematical models are formulated to determine the machining parameters for a particular objective such as minimization of unit cost or maximization of production rate. The empirical equations formulated based on production cost, minimum production time and minimum tool wear and other practical restrictions on machining variables are used in this type of development. The resultant function from this mathematical modelling is called objective function, which is subjected to practical constraints. The developed model is then solved using an optimization technique to yield optimal parameters that reflects the shop floor capabilities. This procedure is illustrated in figure 1.4. The success of this approach depends on the reliability of the empirical equations used in the model formulation.

![Figure 1.4 Mathematical model approach](image-url)
1.6 ALGORITHM USED IN THESIS

1.6.1 Genetic Algorithm (GA)

Algorithm is started with a set of solutions (represented by chromosomes) called population. Solutions from one population are taken and used to form a new population. This is motivated by a hope, that the new population will be better than the old one. Solutions which are selected to form new solutions (offspring) are selected according to their fitness - the more suitable they are the more chances they have to reproduce. Genetic Algorithm is computerized search and optimization algorithm is based on the mechanics of natural genetics and natural selection. GA is a search technique for global optimization in a search space. As the name suggests it employs the concepts of natural selection and genetics using past information. It directs the search with expected improved performance and achieves fairly consistent and reliable results.

1.6.1.1 GA operators

The operation of GA begins with a population of random strings representing design and decision variables. Thereafter each string is evaluated to find the objective value. The population is then operated by three main operators namely reproduction, crossover and mutation as shown in Figure 1.5 Reproduction selects good strings in a population and forms a mating pool. The reproduction operator is sometimes known as the selection operator. In this thesis tournament selection is used. At each iteration the method selects a number $k$ (called tournament size) of individuals and selects the best one from this set into the next generation as shown in Figure 1.6. In the crossover, new strings are created by exchanging information among strings of the mating pool. In crossover operation two parent strings are picked from the mating pool at random and some portions of these strings are exchanged to produce offspring strings.
Single point crossover operation is explained in the Figure 1.5.

![Block diagram of GA](image)

**Figure 1.5 Single point crossover methods**

1.6.1.2 GA parameters

Sample size = 18, Crossover probability (Pc) = 0.75, Mutation probability (Pm) = 0.01, Number of generations = 500. The above parameters are fixed on the basis of literature review.
1.6.1.3 Simple GA algorithm

1. Produce an initial population of individuals.

2. Evaluate the fitness of all individuals.

3. Repeat
   a) Select fitter individuals for reproduction.
   b) Recombine between individuals.
   c) Mutate individuals.
   d) Evaluate the fitness of the modified individuals.
   e) Generate a new population

Until termination condition is satisfied (500 iterations).
Based on the above algorithm in this thesis NSGA II non-dominated sorting genetic algorithm is proposed. The presence of multiple objectives in a problem, in principle, gives rise to a set of optimal solutions largely known as Pareto-optimal solutions, instead of a single optimal solution. When such a method is to be used for finding multiple solutions, it has to be applied many times, hopefully finding a different solution at each simulation run.

1.6.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) approach is inspired by the ability of the flock of birds, school of fish, and herd of animals to adapt to their environment, find rich source of food, and avoid predators. PSO has developed into a heuristic optimization approach and it depends on information shared among population members and enhances the search process using a combination of deterministic and probabilistic rules.

Each individual or particle in a swarm behaves in a distributed way using its own intelligence and the collective or group intelligence of the swarm. As such, if one particle discovers a good path to food, the rest of the swarm will also be able to follow the good path instantly even if their location is far away in the swarm. Optimization methods based on swarm intelligence are called behaviorally inspired algorithm.

In the context of multivariable optimization, the swarm is assumed to be of specified or fixed size with each particle located initially at random locations in the multidimensional design space. Each particle wanders around in the design space and remembers the best position (in terms of the food source or objective function value) it has discovered. The particles communicate information or good positions to each other and adjust their individual positions and velocities based on the information received on the good positions.
As an example, consider the behavior of birds in a flock. Although each bird has a limited intelligence by itself, it follows the following simple rules.

- It tries not to come too close to other birds.
- It steers toward the average direction of other birds.
- It tries to fit to the average position between other birds with no wide gaps in the flock.

The basic PSO algorithm consists of three steps, namely generating particles’ position and velocities, velocity update and finally the position update. The new velocity of the particle is influenced by three factors: the present velocity ($V_k$), the global best value of all particles in the swarm ($g_{bestX}$), and the personal best position of each particle over time ($P_{bestX}$). The velocity value is thus a function of inertia ($Inertia$), self confidence factor ($c_1$), and swarm confidence factor ($c_2$).

The proposed algorithm which we shall call multi-objective PSO extends the algorithm of the single-objective PSO to handle multi-objective optimization problems. It incorporates the mechanism of NSGA II computation into the algorithm of PSO specifically on global best solution and in the deletion method of an external archive of non-dominated solution. The competition time of the algorithms was also observed and has been found to have a vastly superior execution time compared to the other algorithms.

1.7 EXPERIMENTAL TECHNIQUE CONDUCTED

Computer Numerical Control Machines (CNC) have been found reliable for their fastness, accuracy and consistency in the automated selection of machining parameters compared to their manual counterparts. For a particular machining operation various optimization techniques can be used to
find the optimal machining parameters. The optimizations technique can be
used to minimize the production cost and minimum production time and
minimum tool wear. Optimization of turning parameters is usually a difficult
work, where the following aspects are required, like knowledge of machining,
empirical equations relating the tool life, specification of machine tool
capabilities and knowledge of mathematical and numerical optimization
techniques are also compulsory.

In actual practice the operation is carried out for the test
component. NC codes are used to find the optimum parameter to finish the
component. The actual time taken, tool wear number of passes are noted for
the component. Using Genetic Algorithm (GA) and Particle Swarm
Optimization (PSO) concept by using C++ language for programming, the
optimum cutting speed, feed and depth of cut are applied for test component
to find the operation time and tool wear. The time taken, tool wear and
production cost noted down for each component and the results are validated.

1.8 SUMMARY

Based on the chronology mentioned above investigations are
carried out and reported in the following sequences: literature survey,
development of mathematical model, multi objective optimization in Genetic
algorithm, Particle swarm optimization, experimental validation. The
conclusions of all phases of investigations are summed up in the last chapter.