Cubic Bézier Surface Machining using Control Points to Find the Accuracy of Machining

Milap M. Gohil
Assistant Professor
Mechanical Engineering Department
HJD-ITER Kera Kutch-Gujarat India
e-mail: milapgohil@hotmail.com

Pravin P. Rathod
Associate Professor Ph.D.
Mechanical Engineering Department
GEC-Bhuj-Kutch-Gujarat India
e-mail: pravinprathod@gmail.com

Jay K. Pandya
Asisistant Professor
Mechancial Engineering Department
HJD – ITER Kera-Kutch-Gujarat India
e-mail: pandyajayk@gmail.com

Abstract— Bézier surface is a powerful design tool for automation in production of various machine elements. Cubic Bézier surface is generated by 16 control points. It is created with computer aided manufacturing software SurfCAM, for study of cases of Bézier surface 13 cases have been taken by varying control points in X and Y directions. These surfaces are imported into Unigraphics NX Software to generate tool path and CNC machine code according to prescribed cutting parameters, and Simulation has been done for that. These CNC codes are imported into Vertical Machining Centre VMC having Siemens controller, machining work has been completed on three different materials like Wood, Nylon and Aluminum. One surfaces is machined on each material. Generated surfaces are measured with the help of Co-ordinate Measuring Machine (CMM). Each surfaces are compared with the actual dimensions and analysis has been carried out for accuracy of machining. Conclusion is drawn based on that machining are done

Keywords- *Bézier surface, CMM, Control points, VMC, Accuracy.*

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I. INTRODUCTION

Pierre Étienne Bézier was French engineer, founder of solid, geometric and physical modelling as well as in the field of representing curves in CAD/CAM that curve known as Bézier curve. Paul de Casteljau is also French physicist and mathematician has developed an algorithm to evaluate calculation on definite curves called de Casteljau curve or Bézier curve in 1959. Bézier curve is powerful design tool for automated manufacturing that are various types as cubic, quadratic etc. Cubic Bézier curve formation needs two control points and one starting and end points. Extruding of Bézier curve makes surface. keeping X-Y co-ordinate contestant give the flat surface and varying co-ordinate gives sculptured surface both of are called the Bézier surface.

II. LITERATURE SURVEY

Sata, et al. (1980) [1] Studied: Interpolation of tool path defined by Bézier for machining. Results: Generate data for numerical controlled tool path, proposed method compressed considerable data required for machining and modification in tool change and insertion of tool during machining. Gorowara (1990) [2] Studied: computed the Bézier surface control point in terms of given vector. Results: One point P0 is easy to computer then rest of all. To find out all equated co-efficient to surface co-ordinate and solved 16 linear equation. Radzevich (2002) [3] Studied: how to define and how to describe analytical surface for that set of necessary and sufficient condition of proper sculptured surface (Bézier) machining (SSM). Results: To confirm sculptured surface generation six necessary and sufficient condition of proper SSM is developed. It increase an efficiency of high speed machining in convectional, CNC machine and rapid prototyping. Masood et al (2002) [4] Studied: Minimum distance algorithm for machining of sculptured surface (Bézier) on CNC machine. Results: Using algorithm in CAMSURF software gives smooth surface with desired tolerance level surface generated. Capability of tool path simulation allows to analysis the surface in terms of selected tool size, tolerance value and number of NC points required. Giri et al. (2005) [5] Studies : Isoscallop strategies of SSM, one of the surface edge is chosen from Master Cutter Path (MCP) other cutter path derived such that roughness produced uniformly. Results: The proposed strategies of cutter path generation minimize machining time or CL data file size to a higher degree compared to that obtained by conventional isoscallop strategy. MCP in the direction of maximum convex curvature reduces machining time, and in the direction of maximum flatness reduces the CL data file size. Yau et al. (2005) [6] Studied : Real-time look ahead interpolation of NC part program using Continues Short Blocks (CSBs) to fit in Bézier curve. Results: Real time Bézier curve fitting brings federate, acceleration and jerk as well as the trajectory into good continuity. Simulation and experiment employing PC-based real-time interpolator assures feasibility of CSBs fitting by cubic Bézier surface. Agrawal et al. (2006) [7] Studied: minimization of machining time while implementing Isoscallop machining by optimization of Primary or Master Cutter path through G.A.. Results: A significant reduction of machining time, compared to other methods of cutter path generation. It has been also shown that there is a scope for further reduction machining time, while employing isoscallop strategy of cutter path generation. This achieved by an optimum orientation of the cutter paths. Yau and Wang (2007) [8]. Studied: This study presents a real-time fast Bezier interpolation method that solves linearly segmented contour problems that occur during milling using conventional CNC machines. Results: Explored the feasibility of using the FBI with a real-time look ahead function to solve linearly segmented contour problems. Simulation with new Continues Short Block demonstrate that the algorithm of the FBI provides high-accuracy interpolated position commands. In addition, the CSB criterion obtains more efficiency and acceptance due to the high Bezier fitting rate and fitted blocks distribution. Experimental results have proven the feasibility of the well- developed FBI. Choi et al. (2007) [9] Studied: Tool path generation method for multi-axis machining of free-form surfaces using Bézier curves and surfaces. The tool path generation includes two core steps. First is the forward-step function that determines the maximum distance, called forward step. The second component is the side step function which determines the maximum distance, called side step. Results: The proposed algorithm for tool path generation is developed and implemented successfully. The implementation of this algorithm shows that the algorithm is very efficient for finish machining. This approach is very suitable for sculptured and analytic surfaces. Last, they verified true machining error by comparing designed surface and machined surface using point cloud method. Kim (2007) [10] Studied: A new approach to generating constant cusp height tool paths. First, we define a Riemannian manifold by assigning a new metric to a part surface without embedding. This new metric is constructed from the curvature tensors of a part and a tool surface, which we refer to as a cusp-metric. Then, we construct geodesic parallels on the new Riemannian manifold. Results: Proved that by constructing geodesic parallels with respect to what we call the cusp-metric, constant cusp height tool paths accurate to second-order can be constructed. Jackman and Park (1998) [11] Studied : The rapid increasing use of Co-ordinate measuring machine (CCM) in Computer Integrated Manufacturing (CIM) replacing current ad-hoc approach and proposed location of sample points using the work piece model from the design. Results: A geometry based approach that finds the probe orientation for each sample point. And probe orientation derived using the concept of visibility and creating visibility maps. This used to development of Inspection program. These methods can be used to determine feasible probe orientation without operator intervention. Li and Gu (2004) [12] Review: This paper provides a comprehensive literature review of methodologies, techniques and various processes of inspections of parts with free-form surfaces. The specific topics cover: measurement data acquiring methods including contact and non-contact measurement approaches; inspection planning; geometric description methods of design models or measurement data; and, the free-form surface localization and comparison techniques, which are emphasized in this paper and mainly include the establishment of corresponding relationship, 3D transformation solving, measurement data to design model comparison or surface to surface distance calculations. Discussion: In this paper contact inspection was mainly focused on CMM measurement, while non-contact inspection was based on laser and optical scanning. Various practical issues such as the measurement point selection, factors influencing localization process, inspection planning, tolerance inspection and inspection with design datum were discussed. Some existing commercial inspection packages were also briefly reviewed.

III. MATHEMATICAL FORMULATION

Cubic Bézier surface is formulated by two way first using 16 control points and second draw curve using 2 control points and 1 starting and end points, and extrude is in z –direction. Here second method is considered cubic Bézier curve is drawn using equation

$$P(u) = \sum_{i=0}^{3} P_i B_i(u) \qquad (1)$$

Where, P = control point and u = parameter range from 0 to 1 and Bi = Bernstein polynomial. Curve in parametric form, value of u is varies from 0.001 to 1. Control points of Bézier curve are shown in table I. And curve shown in Fig. 1..

Tables I: Control Points

P0		P1		P2		P3	
Case 1							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	25	75	25	100	0
Case 2							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	30	75	25	100	0
Case 3							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	35	75	25	100	0
Case 4							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	40	75	25	100	0
Case 5							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	30	25	75	25	100	0
Case 6							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	35	25	75	25	100	0
Case 7							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	40	25	75	25	100	0
Case 8							
P0		P1		P2		P3	
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	25	75	30	100	0
Case 9							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	25	75	35	100	0
Case 10							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	25	75	40	100	0
Case 11							
X0	Y0	X1	Y1	X2	Y2	X3	Y3

0	0	25	25	70	25	100	0
Case 12							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	25	65	25	100	0
Case 13							
X0	Y0	X1	Y1	X2	Y2	X3	Y3
0	0	25	25	60	25	100	0

Now each curve is extruded in z-direction from 0 to 15 mm to generate surface or profile. Using SurfCAM R12 software each surfaces are generated example shown in Figure 1. Tool path, simulation and CNC machining code are generated in next section.

Graph 1. Cumulative Quadratic Bézier curve

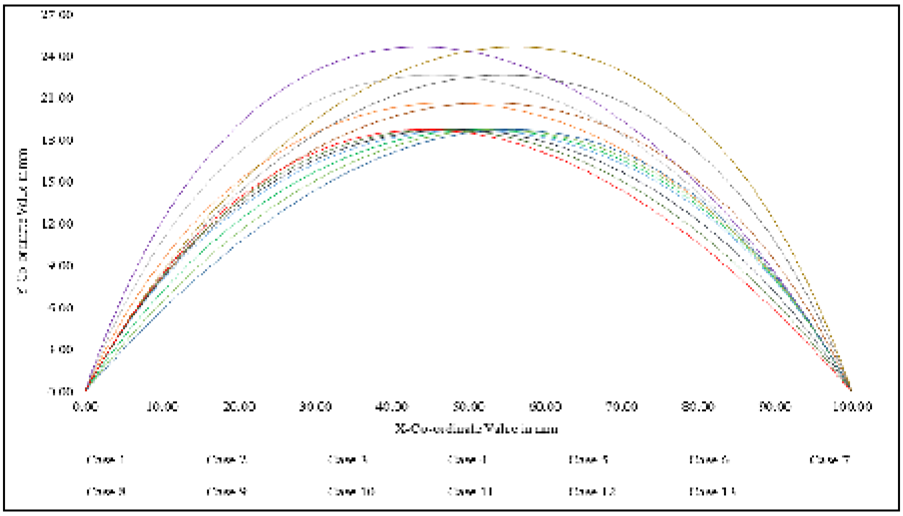


Figure 1. Case 1

IV. Tool Path NC Code Generation and Simulations

A. Tool Path

Tool path for each cases are generated using Unigraphics NX software in three steps, first cavity, second Z and third finishing path or cut. Flat ended 12 mm diameter, 4 flute and carbide material tool used for first and second path or cut. Ball ended tool with same specification used for finishing cut.

During simulation of the tool path it is observed that case number 2 to 7 are mirror image of 8 to 13 number case respectively with accuracy of 1 micron. Case 1 it is not mirror from

In considered cases. No error in tool path and did machining codes generation process from tool path, CNC machining codes are generated automatically and stored in text file in computer, its according to the VMC controller of Siemens. Tool path for case 1 are shown in Figure 1 and remaining cases tool path generated in same way.

B. NC Code Generation

NC codes are generated automatically for each case of Bézier surface that is shown in Figure 1, for each three cut i.e. cavity cut, Z-cut and finishing cuts tool path are shown in Fig. 2 with cutting parameter shown in table II. It is same for each

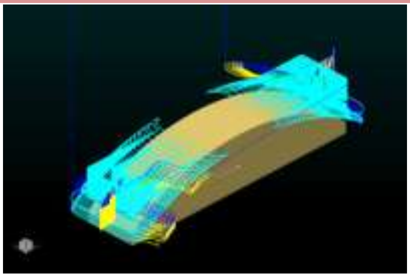
surface and material, using Unigraphics NX software NC code automatically generated, using the CNC machine (VMC) controller`s Siemens post processing file. After these, codes are directly used for machining.

C. Simulation

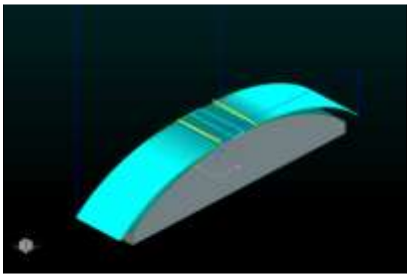
Simulation is done on CNC machine using software named Unigraphics NX. It shows the generated NC command execution before it goes to actual machining. Simulation has been done for all thirteen cases. It shows any error in NC programming can solved it, and process is again repeat until gets successfully generated surface. Step by step process gives the entire movement of tool reference of thesis. procedure.

Tables II Cutting parameters

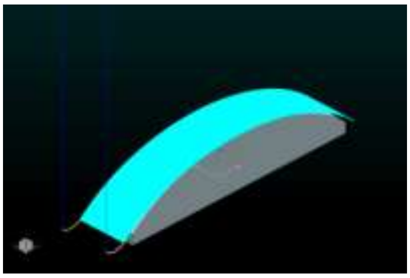
Cut	Cutting Speed (RPM)	Feed (MMPM)	Depth of Cut (mm)	Tool Diameter (mm)
Cavity	4000	1500	0.5	12
Z	4000	2000	0.1	12
Finish	4500	2000	0.08	12



(a) Cavity cut



(b) Z-Rough cut



(c) Finish cut

Figure 2. Tool path for case 1

V. EXPERIMENTAL PROCESS

A. *Machining Process*

Machining process is done on three materials Nylon, Wood and Aluminum case machining on each materials and on Aluminium two pieces are done, total four pieces has been made on CNC VMC Machine.

1) Holding the work-piece on machine fixture.
2) Inserting the cutting tool of given specification in machine spindle as per tool path or cut (i.e. cavity, z and finishing).
3) Setting work piece co-ordinate points are taken from sides, length and datum of work piece that are set at zero-zero position.
4) Inserting the machining code for each cases in controller of machine.
5) Machining code for each cut are executed step by step.
6) Giving command of machining mode in VMC, machining will starts.
7) Machining process for case 1 is shown in Figure 3 and for considered cases machining done in same method.
8) Complete machined surfaces are show in Figure 4

(a) Cavity cut

(b) Z-rough cut

(c) Finishing cut

Figure 3. Machining process of case 1

(a) Case 1 (Aluminium)

(b) Case 2 and 8 (Nylon)

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(c) Case 4 and 10 (Wood)

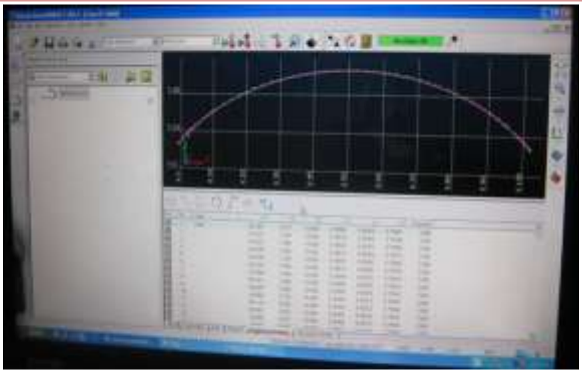
(d) Case 7 and 12 (Wood)

Figure 4. Machined surface

B. *Measurement process*

Measurement of Bézier surface was done on FARO arm CMM shown in Figure 5 (a). The process for measurement of machined surface were shown in Figure 5. First, job was fixed on table by adhesive and reference plan points were taken from four sides front, back, right and left side each side of four points. It has formed four plans. Now FARO arm pointer touches the surface at middle and put points at the interval of 10 mm in x-direction for each machined case. The software they used was Delnet Inspection. It gives the complete curve of measurement as shown in Fig. 5 (b), for each machined case. Now measured dimensions has to be compensate by Ferro arm pointer radius of 1.5 mm as per machine specification. One sample process has been shown in Fig. 6 and for remaining cases done same.

(a) Measurement on CMM



(b) Measured surface curve

Figure 5. Measurement Process

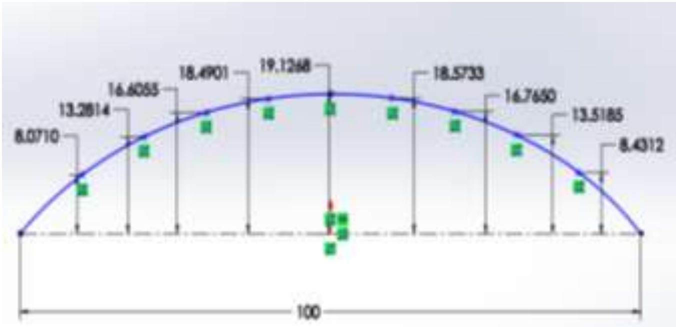
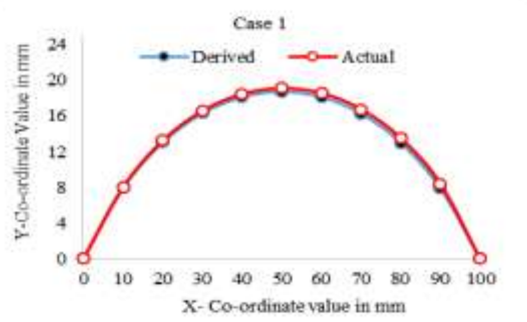
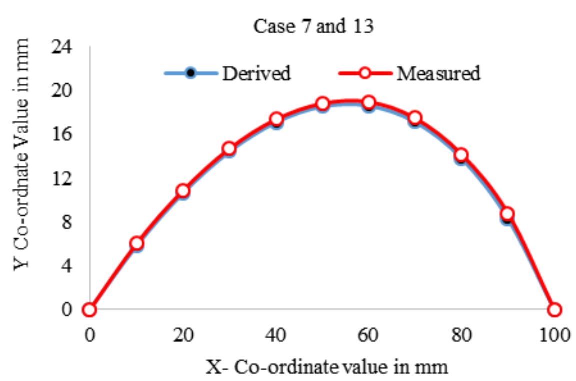


Figure 6. Measurement of case 1

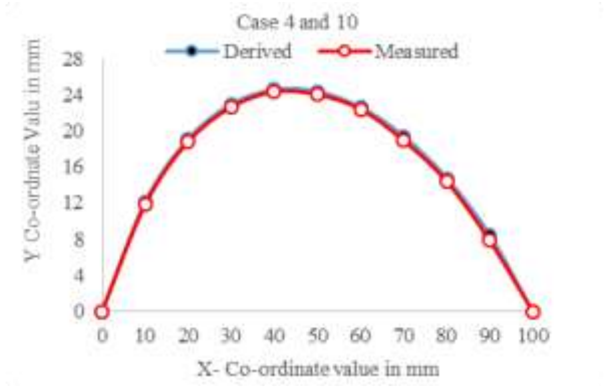
Graph 2 : Derived and measured dimension of surface for case 1, material aluminium



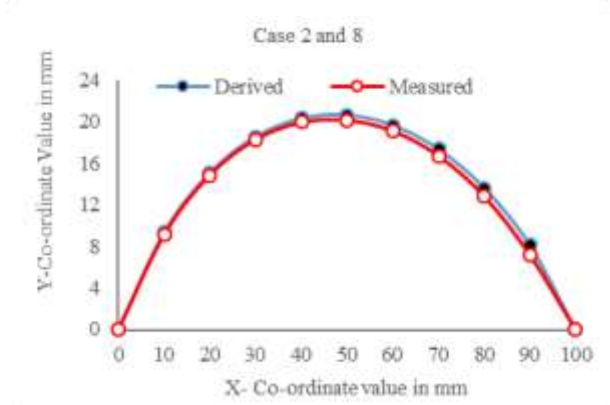
Graph 3 : Derived and measured dimension of surface for case 7 and 13, material sluminium



Graph 4. Derived and measured dimension of surface for case 4 and 10, material wood



Graph 5. Derived and measured dimension of surface for case 2 and 8, material nylon



VI. Analysis of Machining Accuracy

A machining accuracy are shown in table III, in percentage of error variation comes due to control points were varies in X and Y direction in step of 5 mm. The comparison of actual dimensions with derived dimensions are shown in Graph 2 to 5, yellow shaded cells in table III are error of percentage is actual and reaming error of percentage is achieved by langrage's linear interpolation method. Machining done on two Aluminium pieces for implementing langrage's interpolation method.

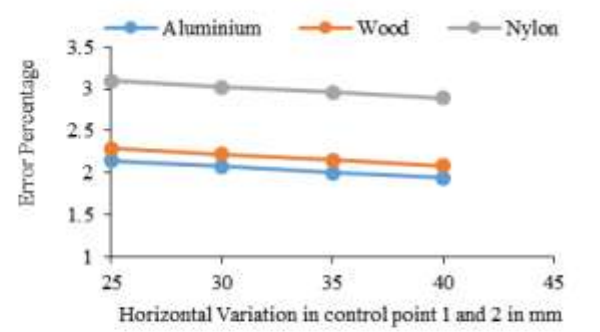
A. *Analysis*

Compared with the case 1 in table III, the percentage variation of CBS for Aluminium Wood and Nylon materials, more percentage of variation in Nylon compared to Aluminium and Wood. Whereas Aluminium and Wood have a very little percentage variation found. Deviation comes in Aluminium is varies between 1.9395 to 2.1429 percentage of error, similarly Wood and Nylon varies between 2.0860 to 2.2894 and 2.8924 to 3.0935 percentage of error respectively. The graph is plotted between percentage of error and control points variation in X and Y directions. While control points varies in X direction the accuracy of Aluminium and Wood is constantly increases with little variation in accuracy as shown in Graph 6, for Nylon accuracy is also constantly increase but varies about one percentage. Control points varies in Y direction the accuracy of machining is similar to vary the control points in X direction shown in Graph 7.

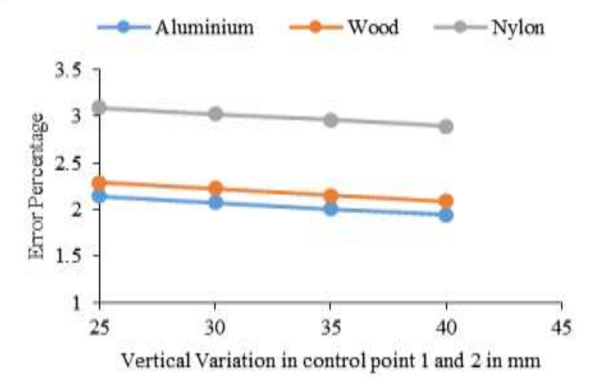
Tables III : Percentage of variations of cubic Bézier surface

Cases	Control Points (X)	Control Points (Y)	Aluminium	Wood	Nylon
1	25	25	2.1429	2.2894	3.0935
2	25	30	2.0748	2.2213	3.0240
3	25	35	2.0053	2.1518	2.9582
4	25	40	1.9395	2.0860	2.8924
5	30	25	2.0748	2.2213	3.0240
6	35	25	2.0053	2.1518	2.9582
7	40	25	1.9395	20860	2.8924

Graph 6. Control points varies in X-direction



Graph 7. Control points varies in Y-direction



VII. Conclusion and Future Scope

A. *Conclusion*

1) The accuracy of machining on Aluminium, Wood and Nylon forms a pattern, as the complexity of curve increases the error of machining is reduces.
2) In present study specific curve has been chosen for measuring the machining accuracy for the case of Aluminium, Wood and Nylon are improved from 2.1429 to 1.9395, 2.2894 to 2.0860 and 3.0935 to 2.8925 percentages with varying control points.
3) Close argument of accuracy has been found for Aluminium, Wood and Nylon as increases with average percentage of accuracy is 2.0406, 2.1871 and 2.9920 respectively.
4) The accuracy of machining for cases 2 to 4 for Aluminium, cases 1 to 3 for Wood and cases 1, 3 and 4

for Nylon has been derived using Lagrange's linear interpolation method. Which is having hypothetical accuracy, it is achieved exactly same while performing machining.

B. Future Scope

1) The complexity of CBC increasing the order of curve from fourth power onwards.

2) Similar work can be applied for investigating pattern of precision during machining.

3) The curve can also be change such as B-spline, Hermit Curve and in appropriate blending.

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