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Research Article

Fixture Design and Work Piece Deformation Optimization Using the Iterative Simplex Algorithm

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Abstract

Presents article is deal with optimization of the fixture for end milling process, the most important objective being the minimization of work piece deformation by changing the layout of fixture elements and the clamping forces. The main objective of this work has been the optimization of the fixtures Work piece deformation subjected to clamping forces for End milling operation. The present analysis is used in hollow rectangular isotropic material work piece for FEA analysis and its optimization A linear programing (L.P) simplex model optimization activity has been performed both on fixture-work piece systems modeled with FEM and on fixture-work piece systems modeled with 3-D solid elements. The optimization constraints is selected as W/P deformation in x,y,z direction for various clamping forces, in order to provide a new design of fixture. The MATLAB code has been developed for L.P. model optimization purpose. Present MATLAB code is validated by using available literature. This paper deals with application of the L.P. model for w/p deformation optimization for a accommodating work piece. A simplex iterative algorithm that minimizes the work piece elastic deformation for the entire clamping force is proposed. It is shown via an example of milling fixture design that this algorithm yields a design that is superior to the result obtained from either fixture layout or w/p deformation optimization alone.

Keywords: 3-2-1 Location Principle; FEM; Linear Programming simplex Algorithm; Hollow Rectangular Work Piece Fixtures.

1. Introduction

In directive to make a work piece by milling processes, it is necessary that the work piece is installed in the machining fixture or directly on the table of the machine tool in a strictly determined position against the path of the cutting tool. The installation of the work piece has two functional phases: a) orientation and b) clamping. In order to achieve the clamping, it is necessary to apply a system of clamping forces which will make the contact of the workpieces with the locators and maintain this contact during processing, while also ensuring a maximum rigidity to the workpiece-fixture assembly, leading to the reduction or elimination of w/p deformation. Determination of the clamping forces must be made by taking into account the least favorable situations, even if these situations are very unlikely to occur. Also, the evaluation of the contact forces between the elements of the work piece-fixture system (locators, workpiece, clamping elements) is very important because their magnitude is not constant during the processing of the workpiece, depending on the cutting forces and moments, which have position and direction which vary during the processing. Finite Element Method (FEM) is a powerful tool for determining the deformation at any point on the work piece. The many researchers have been focused mead on fixture design for milling operation, the Krishna Kumar(2002) studied fixture design for manufacturing purpose**.** Chavan and Karidkar (2012)investigated experimental stress analysis of a fixture systems for end milling operation by using FEM. Hashemi(2014)studied fixture design automation and optimization review techniques and future trends. Calabrese et al. (2017) investigated the optimization of the fixtures performance used in thin-walled workpiece machining depending on the local rigidity characteristics of the component to be machined. Selvakumar et al. (2010) studied clamping force optimization for minimum deformation of workpiece by dynamic analysis of workpiece-fixture system. The stress analyses of mechanical component werestudied by Shivajichavan (2014). Ahmad et al. (2018) studied fixture layout optimization for multi pointrespots welding of sheet metals. Chaari et al. (2014) investigated the clamping force optimization problem formulated as a bi-level nonlinear programming problem and solved using a computational intelligence technique called particle swarm optimization (PSO).Cioata et al. (2017) presented the optimization of the position and the magnitude of the clamping forces in machining fixtures. Zhongqiwang et al. (2011) investigated the development of a prediction model based on neural network for sheet metal fixture locating layout design and optimization. Li and Melkote(2001) investigating fixture clamping force optimisation and its impact on workpiece location accuracy. Moshenia, and Fakharian,(2018), studied direct optimal motion planning for omni-directional mobile robots under limitation on velocity and acceleration. Amin Asadi et al. (2019) investigated A Two-

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Dimensional Warranty Model with Consideration of Customer and Manufacturer Objectives Solved with Non-Dominated Sorting Genetic Algorithm. Pansoo Kim And Yu Ding,(2014) developed Optimal Design Of Fixture Layout In Multi station Assembly Processes. Anual, et al. (2018) presented transient thermal analysis of welding fixtures design. Jonsson and Kihlma (2014) studied fixture design using configurators for robotics, Ivanovet al. (2018) investigated experimental diagnostic research of fixture. Siva Kumar and Paulr(2014) studied simulation system integrates the effects of work piece fixture dynamics with the other factors contributing to the machining process dynamics. Lu Jiping et al. (2010) reported the stability of work piece–fixture system and quantitative optimization of clamping forces during precise machining. Kaya (2006) developed the genetic algorithms (GAs) to the fixture layout optimization to handle fixture layout optimization problem.

In this article presents a simplex algorithm for iterative fixture layout and w/p deformation optimization of an accommodating work piece using the L.P. modeling. The paper is organized as follows. Section 2 presents a problem definition. This is followed by the description of the approach used in this work. Section 3 presents the FEM and solution of fixture work piece. Section 4 ismathematicaldescription of the L.P. model. Section 5 is results and discusses the finite element modeling and solution and details solution of simplex algorithm for W/P fixture system. The results of independent versus iterative layout and clamping force optimization for the example problem are presented and discussed in. Finally, the main conclusions of the paper are summarized in section 6.

2. Problem of Statement

The fixture design for end milling manufacturing process of workpiece fixture system is shown in Fig 1. The 3-2-1 Locator principle is used in fixture design, as it provides the maximum rigidity with the minimum number of fixture elements. A work piece in 3D may be positively located by means of six points positioned, so that they restrict one direction of six degrees of freedom of the work piece. The main objective of this study is to minimize the w/p deformation in fixture system by using simplex algorithm.

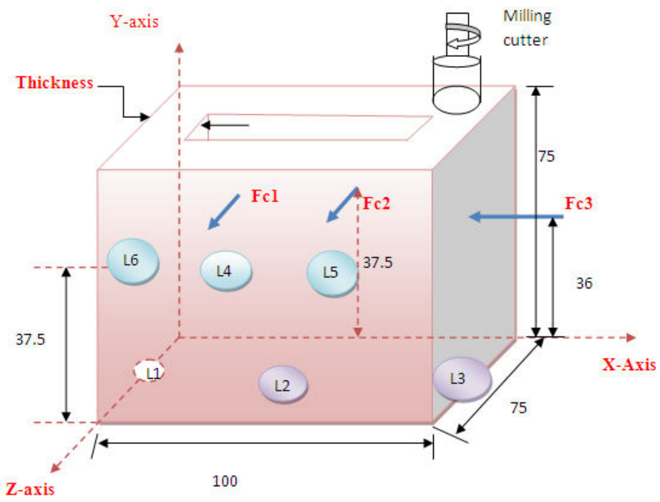


Fig.1. 3-2-1 principle W/P fixture system for End milling operation with three clamping force

3. Finite Element Model

The finite element model of W/Pis developed well known software ANSYS 11.0 and solution details for an example milling fixture design optimization problem are presented in the following sections. The dimensions of the work piece are 100X75X75 mm. The wall thickness is 10 mm. Hollow work piece geometry is chosen to highlight the effects of work piece as shown in Fig. 1. The finite element model of this work piece is shown in Fig 2. A FE W/P model is discretized into 3-D (Tatrahydral) solid element with 1737-Elements and 652-nodes.

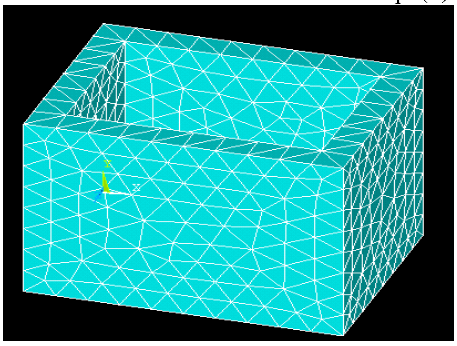
Boundary Conditions are given by. An entire clamping forces node on w/p is equal in magnitude $\{F_{c1}=F_{c2}=F_{c3}\}$ as shown in Fig.1. The locators (L_1,L_2,L_3,L_4,L_5 and L_6) nodes are fixed condition (All degree of freedom set to be zero). Present analysis is only considered clamping forces, no effect of the machining forces.

FEM solution for static analysis:

The Finite element analysis involves solving a set of simultaneous linear equations given by:

$$\{F_{c1}=F_{c2}=F_{c3}\}=[K]\begin{Bmatrix}\delta_1\\ \delta_2\\ \delta_3\end{Bmatrix} \qquad (1)$$

Where, $\{F_{c1}=F_{c2}=F_{c3}\}$ is clamping forces in entire w/p fixture system, [K] is stiffness matrix of W/P and $\{\delta_1\,\delta_2\,\delta_3\}^T$ is W/P deformation in x,y,and z direction respectively. The ANSYS software is solve Eq. (1) and obtained unknown deformation of fixture W/P.



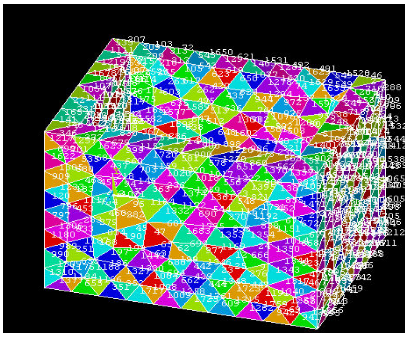


Fig. 2. FE model in ANSYS mesh with 3-D (Tatrahydral) solid element (1737 Elements and 652 nodes)

4. Solution Approach - Simplex Algorithm for Minimization of Fixture W/P Deformation

Before formulating linear programing (L. P.) model some assumption as following:

- **Linearity**: the amount of resource required for a given activity level is directly proportional to the level of activity.
- **Divisibility** : this mean the fraction value of the design variable are permitted
- **Non-Negativity:** this mean to get the decision variable are permitted to have only the value which are greater than or equal to zero.
- **Additivity:** this mean that the total output for a given combination of activity level is the algebraic sum of output of each individual process.

General LP in Matrix/canonical Form:

$$Min(z) = cx \text{ Stuject to: Ax=b; } x \geq 0 \tag{2}$$

Where,[c] is the vector contain the coefficient of the objectives function. [A], is technological coefficient matrix functional constraints, [b] is RHS coefficients matrix.

The Slack variavle vector is $x_s = \begin{bmatrix} x_{n+1} \\ x_{n+2} \\ x_{n+m} \end{bmatrix}$; Augmented constraints is given by = $[AI]\begin{bmatrix} x \\ x_s \end{bmatrix} = [b]$;

No basic variable form of the set $\begin{bmatrix} x \\ x_s \end{bmatrix} \geq 0$.

Let the set of basic variables be called and the matrix containing the coefficients of the functional Constraints be called (basis matrix) so that,

$$\overline{A}x_B = b\ ;\ x_b = \begin{bmatrix} x_{B1} \\ x_{B2} \\ x_{Bm} \end{bmatrix}; \tag{3}$$

Vector [x_B] is called basic variable.

$$\overline{A} = \begin{bmatrix} a_{11} & a_{12}\cdots & a_{1m} \\ a_{21} & a_{22}\cdots & a_{2m} \\ a_{m1} & a_{m1}\cdots & a_{mn} \end{bmatrix} \tag{4}$$

The original set of equations to start the Simplex Method is,

$$\begin{bmatrix} 1 & -c & 0 \\ 0 & A & I \\ & & \end{bmatrix}\begin{bmatrix} Z \\ x \\ x_s \end{bmatrix} = \begin{bmatrix} 0 \\ b \end{bmatrix} \tag{5}$$

After each itration in the simplex method solve Eq. (5)

$$x_B = (\overline{A})^{-1}b \text{ and } Z = c_B x_B \tag{6}$$

The RHS of the new set of equations becomes,

$$\begin{bmatrix} z \\ x_B \end{bmatrix} = \begin{bmatrix} 1 & c_B(\overline{A})^{-1} \\ 0 & (\overline{A})^{-1} \end{bmatrix} \begin{bmatrix} 0 \\ b \end{bmatrix} = \begin{bmatrix} c_B(\overline{A})^{-1}b \\ (\overline{A})^{-1}b \end{bmatrix}$$

And

$$\begin{bmatrix} 1 & c_B(\overline{A})^{-1} \\ 0 & (\overline{A})^{-1} \end{bmatrix}\begin{bmatrix} 1 & -c & 0 \\ 0 & A & I \end{bmatrix} = \begin{bmatrix} 1 & c_B(\overline{A})^{-1} - c & c_B(\overline{A})^{-1} \\ 0 & (\overline{A})^{-1}A & (\overline{A})^{-1} \end{bmatrix} \tag{7}$$

Eq. (7) is solve after any iteration matrix will be,

$$\begin{bmatrix} 1 & c_B(\overline{A})^{-1} - c & c_B(\overline{A})^{-1} \\ 0 & (\overline{A})^{-1}A & (\overline{A})^{-1} \end{bmatrix} \begin{bmatrix} Z \\ x \\ x_s \end{bmatrix} = \begin{bmatrix} c_B(\overline{A})^{-1}b \\ (\overline{A})^{-1}b \end{bmatrix} \tag{8}$$

The Eq. (8) can be solved and results in tabular format as discussed in next section.

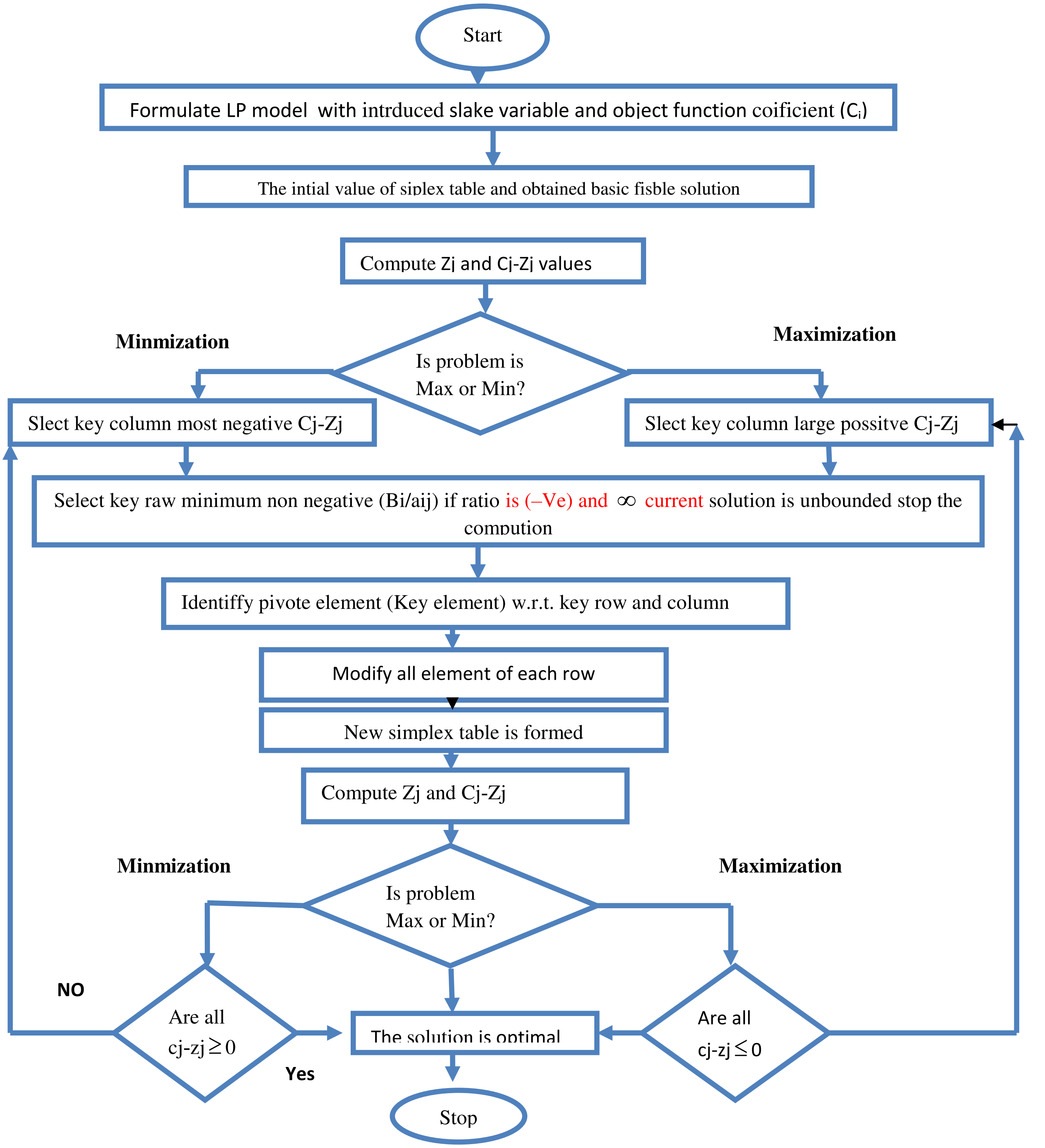
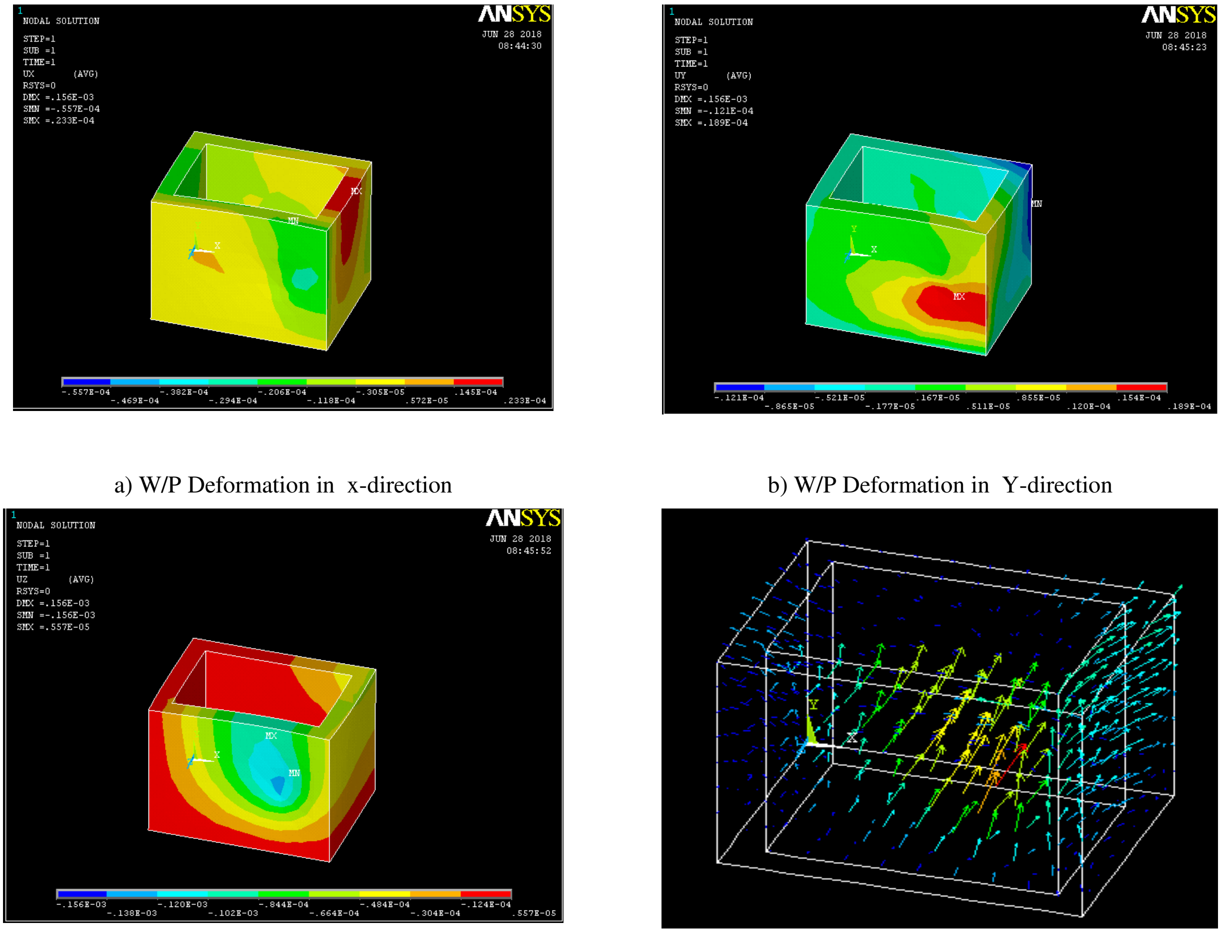


Fig. 3. The detail procedure of simplex Algorithm

5. Results and Discussion

The first deterministic values of w/p deformation are obtained from ANSYS 11.0 software. The Work piece Geometrical and materials properties is given by: The work piece material is taken form Kulankara and melkote[1] cast aluminum 390 alloy. The elastic modulus E=57 GPa, Poisson's ratio ($\nu = 0.3$).

The dimensions of the work piece are 100X75X75 mm. The wall thickness is 10 mm. W/P deformation is simulated in ANSYS as shown in **Fig.4**. The ANSYS is solved Eq. (1) and obtained value of fixture w/p deformation in x,y, and z direction. These values are listed in Table 1. Thew/p is subjected to clamping forces (Fc_1,Fc_2, Fc_3).



a) W/P Deformation in x-direction

b) W/P Deformation in Y-direction

c) W/P Deformation in Z-direction

d) Vector sun of Deformation of W/P

Fig. 4. simulated results in ANSYS of fixture W/P.

Table1

Fixture W/P deformation is simulated in ANSYS for different clamping forces (Fc1,Fc2, Fc3).

	$\delta_1(x)$	$\delta_1(y)$	$\delta_1(z)$	$\sum \delta$
$F_{c1}=F_{c2}=Fc_3=100$	0.0557	0.121	0.0557	0.0156
$F_{c1}=F_{c2}=Fc_3=500$	0.116	0.943	0.279	0.7830
$F_{c1}=F_{c2}=Fc_3=800$	0.235	1.892	0.556	1.5660

5.1 Validation of MATLAB code for simplex algorithm

The many algorithm in this model, the present L.P model is implemented in MTLAB Code, the own developed MTLAB CODE is compare with other L.P. model by solving such numerical example. The maximization problem of L.P model is taken from [R. Panneerselvam] for validation purpose.

Ex.1solve the following LP problem using simplex method:

$$\begin{aligned} &\text{Minimize } (Z)=10x_1+4x_2+20x_3 \\ &\text{Subject to} \\ &2X1+4X2+6X3 \le 24 \\ &3x1+9x2+6x3 \le 30 \\ &X1,X2,X3 \ge 0 \end{aligned} \tag{8}$$

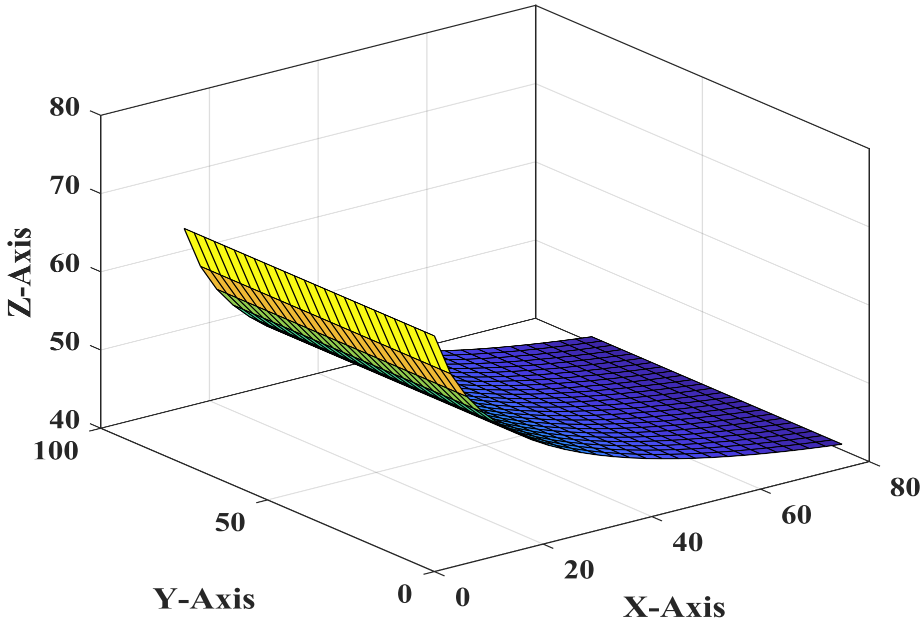


Fig.5. The W/P deformation in fixture system subjected to clamping force=100N

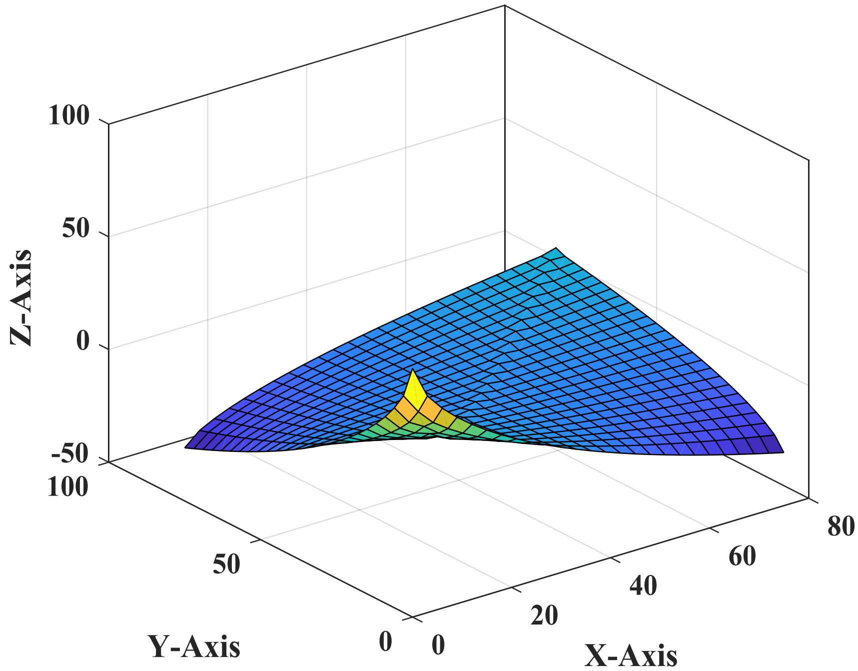


Fig. 6. The W/P deformation in fixture system subjected to clamping force=500N

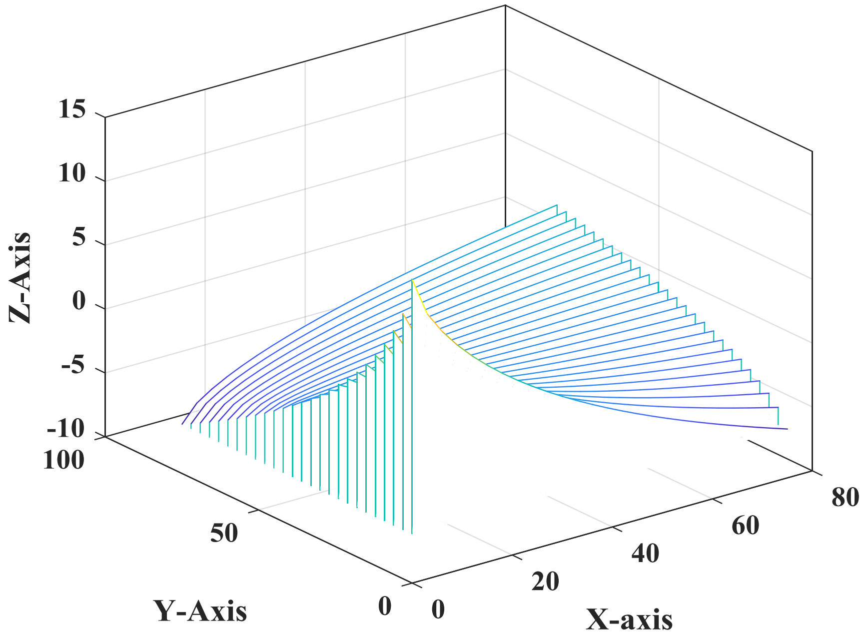


Fig.7. Tthe W/P deformation in fixture system subjected to clamping force=100N

Solution: The detail procedure of simplex algorithm is given in Fig.3.The optimal solution is given byTable-2 [R. Panneerselvam]. The present MTLAB Code results are tabulated in Table 2 as shows following.

Table 2
Optimal solution of given L.P. problem for simplex algorithm by [R. Panneerselvam]

Basic variable	CB_i	X_1	X_2	X_3	S_1	S_2	B_i
X_3	20	0	-1	1	1/2	-1/3	2
X_1	10	1	5	0	-1	1	6
C_j		10	15	20	0	0	Solution =100
Z_j		10	30	20	0	10/3	
C_j-Z_j		0	-15	0	0	-10/3	

Table.3
Optimal value of MATLAB Code results for given L.P. Problem for simplex algorithm.

Basic variable	CB_i	X_1	X_2	X_3	S_1	S_2	B_i
X_3	20	0	-1	1	1/2	-1/3	2
X_1	10	1	5	0	-1	1	6
C_j		10	15	20	0	0	Solution =100
Z_j		10	30	20	0	10/3	
C_j-Z_j		0	-15	0	0	-10/3	

It is observed the present MATLB coed results in Table 2 and literature PL model results in Table 1 are perfectly match, hence MATLB code is validated. Farther our present fixture model can be formulated by incorporating ANSYS results. The subject constraint is based on W/P deformation in x,y,z direction. The constant coefficient matrix [A] (Technological coefficient matrix) is considered as value of deformation obtained from ANSYS. The deformation in x,y,z direction treat as $\delta_1\,\delta_2\,\delta_3$ respectively, in the present three constraint are considered by changing clamping forces which is taken from Table1. Presently, the L.P model formulated for W/P deformation is minimizing:

$$f\left(\delta\right)_{\min} = 0.156\delta_1 + 0.783\delta_2 + 1.566\delta_3$$

Constraint subject to,

$$0.0557\delta_1 + 0.121\delta_2 + 0.0557\delta_3 \geq 100\,;$$
$$0.116\delta_1 + 0.943\delta_2 + 0.279\delta_3 \geq 75$$
$$0.235\delta_1 + 1.892\delta_2 + 0.556\delta_3 \geq 75 \qquad (9)$$
$$\delta_1, \delta_2, \delta_3 \geq 0$$

Where, δ_1, δ_2 and δ_3 are the deformation of work piece in x, y and z direction respectively.

Solution: The detailed procedure is given in **Fig.3**. The L.P. iteration table is formed by using Eqs. (2-8). we obtained value of all iteration.

Table 4
Initial basic feasible solution of W/P fixture L.P. simplex algorithm (Pivot Element=0.1)

Basic variable	CB_i	δ_1	δ_2	δ_3	S_1	S_2	S_3	B_i	$R=B_i$/key column
S_1	0	0.1	0.1	0.1	01	0	0	100	$1.7953\text{x}10^3$
S_2	0	0.1	0.9	0.3	0	01	0	75	$0.2688\ \text{x}10^3$ ←
S_3	0	0.2	1.9	0.6	0	0	01	75	$0.1349\ \text{x}10^3$
C_j		0.156	0.783	1.566	0	0	0	Solution =0	
Z_j		0	0	0	0	0	0		
C_j-Z_j		0.1560	0.783	1.5660	0	0	0		
Entring Variable		↑							

Table 5
First iteration of W/P fixture L.P. simplex algorithm (Pivot Element=0.0927)

Basic variable	BC_j	δ_1	δ_2	δ_3	S1	S2	S3	B_i	R=Bi/key column
S1	0	0.0518	0.0895	0.0464	1	0	-0.0167	98.75	$1.7729\text{x}10^3$
S2	0	0.1043	0.8484	0.2512	0	1	-0.0500	71.25	$0.2554\text{x}10^3$
δ_3	1.566	0.0392	0.3153	0.0927	0	0	0.1667	14.50	$0.0225\text{x}10^3$ ←
cj		0.156	0.783	1.566	0	0	0	Sol. = 22.707	
Zj		0.0613	0.4938	0.1451	0	0	0.2610		
Cj-Zj		0.09497	0.2892	1.4209	0	0	-0.2610		
			E. V.	↑					

Table 6
Second iteration of W/P fixture L.P. simplex algorithm (Pivot Element =0.0423)

Basic variable	BC_j	δ_1	δ_2	δ_3	S1	S2	S3	B_i	R=Bi/key column
S1	0	0.0498	0.0737	0.0418	1	0	-0.0250	98.1243	1.7617
S2	0	0.0936	0.7630	0.2261	0	1	-0.0952	67.8927	0.2432
δ_3	1.566	0.0423	0.3402	1	0	0	0.1798	10.4844	0.0243 ←
C_j		0.156	0.783	1.566	0	0	0	Solution = 16.4185	
Z_j		0.0613	0.4938	0.1451	0	0	0.2610		
C_j-Z_j		-0.0947	0.2892	1.409	0	0	-0.2610		
Entering Variable		↑							

Table 7
Third iteration of W/P fixture L.P. simplex algorithm

Basic variable	BC_j	δ_1	δ_2	δ_3	S1	S2	S3	B_i
S1	0	0.0076	-0.2665	-0.0582	1	0	-0.2048	84.64
S2	0	0.0514	0.4228	0.1261	0	1	-0.2750	54.374
δ_3	1.566	.0423	0.3402	0.100	0	0	0.1798	09.4844
cj		0.156	0.783	1.566	0	0	0.2816	Solution = 14.8524
Zj		0.662	0.8327	3.1565	0	0	0.2816	
Cj-Zj		0.506	0.0497	1.5905	0	0	0	

In the Table 7. All the value for Cj-Zj are either 0 or 1 hence the optimal is reached. The corresponding optimal solution is follows: δ_1 =0, δ_2 =0 and δ_3 =09.4844. The objective function value is $f(\delta)_{\min}$ =14.8524 mm. After performing the simplex algorithm, optimal values of the design variables were obtained, for which the objective functions and imposed constraints are accomplished. These are presented in Table 7. The values of the objective functions for the optimal design variables are presented in Table 7**.** The graphical representations from Figs-5-7 present a few of the dependences of the objective functions on the design variables, which are useful representations for the deformation of objective functions. The fig.5 displays the influence of the position of the clamping force in y-direction on the work piece. The influence that the magnitude of the clamping forces has on the maximum contact force between the locators (L1, L2 and L3) and the work piece is presented in Fig.6. Fig. 7displays the influence of the magnitude of the clamping forces on the maximum total deformation of the evaluated edge.

6. Conclusion

This article is presented a simplex iterative fixture W/P deformation optimization procedure for an accommodating work piece. It is observed that the values of the objective functions are smaller than those resulted in the preliminary analysis, and the constraints are accomplished. The optimal values of the clamping forces are smaller, which implies reduced energy consumption, and the contact forces are better than zero, which means that the integrity of the orientation layout is maintained. It is shown that the reduction in work piece form error induced by elastic deformation during clamping forces. It's considerably larger with the iterative procedure than with the layout or clamping force optimization alone. Future efforts will focus on extending this technique to incorporate fixture element elasticity and dynamic effects. By studying the graphical representations in figs.5-7, it can be noticed that for certain values of the position dimensions of the clamping elements, the magnitude of the contact forces is close to zero, which would lead to the compromising of the orientation layout. These representations are useful in order to avoid those areas for applying clamping forces by using clamping elements By calculating the optimum clamping forces the deformation of the work piece may be minimized. Because of minimum deformation, the dimensional and form errors of the work piece may be reduced.

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Appendix. 1. MATLAB CODE FOR maximization

```
                    %%%##############################################
                    %%%%%%%%%### MATLAB CODE FOR maximization ####
                    %%%%##############################################
clc;
cj=[30 20 36 0 0 0];I=[1 0 0;0 1 0;0 0 1];
A0=[4 3 1 1 0 0; 2 6 3 0 1 0; 5 1 6 0 0 1];
B0=[40;30;25];
CB0=[0; 0; 0];
sol_0=CB0'*B0;  %%%%initial basic solution=0%%%%%%
z0=A0'*CB0;
zj0=z0';
opt_0=cj-zj0;   %%%%% check the optimality %%%%%%%%
[ent_vrb_0,key_colmn_position_0]=max(opt_0);
key_column0=A0(:,key_colmn_position_0);
Ratio_0=B0./(key_column0);
[key_row0,key_row_position_0]= min(Ratio_0);
 pivit0=A0(key_row_position_0,key_colmn_position_0);
 AGU_0=[A0,B0];                  %AUGMENTED MATRIX A,B
Initail_table=[CB0 AGU_0  Ratio_0];  %%% INITIAL BASIC TABLE %%%%

                         %%%%####################################
                         %%%%   FIRST ITRATION       %%%%%%%%%
                         %%%%####################################

 R1_3=AGU_0(3,:)./ pivit0;
 R1_2=AGU_0(2,:)-key_column0(2,1)*R1_3;   %% modified R1_1,R1_2 R1_3
 R1_1=AGU_0(1,:)-key_column0(1,1)*R1_3;
 AGU_1=[R1_1; R1_2; R1_3];               %%% check the Identity matrix
 B1=AGU_1(:,7);
 CB1=[0; 0; 36];
 z1=AGU_1(:,1:6)'*CB1;
 zj1=z1';
 opt_1=cj-zj1;                  %%%%% check the optimality %%%%%%%%
 sol_1=CB1'*B1;                  %%%% solution  of first iteration %%%%%%
 [ent_vrb_1,key_colmn_position_1]=max(opt_1);
 A1=AGU_1(:,1:6);
 key_column1=A1(:,key_colmn_position_1);
 Ratio_1=B1./(key_column1);
 [key_row1,key_row_position_1]=min(Ratio_1);
 pivit_1=A1(key_row_position_1,key_colmn_position_1);

                         %%%%####################################
                        %%%%   SECOND ITRATION       %%%%%%%%%
                         %%%%####################################
 R2_2=AGU_1(2,:)./ pivit_1;
 R2_1=AGU_1(1,:)-key_column1(1,1)*R2_2;
 R2_3=AGU_1(3,:)-key_column1(3,1)*R2_2;

 AGU_2=[R2_1; R2_2; R2_3];
 B2=AGU_2(:,7);
 CB2=[0; 20; 36];
 z2=AGU_2(:,1:6)'*CB2;
 zj2=z2';
 opt_2=cj-zj2;             %%%% check the optimality       %%%%%%
 sol_2=CB2'*B2;            %%%% solution  of first iteration %%%%%%
 [ent_vrb_2,key_colmn_position_2]=max(opt_2);
 A2=AGU_2(:,1:6);
 key_column2=A2(:,key_colmn_position_2);
```

```
Ratio_2=B2./(key_column2);
[key_row2,key_row_position_2]=min(Ratio_2);
pivit_2=A2(key_row_position_2,key_colmn_position_2);

                              %%%%##################################
                              %%%%   THIRD ITRATION       %%%%%%%%%
                              %%%%##################################
R3_3=AGU_2(3,:)./pivit_2;
R3_1=AGU_2(1,:)-key_column2(1,1)*R3_3;
R3_2 =AGU_2(2,:)-key_column2(2,1)*R3_3;
AGU_3=[R3_1; R3_2; R3_3];
B3=AGU_3(:,7);
CB3=[0; 20; 30];
z3=AGU_3(:,1:6)'*CB3;
zj3=z3';
opt3=cj-zj3;
sol_3=CB3'*B3;
                              %%%%##################################
                              %%%%   END OF ITRATION       %%%%%%%%
                              %%%%##################################
```

Appendix. 1. ABBREVIATION

FC1,FC2 and FC3 = Clamping Forces
L1,L2,L3,L4,L5 and L6 = Locator In Fixture System
δ_1 ; δ_2 and δ_3 = Work Piece Deformation In X,Y And Z Direction.
[C]= Coefficient Of Objective Function Matrix
[A]= Technological Coefficient Of Matrix
[b] = Constant Constraint Matrix
[x]= Slack Variable Matrix
[I]= Unite Vector Matrix
E= Young Modulus Of W/P Materials
υ = Poison Ratio Of W/P Materials