CONTROLLING THE WORKING AREA IN FLEXIBLE SHEET FORMING DIES

Wissam K. Hamdan
Production Engineering and Metallurgy Department / University of Technology

Abstract

Design and fabrication of a die, in the case of sheet metal forming, is an experimentally iterative process. So, the hard sheet metal forming dies are generally dispensed with flexible dies. This paper presents a simple approach to control the motion of the die pins and estimation of blank working area. The proposed method is directed to control any free form shapes such as Bezier surfaces. The results of the study are simulated in suitable programming code (MATLAB and IronCAD) to show the effect of proposed method.

Keywords; Flexible die, Rapid prototype, Digitized die, Working area.

الخلاصة:

من الطرق التي تحتاج إلى عمليات تكرار متعددة هي عملية تصميم أو بناء قوالب التشكيل وخصوصا قوالب تشكيل الصفائح المعدنية. ولهذا فان القوالب الصلدة تم استبدالها بقوالب مرنة لتقليل الكلف. يهدف البحث إلى عرض طريقة مبسطة للسيطرة على حركة المسامير المكونة لهذه القوالب وتخمين المساحة العاملة للغفل. تختص الدراسة بنمذجة الأسطح الحرة مثل سطح بيزير. تمت محاكاة نتائج الطريقة المقترحة باستعمال بعض البرامج الحاسوبية المعروفة مثل MATLAB و IronCAD لعرض نتائج البحث وبيان أهمية الطريقة المعتمدة.

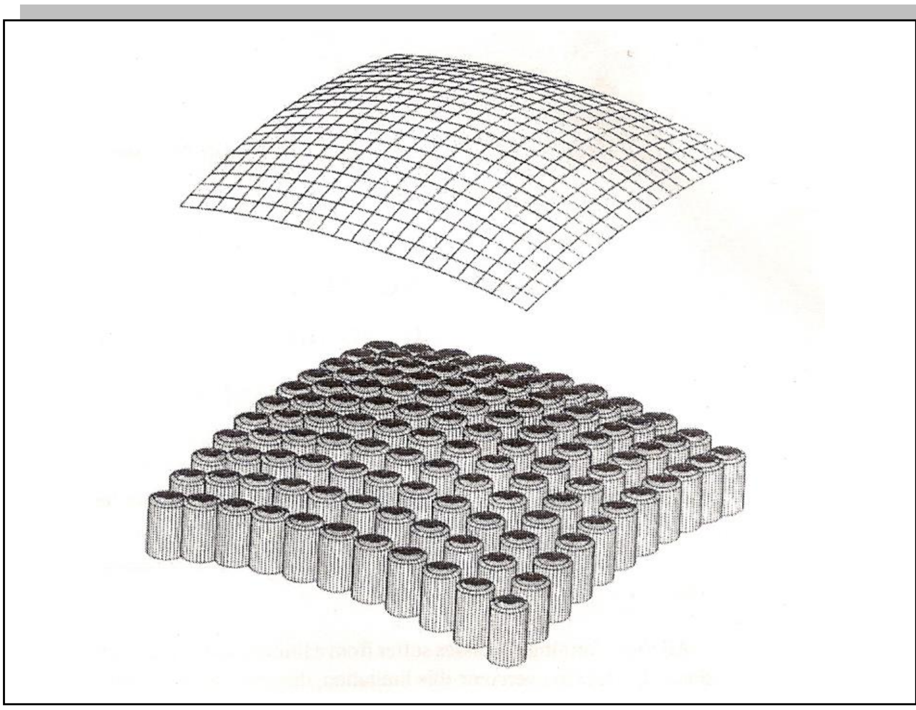

Figure 1. Flexible die device of individually positionable discrete pins (Rao et al. 2004).

Ming-Zhe Li et al.2007 proposed an iterative scheme assuming that the straines in the final shape are evenly distributed. From the geometry of the initial blank and the desired part, intermediate shapes at a series of specific time are interpolated. M. Z. Li et al.2002 start to use flexible die as a tool for designing and fabrication of three dimensinal sheet forming.

The actuation of the flexible die pins can be computer controlled to allow quick and accurate surface construction definition. Small stepping motors can be interfaced with threaded pins, allowing individual pin displacement control without position feedback. The threaded pins should be self – locking against the forming pressure. A variety of free form surfaces can be defined by using the well known Bezier surface to control the height of the pins.

The parametric cubic Bezier surface **S**(u,v) is described in matrix form as follows Ding Qiulin and Davies 1987:

$$\mathbf{S}(u,v)=U\,M\,\mathbf{B}\,M^t\,V^t \qquad (1)$$

where $U=[1\ u\ u^2\ u^3]$; $V = [1\ v\ v^2\ v^3]$

$$M=\begin{pmatrix} 1 & 0 & 0 & 0 \\ -3 & 3 & 0 & 0 \\ 3 & -6 & 3 & 0 \\ -1 & 3 & -3 & 1 \end{pmatrix} \quad ; \quad \mathbf{B}=\begin{pmatrix} P_{00} & P_{01} & P_{02} & P_{03} \\ P_{10} & P_{11} & P_{12} & P_{13} \\ P_{20} & P_{21} & P_{22} & P_{23} \\ P_{30} & P_{31} & P_{32} & P_{33} \end{pmatrix}$$

M is the coefficient matrix and B is the matrix of sixteen control points of the Bezier characteristics polygon. The shape of the characteristic polygon reflects the shape of the intended surface; therefore the designer can produces different free form shapes by changing the position of any control point. **Fig. 2** shows the effect of changing the position of any control; point on the shape of the surface.

The independent variables u, v in the U,V vectors of **eq.1** are of the following range $0 \le u \le 1$, $0 \le v \le 1$,with a specific increment of u and v.

Substituted a successive increments of u and v in **eq.1** will give the coordinates of the surface and the corresponding height of the flexible die pins.

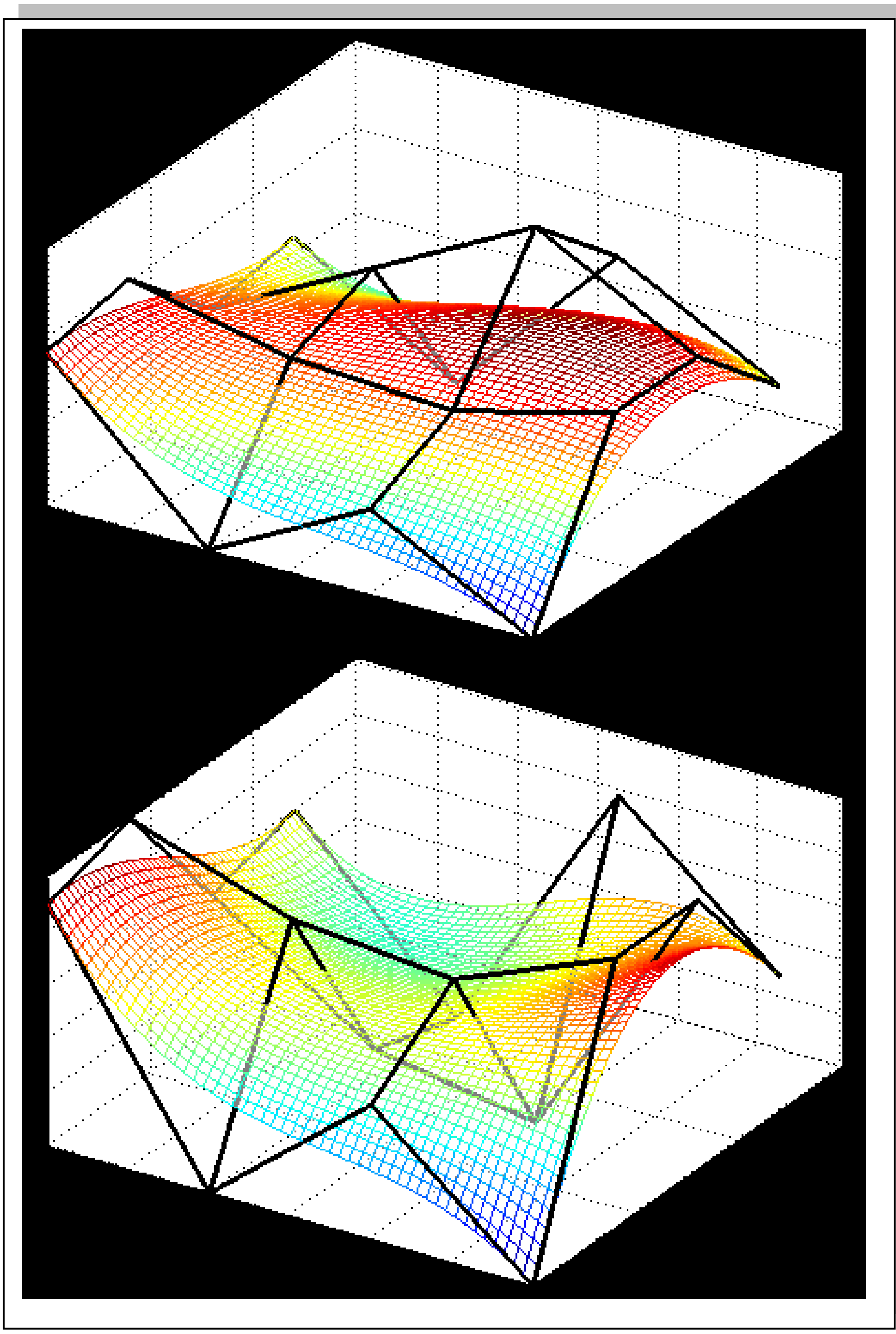

Figure 2 The shape of the Bezier curve can be changed by repositioning of the control point

The advantage of such a tooling system is that it is adjustable. A variety of surfaces shapes can be realized by properly adjusting the height of surface tool elements. Moreover, automated nature of the process may relegate the need of some of the experts labors involved in tool design and development Rao and sonjay 2002.

2. ESTIMATION OF BLANK WORKING AREA AND INCREMENTAL VALUES OF Δu AND Δv

The spacing between pins in x direction is assumed to be equal to the spacing in y direction (see **Fig**.3). But the working area of the blank (solid lines in **Fig**.4) doesn't necessarily to cover all the pins of the die. In view of this the pins can be classified into working pins and idler pins. The number of working pins P_w (covered by the blank) and idler pins P_i (out of the boundary of the blank) depends on the size of the blank . Consequently, the working area of the blank should be determined from the final shape or the desired surface shape in order to determine the incremental values of Δu and Δv.

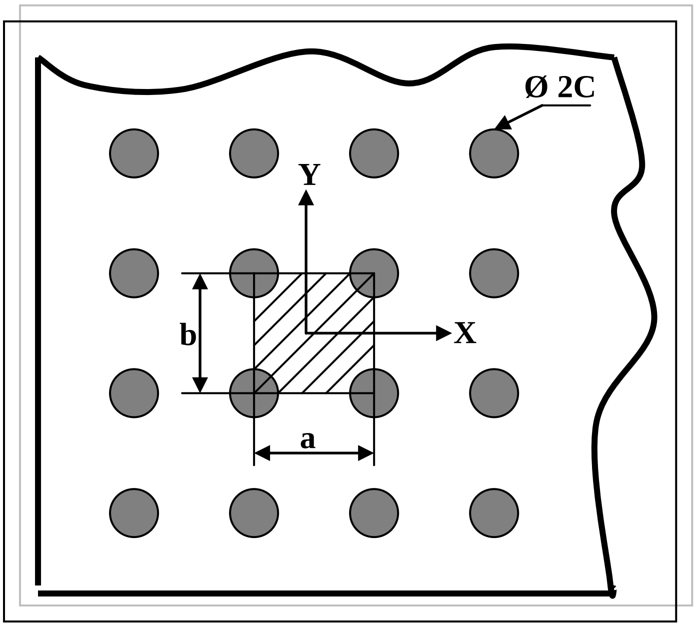

Figure 3 continuous plate supported by rows of columns (H.S. Kleespies and R.H. Crawford 1998)

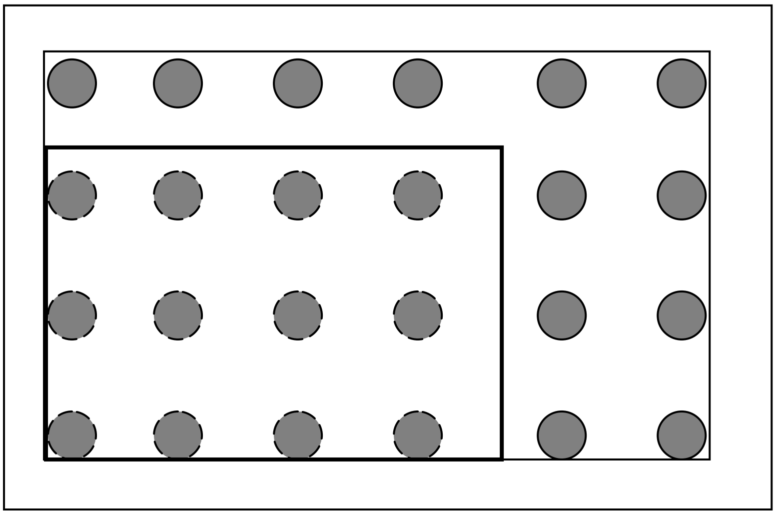

Figure 4 Top view of flexible die showing the working area of blank, working pins(dashed pins) and idler pins(solid pins).

For simplicity, it is convenient to assume that each opposite boundary curves have the same length (regular surface). The working area of the blank is thus (see **Fig** 4):

$$A_w = L_u \times L_v \quad (2)$$

The number of working pins along x–direction and y-direction respectively is:

$$NP_x = \frac{Lu}{a} + 1 \quad (3)$$

$$NP_y = \frac{Lw}{a} + 1 \quad (4)$$

Where a and b is the pin spacing, the incremental values of Δu and Δv is:

$$\Delta u = \frac{1}{NPx - 1} \quad (5)$$

$$\Delta v = \frac{1}{NPy - 1} \quad (6)$$

3. RESULTS AND DISCUSSION

Due to the limited site of stepping motors, the minimum achievable pin spacing is (1 in = 25.4mm) H.S. Kleespies and R.H. Crawford 1998 . In this work , the pin spacing is taken to be (1 in) the flexible die is constructed using 81 pin distributed as a 9×9 pin matrix in the x – y plane.
The pin diameter (2c=20mm) with a circular flat tip. Accordingly the dimensions of the fluid chamber are thus (223×223mm).
The required free form surface prototype is assumed to be of a compound curvature form (convex–concave) surface with the following proposed control points :

$$\mathbf{B} = \begin{pmatrix} (0,0,0) & (0,40,50) & (0,80,0) & (0,120,90) \\ (40,0,100) & (40,40,0) & (40,80,80) & (40,120,0) \\ (80,0,0) & (80,40,0) & (80,80,10) & (80,120,50) \\ (120,0,50) & (120,40,100) & (120,80,0) & (120,120,60) \end{pmatrix}$$

Substituting these control points in **eq**.1 results in the plot of the required prototype surface (see **Fig.**5).

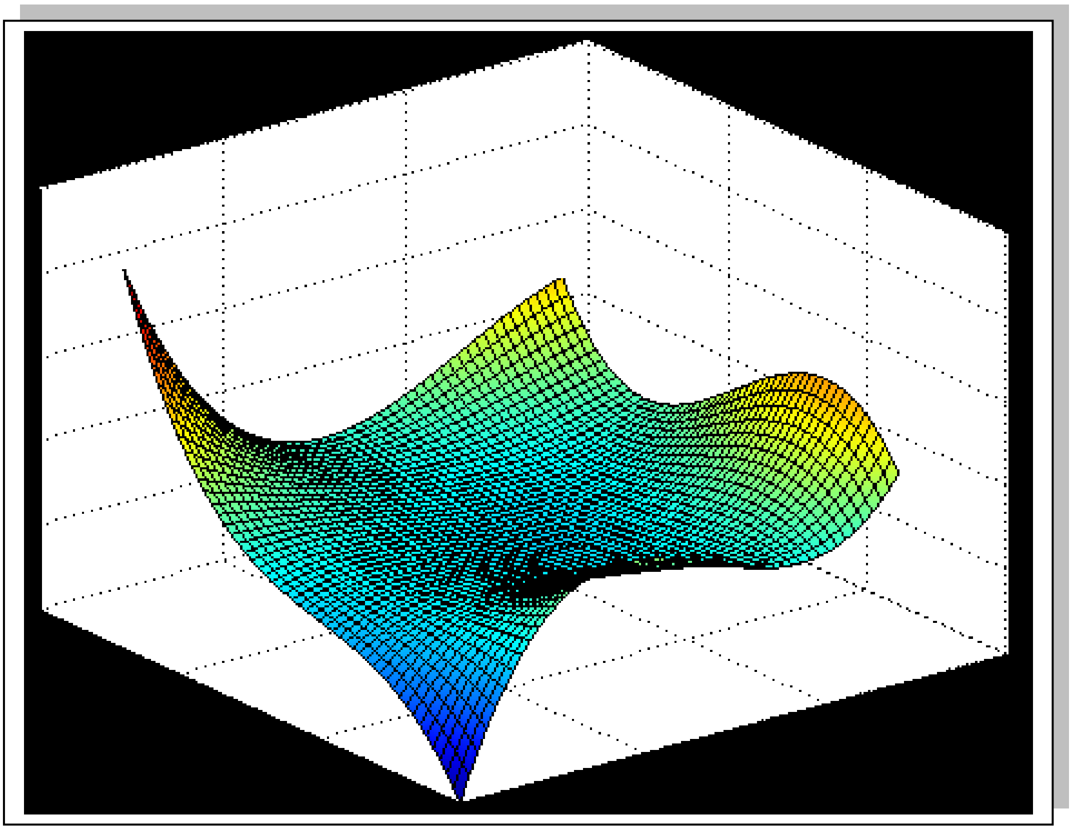

Figure 5 The proposed Bezier surface of the control points given by B matrix

From the above control points:

L_u = 120 mm
L_v = 120 mm

Eq.2 gives:

$A_w = 120 \times 120\ mm^2 < 223 \times 223\ mm^2$

Thus , the prototype surface can be achieved within this flexible die. The number of worked and idle pins is as follows :

$$NPx = \frac{Lu}{a} + 1 = \frac{120}{25} + 1 = 6 \text{ pins}$$

$$NPy = \frac{Lw}{a} + 1 = \frac{120}{25} + 1 = 6 \text{ pins}$$

$$\therefore\ \Delta u = \Delta v = \frac{1}{6-1} = 0.2$$

$0 \le \Delta u \le 1$ and $0 \le \Delta v \le 1$ (**eq**.l)

∴ The required vectors are:

$\Delta u = [0 \quad 0.2 \quad o.4 \quad 0.6 \quad 0.8 \quad 1]$
$\Delta v = [0 \quad 0.2 \quad o.4 \quad 0.6 \quad 0.8 \quad 1]$

Hence the number of working pins is only 36 from the whole 81 pins of the flexible die. Substituting the tow above vectors in equation1 gives the height (Z value) of each pin in the following theoretical Z – matrix:

$$Z_{th} = \begin{pmatrix} 0.0000 & 38.8000 & 46.4000 & 39.6000 & 35.2000 & 50.0000 \\ 19.9200 & 33.4554 & 34.2573 & 32.7475 & 39.3478 & 64.4800 \\ 27.3600 & 32.1965 & 30.6470 & 29.7274 & 36.4531 & 57.8400 \\ 33.8400 & 34.8659 & 32.2362 & 30.2054 & 33.0285 & 44.9600 \\ 50.8800 & 41.3062 & 35.6915 & 33.8477 & 35.5866 & 40.7200 \\ 90.0000 & 51.3600 & 37.6800 & 40.3200 & 50.6400 & 60.0000 \end{pmatrix}$$

These values are used to control each stepping motor corresponding to its Z value. Assuming that the pitch of pin thread (P = 1.6 mm) , the Z-matrix can be directly converted to the N-matrix which represent the number of revolutions to each stepping motor ; i-e :

$$N = \frac{Z_{th}}{P} \qquad (7.a)$$

Or

$$N = \begin{pmatrix} 0.000 & 24.2000 & 37.6000 & 41.4000 & 36.8000 & 25.0000 \\ 9.9600 & 28.0480 & 40.4336 & 46.0032 & 43.6432 & 32.2400 \\ 13.6800 & 28.9392 & 39.8784 & 44.7120 & 41.6544 & 28.9200 \\ 16.9200 & 29.9744 & 38.1904 & 40.4352 & 35.5760 & 22.4800 \\ 25.4400 & 34.2544 & 37.6256 & 36.0816 & 30.1504 & 20.3600 \\ 45.0000 & 44.8800 & 40.4400 & 34.5600 & 30.1200 & 30.0000 \end{pmatrix}$$

Since the fraction of revolution is neglected or can't be achieved in open loop systems , the N-matrix is modified to give :

$$N_{mod} = \begin{pmatrix} 0.0000 & 24.0000 & 37.0000 & 41.0000 & 36.0000 & 25.0000 \\ 9.0000 & 28.0000 & 40.0000 & 46.0000 & 43.0000 & 32.0000 \\ 13.0000 & 28.0000 & 39.0000 & 44.0000 & 41.0000 & 28.0000 \\ 16.0000 & 29.0000 & 38.0000 & 40.0000 & 35.0000 & 22.0000 \\ 25.0000 & 34.0000 & 37.0000 & 36.0000 & 30.0000 & 20.0000 \\ 45.0000 & 44.0000 & 40.0000 & 34.0000 & 30.0000 & 30.0000 \end{pmatrix}$$

Fig. 6 shows the actuated pins (dark pins) to from the required configuration of the flexible die .

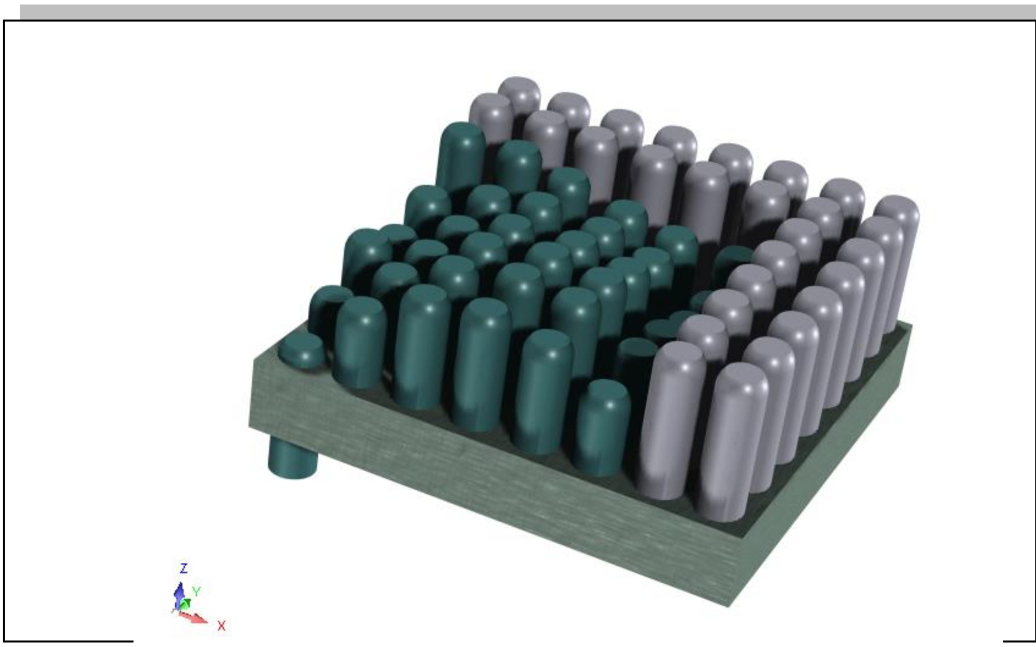

Figure6 The actuated pins of flexible surface tooling for the proposed surface

Similarly, the actual height of each pin can be calculated by using **eq.** 7;

$$Z_{act}=N_{mod} * P \tag{7.b}$$

$$Z_{act}=\begin{pmatrix} 0.0000 & 38.4000 & 59.2000 & 65.6000 & 57.6000 & 40.0000 \\ 14.4000 & 44.8000 & 64.0000 & 73.6000 & 68.8000 & 51.2000 \\ 20.8000 & 44.8000 & 62.4000 & 70.4000 & 65.6000 & 44.8000 \\ 25.6000 & 46.4000 & 60.8000 & 64.0000 & 56.0000 & 35.2000 \\ 40.0000 & 54.4000 & 59.2000 & 57.6000 & 48.0000 & 32.0000 \\ 72.0000 & 70.4000 & 64.0000 & 54.4000 & 48.0000 & 48.0000 \end{pmatrix}$$

To show the effectiveness of the proposed method the produced error between the theoretical and actual surface can be calculated as follows:

$$E = \left| 1- Z_{the}/Z_{act} \right| \tag{8}$$

$$E=\begin{pmatrix} 0.0000 & 0.0104 & 0.2162 & 0.3963 & 0.3889 & 0.2500 \\ 0.3833 & 0.2532 & 0.4647 & 0.5551 & 0.4281 & 0.2594 \\ 0.3154 & 0.2813 & 0.5089 & 0.5777 & 0.4443 & 0.2911 \\ 0.3219 & 0.2486 & 0.4698 & 0.5280 & 0.4102 & 0.2773 \\ 0.2720 & 0.2407 & 0.3971 & 0.4124 & 0.2586 & 0.2725 \\ 0.2500 & 0.2705 & 0.4113 & 0.2588 & 0.0550 & 0.2500 \end{pmatrix}$$

Fig. 7 shows the error surface distribution, the maximum error is found to be 0.5777. Within these contexts, the flexible dies proved to be an effective tool to design and fabrication any complex shape. Meanwhile, the method is needed to suitable way to control the position of the pins. The methods presented here to control the motion and to estimate the blank working area are efficient and accurate in view of the obtained results.

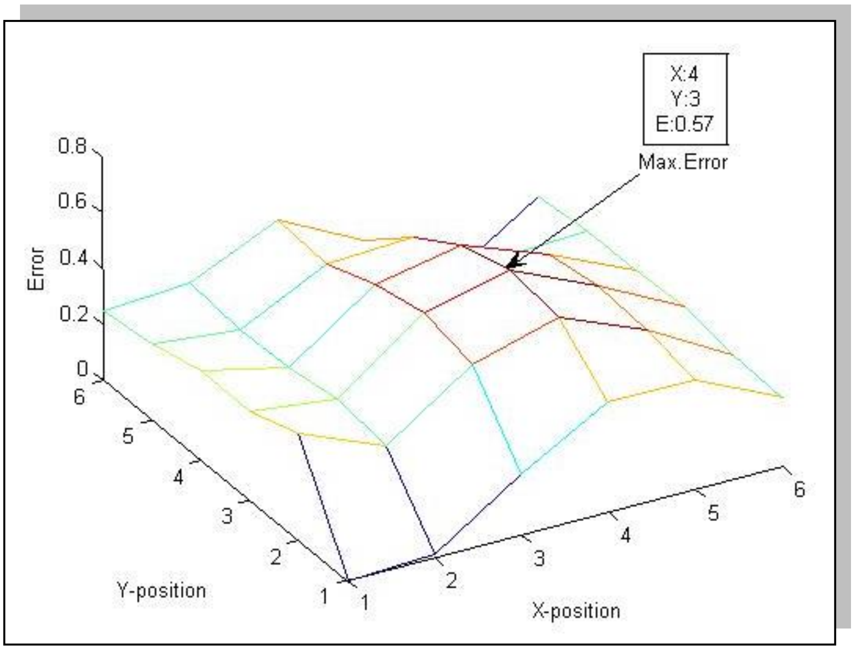

Figure 7 the error distribution over each pin

REFERENCES

Bahram Asiaban and behrokh khoshnevis "Machine path generation for the SIS process" robotics and comptuer integ- rated mauufacturing 2004 , 20 : 167- 175 .

Ding Qiulin and Davies B.J. " Surface engineering geometry for Computer aided design and Manufacturing" New York : John Wiley &Sons , 1987 .

H.S. Kleespies and R.H. Crawford "Vacuum forming of compound curved surface with a variable geometry mold" Journal of Manufacturing system .1998;17 (5) :325-337.

Ming-Zhe Li, Zhong-Yi Cai, Chun-Guo Liu "Flexible manufacturing of sheet metal parts based on digitized-die" Roboics and Computer-Integrated Manufacturing. 2007,23,107-115.

M. Z. Li, Z. Y. Cai, Z. Sui, Q. G. Yan *" multi- point forming technology for sheet metal "* Journal of material processing Technology. 129 (2002) 333-338.

Rao p.v.m. and sonjay "A flexible surface tooling for sheet forming processes: conceptual studies and numerical simulation" Journal of Material processing Technology 2002; 124:133-143.