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Cost Optimization for Generating 3D Curved Surfaces in CNC 3-Axis Machine by Using CAD/CAM

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Abstract

The advancements in the manufacturing technology are now looking for the low cost methods for the manufacturing of parts using effective modeling and programming. Many efforts have been made by the researchers to propose ideas to optimize the cost of manufacturing of parts using CNC. Multiple-axis CNC has provided ease in the manufacturing of the designs that have curved surfaces. The demand of non-uniform surface designed parts is increasing in the modern machineries. This increases the role of CAD-CAM software in the process of manufacturing of parts. Still, the manufacturing of free-form surfaces remains a critical issue in the CNC too-path generation programming to get an optimized process performance. The programming to generate proper tool-path for a CNC Machine is the main criteria to get the desired surface quality, minimized machine time, etc. The work that is selected to be performed under the proposed title involves CAD-CAM based Modeling and CNC machine programming to manufacture a curved/3D surface of a part keeping in view the optimization in the machining cost. A 3D freeform surface is designed using Pro-E Tool for a CNC machine part and the CNC tool-path programming algorithm is implemented for the 3-axis CAM based manufacturing of the CAD Model of the freeform surface. An analysis of machine time versus machine cost is presented with respect to the performed machining operation.

Keywords

Free form surface, CAD Design, Machine Time, Tool-Path, CNC Programming.

I. Introduction

The functional requirements and the minimization of total machine parts in the modern industrial and automobile machines is increasing the need of manufacturing of freeform or curved surfaces of the machine parts. A complex effort is thus required by the experts at the various stages of manufacturing to meet the required optimization in the manufacturing of a machine part. CAD tools are providing a suitable environment to develop the model of the desired product by considering the essential physical parameters. The CAD Models represent the desired shape of the part in a form that can be analyzed by the user for verifying desired surface profile. A CAD design and modeling very effectively covers the geometric parameters and issues using software. Based on the desired CAD model the tool path of the CNC is programmed to generate the desired profile on the objectpiece. The problems are very often faces in the actual manufacturing of the object using a Lathe or CNC machine. The main problem is with the profile of the tool-path that gives shape to the object piece in the desired way. An effective manual or program based control is thus required when performing such operations. A programmed control is much better than manual control for a tool-path generation. The tool-path program is stored in the machine tool control (MTC) unit of the CNC machine. The performance of this CAM process directly affects the quality of the desired product with respect to time, cost, quality, etc. The programming of the CNC machine is thus a very important phase of the complete manufacturing process to get the desired optimization in the design and development of a part.

The steps required to perform freeform surface machining can be classified usually into roughing, semi-finishing and finishing machining operations. Rough cutting operation involves removal of most of the material from the surface to generate an approximate shape of the surface. After rough cutting, shoulders are removed in semi-finishing to yield a continuous offset surface for finishing. The last stage is the finishing stage in which the rough surface is transformed into the exact shape [1-2]. Reference [3] proposed a method that deals with the generation of curved surfaces using CNC lathe turning. In this paper a simulation based experiment is performed on different material by optimizing the path of tool for machining operation. An algorithmic procedure is proposed in [4] for tool-path generation based on constant pre-defined level of cutting forces for 3-axis ballend milling processes. The algorithm presented in this paper was experimentally verified for a number of advantages over the conventional machining strategies. Reference [5] proposed feed-rate scheduling method to maintain the cutting force at a constant value with a significant reduction of the total machining time compared to the method of maintaining a constant depth of cut and feed-rate. A method for optimizing roughing operations in CNC machining for parts production through a subtractive rapid manufacturing process is presented in [6]. This method utilizes the characteristics of rapid removal rates, suitability for a wide range of materials and precision whilst obtaining the benefits of shape flexibility and redution in process planning effort. A new off line error compensation model is proposed in [7] by taking into account the geometric and cutting force induced errors in a 3-axis CNC milling machine. Reference [8] addresses the effects of cutting speed and feed on the work piece deflection and surface integrity during milling operation of cantilever shaped Inconel 718 plate under different cutter orientations. Reference [9] examines the cost effectiveness of 3- versus 5-axis machines for the machining of a turbine blade made of alloy steel EN 34CrNiMo6. The acceptable surface finish cannot be achieved when a free surface is machined on a 3-axis CNC center due to the variation of the tool's position in relation to the part's surface. A feed-rate adjustment algorithm is proposed in this paper as a way to compensate for that limitation. A new approach based on vector field clustering for tool path optimization of 5-axis CNC machining is presented in [10]. The paper presents a strategy to produce an efficient tool path with respect to the optimal cutting direction vector field. The authors used the normalized cut clustering technique to partition the vector field into clusters and then applied spiral and zigzag patterns to generate tool path on the clusters. A cost effective method for manufacturing of Micro Gas Turbine (MGT) is proposed in [11] by reducing the manufacturing cost of individual component of MGT. In this paper a comparison of the dimensional accuracies, typical cost and surface finish in the compressor component is presented. The manufacturing is based on Rapid Prototyping (RPT) followed by investment casting. Reference [12] presents a feed scheduling algorithm for CNC systems to minimize the machining time for five-axis contour machining of free-form sculptured surfaces. In this paper, the most optimal feed is found

by considering velocity, acceleration and jerk limits of the 5-axes along the tool-path to ensure smooth and linear operation of the servo drives with minimal tracking error.
In this paper a free-form surface is modeled with a spherical profile and the CAM operation is performed using a 3-axis CNC to analyze the cost of manufacturing and the same is compared with the cost against a 5- axix CNC based on market cost survey. The CNC real time data is observed and also presented in the paper. The present paper is organized as follows: Section-II presents the free-form design of object using CAD Tool. Section-III presents the CAM operation execution detail using a 3-axis CNC. This section also presents the details of the CNC machine and the tool used for carrying out machining of the job-piece. Section-IV presents the operation output and cost based analysis of the proposed operation and Section-V presents the conclusion drawn on the basis of the performed CAD-CAM operation. Finally the references are mentioned in Section-VI.

II. CAD Modeling of Free-form Surface

A CAD Tool makes it easy to define the geometry parameters of a complex mechanical object with the aid of computer. In the present work a CAD based model is designed for a freeform surface generation. The present work utilizes the features of Pro-E Tool for defining the object parameters. The Tool features allow us to efficiently parameterize the model from various directions and for various angles. The free-form surface parameters are mentioned in Table I. The modeled object geometries are shown in fig. 1 and the Play-path of the model is pictured in fig. 2.

Table 1: CAD Model Specification

Tool Parameter	Specification
Length of Object Surface	160 mm
Width of Object Surface	60 mm
Height of Object	55 mm
Radius of Top Free-form Surface	2452 mm

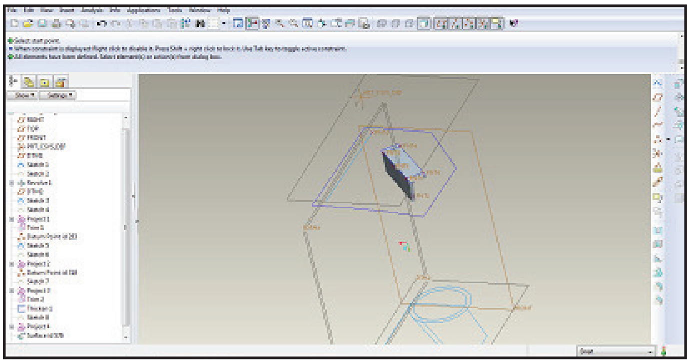

Fig. 1: CAD Model of Present Design

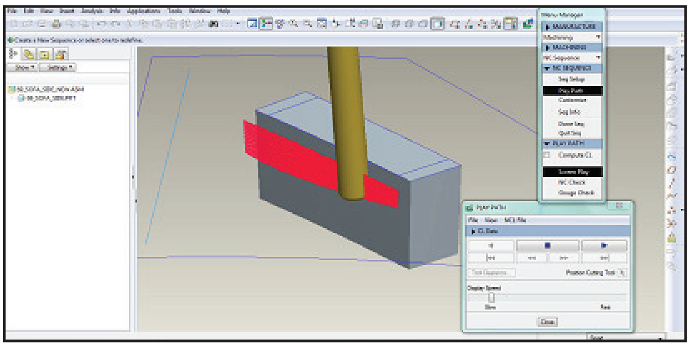

Fig. 2: Play Path of CAD Model

An L-shaped bed is modeled using the software. The similar shaped beds are used in coil bending machines and other similar mechanical work machines. The applications of such bed are highly dependent on the surface profile of the bed-surface. The vector force application of these beds depends on the surface profile during operational condition. So a highly matched profile of the exposed surface is mandatory for desired operations in the machines. This requires a high precision exact profile design and generation using CAD-CAM application.

III. CAM Operation on a 3-axis CNC for Free-form Surface Generation

The computer controlled machine operation is performed using the program that follows the user defined tool-path description. The tool-path is programmed using the machine language. This defines the path of the tool during machine operation. The tool is moved on the defined path with the object-piece placed on the machine bench. The A generalized algorithm for a CNC machine operation is described in Fig 3. As per the algorithm, the work-piece geometry and freeform surface geometry are first compared. The present work flows according to this algorithm.

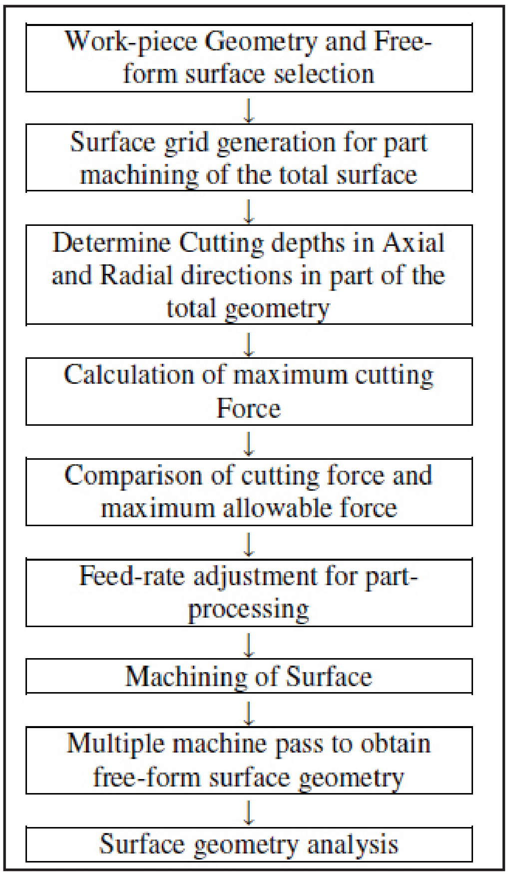

Fig. 3: Algorithm for Tool-path Generation

The operation performance is also dependent on the accuracy, feed rate, and other specifications of the Machine. In the present work, a high accuracy CNC Machine is used for CAM operation. The machine has a Position Accuracy of ±5 microns and a Repeatability Accuracy of ±3 microns. Such accuracy is sufficient to generate the surface finish of the Work-piece for most of the geometry generation. The Cutting Capacity, Load and Table Size are the basic parameters that limit the size of the Work-piece to be used for any CAM operation using a particular CNC Machine. The important specifications of the CNC Machine are presented in Table II.

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Table 2 : Specifications of CNC Machine

S. No.	Type: CNC Vertical Boring and Milling Machine Model: BMV-50		
1	Table Size		1200mm X 510mm
2	Load		1000 Kg
3	Traverse	X-axis	1020mm
		Y-axis	510mm
		Z-axis	600mm
4	Spindle	Power	7,5/11-F & 9/13-S
		Speed	6000rpm (std) / 8000rpm (opt)
		Taper	40 No.
5	Feed	Rate	1-5000 mm/min
		Rapid (X/Y/Z)	24/24/15 m/min
6	Accuracy	Positioni ng	±5 microns
		Repeata bility	±3 microns
7	CNC System		Fanuc 0i / Sinumerik 810D
8	Cutting Capacity	Milling	220 cc/min
		Drilling	Ø25 mm
		Tapping	M24 size

Fig. 4 shows the image of the object-piece before CNC machine operation on it and Fig. 5 shows the image of the tool that is selected for performing the CNC machine operation on the job-piece. Table III lists the main specifications of the selected machine tool.

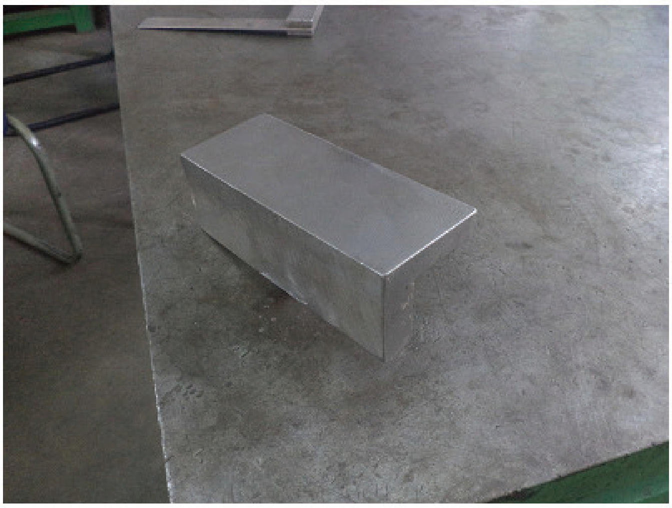

Fig. 4: Appearance of Job Piece

Fig. 5: Machine Tool Selected for CNC Operation

Table 3: Tool Specification

Tool Parameter	Specification
Cutter Type	Bull Nose Cutter
Cutter Dimensions	Diameter = 25mm
Number of Inserts	02
Insert Diameter	10mm

The CAD design is the reference for the tool-path generation. The Play-Path feature of the CAD Tool virtualizes the CNC machining process. This guides us in writing the Tool-path program. If required, the tool-path program can also be interrupted manually during machining process. A keen observation of the machining process and the real-time machine data can be used for analyzing the parametric efficiency of the operation. The tool operation is captured during process on the 3axis CNC machine and it is shown in Fig. 6. The job-piece view after the completion of the machining operation is shown in Fig. 7. Table IV gives the machine data that is observed during the machining process.

Fig. 6: Appearance of Job-Piece during Machining Operation on the 3-axix CNC

Fig. 7: Job-Piece after Machining Operation

Table 4: Real Time Observed Data

Tool Parameter		*Specification*
Spindle Speed		2400 rpm
Feed		1500 mm / min
Depth of Cut		1.5 mm
Incremental Passes	Top Surface	0.5 mm
	Side Surface	0.025 mm
Setting Time		60 min
Machining Time		8 hours

IV. Operation Output and Cost based Analysis of Proposed Operation

The machined job-piece is closely analyzed for the desired surface profile and the smoothness of the surface. The use of computer programming based control avoids any disruption in the size or shape of the object during machining by providing the desired precision. The effects of using a particular tool can be observed in the form of the surface profile at steep turns and corners. The observation and analysis of the freeform surface in the job-piece in the present work is shown in Fig. 8 and Fig. 9.

Fig. 8: Machined Freeform Surface Geometry Observation

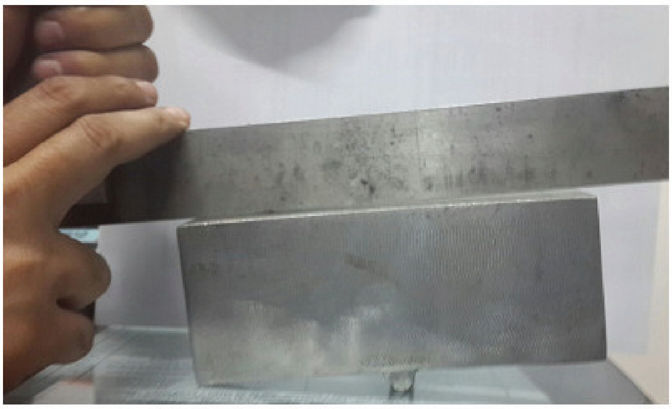

Fig. 9: Machined Freeform Surface Geometry Analysis

The machine cost analysis of the surface manufacturing is presented in Table V. The operational cost of the 3-axis CNC machine involved in the present work is Rs 500 for one hour whereas the machine operational cost of a 5-axis machine is Rs.2000. Thus a comparatively cost effective operation can be performed using a 3-axis machine. Fig 10 presents the comparative cost chart for the CNC machine operation using 3-axis and 5-axis machine. The effectiveness of the operation in terms of machine cost from the present work concludes that the operation is economic on a 3-axis machine as compared to a 5-axis machine.

Table 5: Table of Machine Time and Cost Analysis

Cost / Time	*3-axis CNC*	*5-axix CNC*
Time of Machining	8 hour	6 hour approx.
Cost of Machining (per hour)	Rs 500	Rs 2000 (as per survey)
Total Cost of Machining	4000	12000

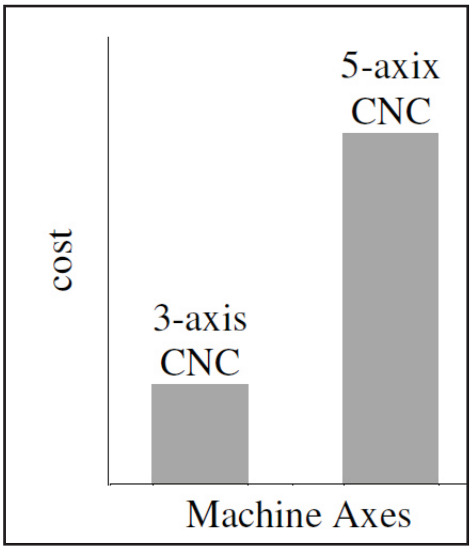

Fig. 10: Machining Cost Comparative Analysis

V. Conclusion

The paper presents a cost optimized process analysis for generating freeform surface using a 3-axis CNC machine. For the experimental results a CAD based 3D surface model is designed using Pro-E Tool. The designed surface model is machined using a 3-axis CNC machine. The experimental result is analyzed against the machine time and cost of surface manufacturing using bull nose cutter tool. The results conclude that a curved freeform surface design can be machined using a 3-axis CNC for manufacturing with a comparative low cost against an exceeded axes CNC, and thus the machine cost can be reduced. Another important conclusion that can be drawn from the present work is that the cost compensation can be used to extend the time of machining for a better surface generation to avoid any deformation in the work-piece due to the implemented CAM steps. The presented considers the freeform surface generation for small area surfaces.

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