Studying Curve Interpolator for CNC System

Abbas M.Jabber Al-Fnzi*, Laith A.Mohammed*
& Maan Aabid Tawfiq*

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Abstract

This thesis focuses on developing algorithm to calculate best length line segments in (u) and (w) directions. By of tool paths for free form surfaces based on the required accuracy of the manufactured part, which is represented by mathematical curves and surfaces. Bezier method was used to apply the proposed algorithms. The proposed algorithms consist of two parts; the first part is to calculate the better length line segment in (u) direction between cutter contact points (CC), the second part is to calculate the better line segment in (w) direction depending on the type of surface, cutter radius, tolerance and height scallop being given. The algorithms are applied in production field such as design of extrusion dies using three types of curve interpolation such as approximation cubic Bezier, interpolator Bezier and compound-CRHS profile die. In this paper, the manufactured parts are machined using a 3-axis CNC milling machine. The machining operations are simulated using SURFCAM software depending on the different interpolation techniques mentioned. An evaluation test is applied to the three interpolation methods based on Finite Element Method (FEM) using ANSYS 9.0 software to expect the strain and force required to extrude billet through the dies which are designed using the three mentioned interpolation methods. The G-code programs have been implemented on 5-axis CNC machine (Okuma VH-40-HS dynamic machine), the sample material is (cibatool) and the machining process is achieved without a lubricant at the Protoshop Oy in Helsinki/Finland.

Keywords: Curve Interpolator, CNC System, Bezier technique, CAD/CAM, G-code

دراسة استكمال المنحني لنظام مكائن السيطرة الرقمية

الخلاصة

يركز هذا البحث على تطوير خوارزمية لحساب أفضل طول قطعة مستقيم في اتجاه (u) و (w). مسار العدة للسطح يعتمد على الدقة المطلوبة للجزاء المصنع, اي هو ممثل بواسطة الاقواس والسطوح الرياضية. طريقة بيزر هي الطريقة المستخدمة لتطبيق الخوارزمية عليها. الخوارزمية المقترحة تتكون من جزأين, الجزاء الاول هو حساب افضل طول قطعة مستقيم في اتجاه (u) بين نقاط تماس عدة القطع (cc), الجزاء الثاني حساب طول قطعة المستقيم الامثل في اتجاه (w) بالأعتماد على نوع السطح وكذلك على نصف قطر عدة القطع والتجاوز و(height scallop) المعطى. الخوارزمية المقترحة تم تطبيقها في مجال الأنتاج (تصميم قوالب البثق) بواسطة استخدام ثلاثة انواع مختلفة من الأقواس المستكملة هي (cubic Bezier, interpolator Bezier and compound-CRHS extrusion profile die). في هذا البحث الاجزاء المصنع هي مشغلة بواسطة استخدام ماكنة تفريز CNC ذات ثلاثة محاور 3-axis وذلك لغرض أستكمال الطرق وتحليلها ومقارنتها. حيث تم ايجاد طريقة تتجنب حدوث (gouging) خلال استخدام هذه الماكنة. تم

* Production and Metallurgy Department Engineering ,University of Technology/Baghdad

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

محاكاة عمليات التشغيل باستخدام برنامج يدعى (SURFCAM) لمختلف الطرق المستكملة من اجل تقييم وتخمين السطوح قبل تشغيلها. تم أستخدام طريقة العناصر المحددة (FEA) للتقييم طرق الاستكمال الثلاثة من خلال استخدام برنامج (ANASYS 9.0) من اجل التعرف على الانفعالات والقوى المطلوبة لبثق المعدن خلال القوالب المستكملة الثلاثة. ان برنامج (G-code) تم تطبيقه على ماكنة ذات خمس محاور(Okuma VH-40-HS dynamic machine), المادة التي تم تشغيلها هي (cibatool), وأن التشغيل تم بدون سائل تبريد في مصنع (Oy) في فنلندا(Helsinki/Finland).

1. Introduction:

The input to which system will be two (2D) or three dimension (3D) model. The model of the input contains not only dimensions of the shape but also the tolerance, height scallop, better length segment and special features. To facilitate a CAD, CAM system in the manufacturing process, we generate a NC program extrusion die design. The algorithm is applied to the extrusion die and the proposed algorithms (interpolator Bezier profile die) will be compared with cubic Bezier and component (CRHS) profile die. A real part is machined using SURFCAM software to simulate the part machining before machining on the CNC machine. We refer to G-codes as the machine language output from SURFCAM software in this research. After determining the length line segment and comparing between cubic Bezier, interpolator cubic Bezier and component (CRHS) profile die, we calculate the homogenous strain and force required for extrusion die utilizing the ANASYS 9.0 software.

Theories and algorithms which relate shapes and geometries of CAD models to the path and motion controls of CNC machine tools constitute a subject area called motion intelligence. This area of concern consists mainly of three categories [1]: Curve and surface containing the all features being mentioned.In this work (DXF-file) shall be converted from MATLAB to SURFCAM software to visualize the product before machining. In this work, we propose a modified methodology will be proposed to calculate segments of appropriate length in (u,w) directions that are within the tolerance, height scallop and ultimately generate the tool path for presentation, tool path generation approaches and surface machining approaches. Many researches have been done for represent curve and surface. **Thilo Kielmann (2007)** [2] investigated computer graphics curves and surfaces**.** In this research, he studied mathematical representation of curves (explicit, implicit, and parametric), the representation of parametric surfaces for quadratic and cubic polynomial. He studied cubic interpolation and joining interpolating segments. The study is applied to Hermit, Bezier and B-Spline curves and surfaces. **Akeel S. Bedan (2006)** [3] investigated automation surface generation from wireframe data in CAD application. He created an efficient and accurate 3D surface interior data depending on primary initial data based on approximation and interpolation techniques. The research presented a mathematical algorithm to generate 3D surface design using three different approximation methods (Hermit, Bezier and B-Spline technique). A comparison has been made between the two adopted techniques of surface generation (approximation and interpolation) depending on several standard functions (sine-cosine functions, exponential functions, parabola functions, fractional functions and polygons). Many researches have been done for represent tool path generation approaches. **Young-Keun Ehoi et al (2007**) [4] investigated tool path generation and tolerance analysis for free-form surfaces**.** They focused on developing algorithms that generate tool paths for free-form surfaces based on the accuracy of a desired manufactured part. A manufacturing part is represented by mathematical curves and surfaces. This algorithm reduces manufacturing and computing time as well as the (CC) points while keeping the given tolerance and scallop height in the tool paths. **His-Yung Feng et al (2002)** [5] studied constant scallop-height tool path generation for three-axis sculptured surface machining**.** They present a new approach for the determination of efficient tool paths in the machining of sculptured surface using 3-axis ball end milling. The objective was to keep the scallop height constant across the machined surface such that redundant tool paths are minimized. Their work determines the tool paths without resorting to the approximated 2D representation of the 3D cutting geometry. Two offset surfaces are employed to successively establish scallop curves on the scallop surface and cutter location tool paths for the design surface. The results indicate the constant scallop-height machining achieves the specified machining accuracy with fewer and shorter tool paths than previous path generation approaches.). **D.K. Pratihar et al (2005)** [6] studied optimization of CNC isoscallop free form surface machining using a generate algorithm. They presents isoscallop machining with edge-based master cutter path (MCP), which essentially ensures uniformity of surface, roughness over entire surface of part but may not necessarily ensure minimization of machining time. In their work it has been shown that there is a provision for minimizing machining time while implementing isoscallop machining by optimizing the orientation of the primary or master (MCP) through application. The results indicate substantial reduction in total machining time for the proposed approach compared to those obtained through previously reported cutter path generation strategies. **Jianguo Wang (2005)** [7] investigated global finish curvature matched machining. The thesis focuses on how to determine the uncut or rework areas of the previous CM2 (curvature matching machining) and how to define the boundary of these regions. Strategies for generating more efficiency CM2 tool paths are also discussed. The goal was to improve surface finish and achieve design surface dimensions more accurately.

2. Bezier Representation: P. Bezier of the French automobile company of Renault first introduced the Bezier curve**.** A system for designing sculptured surfaces of automobile bodies (based on the Bezier curve) was introduced in (1962) [8]. Bezier has chosen a family of functions called 'Bernstein polynomials' to satisfy these properties. Bezier started with the principle that any point on a curve segment must be given by parametric function of the following form where (u and w) are surface parameters, Bi,n is Bezier coefficient [9]:

$$P(u) = \sum_{i=0}^{n} P_i B_{i,n}(u)$$

$$u \in [0,1] \quad \ldots\ldots\ldots (1)$$

where the basic functions are:

$$B_{i,n}(u) = \binom{n}{i} u^i (1-u)^{n-i}$$

$$B_{i,n}(u) = \frac{n!}{i!(n-i)!} u^i (1-u)^{n-} \quad \ldots (2)$$

3. Algorithms Proposed For Representing Interpolator Curve for CNC System Approach:-

In this section, we will summarize algorithms proposed that can be used to calculate optimum length of line segment with tolerance given and calculating better side step with given height scallop.

*** Defining the Designed Surface in the (u,w) Direction:**

The designed part is represented by Cubic Bezier surface. The surface is represented by parameterized over a domain (u,w) and defined by parallel curves called isoparametric curves. Boundary of curves must be equal to the boundaries of the surface.

*** Calculating the Radius of Curvature:**

On the designed part, we calculate the radius of curvature at each point on the surface to obtain the minimum radius of curvature. Calculating the radius of curvature very important because it is used to determine the length of line segment and determining better cutter radius must be equal to or smallest than the minimum radius of curvature to avoid gaouging and interferance for the parametric surface.

*** Calculating The Optimum Line Segment in (u,w) Direction With Scallop Height and Tolerance Given:**

During surface machining, the surface part is approximated by series of line segments. Therefore in this thesis, we calculate the length of line segment in (u) and (w) direction. We approximate the tool path by better length segment (linear interpolation). The better length segment is the distance between (CC) points during current tool path with in the limited given tolerance. This work will determine the length line segments for forward step (L). After calculating length line segment in (u) direction, we calculate the better length segment in (w). Length line segment in (w) direction is the better distance between two adjacent tool paths which can keep the height scallop (h) given. Hence the radius of tool must be less than or equal to the minimum radius of curvature. The side step (g) is a function of the scallop height (h), tool radius and the local radius of the curvature (ρ); therefore three different cases are considered to calculate side-step size (g) [11]:

1- A flat surface as shown in figure (3A):

$$h = r - \sqrt{r^2 - (\frac{g}{2})^2}$$

$$g^2 = 4r^2 - 4(r-h)^2$$

$$g = 2\sqrt{r^2 - (r-h)^2} \text{.......}(3)$$

2- A convex curvature is shown in figure (3B).

$$d = OB - OA$$

$$OA = \sqrt{r^2 - p^2}$$

$$OB = r$$

$$h = r - \sqrt{r^2 - p^2 + d}$$

$$g = 2 - \sqrt{r^2 - (r+d-h)^2} \text{..........}(4)$$

3- For a concave curvature as shown in figure (3C) we calculate the step size for concave surface:

$$d = OB - OA$$

$$OA = \sqrt{r^2 - p^2}$$

$$OB = r$$

$$h = r - \sqrt{r^2 - p^2 - d}$$

$$g = 2 - \sqrt{r^2 - (r-d-h)^2} \text{...}(5)$$

Where (ρ) is the local radius of the curvature surface .Using the above equations, (g) is calculated at each point on the current curve [11].

*** Converting the Length Line Segment in (u,w) Direction into Parametric Domain:**

The length line segment in (u,w) direction is determined by a physical unit, therefore it must be converted into the parametric system (u,w) to represent different surface in the machining.

*** Converting (CC) Point to (CL) Points:**

The (CC) points must be converted to the (CL) points to generate tool path and manufacture part. (CL) are stored as a (CL) data file. After these steps we calculate strains and forces for interpolator Bezier profile die then compare the results with cubic Bezier and compound-CRHS profile die.

4. (CRHS) Dies:-

The principles and techniques used in the design of tools according to the CRHS concept are discussed below. Four basic rates of deformation (S) for CRHS profile dies are adopted in this investigation [13]:

- S= 0.8 for decelerated rate of deformation.
- S = 1 for uniform rate of deformation.
- S = 1.2 for accelerated rate of deformation.
- S= (0.8 + 1 + 1.2) compound rate of deformation.

The concept of the (CRHS) depends on homogenous strain and neglected elastic strain because elastic strain is little mounted

$$z_1 = (\frac{R0}{Rn})^2 \text{..............................}(6)$$

$$z_n = (z_1)^{s^{(n-1)}} * (z_{n-1})$$

$$z_n = (z_1)^{s^1} * z_1$$

$$z_3 = (z_1)^{s^2} * z_2 = (z_1)^{s^2} * (z_1)^{s^1} * z_1 = z_1^{s^2+s+1} \text{..}(19)$$

5. Example of Proposed Algorithm:-

The proposed algorithm must be implemented and tested with another case study (cubic Bezier, interpolate Bezier with component-CRHS profile die) and we calculate the appropriate (CC) points by using proposed algorithm. The software used in this proposed algorithm is:

* MATLAB 7.4.
* SURFCAM.
*ANSYS 9.0.

The proposed algorithms are performed on a personal computer (Core, 1.663 2CPU, 512 Mb of Physical Memory) with Microsoft XP professional. The desired surface was generated by MATLAB (7.4) software.

A. Case Study (Cubic Bezier Profile Die):

Tool path resolution (length line segment) is related to machining tolerance. The machining efficiency of tool paths is directly related to the machining time. Machining time is typically proportional to manufacturing costs. Figure (6) shows control polygon, cubic Bezier profile die, and represents zig-zag tool path. After we explain and visualize of cubic Bezier profile die SURFCAM software will be used to simulate machining of Bezier profile die and tool path achieved by MATLAB (7.4) software. DXF-file is used to convert profile die and tool path from MATLAB (7.4) to SURFCAM. Two milling cutters are used in roughing process; the cutter diameter is (16 mm) to reduce machining time. After this process better cutter radius (cutter radius doesn't exceed the minimum radius of curvature) is used to apply finishing process by using (5mm) cutter diameter. Cibatool is the material selected in this recearch. Figure (7) shows machining extrusion die (Cubic Bezier profile die) by using SURFCAM software.

B. Case Study (Interpolator Cubic Bezier Profile Die):

Figure (8) represents interpolator Bezier (representing extrusion profile die), and represents the tool paths for interpolator Bezier surface with allowed tolerance, height scallop and length line segment. After determining length line segment for interpolator Bezier profile SURFCAM will be used to simulate machining for proposed algorithms. Figure (9) shows machining extrusion die (interpolator Bezier surface) by using SURFCAM. Figure (9A) shows the workpiece (cibatool) before maching (block), Figure (9B) shows the roughing operation for model (using 16mm cutter diameter) and Figure (9C) shows the finishing operation for the designed model (using 5mm cutter diameter).

C. Case Study (Compound-CRHS Profile Die):

After the use of a cubic Bezier surface and Interpolator Bezier surface for extrusion die design, we will now focus on compound (CRHS) dies design. Compound (CRHS) consists of three sections, of which the first section is designed according to the (ACRHS) concept, while the mid of the die is designed according to the (UCRHS) concept. And the end section is designed according to the (DCRHS) concept as shown below such as shown in the figure (10).

6. Extrusion Force:

Strain and force required in each extrusion die will be calculated to determine better extrusion die (strain and force needed to extrude billet). For simulation of the extrusion dies process by using commercial ANASYS 9.0 software we used element SOLID 45, aluminum material properties, model generation within ANASYS (direct generation used in this research), meshing model (mapped), contact surface (target surface TARGE 170 and contact surface CONTA 174 used in this research), pilot point to control the boundary conditions and motion of the entire target surface. Extrusion die processes consist of four parts they are Rim, billet, container and die.

The force required for extrusion depends on the flow stress of the billet container interface, the friction condition at the die material interface, and the other process variables, such as initial billet temperature and speed extrusion. The required extrusion force (F) is given by:

$$F=P*A \qquad \text{……….. (7)}$$

where:

- **P=** extrusion pressure.
- **A=** area of the container bore.

Figure (12) show the force (N) with displacement (mm) for proposed algorithm compared with cubic Bezier and compound-CRHS profile die.

7. Cutting Conditions for Interpolator Extrusion Die:

Our fabricating work is of experimental nature. The material that was used is (cibatool) .The tool used in this work is tip ball mill cutter, tool material is (HSS) with Ø16mm roughing process and Ø5mm to finishing process applied to interpolator Bezier profile die, the machining was achieved on CNC machine (Okuma VH-40-HS dynamic 5-axis CNC machine, with specification of linear motor drives (10.000 m/min), motor spindle 7.5KW 8000 rpm), machine control OSP 7000 M. The machining process is achieved at the Protoshop Oy in Helsinki/Finland as shown in figure (13), and the G-codes applied to the CNC machine were achieved by using SURFCAM. The G-code was designed by 3-axis FANUC 15 MB system, and the machining process was done without a lubricant.

8. Conclusions:

The proposed algorithm for interpolator cubic Bezier surface developed and implemented successfully through the integration of mathematical modeling used for calculations near optimum length line segment for free form surface with given tolerance and height scallop.

The advantages of the proposed system are summarized as follows:

1- The Bezier technique is regular, easy to derive and by changing control points to represent different types of extrusion dies comparable to CRHS profile dies.

2- Interpolator Bezier profile die has a tolerance (0.01mm) in (u) direction, which is less than for the cubic Bezier profile die within (%84.375) and within (87.99) for the compound-CRHS profile die.

3- Interpolator Bezier profile die has a tolerance (0.01mm) in (w) direction, it has a tolerance less than cubic Bezier and compound-CRHS profile die within (%95).

4- Interpolator Bezier profile die has height scallop (0.04mm), it has less height scallop than cubic Bezier and compound-CRHS profile die within (%33).

5- The selection of better cutter radius depends on the minimum radius of curvature (not to exceed the minimum radius of curvature).

6- Zig-zag tool path generation is the better tool path compared to isoparametric and isoscallop tool paths.

7- We employ DXF-files to convert cubic Bezier, interpolator Bezier and compound-CRHS profile die from MATLAB (as CAD tool) to SYRFCAM (as CAM tool) and to obtain the G-code functions and simulate the machining process. The algorithms proposed generate (6569) blocks of G-code, which is has more than for cubic Bezier profile die within (%16) and within (%32.37) for compound-CRHS profile die.

8- A ball end-mill is a better tool in machining profile die compared to a flat and a bullnose end-mill.

9- Time secondary operations (grinding and polishing) are reduced through determining the appropriate line segment.

10- We can reduce the error during machining by using a 5-axis machine.

11- Interpolator Bezier profile die gives better surface quality because it is better than cubic Bezier profile die within (%74) and than compound-CRHS within (%66).

12- Force required to extrude the metal (aluminum) during interpolator Bezier profile die is equal to (100786 N), it has more than cubic Bezier profile die within (%8.5) and less than compound-CRHS within (%3.8).

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[56]- Mukdam Habib S. kena, "Analysis and Application of SubdivisionSurfaces", M.Sc, thesis Department of Production Engineering and Metallurgy, University of Technology, 2007.

- **Table below shows summary of machining parameters for cubic Bezier, interpolator Bezier and compound-CRHS profile dies.**

No.	Profile Die			
	Properties	Bezier Profile Die	Interpolator Bezier Profile Die	Compound-CRHS Profile Die
1	Tolerance in (u)and(w) direction	0.064 & 0.2 mm	0.01 & 0.01 mm	0.0833 & 0.2 mm
2	Height Scallop	0.06 mm	0.04 mm	0.06 mm
3	Minimum Radius of Curvature	1.948 mm	1.948 mm	1.949 mm
4	Radius of Cutter (Roughing)	8 mm	8 mm	8 mm
5	Radius of Cutter (Finishing)	2.5 mm	2.5 mm	2.5 mm
6	Length Line Segment in (w) Dir.	0.8 mm	0.7 mm	0.8 mm
7	Length Line Segment in (u) Dir.	variable	0.3 mm	1 mm
8	(CC) Points	1080	4216	1404
9	Number of Segment For Tool Path	1295	3843	1619
10	Number of Tool Path	108	124	108
11	Length of Tool Path	330 m	377.8 m	333.8 m
12	Size Store in Memory in (Bytes)	1229914 Bytes	148738 Bytes	131406 Bytes
13	Number of G-code	5515 Blocks	6569 Blocks	4442 Blocks
14	Numbers of Cutter Flutes	4	4	4

15	Total Time of Machining (min.)	197.471	226.074	199.745
16	Time 0f finishing machining (min.)	59.301	74.440	65.8836
17	Max. Strain	0.636	0.636	0.636
18	Max. Force to Extrude Billet (N)	92191	100786	104617

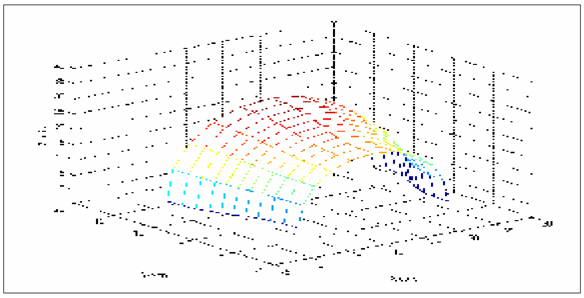


Figure (1) Represents surface cubic Bezier extrusion profile die.

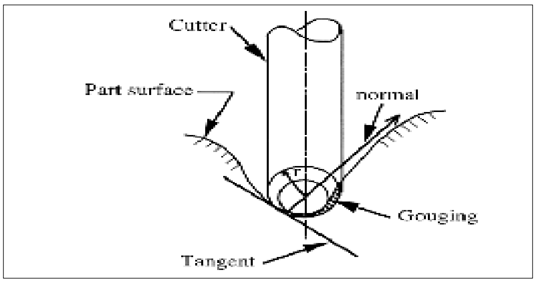
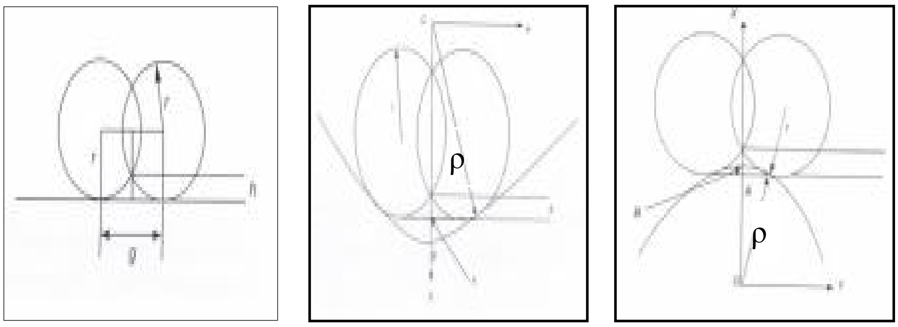


Figure (2) Local gouging on concave region [10].



(A) (B)

(C)

Figure (3) Represent tool position on the: (A) Flat surface. (B) Convex surface. (C) Concave surface [11].

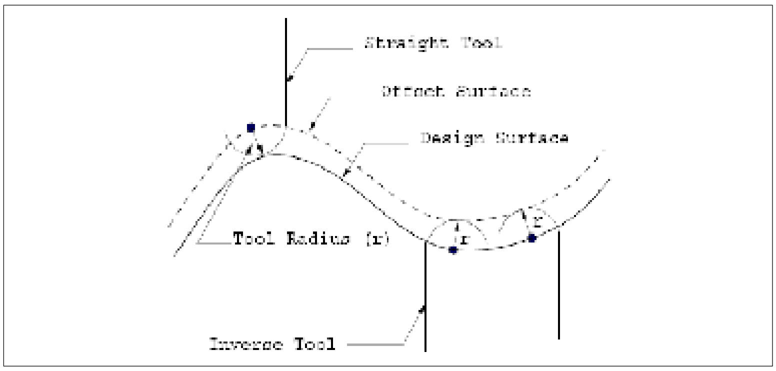


Figure (4) Inverse tool offset algorithm [12].

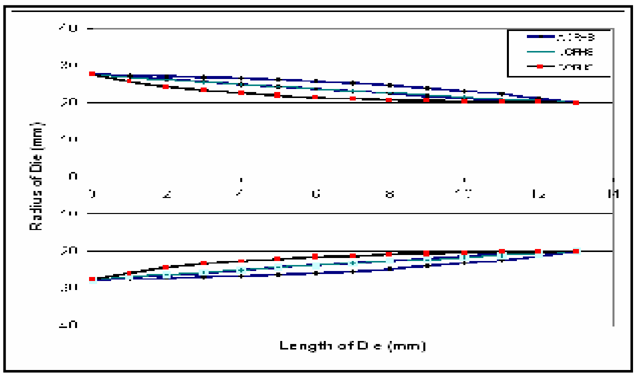
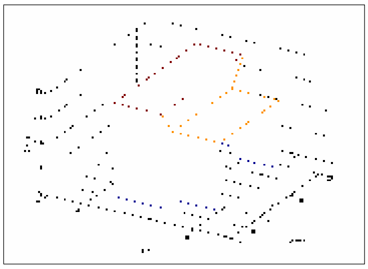
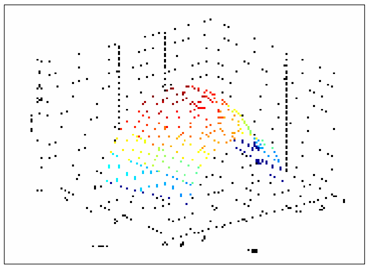


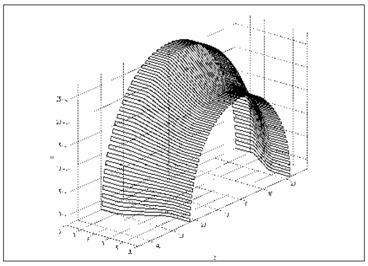
Figure (5) The geometric shape (for the Forward Extrusion) dies profile designed by CRHS.



(A)

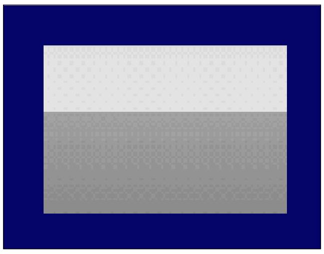


(B)

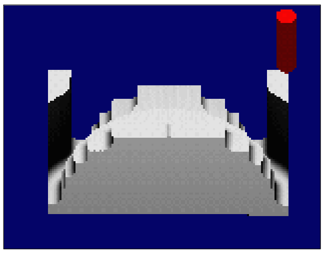


(C)

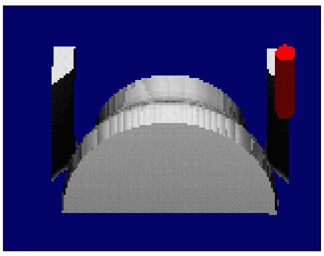
Figure (6) Representation of profile dies by using cubic Bezier surface (By using approximation length segment): (A) Control polygon. (B) Bezier profile dies. (C) Tool path for Bezier profile die.



(A)

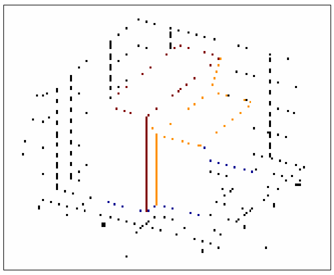


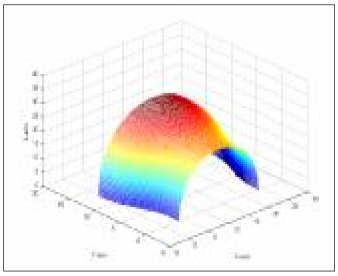
(B)



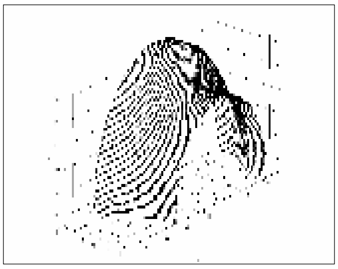
(C)

Figure (7): Using SURFCAM software to simulate the machining of cubic Bezier profile dies. (A) Workpiece (cibatool).(B) Roughing process. (C) Finishing process.



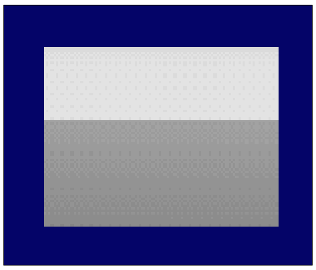


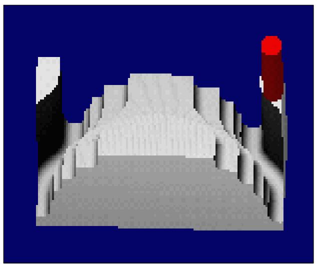
(A) **(B)**



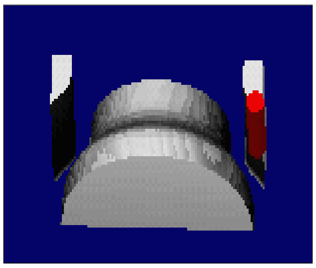
(C)

Figure (8): Represents profile die by using interpolator Bezier surface (By using better length segment). (A)Control polygon. (B) Bezier profile dies. (C) Tool path for Bezier profile die.





(A) **(B)**



(C)

Figure (9): Using SURFCAM software to simulate the machining of interpolator Bezier surface (A) Workpiece (cibatool). (B) Roughing process. (C) Finishing process.

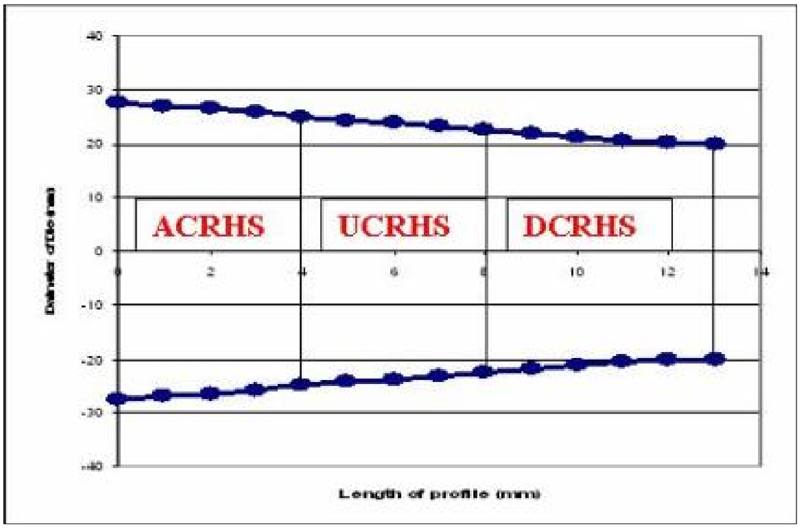
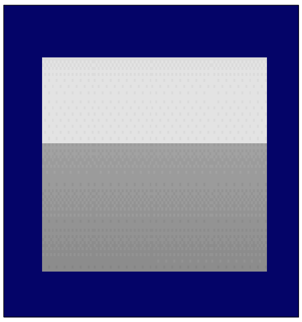
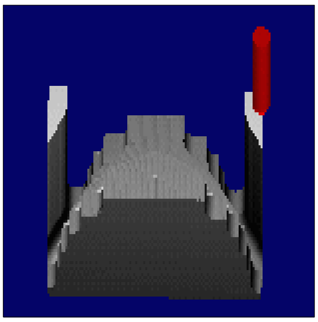
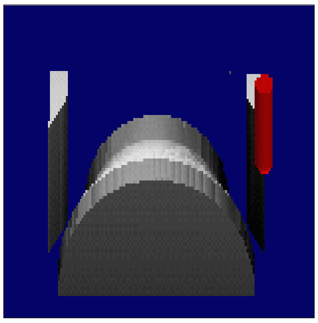


Figure (10): Profile die by using compound-CRHS.





(A)



(B)

(C)

Figure (11): Using SURFCAM program to simulate the machining of compound-CRHS profile die. (A) Workpiece (cibatool). (B) Roughing process. (C) Finishing process.

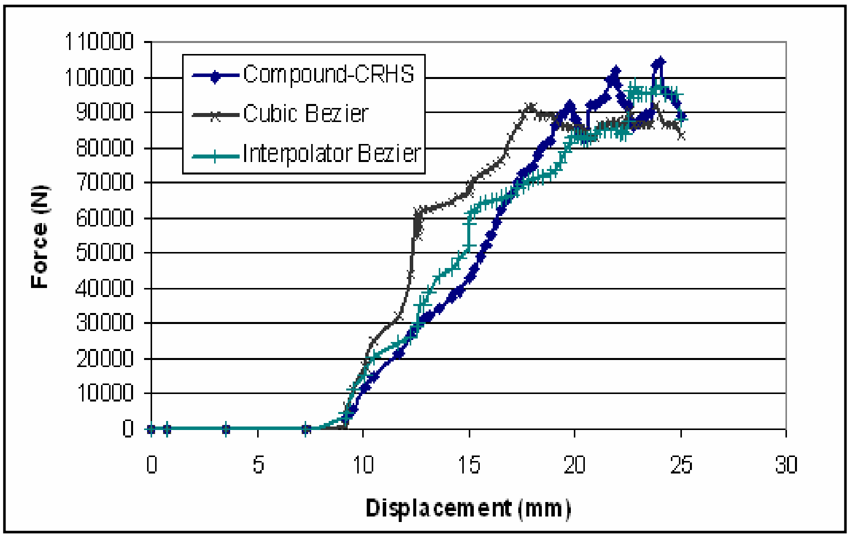


Figure (12): Represents force (N) with displacement (mm) for Cubic Bezier profile die, Interpolator Bezier profile die, Compound-CRHS profile die.

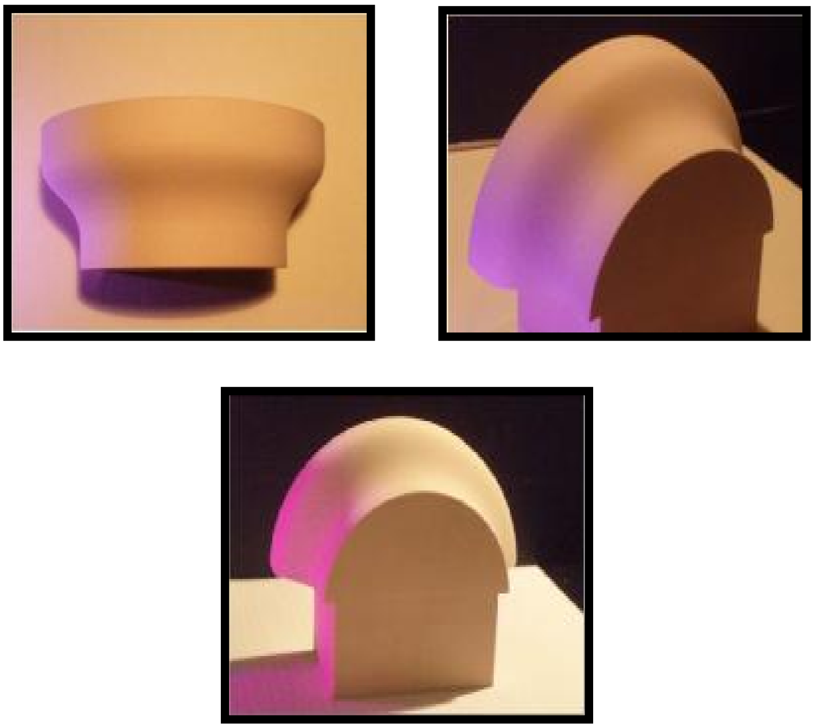


Figure (13): The machined models produced by CNC milling machine (3-axis). Sample designed by interpolator Bezier profile and machined with cutter diameter equal (roughing=16mm and finishing=5mm).