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Error Investigation for Free Form Surfaces in Bezier Techniques

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ABSTRACT

Surface modeling utilizing Bezier technique is one of the more important tool in computer aided geometric design (CAD). The aim of this work is to design and implement multi-patches Bezier free-form surface. The technique has an effective contribution in technology domains and in ships, aircrafts, and cars industry, moreover for its wide utilization in making the molds. This work is includes the synthesis of these patches in a method that is allow the participation of these control point for the merge of the patches, and the confluence of patches at similar degree sides due to degree variation per patch. The model has been implemented to represent the surface. The interior data of the desired surfaces designed by MATLAB software have been transformed to UG-NX8 software to get the machining process simulation and G-code programs for the model, as well as a virtual machining process has been simulated to show the machining pitfalls, using CIMCO edit software. The sample has been machined using 3-axis vertical CNC machine. Finally, the sample has been measured using (CMM inspection) and it's found that the average of error (0.144 mm).

Key wards: Bezier, CNC, CMM

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التحقق من الخطأ لاشكال السطوح الحرة في تقنية بيزر

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الخلاصة

تعد نمذجة السطوح بأستخدام تقنية الـ (Bezier) من اهم الوسائل المتسخدمة في التصميم الهندسي المعان بالحاسوب (CAD). البحث يهدف الى تصميم وتطبيق الرقع المتعددة لأسطح الـ (Bezier) الحرة، لما لهذه التقنية من مساهمة فاعلة في المجالات التكنولوجية كذلك في صناعة الطائرات، السفن والسيارات، علاوة على ذلك استخدامها الواسع في صناعة القوالب.يتضمن هذا العمل عملية ربط وتوليف

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هذه الرقع فيما بينها بطريقة تضمن عملية اشتراك نقاط السيطرة للرقع المدمجة، كذلك التقاء هذه الرقع من المناطق التي تكون فيها الاوزان متماثلة نظراً لاختلاف الاوزان للرقعة الواحدة.تم تطبيق النموذج لتمثيل السطح. ثم تصميم بيانات الاسطح المطلوبة بأستخدام برنامج (MATLAB) والتي تم نقلها بيرنامج (UG-NX8) من اجل محاكاة عملية التشغيل والحصول على برامج الـ (G-code) للنموذج كذلك تم تطبيق عملية تشغيل افتراضي لإظهار المشاكل والعوائق المصاحبة لعملية القطع بأستخدام برنامج (CIMCO edit) ومن ثم تشغيلها باستخدام ماكنة التحكم الرقمي CNC ثلاثية الابعاد. أخيراً تم فحص النموذج المصنع وتقييمه من خلال عملية القياس بأستخدام جهاز (CMM inspection) وقد تبين ان معدل خطأ هو(0.144 ملم).

1. INTRODUCTION

The impact of globalizations on business had forced more industry to become more innovative and implements newer strategies to retain markets leaderships and growth with the desire profitability. Knowledge based engineering are a complex concept that increase the productivity. Computer aided design (CAD) are one of the main roots and play an important role in knowledge based engineering. In a design processes, CAD is considered as the basis of the generative design with many expectation for hands-off performance along with the knowledge based engineering which would result in a limited human involvement in the design process, **Jaby, et al., 2008.** Geometric modelings are the processes in which geometric models are created to represent the sizes and shapes of a component, **Kumar, and jha, 2005**. It is deal with mathematical representation of curve, surface, and solid necessary in the definition of complexes physicals or engineering object. The associated fields of computational geometry are concerned with developments, analysis, and computers implementations of algorithms encounter in geometric modeling.

Park, et al., 2000, presented an approximate methods for make a set of curve of various types compatible. Their methods are based on refitting inputs curves simultaneously on a common knot vector while making the refitted curve had parametrically regular transition across curve. Their methods could be utilized in several construction task include surfaces skinning and surfaces creation from a mesh of curve. It is play an important role in improving the quality of surface and realizing efficient reduction of their control points. **Jiang, and Lancheng, 2006,** provided a new algorithm for a surfaces fitting to scattered point. The algorithm could be extended to Bezier or B-spline surface fitting to measured point. Let ordered measured points be control points to construct NURBS surfaces, then based on the constructed surface, it can obtain the final models by modification of this surface. **Choi, 2004,** developed algorithm that are generate tool path for free-form surface based on the accuracy of a desired manufacturing parts. Manufacturing parts are represented by mathematical curve and surface. Using the mathematical represent of the manufacturing parts, he generated reliable and near optimum tool paths as well as cutter locations (CL) data file for post process. His algorithms include two components. First, it's the forward step function which is determine the maximum distances, know forward step, between two cutter contacts (CC) point with a give tolerance. These functions are independent of the surfaces type and are applicable to all continuous parametric surfaces that are twice differentiable.

2. PARAMETRIC SURFACE REPRESENTATION (BEZIER SURFACE)

There are many ways to represent a polynomial surface but Bezier techniques are one of the most famous tool in Computer Aided Geometric Design. Other technique define a surface that only pass near or approximate the given point. Interpolation technique like the Hermite has certain disadvantage when incorporated into interactive geometric modeling systems. It usually does not

give the user an intuitive sense of how to change or control the shape of a surface, **Andres, 2001**. Point on a Bezier patch is given by the follow matrix form, which are a simple of the general equation for all point on Bezier curve **safaa, 2015.**

$$P\ (u,\ w) = U\ M_B\ B\ M_B^T\ W^T \tag{1}$$

Where

$U = [u^3\ u^2\ u\ 1]$

$W = [w^3\ w^2\ w\ 1]$ where $0 \leq u,\ w \leq 1$ **safaa, 2015**

B = set of control points.

M_B: is the basis function of bicubic Bezier matrix **safaa, 2015**:

$$M_B = \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

It is clear from Eq. (1) that the 3D space surface can be represented by two independent variables (u, w), **Jawad, 2009.**

3. DESIGN AND IMPLEMENTATION OF EXPERIMENTAL WORK:
CAD/CAM modules are embed in the computers which are responsible for surfaces construction and reconstruction, generate the offset models, process the offset surfaces to generate the require tool paths and post process the tool paths to generating the required NC- coding. These tasks had been implemented on a personal computers using three well known software namely are MATLAB, UG-NX8 and CIMCO edit software.

3.1 MATLAB software:
MATLAB- which is the acronyms a numerical computing environments developed by Math Works. MATLAB is allowing matrix manipulations, plotting of functions data, and implementation of algorithms.
Using the programming language in this program, surfaces are designed of different types of Bezier surface by building algorithms including the basis functions matrices for each type. There is no any embedded function in this software dedicated for the construction of the Bezier surfaces. Accordingly, special sub-routines have been implemented to construct any Bezier or multi patches Bezier surfaces.

3.2 UG-NX8 software:
   UG-NX, also known as Unigraphics, is packages CAD/CAM software develops by PLM Siemens Software PLM. It is providing integrated design managements and used, among other task, for:

- Engineering analysis.
- Design
- Machining the finished.

UG-NX is provide fully integrate tool for simulations and validations of the entire cutting processes, as well as it is allow immediate replayed of the compute tool paths with a range of displays option, is include dynamic materials removal from the stock model.

3.3 Transferring CAD data to CAM module:

The CAD modules, where profile of the curves generating the surfaces is modeled-using MATLAB and then transferred to the UGS-NX8-through TXT data-exchanges file to view the required shape. After the construction of the B-spline surface converted to a series of curves using Iso-parametric conversion scheme is shown in **Fig. 1**.

Each matrix is saved as (txt) file and exported to the UG-NX8 program. Each imported curve has been opened individually in the UG-NX8 program using the following instructions see **Fig. 2**.

Insert curve $\longrightarrow$ *Spline curve* $\longrightarrow$ *Through points* $\longrightarrow$ *Points from file*

After importing each curve as shown in **Fig. 3**, a skinning procedure is to be followed converting these curves to a surface using the following instructions see **Fig. 4**:

Insert Surface $\longrightarrow$ *Mesh surface* $\longrightarrow$ *Through curves*

3.4 Tool path description:

There are several strategies of distributing the tool paths (Spiral curves, Zig-zag or raster curves, space filling curves, contour curves, sequential generated curves) is domain of the design parts. The goals of tool paths distribution all strategy is to span the entire design parts **Jawad, 2009**.

The more commonly was use tool paths distribution strategies are the Spiral curves strategy, to the simple algorithms involve in calculate the path element. **Fig. 5** shows the above strategy of tool path distribution on a unit square by means of spanning elements **Raheem, 2011**.

4. HARDWARE EXPERIMENTAL EQUIPMENT

The Hardware CAD/CAM consists of the personal computer which is connected to the CNC machine. In fact, this type of CAM system is called off- line programming system. Undoubtedly, this type of programming system is very effective as it facilitates the manufacturing system where the NC- code can be directly transferred to the machine tool.

4.1 CNC milling machine

Milling processes have been performed on a vertical 3-axes CNC Milling machine to achieve the milling process for the models that have been designed as shown **Fig. 6**.

The machining process has been conducted on models from Al-Alloy material.

4.2 Cutting tools

Two type of cutting tool are used in this research:
  1- End milling flat- tool with diameter Ø 8 mm material is high speed steel HSS with four flute cutter had been use for roughing process.

2- End milling ball- tool with diameter Ø 8 mm material is HSS for finishing operation. **Fig. 7** shows the two types of cutting tools. The cutting operations are conducted on wood models in different dimensions to meet each part with its intended design.

4.3 Material used:

In all experiments carried out in this work, blocks of Aluminum casting alloys were used as work-pieces. The chemical compositions of these alloys are analyzed by emission spectrometer, OES type German origin model 2009, and the chemical compositions are listed in **Table 1.**

4.4 CMM inspection:

The CMM is a portable coordinate's measured machine that is allow manufacturers easy verification of product quality by using performing three dimension inspections, tool certifications, dimensional analysis, CAD comparison and reverse engineering. This portable consists of one degree of freedom which facilitate the measurement process. **Fig. 8** shows the portable measuring.

At the end of arm, there is a spherical probe used for measuring data of the surface. The sphere geometry of the probe allows suitable movement across the sculpture surface, as well as the normal vector of the probe will be perpendicular on the entire contact points.

5. RESULTS

5.1 Measurement of lofted surface

Fig. 9 shows the comparison of CAD models and real part of the face surface, **Table 2** shows sample of measuring data for the part.

In order to get more accurate measurement, a machining scheme between the CAD model and the real part using CMM inspection. This process required machining the planes which has been considered as the origin point, where one of the basic steps of measuring process is defining the planes of the reference point, by passing the probe on each plane. Number of points is taken to define that plane. Therefore machining these planes will help to set the points correctly leading to a successful match between the CAD model and the real part. **Fig. 10** shows the machined planes of the reference point.

6. DISCUSSION

Within the context of multi-patches Bezier surfaces construction and manufacturing the following attributes can be discussed. The patches of Bezier surface have a similar weight, therefore the process of merging these patches In order to build the entire surface associated with the problem of synthesis of these patches with each other. But at the end of the patch, the control points develop beyond the patch itself. In designing the patches of the Bezier surface using MATLAB software, the problem of blending these patches become clear, whereas for the first patch (as mentioned before), the vertices of control points coincide with patch itself at the start of the patch. Accordingly the second patch shares the last control points of the first patch and the control points at the end of this patch coincide with patch itself, but the control points dispatch at the start of the patch. Finally it shows the average error is 0.144 mm, standard deviation 0.0525 mm and maximum error 0.185 mm for the cross-sectional surface.

7. CONCLUSIONS

1- The tools discussed in this paper benefit the designer by providing more information and insight into the characteristic differences between two closely matched surfaces.

2- Blending method for more than one patch requires the confluence of these patches at similar degree sides due to degree variation per patch, thus the degree in the external sides is normally higher than middle of the surface.

3- Using ball-end tool with (8 mm) in diameter with constant value of side step for generating tool paths, will give lower value of the scallop heights which leads to less surface error in the machined surface in case the diameter of the tool doesn't exceed the lowest value of concavity existing in the surface to prevent generating gauging areas.

4- Implementing flow part strategy for generating the required tool path for the surfaces will effect on machining time, where it takes shorter time than using zig-zag tool path.

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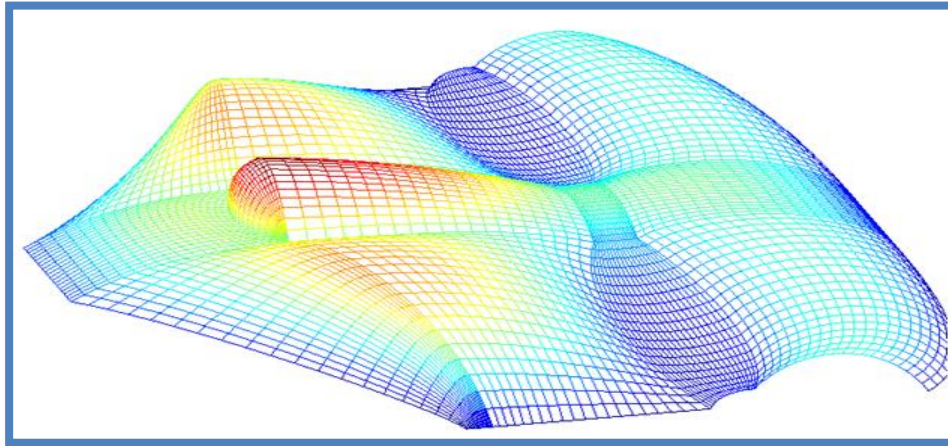

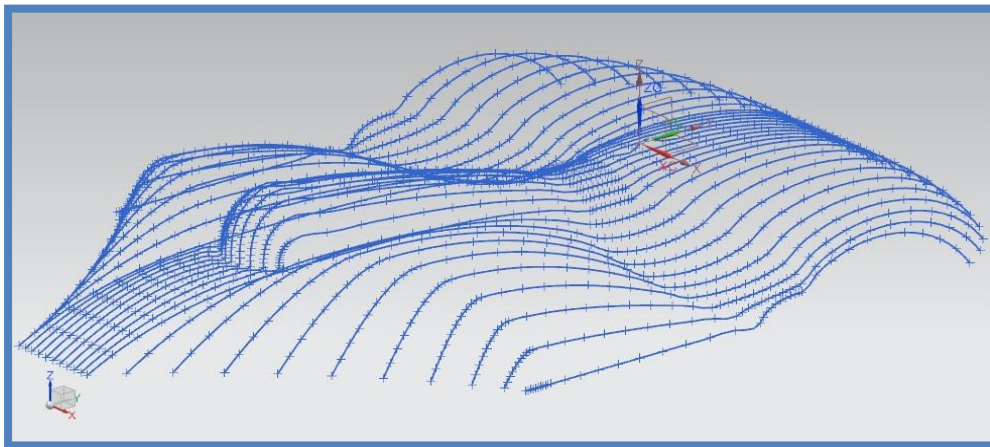**Figure 1.** Surface digitization scheme surface in MATLAB environment.
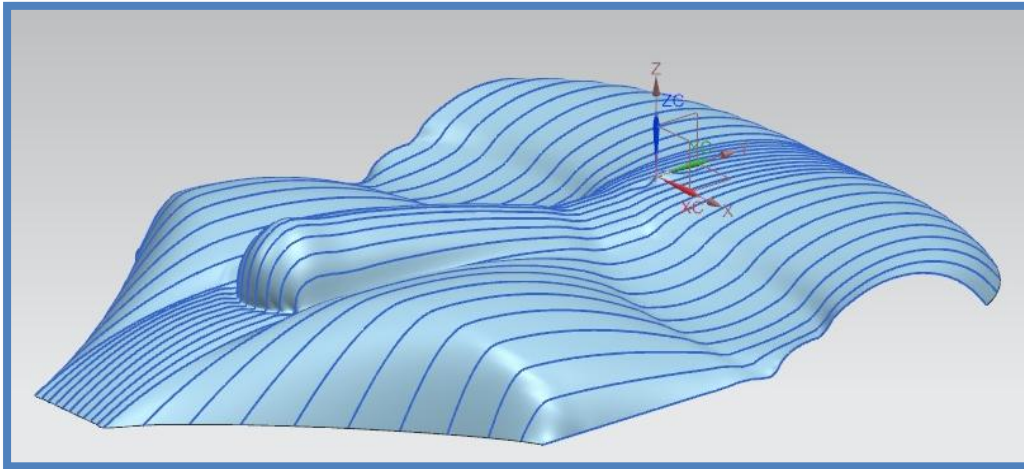

Figure 2. Importing the curves data to UG-NX8.

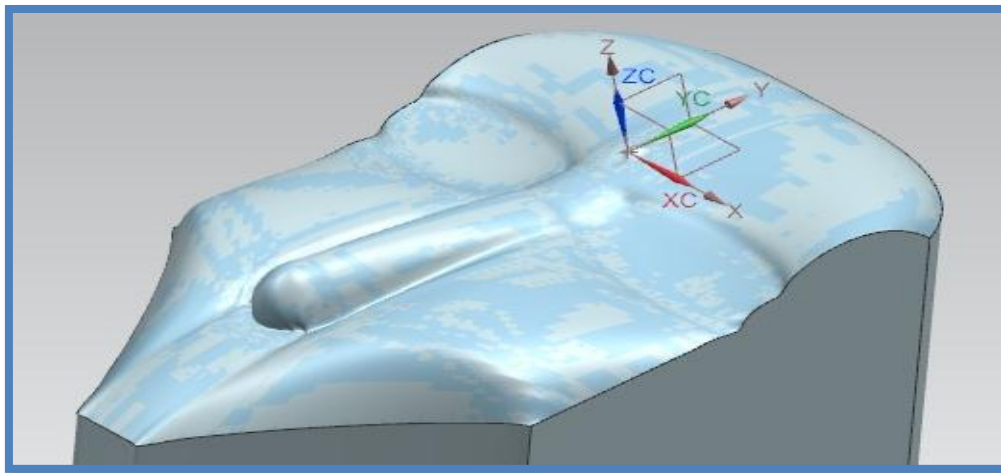**Figure 3.** Imported surface which is ready to manufacturing process.

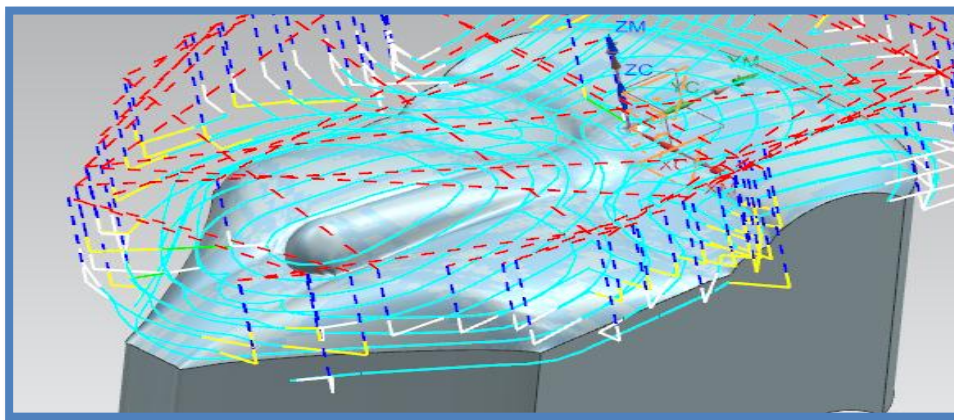**Figure 4.** Building the surface through extrude process.

Figure 5. Strategies of tool path for model.
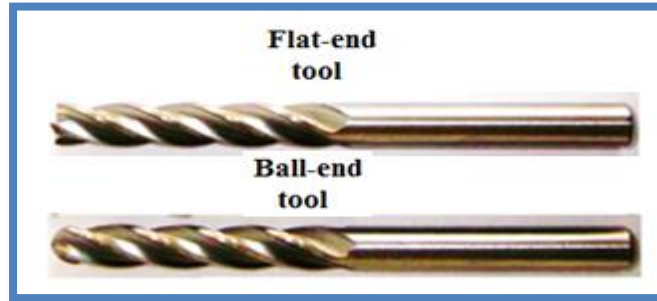
Figure 6. CNC C-TEK 3-axes Milling Machine.

Figure 7. Cutting tools used for machining.

Figure 8. Portable (CMM)

(a)   (b)

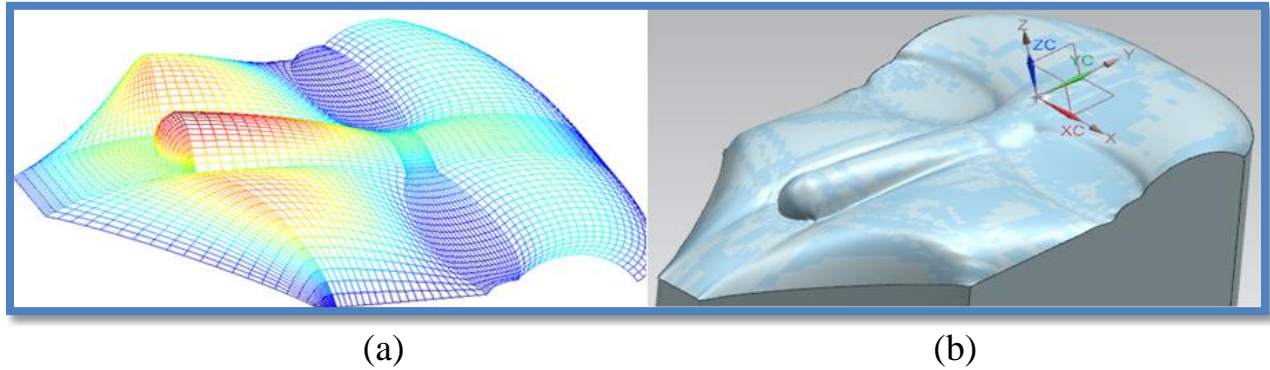**Figure 9.** Comparing between CAD and CAM models of the experimental work, (a) Point from CAD model in (MATLAB software), (b) Points from real part.
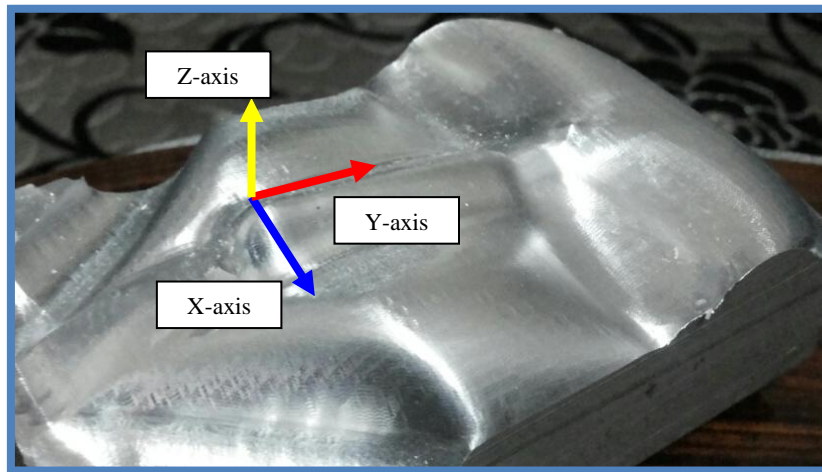

Figure 10. The machined planes of the reference point.

Table 1. Chemical composition of the aluminum blocks (%of mass).

Element	Al	Si	Fe	Cu	Mn	Mg	Ti	V	Zn	Ni	Ca
%of mass	98.22	0.49	0.63	0.041	0.35	0.18	0.012	0.005	0.098	0.006	0.0003

Table 2. Sample of measuring data for the face part.

No.	CAD-POINTS	EXPERMENTAL POINTS	DEVATION FOR Z-AXIS
1	0	0	0
2	0	0.002	-0.00002
3	0.0651	0.0666	-1.5E-05
4	0.1234	0.135	-0.00012
5	0.1748	0.163	0.000118
6	0.2194	0.229	-9.6E-05
7	0.2571	0.254	3.1E-05
8	0.2879	0.286	1.9E-05
9	0.3119	0.42	-0.00108
10	0.3291	0.333	-3.9E-05
11	-3	-3.027	0.02701
12	-3.2855	-3.333	0.000475
13	-3.544	-3.652	0.00108
14	-3.7785	-3.885	0.001065
15	-3.992	-3.528	-0.00464
16	-4.1875	-4.199	0.000115
17	-4.368	-4.365	-3E-05
18	-4.5365	-4.462	-0.00075
19	-4.696	-4.685	-0.00011
20	-4.8495	-4.854	4.5E-05
21	-5	-4.999	-1E-05
22	-2.573	-2.478	-0.00095
23	-2.81757	-2.965	0.001474
24	-3.0377	-3.005	-0.00033
25	-3.23468	-3.334	0.000993

ABBREVIATIONS:

CAD/CAM: Computer Aided Design and Computer Aided Manufacturing.
NC: Numerical Control.
CNC: Computer Numerical Control.
CMM: Coordinate Measuring Machine.
CC: Cutter Contact.
CL: Cutter Location.