

Machining Process Simulation of SOM 125 Series Printing Machine Components Using CATIA V5 Machining

C.R. Rejeesh^{1*}, M. Mathew², R. Renjith²

¹Computer Integrated Manufacturing, Federal Institute of Science and Technology, Kerala, India

²Department of Mechanical Engineering, Federal Institute of Science and Technology, Kerala, India

ABSTRACT

Based on the additional competition in the marketplace, producers who used traditional manufacturing contracts and policies, has to adopt computer aided manufacturing techniques for the point of producing process planning and NC-programming more effective. By applying appropriate software with multiple skills, significant gains in terms of production lead-time can be achieved and a higher level of precision in the manufacture can be certified. In this study, an attempt to use CATIA V5 software to pretend the actual period machining processes in the manufacturing of printing machines is reported and the relating clarifications are presented.

Keywords: CAD/CAM system, computer aided manufacturing, postprocessor, machining process

***Corresponding Author**

E-mail: rejeeshcr@fisat.ac.in

INTRODUCTION

In an environment of facing the aftermaths of globalization, manufacturing sector in India is facing greater competition from countries which could use cheaper labor available. This urges the manufacturer to constantly improve their quality and competitiveness to maintain their market share. Aside from product quality, price and lead-time are key factors impacting a concern's ability to close a deal. ^[1-3]

The selected part for simulation is a lever commonly used in vibrator control assembly of every 125 series printers manufactured by HMT machine tools, India (Single Color Sheet fed Offset Printing Machines SOM 125G/125N/125B). Conventional methods to manufacture this component are compared with manufacturing it in a five-axis milling machine. The aim of this work is to simulate the machining process using CATIA V5 by generating CNC codes and

necessary documents for machining the part.

Process Planning

Process planning is a vital element in the planning phase for production and results in a document called the route sheet or process plan which is the step by step instructions for selecting the most appropriate resources, manufacturing operations and their sequence in production. ^[2] The process starts with a part or a family of parts for a completed product arriving in planning along with the complete product certification. On every part a create or buy choice is made by manufacture engineering. If the part is to be made in-house, a task involves the selection and definition of the processes, which will implement in order to convert the work piece into a complete part of given shape and surface. Decisions on processes to be used are largely based on the initial material of the part. When the

material is detailed, the range of probable processing operations is decreased considerably.^[2, 3]

The use of a process plan aims to provide specific and clear serial direction on the path of the work piece is directed through fabrication in the manufacturing capacity. Thus, it influences the design of the manufacturing facility and the preparation of the production process. An optimum route sheet indicates the most economical way of production that alter activities related to manufacturing by proper selection and arrangement of machining processes, tools, and machines.^[2, 3, 5] A characteristic process rout/plan sheet for part manufacturing contains information on

- Operations and their sequence
- Operation explanation
- The work center in which the work is have to do
- Extra manufacturing equipment
- Additional material and raw material
- Setup cycle time and times

The process planning heavily depends on the expertise of the procedure plan and differs with the definite limitations associated with the appropriate industry. Although process planning is a complex process of selection, the major activities can be listed as:

- Clarification of the product design data
- Collection of machining processes and machine tools.
- Sequencing of operations
- Generation of NC programs

Design Automation: CAD

Computer-aided design (CAD) is a frequently adopted technology in the area of product design and is described as the use of computers and graphic software to aid or enhance the process of product design from conceptualization to documentation. While CAD supports all stages in design process like creation,

modification, analysis and evaluation, the most demanded application lies in design documentation.^[3, 6]

The development of a drawing using a CAD system is similar to the manual drafting, and the primary difference lies with productivity gains provided by the utilization of specific draw commands and editing commands, which leads to a reduction in effort and time, spend by the designer and contributes to reduction in total lead time^[7, 8] The techniques for automating and modelling designs in CAD, allows several functions that result in the following advantages:

- Enhance the quality of design through engineering analysis and design alternatives.
- Improves design documentation through precise and standardized engineering drawings.
- Supports manufacturing system by sharing and reutilizing product details in CAD drawings through a common data base.
- Utilizing CAD geometric models for prototypes or digital mockup of the product minimizes the lead time instead of building a physical prototype.

One of the important outputs generated by CAM is simulation, which is a computer generated model to study the production system ideas. Computer simulation is broadly defined as developing a theoretical or graphical model of a proceduces or creation system to estimate the conduct under varied conditions and in changing environment. Using the software, finished parts are produced virtually with information extracted from design data.^[3, 6, 7] The major steps involved in the process are:

- Modelling of the part using a CAD software and drawing techniques

- With the part geometry collected from the CAD drawing file, the part geometry is transferred to the CAM workstation.
- CAM software creates machine code to machine the part on CNC machine.

Like many other 3D modelling software, CATIA also integrates CAD and CAM. The CAD file in its original format may be transported to CAM without any loss in data. CAD/CAM systems may be further explored to automate the different phases in design and manufacturing as well as the transition from design phase to manufacturing phase. Their implementation is also beneficial for design specification of a product, as it exists in the CAD database and were converted into a process plan for making the product, this conversion can also be done automatically by the CAD/CAM system. [8, 9]

Advantage of Combining CAD with CAM

The main advantage of combining CAD and CAM is online the online manufacturing process. In which the designer can sit somewhere and able to generate all documentations including

CNC codes and control the manufacturing process.

- NC programming up to 10 times faster
- Faster machining times
- Improved quality

Key Features

- Native 3d simulation
- Integrated simulation of ISO codes
- Emulation of Numerical Control
- Easy and accurate collision detection
- The simulation allows:
 1. Integration of the 3d machine environment
 2. Integration of end tool and cutting tool

Process Simulation in CATIA V5 Machining Module

CATIA V5 machining could predict the machine time to be utilized while operations and resources are assigned. The interface in CATIA V5 machining module is as illustrated in Figure1. The Process Product Resources (PPR) specification tree shows all the operations associated with a process, along with sufficient geometrical data required for defining the machining operations and other relevant resources like a tool library catalogue. [10-12]

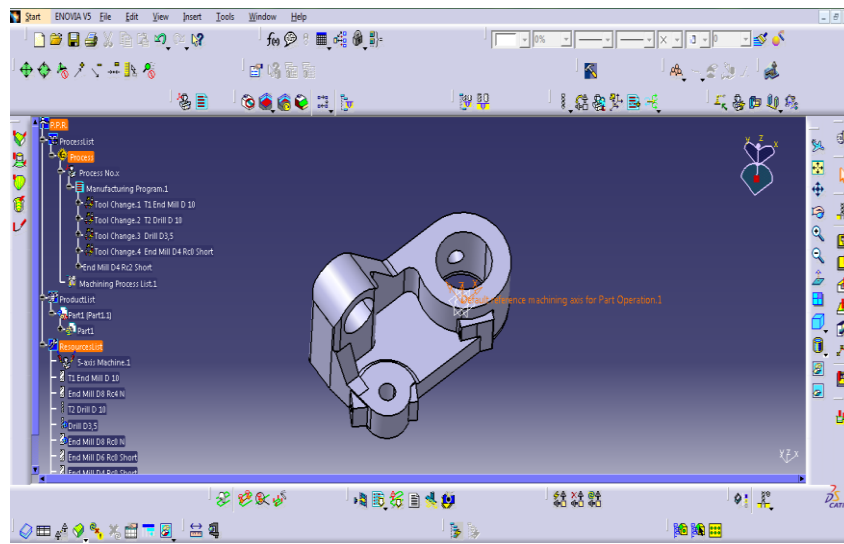


Fig. 1. PPR tree in CATIA V5 Lathe Machining.

Machining of parts that consistently addresses emerging functional needs in manufacturing industry is quite beneficial from the state of the art proven machining techniques already supported by CATIA to

reduce machining time through optimized roughing strategies, HSM (High Speed Manufacturing) capability, and strategy for hard materials and 5-axis flank milling.

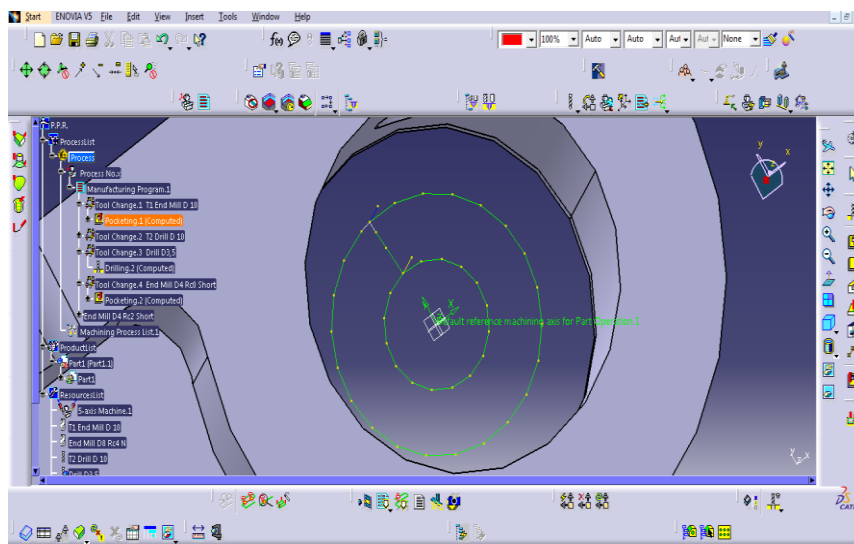


Fig. 2. Process simulation in CATIA V5.

Automation and standardization in machining processes results in more productive solutions. Use of CATIA V5 could provide better surface machining quality in less machining time and could

ensure collision-free tool paths, accurate tool path verification and realistic machine simulation integrated in the NC programming environment.

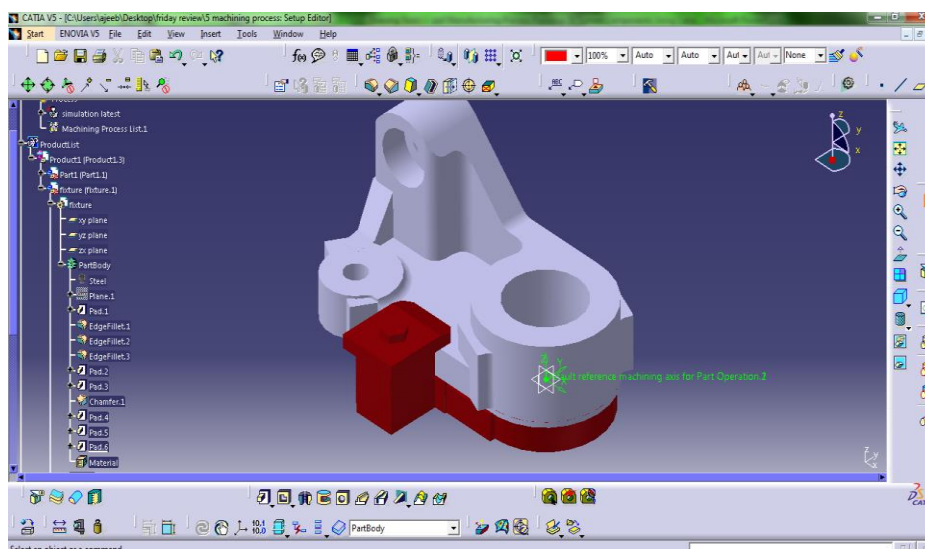


Fig. 3. Selection of fixtures

Process planning is one of the most important functions of CATIA V5

machining module, and the basic activities required for process planning simulation includes [10-12]:

- (1) Selection of machine
- (2) Selection of design part
- (3) Selection stock
- (4) Selection of fixtures
- (5) Selection of machining areas
- (6) Selection of machining methods
- (7) Selection manufacturing tools
- (8) Tool path replay or simulation using tool path

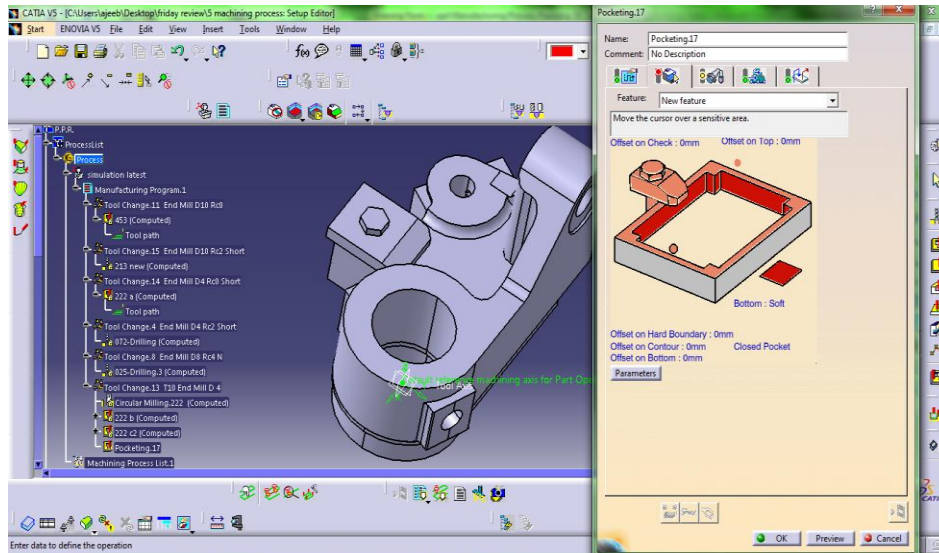


Fig. 4. Selection of machining areas.

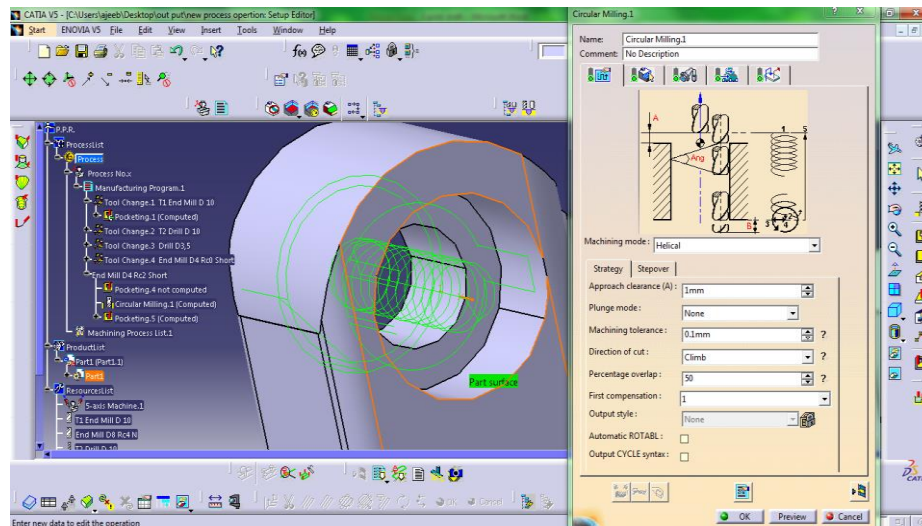


Fig. 5. Tool path replay or simulation using tool path.

Additional activities at the beginning of process planning for simulation using NC code:

- Selection of postprocessor provider
- Selection of NC machine
- Definition of postprocessor and controller emulator on the NC machine
- Generation of NC code

Post-processor

Post-processor links a CAD model to a machined part. Harmony between a postprocessor and CNC control is particularly important for high speed machining (HSM), as it brings in new features that may be not necessary with respect to basic CNC users. [12] In order to

perform high-speed machining with moderate accuracy, non-uniform rational B-Spline (NURBS) curve were implemented with variable feed rate using a real-time control algorithm based on Taylor's expansion.

THE ALGORITHMS TO GENERATE AND SIMULATE NON-LINEAR TOOL PATH OF THE FIVE-AXIS MILLING MACHINE

The accuracy of a 3D tool path can be analyzed using a simulator based on the cutter location (CL) points, the cutter contact (CC) points and the tool inclination angle. The simulation results in a tool path trajectory which depends on the initial set up of the machine and the milling process is simulated. Furthermore the simulator is used to verify the finishing pass and estimate any errors in the tool path before actual machining and thus reduce costly and iterative trial and error processes. Tool path generation and simulation is verified by a series of cutting experiments achieved by means of the planned software and the correctness of milling is projected. It has been shown that the proposed graphical 3D software presents an efficient interactive approach to the variation of a tool path based on a proper set of conversions as well as confirmation of the tool path optimization algorithms.

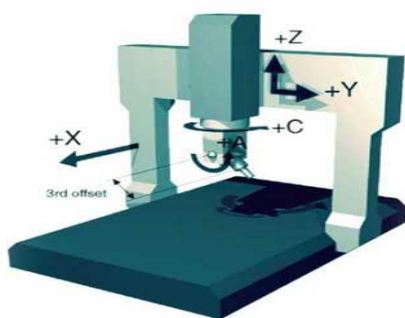


Fig. 6. Configuration of the five axis – milling machine.

Simulation process employs the 3D geometric modeling approach derived from the framework of inverse kinematics

of 5- axis milling machine. The CATIA V5 is used to develop a solid model for simulation, verification and optimization of the cutting operations. Moreover, it is possible to build a virtual environment that enables the user to interactively evaluate the kinematics of the mechanism and estimate the geometric errors. Figure 6 shows a possible configuration of 5 axis milling machines guided by axial commands.

$$\pi = (W, \mathfrak{R}) \in \mathbb{R}^5$$

Carrying the three spatial coordinates $W = (x, y, z)$ of the tool tip in the machine coordinate and the two rotation angles,

$$R = (a, b).$$

The tool path $\pi = \{\pi_0, \pi_1, \dots, \pi_m\}$ is a sequence of coordinates in the five dimensional spaces. The spatial coordinates of the tool path usually lie on the required surface $S = S(u, v)$. Usually the tool visits the positions following a structured spatial pattern such as a zigzag or a spiral pattern. However the path could be also composed from a variety of unconventional patterns and include tool retraction.^[12, 13]

A full optimization scheme involves a model of cutting operations topologies of the prescribe tool path patterns and an optimization procedure. Let p , be the parameters related to the configuration of the machine (such as coordinates of the center of rotation, work piece offset relative to the machine coordinates, etc). And p_i the parameters related to the tool (such as the diameter, length, shape, etc).

The model of the cutting operations being fed with P_c, P_t, S and π , produces a result of machining, namely, the output surface $T = T(u, v)$. The optimization is usually performed with regard to π and P_t . The cutting operations could be optimized with

regard to the machine configuration as well however, the optimal machine is often a purely theoretical issue. Let $S = S(u, v)$ be the required surface. The general optimization problem is then formulated by

$$\text{Minimize } \|\varepsilon\|, P_t, \pi$$

where ε denotes the cost function representing the error given by $\varepsilon(u, v) = S(u, v) - T(u, v)$ where $\|\cdot\|$ is an appropriate normal.

TOOL PATH GENERATION

A typical configuration of five-axis milling machine with the rotary axis on the work table assumes a set of successive coordinates called cutter location points or CL-points (X, Y, Z, I, J, K) in the work piece coordinate system. The CL-points are distributed along a set of curves which constitutes zigzag or spiral pattern. [14, 15]

Considering how the axial command transforms the centers of rotation, and in the same time rotates the W-coordinates. Let W_p and W_{p+1} be the two successive spatial positions belonging to the tool path and $\mathfrak{R}_p, \mathfrak{R}_{p+1}$ the corresponding rotation angles.

The tool trajectory between W_p and W_{p+1} calculated using inverse kinematics to transform part-surface coordinates into machine coordinates:

$$M_p \equiv (X_p, Y_p, Z_p) \text{ and } M_{p+1} \equiv (X_{p+1}, Y_{p+1}, Z_{p+1}).$$

The rotation angles (R) and machine coordinates (M) are expressed as $\mathfrak{R} \equiv \mathfrak{R}(t) = (a(t), b(t))$
 $M \equiv M(t) \equiv (X(t), Y(t), Z(t))$

And they are assumed to change linearly between the prescribed points, namely $M(t)$ and $R(t)$.

$$M(t) = tM_{p+1} + (1-t)M_p, \\ \mathfrak{R}(t) = t\mathfrak{R}_{p+1} + (1-t)\mathfrak{R}_p,$$

where t is the fictitious coordinate ($0 < t < 1$). Finally, invoking the transformation from M back to W (for every t) yields

$$W(t) \equiv (x(t), y(t), z(t)).$$

Note that $W(t)$ represents the actual tool trajectory in the work piece coordinate.

In commercial CAD/CAM systems like CATIA, tool path is simulated directly from the CL-points and hence it does not represent the actual tool trajectory, kinematics errors may go undetected and cannot be minimized.

The kinematics are represented by the functions $A \equiv (a(t))$, $B \equiv (b(t))$ associated with the rotations around the primary and the secondary (tilt-table) axes respectively. They are specified by the structure of the machine the kinematics involving two rotations and there translations are given by:

$$M(t) = B(t)(A(t)(W(t) + R) + T) + C,$$

where R, T, and C are in the order which coordinates of the beginning of the work piece in the rotating table coordinates, coordinates of the origin of the rotary table coordinates in the tilt table coordinates and the origin of the tilt table directs in the cutter center coordinates.

The general inverse kinematics are given by:

$$W = (A^{-1}(B^{-1}(M - C) + T)) - R$$

Generation and Simulation of the Tool Trajectory Using Transformation

1. Transform a CL-point $P_1(x, y, z, i, j, k)$ into the local coordinate system (LCS) of the rotary table by means of the rotation matrix R_1 and the translation vector T_1 . The new position is, $P_2 = R_1(P_1 + T_1)$.
2. Transform P_2 into the LCS of the tilt table by translation vector T_2 and rotation R_2 and R_3 . The new position is, $P_3 = R_3 R_2 (P_2 + T_2)$.
3. Transform P_3 until it is coincident with the LCS of the tool tip by translation vector T_3 . The final position is, $P_4 = P_3 + T_3$.

The translation vectors are given by, $T_1 = [t_{1x}, t_{1y}, t_{1z}]$, $T_2 = [t_{2x}, t_{2y}, t_{2z}]$, $T_3 = [t_{3x}, t_{3y}, t_{3z}]$,

where t_{ix}, t_{iy}, t_{iz} are the corresponding offsets which depend on the reference position of the machine. The rotation matrices are given by:

$$R_1 = \begin{bmatrix} \cos(A) & \sin(A) & 0 \\ -\sin(A) & \cos(A) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix} \quad R_3 = \begin{bmatrix} \cos(B) & 0 & -\sin(B) \\ 0 & 1 & 0 \\ \sin(B) & 0 & \cos(B) \end{bmatrix}$$

The rotation angles are:

$$A = \tan^{-1}(j/i), \quad 0 \leq A \leq 2\pi$$

$$B = -\sin^{-1}[k], \quad -\frac{\pi}{2} \leq B \leq \frac{\pi}{2}$$

Computation of CC-Points and Tool Inclination

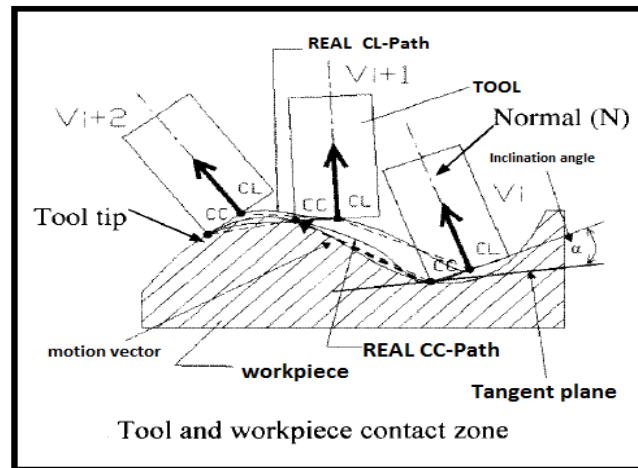


Fig. 7. Tool geometry and cutter movement.

The successive set of CL points generated using CATIA software usually are converted into the G-code to represent the machine motion in which the tool tip coincides with the CL--point. Optimization of tool angle position at each cutter contact point (CC-point) has to be done to minimize undercuts and overcuts as non-planar surface machining with CL-points

usually result in undercuts and overcuts. The tool geometry and cutter movement is as depicted in Figure 7.

RESULTS AND DISCUSSION

The results from simulated machining using CATIA V5 and the observed data

from conventional milling methods are described in the following sections.

Case 1: Conventional Method

In conventional method, the machining process is carried out at different sections, called P251 and P525. In each section,

separate operators are appointed to handle the process. In P251, drilling process is carried out and P525 is the milling section. Table 1 shows the standard time (Ts) and operation time (To) for different operations.

Table 1. The observed readings from P251 and P525.

	Machine section no.	Machine no.	Ts (sec)	To (sec)	Operations
1	P525	453	80	58.5	Milling
2	P251	453	35	23	Drilling
3	P525	213	40	30.5	H-Milling
4	P525	222 a	120	80	Milling
5	P525	222b	50	30	Milling
6	P525	222c	80	58	Milling
7	P251	028	35	20	Drilling

Total machining time (Σ) = 300 seconds.

Case 2: Simulated Machining Time Using CatiaV5

In proposed 5 axis milling machine, the selected Post processor and control emulator is ICAM (semn 840). The Post processor is the last link between the computer and the 3 axis milling machine. It was observed that the machining processes currently carried out in P251 and P525 when integrated with computer aided manufacturing, the dimensional accuracy can be improved dramatically. Using CATIA V5, the CNC code generation is up to 10 times faster.

time which helps to reduce the machining cost. Using the software the tool path can be simulated easily. For this simulation process, the part (lever used in Vibrator control shaft assembly) is modelled and the areas to be machined are selected. The software calculates the machining area automatically using specific parameters. The selection of appropriate tools is a major task in this process. Then the tool path simulation can be done for each machining area together. Table 2 shows the simulated machining times for various operations.

Total Machining Time is calculated by introducing an uncertainty factor.

$$Total_t = (\sum Time) \times uncertainty\ factor$$

where, *Uncertainty factor = 1.1*

Machining cost is also dependent on the machine cost along with total machining time

$$Machining\ cost = (Total_t/60) \times Machine\ cost$$

In 5 axis milling, all the seven operations are finished in one time, thus saving a lot

Table 2. The simulated machining times.

	m/c section no.	Machining time (sec)	Operations
1	P525	56	Milling
2	P251	20	Drilling
3	P525	27	Drilling
4	P525	73	Milling
5	P525	24	Milling
6	P525	50	Circular Milling
7	P251	16	Drilling

Total machining time (Σ) = 266.

Percentage of Time savings is 11.33%.

CONCLUSION

In comparison to the machining time, it has been observed that the machining time calculated by CATIA V5 is accurate as

long as the inputs are correct. Feed rates and Cutting speeds are very important parameters for precise time estimation. Since process planning can also be carried out in CATIA V5, one can utilize the data generated by CATIA V5 modelling and machining for this purpose.

Acknowledgement

This study has been carried out under close co-operation with HMT machine tools ltd, kalamassery, India. The authors are thankful for the support offered by various officials of the company for the real time observations and analysis during the investigation.

APPENDIX

Process Documentation

Case 1: Operation (milling)

Tool path style	Outward helical
Machining tolerance	0.1 mm
Depth of cut	10 mm
Tool used	T1 End Mill D10
Feed rate	300 mm/mn
Machining time	56 s

Case 2: Operation (drilling)

Diameter	9 mm
Depth of hole	28 mm
Tool used	End D D9Rc0N
Feed rate	130 mm/min
Machining time	20s

Case 3: Operation (drilling)

Diameter	3 mm
Depth of hole	15 mm
Tool used	End D D3Rc2short
Feed rate	130 mm
Machining time	27 s

Case 4: Operation (milling)

Tool path style	Outward helical
Machining tolerance	0.1 mm
Depth of cut	8 mm
Tool used	Endmill D3 Rc2short
Feed rate	300 mm/min
Machining time	73 s

Case 5: Operation (circular milling)

Tool path style	Outward helical
Machining tolerance	0.1 mm
Depth of cut	8 mm
Tool used	Endmill D3Rc2short
Feed rate	300 mm/min
Machining time	50 s

Case 6: Operation (drilling)

Diameter	9 mm
Depth of hole	16 mm
Tool used	End D D9Rc2short
Feed rate	130 mm
Machining time	16 s

REFERENCES

- [1] Ahmad N., Haque A.F.M.A., Hasin A.A. Current trend in computer aided process planning, *Proceedings of the 7th Annual Paper Meet and 2nd International Conference*. October 25–27, 2001, Dhaka, Bangladesh.
- [2] Cheung C.C. Semi-automated Process Planning and Cost Estimation of Turned Components Based on CATIA V5 Machining. *Thesis*, Jönköping University, 2008; Web. 10 June 2016.
- [3] DeGarmo E.P., Black J.T., Kohser A. *Materials and Processes in Manufacturing*. Macmillan College Publishing Company; 1988.
- [4] Dubovska R., Jambor J., Majerik J. Implementation of CAD/CAM system CATIA V5 in simulation of CNC machining process, *Proc Eng*. 2014; 69: 638–45p.
- [5] Dubovská R. The quality control of machining process with CAD/CAM systems support, *8th Intl DAAAM Baltic Conf Industl Eng*. 19–21 April 2012, Tallinn, Estonia.
- [6] Raisanen S.W. Semi-automated turning simulation production using catia V5, *Thesis* 2015, Saimaa University of Applied Sciences, Bachelor of Engineering,

- Lappeenranta, *Mech Eng Prod Technol.* 105p.
- [7] Jambor J. [aroslav]. Quality of production process with CAD/CAM system support, In: *DAAAM International Scientific Book 2012*. B. Katalinic (Ed.), Vienna, Austria: Published by DAAAM International; 2012, 277–86p, Chapter 24.
- [8] Majerik J., Danisova N. Automation & simulation of milling process with CAD/CAM system CATIA V5R19 support, *AI Mag – Autom J.* 2009; II(4)20–2p.
- [9] Lefebvre, Gerald, Introduction to CATIA V5 Automation- Web log post, CATIA V5 Design & Automation, N.p., n.d. Web. 08 June 2016.
- [10] Dassault Systemes, CATIA NC Programming, Catia Resources, Vélizy-Villacoublay: Dassault Systemes. 2003, Catia, Web. 8 June 2016.
- [11] Alan Christman Catia V5 CAM- A Product Review, from IBM/Dassault Systemes, January 2006, CIM data [Accessed 17 March 2016].
- [12] Majerík J., Šandora J. Cutting tools for machining-the new trends, *Mech Eng J.* 2009; XIII(3): 30–1p.
- [13] Majerík J., Šandora J. Drilling and milling tool-new trends, *Mech Eng J.* 2009; XIII(4): 82–3p.
- [14] Lechan P., Jambor J. SEAT Service quality management system, In: *Intl Sci Conf of Vehicles – New Trends in Construction and Exploitation Automobiles*. Slovak University of Agriculture, Nitra 2007, 5, 119–23p.
- [15] Vignesh R., Suganthan R., Prakasan K. Development of CAD models from sketches: a case study for automotive applications, In: *Proc Inst Mech Eng.* 2007; 221.1: 41–7p.
- [16] Ionut G., Adrian G., Simulation techniques in CAD-CAM processing by milling of surfaces on NC Machine-Tools, *Adv Prod, Automat Transportn Sys*, ISBN: 978-1-61804-193-7, 130 – 140p.