Simulation Approach And Optimization Of Machining Parameters In Cnc Milling Machine Using Genetic Algorithm.

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Abstract

In any manufacturing industries the major problem is to reduce the machining time of each operation so as to keep the cost low and high profit rate without sacrificing quality of the component. Due to high capital cost and machining costs of CNC machines, there is an economic need to operate CNC machines as efficiently in order to obtain the required pay back. Since the cost of machining on CNC machines is sensitive to the machining parameters, optimal values have to be determined before a part is put into production.

In this project the simulation model has been developed which develops the required machining time for each operation by specifying the exact tool and machining parameters. This project focuses on the minimization of machining time. Genetic Algorithm is proposed for the optimization of machining parameters such as speed and feed with respect to the constraints (surface finish requirements, maximum machine power and cutting force) for milling operation in CNC milling machine and MASTER CAM is used as simulation software. An objective function based on the minimum machining time has been used. The results obtained from the Genetic algorithm is compared and analyzed with the other optimization procedures like Tabu search, Ant colony algorithm and Particle swarm optimization and feasible method is developed.

Key words: *Simulation, optimization, Genetic Algorithm.*

1. Introduction

In the last few years, manufacturing companies have been competing in an increasingly dynamic environment. Among them, small and medium-sized businesses are increasing considerably, innovations are on the rise and product-life cycles are getting shorter. For this reason, companies need to devote more effort and resources in order to be able to compete in a highly competitive market and to continue to generate profit, as this is increasingly necessary to reduce the cost of production.

Despite availability of different tools and techniques proposed for manufacturing industry, it has been reported that manufacturers are usually facing significant practical problems when trying to model in detail the way they operate or to implement changes in existing environments. A very useful tool that helps avoid unnecessary expenses and also gives an idea of the possible effectiveness of systems in advance is simulation. According to Bennett, simulation can be defined as “a technique or a set of techniques whereby the development of models helps one to understand the behaviour of a system, real or hypothetical”. For this reason, simulation is widely associated with exploring possibilities for evaluating system behaviour by applying internal/external changes and for supporting process enhancement efficiency and organization.

Simulation has numerous other benefits, for example: manufacturing processes can be analyzed without interrupting the real system, to avoid investing the high cost of implementing a system, to enable training and to make learning possible, to check if the analytic solutions offered by the analysis of mathematical models are correct, to answer questions about how or why the phenomena occur, or to know how small change in a part of the system affects the whole manufacturing system. Because of these uses of simulation, if a good simulation is carried out. It can improve effectiveness in production. This is a key competitive advantage for a company, since planning and implementation of production is becoming strategically important within companies and may cause the business to acquire a competitive advantage. Information provided by the simulation models are based on input data. Therefore, it is very important that the variables are analyzed properly and that input data are reliable. In the same way, a comprehensive knowledge of statistics is necessary to interrupt output data correctly.

Optimization algorithms are becoming increasingly popular in engineering activities, primarily because of the availability and affordability of high-speed computers. 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 design activities to minimize the overall weight, simply because every element or component adds to the overall weight of the aircraft. Chemical engineers on the other hand are interested in designing or operating a process plant for an optimum rate of production. Mechanical engineers design mechanical components for the purpose of achieving either a minimum manufacturing cost or maximum rate of production. Thus, the ultimate aim of the optimization is to improve an existing process that meets the given requirements and satisfies all the restrictions/constraints placed on it. This is called the optimum process.

Machining parameters such as speed, feed and depth of cut play vital role in machining the given work piece to the required shape. These have a major affect on the quantity of production, cost of production and production rate; hence their judicious selection assumes significance.

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. Traditionally the selection of machining parameters is carried out based on the experience of the machinist or the planner and referring the available catalogues and handbooks.

Manual selection of machining parameters reflects the problem of variability in experience and judgment among the planners. In addition to this, the induction of cost intensive NC machines onto the shop floor, stresses more emphasis on the effective utilization of these resources using the optimal machining parameters. Present 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 of the present industries.

Computer aided procedures have been found reliable for their fastness, accuracy and consistency in the automated selection of machining parameters compared to their manual counterparts. Various optimization techniques can be used to find the optimal machining parameters for a particular machining operation.

MASTERCAM is CNC simulation software that enables you to machine parts on the computer before actual cutting occurs so you can eliminate errors that could ruin the part, damage the fixture, break the cutting tool, or crash the machine and also optimizes the cutting process so in addition to being error-free, your programs are fast and efficient. A machine crash can be very expensive, potentially ruin the machine, and delay your entire manufacturing schedule, but with MASTERCAM, you can dramatically reduce the chance for error and avoid wasting valuable production time proving-out new programs on the machine.

Machine Simulation detects collisions and near-misses between all machine tool components such as axis slides, heads, turrets, rotary tables, spindles, tool changers, fixtures, work pieces, cutting tools, and other user-defined objects. You can set up “near-miss zones” around the components to check for close calls, and even detect over-travel errors.

Nomenclature

T_m	Machining time in minute
L	Length of the table travel to complete the cut in mm
F_z	Feed rate mm/ tooth
F_m	Feed rate in mm/min
Z	Number of teeth/flutes in cutter
N	Spindle speed in rpm
D	Diameter of the tool in mm
a	Depth of cut in mm
V	Cutting speed in m/min

2. Problem Statement and Simulation Model Development

The case study that has been considered to find the optimum machining time for the operations carried out to complete the part as shown in the figure.

The work piece shown in the (fig. 1) is been produced in a CNC milling machine. The work piece includes five machining operations: face milling, corner milling, pocket milling and two slot milling. Since different tools have been selected to machine these features, the problem becomes maximization of profit rate for multi-tool operation. The goal is to determine the cutting conditions of each feature so that the part can be machined with minimum time for a maximum profit rate. The problem is solved by Genetic algorithm.

Here corner milling operation can be done while performing pocketing operation since its corner radius is 5mm and the diameter of the tool for pocket milling is 10mm so eliminating one operation to reduce the machining time. And from the tables we can see that for the slot milling (1) 12mm diameter tool is chosen and from figure shown the width of the slot is also 12mm, practically we cannot choose the diameter of the tool equal to its width.

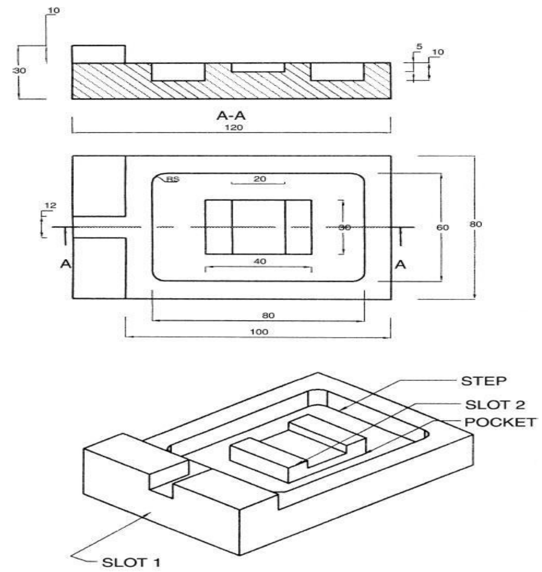

Fig.1 Geometry of the problem

Specifications of the machine, material and values of constants are given below. Also, the geometric information on the required operations and tools is presented in Tables.

Machine tool data:
Type: Vertical CNC milling machine
P_m = 8.5 kW,
E = 95%

Material data:
Quality: 10L50 leaded steel.
Hardness = 225 BHN

Table.1 Tools data

Tool No	Tool type	Quality	D (mm)	z
1	face mill	carbide	50	6
2	End mill	HSS	10	4
3	End mill	HSS	12	4

Table. 2 Required machining operation

Operation No	Operation type	Tool No	a (mm)	L (mm)	Ra (µm)
1	Face milling	1	10	450	2
2	Corner milling	2	5	90	6
3	Pocket milling	2	10	450	5
4	Slot milling	3	10	32	-
5	Slot milling	3	5	84	1

2.1 METHODOLOGY:

The present work focuses on machining time reduction and the proposed methodologies are:

1. Matlab
2. Master CAM

Matlab:

Matlab is widely used in all areas of applied mathematics in education and research at universities and in the industries. Matlab stands for MATRIX LABORATORY and the software is built up around vectors and matrices. This makes the software particularly useful linear algebra. Matlab is also a great tool for solving algebraic and differential equations and for numerical integration. It is also a programming language (similar to C) and is one of the easiest programming languages for writing mathematical programs. Matlab features a family of add-on application specific solutions called toolbox. Toolbox allows learning and applying specialized technology. Toolbox is comprehensive collection of Matlab functions that extend to solve particular classes of problem. Areas in which toolbox are available include signal processing, control system, neural network, fuzzy logic wavelets, simulation and many other.

Procedure:

Solving the problem using optimization toolbox in Matlab:

There are two ways to use the optimization toolbox.

1. Calling the genetic algorithm function “ga” at the command line.
2. Using the optimization toolbox, a graphical interface to the genetic algorithm.

Calling the function ga at the command line:

To use the genetic algorithm at the command line, call a function “ga” with the syntax.

[x fval] = ga(@fitnessfun, nvars, options)

Where,

- ✓ @fitnessfun is a handle to the fitness function.
- ✓ nvars is the number of independent variables for the fitness function.
- ✓ Options are a structure containing for ga. If we don’t mention any pass in this argument, ga uses its default options.

The results are given by

- ✓ fval- final value of the fitness function.
- ✓ x- point at which the final value is attained.

Finding the Time Function for first operation

Firstly have to write the equation of time and defining all its constants into m-file of a Matlab editor, then need to save as timefitnessfn1 as shown in figure.

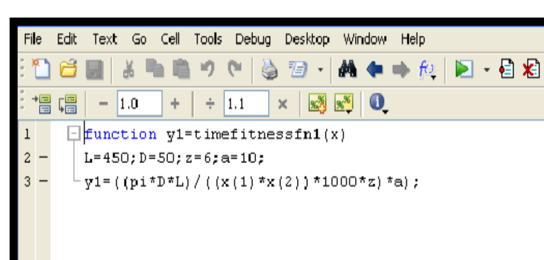

Fig.2. Defining the objective function for time

2.2 Simulation Model Development:

To complete the part it must go through four milling operations (face milling, pocket milling and two slot milling). Initially we have to develop a complete 3D solid model as shown in the figure.

The tool path should be given in a sequence for each operation by specifying the required tool, depth of cut, speed and feed.

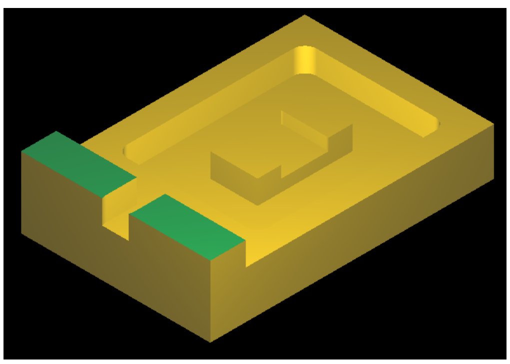

Fig.3 Three Dimensional Solid Model

2.2.1 Face Milling Operation:

Face milling is the first operation in which facing tool path quickly clean the top of the stock in preparation for further machining.

Figure.4 shows the movement of the tool after the completion of facing operation. Depth cuts for facing toolpaths and circle mill toolpaths are similar. You can enter a maximum rough step and Mastercam divides the total depth into equal steps. Or you can enter the exact number of finish steps and the size of each finish step. The system never performs unequal rough depth cuts.

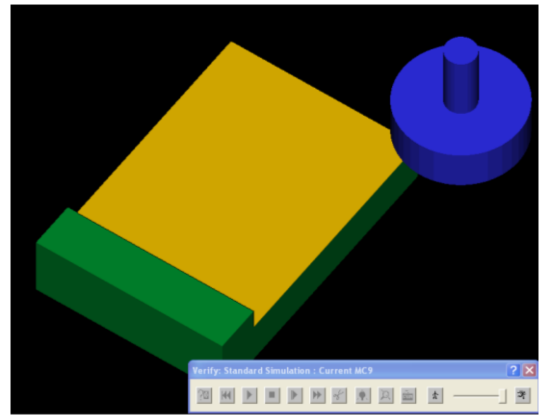

Fig. 4 Face Milling

Required data:

Feed rate (F_z or F_m) = 0.399 mm/tooth

Cutting speed (V) = 119.768 m/min

Tool diameter (D) = 50 mm

Depth of cut = 10 mm

Distance to be travelled by the tool to perform the operation (L) = 450 mm

Number of teeth or flutes in the cutter (z) = 6

Calculations:

Spindle speed

$$N = \frac{1000V}{\pi D}$$

$$N = \frac{1000 * 119.768}{\pi * 50} = 762.466 \text{ rpm} \approx 762 \text{ rpm}$$

To get the feed rate from mm/tooth to mm/min

$$F_m = F_z \, N \, z$$

$$F_m = 0.399 * 762 * 6$$

$$F_m = 1824.22 \text{ mm/min} \approx 1824 \text{ mm/min}$$

Machining time to complete the operation

$$T_m = \frac{\pi DL}{1000VF_z z}$$

$$T_m = \frac{\pi * 50 * 450}{1000 * 119.768 * 0.399 * 6} = 0.246 \text{ min}$$

This time is for one pass but the depth of cut is total depth 10 mm so to complete 10mm of cut the time taken is

$$T_m = \text{depth of cut}(a) * \text{time taken for one pass}$$

$$T_m = 10 * 0.246$$

$$T_m = 2.46\text{min}$$

2.2.2 Pocket milling operation:

Pocket milling is the next operation performed with an island as shown in the fig.1. Here we have eliminated corner milling operation since the corner radius is 5mm and the tool diameter used for pocketing is 10mm, both operations can be done in a single operation, hence minimizing the machining time. Figure shows the movement of the tool after the completion of pocketing operation. Depth cuts are the Z axis cuts that the tool makes in a pocket toolpath.

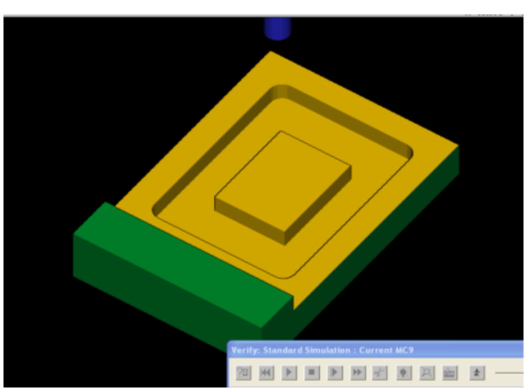

Fig. 5 Pocket Milling

Required data:

Feed rate (F_z or F_m) = 0.5 mm/tooth

Cutting speed (V) = 70 m/min

Tool diameter (D) = 10 mm

Depth of cut = 10 mm

Distance to be travelled by the tool to perform the operation (L) = 450 mm

Number of teeth or flutes in the cutter (z) = 4

Calculations:

Spindle speed

$$N = \frac{1000V}{\pi D}$$

$$N = \frac{1000 * 70}{\pi * 10} = 2228.16 \text{ rpm} \approx 2228 \text{ rpm}$$

To get the feed rate from mm/tooth to mm/min

$$F_m = F_z N z$$

$$F_m = 0.5 * 2228 * 4 = 4456 \text{ mm/min}$$

Machining time to complete the operation

$$T_m = \frac{\pi DL}{1000VF_z z}$$

$$T_m = \frac{\pi * 10 * 450}{1000 * 70 * 0.5 * 4} = 0.1009 \text{ min}$$

This time is for one pass but the depth of cut is total depth 10 mm so to complete 10mm of cut the time taken is

$$T_m = \text{depth of cut}(a) * \text{time taken for one pass}$$

$$T_m = 10 * 0.1009$$

$$T_m = 1.009\text{min}$$

2.2.3 Slot milling 1:

From the table 1 and tale 2 we can see that for the slot milling (1) 12mm diameter tool is used and from fig 1 the width of the slot is also 12mm, practically we cannot choose the diameter of the tool equal to its width, hence 10mm diameter is used for slot milling (1).

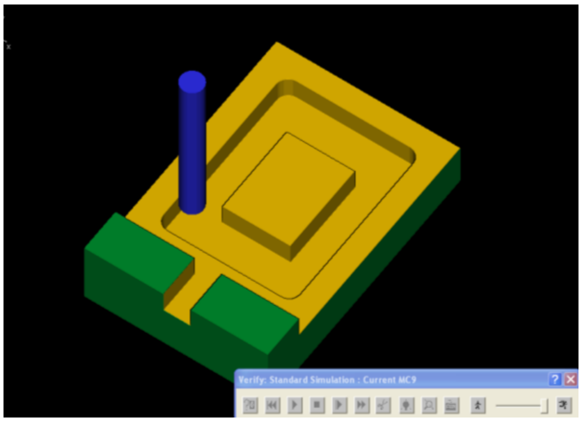

Fig. 6 Slot Milling (1)

Required data:

Feed rate (F_z or F_m) = 0.5 mm/tooth

Cutting speed (V) = 49.99 m/min

Tool diameter (D) = 10 mm

Depth of cut = 10 mm

Distance to be travelled by the tool to perform the operation (L) = 32 mm

Number of teeth or flutes in the cutter (z) = 4

Calculations:

Spindle speed

$$\boldsymbol{N = \frac{1000V}{\pi D}}$$

$$\boldsymbol{N = \frac{1000 * 49.998}{\pi * 10} = 1591.48\ \text{rpm} \approx 1592\text{rpm}}$$

To get the feed rate from mm/tooth to mm/min

$$\boldsymbol{F_m = F_z\ N\ z}$$

$$\boldsymbol{F_m = 0.5 * 1592 * 4 = 2652\ \text{mm/min}}$$

Machining time to complete the operation

$$\boldsymbol{T_m = \frac{\pi DL}{1000VF_z z}}$$

$$\boldsymbol{T_m = \frac{\pi * 10 * 32}{1000 * 49.998 * 0.5 * 4} = 0.01005\ \text{min}}$$

This time is for one pass but the depth of cut is total depth 10 mm so to complete 10mm of cut the time taken is

$$\boldsymbol{T_m = \text{depth of cut}(a) * \text{time taken for one pass}}$$

$$\boldsymbol{T_m = 10 * 0.01005}$$

$$\boldsymbol{T_m = 0.1005\text{min}}$$

2.2.4 Slot milling 2:

In this operation slot is done on the island with a depth of cut 5 mm and 12 mm tool diameter.

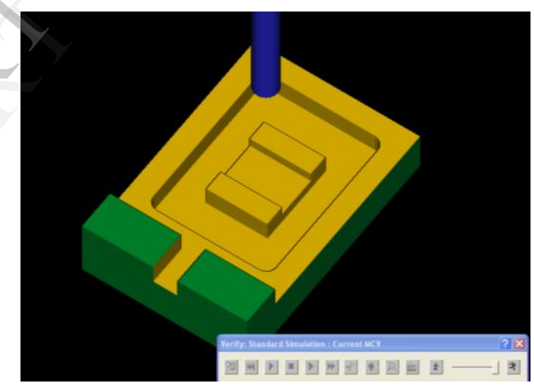

Fig. 7 Slot Milling (2)

Required data

Feed rate (F_z or F_m) = 0.499 mm/tooth

Cutting speed (V) = 47.8532 m/min

Tool diameter (D) = 12 mm

Depth of cut = 5 mm

Distance to be travelled by the tool to perform the operation (L) = 84 mm

Number of teeth or flutes in the cutter (z) = 5

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Calculations:

Spindle speed

$$N = \frac{1000V}{\pi D}$$

$$N = \frac{1000 * 47.853}{\pi * 12} = 1269.34 \text{ rpm} \approx 1269\text{rpm}$$

To get the feed rate from mm/tooth to mm/min

$F_m = F_z\, N\, z$

$F_m = 0.499 * 1269 * 6$

$F_m = 2532.92 \text{ mm/min} \approx 2533 \text{ mm/min}$

Machining time to complete the operation

$$T_m = \frac{\pi DL}{1000 V F_z z}$$

$$T_m = \frac{\pi * 12 * 84}{1000 * 47.853 * 0.499 * 6} = 0.0331 \text{ min}$$

This time is for one pass but the depth of cut is total depth 5 mm so to complete 5mm of cut the time taken is

$$T_m = \text{depth of cut}(a) * \text{time taken for one pass}$$

$$T_m = 5 * 0.0331$$

$$T_m = 0.1657 \text{ min}$$

Total Machining time = $T_{m1} + T_{m2} + T_{m3} + T_{m4}$

= 2.46 + 1.009 + 0.1005 + 0.1657

= 3.8388 min.

3. Results and Discussion:

Fig. 8 shows the Genetic Algorithm (GA) execution file to obtain the optimized machining parameters and machining time for each operations and Fig. 9 shows the optimized speed, feed and machining time for the same.

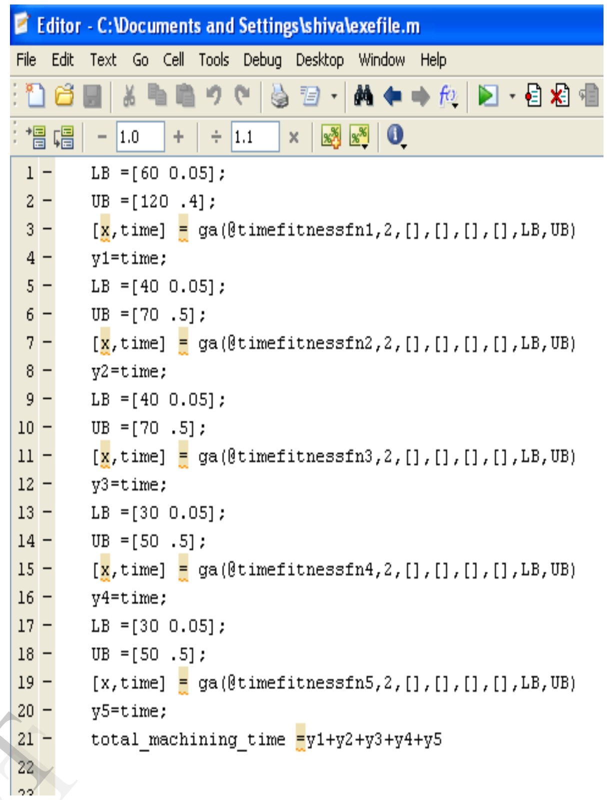

Fig. 8 GA Execution file

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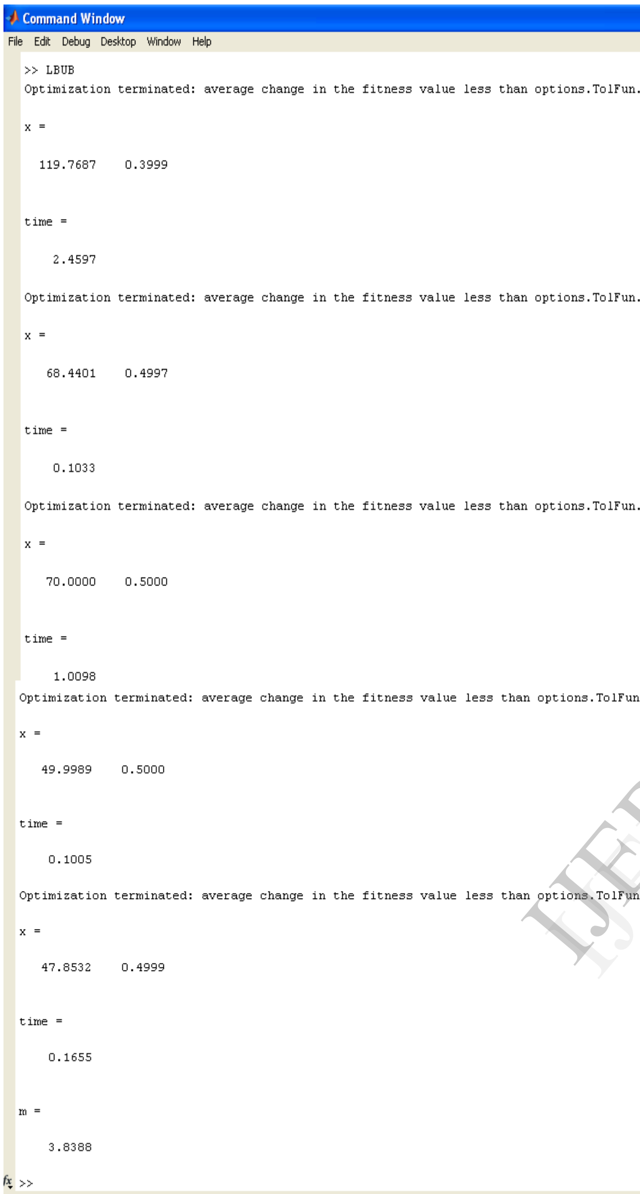

Fig. 9 GA Optimized feed, speed and time

Fig. 10 shows the optimized results obtained from Mastercam simulation software. Machining time, feed, speed, tool used, tool material and other data can be seen.

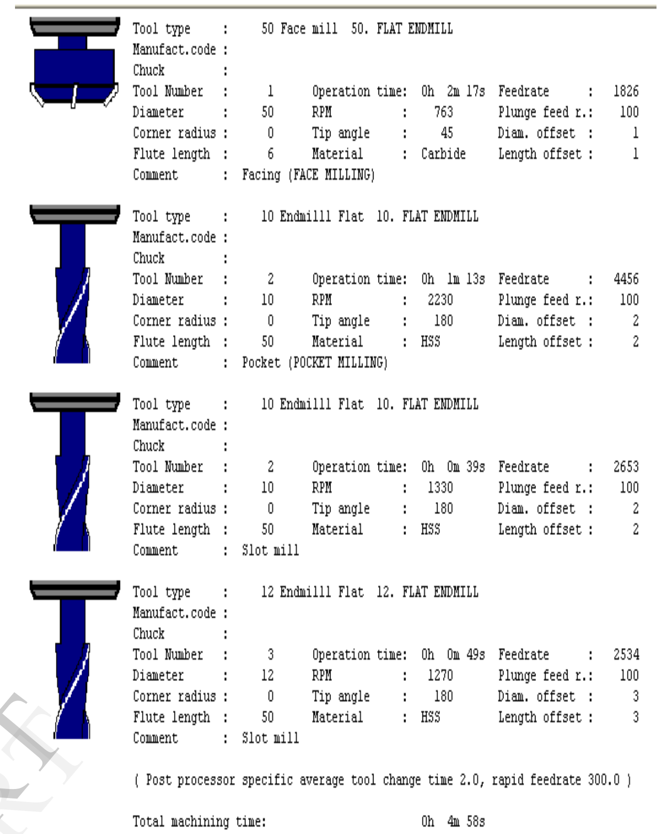

Fig. 10 Optimized results obtained from Master Cam

3.1 Comparisons of the result

The Table shows the result of the continuous ant colony algorithm, genetic algorithm, particle swarm optimization and tabu search for the input values of cutter diameter, cutting length of workpiece, number of machining operation and number of cutting teeth of the tool. The method proposed in the present work based on the Genetic algorithm always yields optimal result as compared to the other methods.

Table.3 Comparison of the results

Methods	Operations	Speed (V) (m/min)	Feed (F_z) (mm/tooth)	Machining time (min)	Total machining time (min)
Genetic Algorithm	Face milling	119.76	0.399	2.45	3.8388
	Pocket milling	70	0.5	1.0098	
	Slot milling1	49.998	0.5	0.1005	
	Slot milling2	47.583	0.499	0.165	
Ant colony Algorithm	Face milling	117.47	0.163	6.152	10.5637
	Pocket milling	51.901	0.222	3.06	
	Slot milling1	46.480	0.185	0.35	
	Slot milling2	13.931	0.191	0.4717	
Particle Swarm Optimization	Face milling	119.38	0.4	2.467	5.4096
	Pocket milling	40.006	0.406	2.175	
	Slot milling1	37.524	0.271	0.296	
	Slot milling2	39.702	0.362	0.275	
Tabu Search	Face milling	80.469	0.398	3.678	6.343
	Pocket milling	65.522	0.354	1.523	
	Slot milling1	40.616	0.295	0.251	
	Slot milling2	32.952	0.432	0.278	

4. Conclusion

- The simulation process of finding minimum machining time in CNC milling machine is carried out for one of the model found in the literature survey and got reasonable results.
- Initially 3D model is generated which is undergone by five milling operations (facing, cornering, pocketing and two slot milling) and required machining parameters (speed, feed and depth of cut) is given.
- While giving the toolpath we found that one milling operation can be minimized i.e., corner milling, since its corner radius is 5mm and tool used for pocketing is 10mm it can be performed by pocketing operation itself. Hence machining time is minimized.
- For slot milling (1) 10mm tool diameter is chosen instead of 12mm since the width of a slot is also 12mm. hence, minimizing any damage to the part.
- The results obtained are compared with the other method and genetic algorithm yields an optimal result.
- The results are tabulated in the table.

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