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Title: **OPTIMIZATION OF NUMBER AND POSITIONS OF MACHINING FIXTURE ELEMENTS**

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Paper Authors

K.NAGARAJU M.TECH(PHD), [2]**DR. K. KAMARAJU**PHD

[1]Sjcet, Kurnool.
[2]Annamalai University - Chidambaram

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OPTIMIZATION OF NUMBER AND POSITIONS OF MACHINING FIXTURE ELEMENTS

[1]K.NAGARAJU M.TECH(PHD), [2]DR. K. KAMARAJUPHD

[1]Assistant Professor Dept. of Mechanical Engineering Sjcet, Kurnool.

[2]Professor Department of Mechanical Engineering Annamalai University – Chidambaram

knagaraju321@gmail.com

ABSTRACT—In fixture design optimization problems, most of the researchers have used 3-2-1 locating principle. Only few researchers addressed the optimization of the number and positions of fixture elements where the initial layout of the locators is determined first, then the number and positions of the locators are optimized based on the initial layout For locating correctness, the minimum number of fixture elements required and the optimum number of locators are determined. The optimization of the number of fixturing elements towards minimum workpiece elastic deformation is rarely considered in the literature. In this chapter, a fixture layout optimization method is presented with optimum number of fixture elements towards minimum workpiece deformation.

1. INTRODUCTION

1.1 METHODOLOGY The methodology for the number of fixture elements and layout optimization is given in Figure 1.1. Initially, the number of locators and clamps are fixed randomly to hold the workpiece for the selected machining process. Then the numbers of locators and clamps are varied and the corresponding workpiece deformation values are found for allworkpiece-fixture configurations by ANSYS. The optimum number of fixture elements is the one which gives minimum workpiece deformation and with the optimum number of elements, position of fixture elements is optimized by using genetic algorithm.

Figure 1.1 Methodology for number and positions of fixture elements optimization

1.2 ILLUSTRATION OF NUMBER OF FIXTURE ELEMENTS OPTIMIZATION The workpiece-fixture configuration for the end milling operation is taken as a case study to illustrate the number of fixture elements optimization.

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1.2.1 Parameters Involved

The parameters influencing the deformation of the workpiece during machining are material of the workpiece, machining forces, clamping forces, number of fixture elements and positions of fixture elements. In this chapter, the fixture layout optimization method is presented with optimum number of fixture elements towards minimum workpiece deformation to reduce dimensional and form errors in the components. So the number and positions of fixture elements are considered as variables and the remaining parameters are taken as constants. In the number of fixture elements optimization problem, along with 3-2-1 locating scheme 3-2-2 and 3-3-1 locating schemes are used and the number of clamps is also varied. Based on the comparison of workpiece deformation, the optimum number of fixture elements is selected for minimum workpiece deformation.

1.2.2 3-2-1 Locating Scheme Theoptimum layout for the workpiece-fixture configuration using 3-2-1 fixturing scheme given by the GAANN approach is considered for this number of fixture elements optimization problem. Table 8.1 shows optimal positions of fixture elements given by the GA-ANN approach using 3-2-1 locati ng scheme.

Table 1.1 Optimal position of fixture elements using 3-2-1 Locating scheme

Fixture Elements	Position of fixture elements (mm)		
	X	Y	Z
L_1	0	19.05	97.1
L_2	0	19.05	33.6
L_3	19.7	19.05	0
L_4	120.6	0	14.94
L_5	79.0	0	112.06
L_6	19.7	0	63.5
C_1	114.3	19.05	127
C_2	127	19.05	29.8
C_3	39.5	38.1	63.5

1.2.3 3-2-2 Locating Scheme

The3-2-2 locating scheme configuration shown in Figure 1.2 is arrived by adding one more locator along X axis with the 3-2-1 workpiece-fixture configuration. Then the position of the newly added locator is varied and the corresponding workpiece deformations are determined by FEM software ANSYS. The positions for the remaining fixture elements are kept as same given by the optimum layout of GA-ANN approach. By comparing all the deformation values, the layout which gives the minimum deformation value is taken as better layout of 3-2-2. Table 1.2 shows the positions of fixture elements. The position of L7 varies along the X direction. In the fixture layout, seven locators and three clamps are used to constrain the workpiece

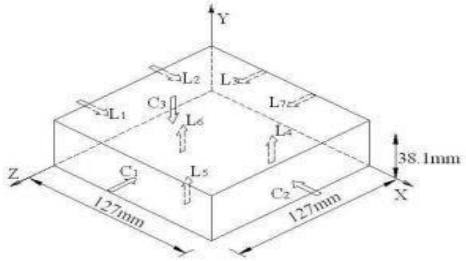

Figure 1.2 Workpiece-fixture configuration with 3-2-2 locating scheme

Fixture Elements	Position of fixture elements (mm)		
	X	Y	Z
L_1	0	19.05	97.1
L_2	0	19.05	33.6
L_3	19.7	19.05	0
L_4	120.6	0	14.94
L_5	79.0	0	112.06
L_6	19.7	0	63.5
L_7	58.5 to 127	0	63.5
C_1	114.3	19.05	127
C_2	127	19.05	29.8
C_3	39.5	38.1	63.5

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The various positions of the newly introduced locator L7 and their corresponding deformation values are tabulated in Table 1.3. Then by comparing all the deformation values, the layout which gives the minimum deformation value is taken as better layout of 3-2-2. The graph in Figure 1.3 shows that workpiece deformation is minimum when the position of newly added locator L7 is at 92.5 mm along X axis and the corresponding deformation is shown in Figure 1.4.

Table 1.3 Fixture layouts for 3-2-2 locating scheme

Layout	Position of fixture elements along particular axis (mm)										D_{max} (mm)
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	C_1	C_2	C_3	
1	97.1	33.6	19.7	120.6	79.0	19.7	59.2	114.3	29.8	39.5	0.0912
2	97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	0.0657
3	97.1	33.6	19.7	120.6	79.0	19.7	79.0	114.3	29.8	39.5	0.0654
4	97.1	33.6	19.7	120.6	79.0	19.7	89.8	114.3	29.8	39.5	0.0654
5	97.1	33.6	19.7	120.6	79.0	19.7	92.5	114.3	29.8	39.5	0.0653
6	97.1	33.6	19.7	120.6	79.0	19.7	96.1	114.3	29.8	39.5	0.0654
7	97.1	33.6	19.7	120.6	79.0	19.7	99.7	114.3	29.8	39.5	0.0655
8	97.1	33.6	19.7	120.6	79.0	19.7	103.4	114.3	29.8	39.5	0.0657
9	97.1	33.6	19.7	120.6	79.0	19.7	107.6	114.3	29.8	39.5	0.0658
10	97.1	33.6	19.7	120.6	79.0	19.7	110.6	114.3	29.8	39.5	0.0659

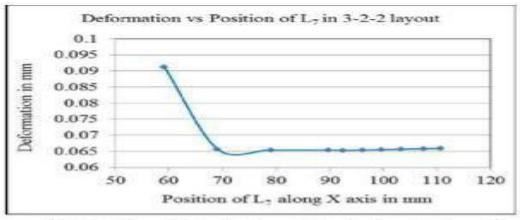

Figure 1.3 Position of locator L_7 vs Workpiece deformation

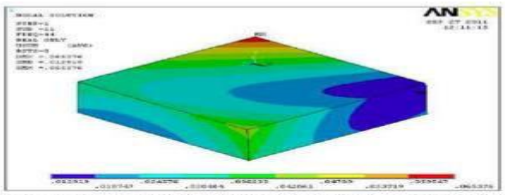

Figure 1.4 Workpiece deformations for better layout of 3-2-2

1.2.4 3-3-1 Locating Scheme

In 3-2-1 workpiece-fixture configuration, one more locator is added along Z axis and 3-3-1 locating scheme configuration is obtained as shown in Figure 1.5. By keeping the positions of other fixture elements as the same given by the optimum layout of GA-ANN approach, the positionof the newly added locator is varied and the corresponding workpiece deformations are determined by ANSYS. Then by comparing all the deformation values, the layout that gives the minimum deformation value is taken as better layout of 3-3-1.

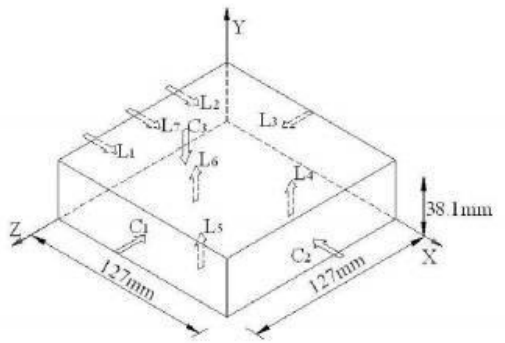

Figure 1.5 Workpiece-fixture configuration with 3-3-1 locating scheme

Fixture Elements	Position of fixture elements (mm)		
	X	Y	Z
L_1	0	19.05	97.1
L_2	0	19.05	33.6
L_3	19.7	19.05	0
L_4	120.6	0	14.94
L_5	79.0	0	112.06
L_6	19.7	0	63.5
L_7	0	19.05	40 to 80
C_1	114.3	19.05	127
C_2	127	19.05	29.8
C_3	39.5	38.1	63.5

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The position of fixturing elements in 3-3-1 locating scheme and workpiece deformation values for various positions of the locator L7 are tabulated in Table 1.4 and 1.5. After comparing all the deformation values, the layout which gives the minimum deformation value is taken as better layout of 3-3-1. Figure 1.6 shows that workpiece deformation is minimum when the position of newly added locator L7 is at 74.7 mm along Z axis and the corresponding workpiece deformation is shown in Figure 1.7.

Table 1.5 Fixture layouts for 3-3-1 locating scheme

Layout	Position of fixture elements along particular axis (mm)										D_{max} (mm)
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	C_1	C_2	C_3	
1	97.1	33.6	19.7	120.6	79.0	19.7	41.0	114.3	29.8	39.5	0.0661
2	97.1	33.6	19.7	120.6	79.0	19.7	44.8	114.3	29.8	39.5	0.0658
3	97.1	33.6	19.7	120.6	79.0	19.7	48.5	114.3	29.8	39.5	0.0656
4	97.1	33.6	19.7	120.6	79.0	19.7	52.2	114.3	29.8	39.5	0.0654
5	97.1	33.6	19.7	120.6	79.0	19.7	56.7	114.3	29.8	39.5	0.0654
6	97.1	33.6	19.7	120.6	79.0	19.7	60.9	114.3	29.8	39.5	0.0649
7	97.1	33.6	19.7	120.6	79.0	19.7	65. 1	114.3	29.8	39.5	0.0645
8	97.1	33.6	19.7	120.6	79.0	19.7	69.9	114.3	29.8	39.5	0.0642
9	97.1	33.6	19.7	120.6	79.0	19.7	74.7	114.3	29.8	39.5	0.0641
10	97.1	33.6	19.7	120.6	79.0	19.7	78.4	114.3	29.8	39.5	0.0645

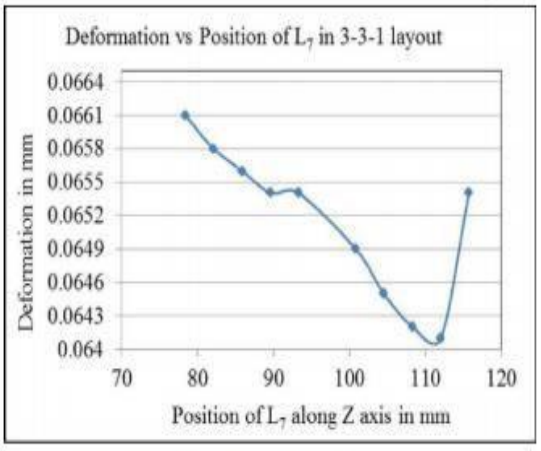

Figure 1.6 Position of locator L_7 in 3-3-1 layout vs workpiece deformation

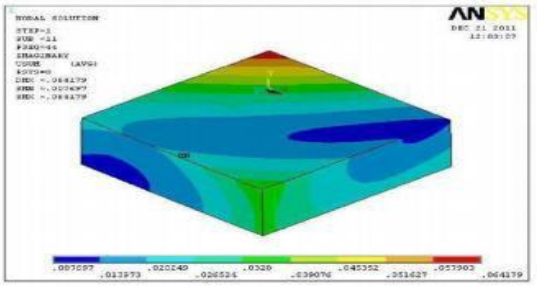

Figure 1.7 Workpiece deformations for the better layout of 3-3-1 configuration

1.2.5 Number of clamps on 3-2-2 Scheme

To optimize the number of clamps, one more clamp is added with 3-2-2 locating scheme and the position of newly added clamp is varied along the X axis to determine the deformation of the workpiece. In Figure 1.8, C4 is the newly added clamp and it takes half of the clamping force CF 1. Table 1.6 shows positions of fixture elements and clamping forces. Table 1.7 presents the various clamping positions of newly added clamp C4 and their corresponding deformation values of the workpiece. Graph in Figure 1.9 shows that workpiece deformation is minimum when the position of newly added clamp C4 is at 59.26 mm along X axis and the workpiece deformations for the selected layout are shown in Figure 1.10.

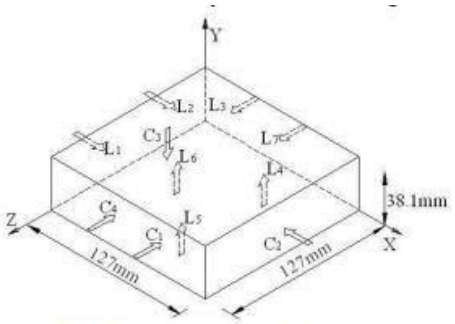

Figure 1.8 Work-fixture configuration of 3-2-1 layout withadditional clamp

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Fixture Elements	Position of Fixture Elements (mm)		
	X	Y	Z
L_1	0	19.05	97.1
L_2	0	19.05	33.6
L_3	19.7	19.05	0
L_4	120.6	0	14.94
L_5	79.0	0	112.06
L_6	19.7	0	63.5
L_7	92.5	19.05	0
C_1	114.3	19.05	127
C_2	127	19.05	29.8
C_3	39.5	38.1	63.5
C_4	0 to 100	19.05	127
C^F_1=369.25 N	C^F_2=341.1N	C^F_3=1026.8 N	C^F_4= 369.25 N

Table 1.7 Fixture layouts for 3-2-2 configuration with additional clamp

Position of fixture elements along particular axis (mm)											D_{min} (mm)
L_1	L_2	L_3	L_4	L_5	L_6	L_7	C_1	C_2	C_3	C_4	
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	19.75	0.0655
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	29.63	0.0653
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	39.59	0.0653
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	49.38	0.0653
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	59.26	0.0653
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	69.14	0.0654
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	79.02	0.0653
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	89.9	0.0653
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	92.52	0.0653
97.1	33.6	19.7	120.6	79.0	19.7	69.1	114.3	29.8	39.5	96.15	0.0653

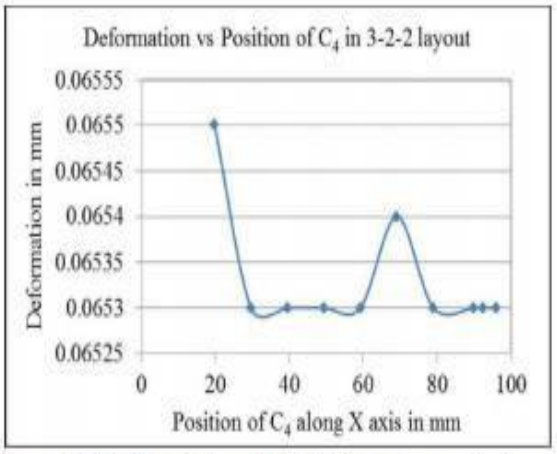

Figure 1.9 Position of clamp C_4 in 3-2-2 layout vs workpiece deformation

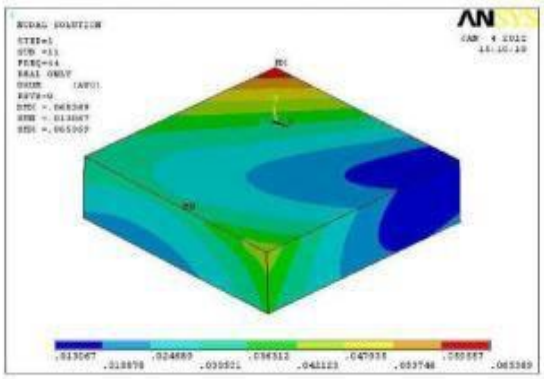

Figure 1.10 Workpiece deformation for the better layout of 3-2-2 configuration with additionalclamp

1.2.6 Number if Clamps on 3-3-1 Figure 1.11illustrates the clamp added 3-3-1 locating scheme, where one more clamp C4 is added with 3-3-1 locating scheme taking half of the clamping force Cf 2.The position of newly added clamp is varied on Z axis to determine the deformation of the workpiece. Table 1.8 shows positions of fixturing elements and clamping forces with clamp added 3-3-1 locating scheme.Table 1.9 and Figure 1.12 show the various positions of newly added clamp and their corresponding deformation values of the workpiece. The minimum deformation of 3-3-1 scheme with four clamps is displayed in Figure 1.13.

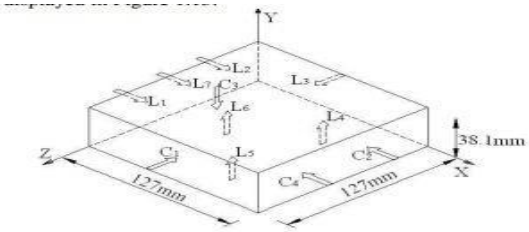

Figure 1.11 Workpiece-fixture configuration of 3-3-1 layout with additional clamp

Table 1.8 Position of fixturingelements with additional clamp using 3-3-1 locating scheme

Fixture Elements	Position of Fixture Elements (mm)		
	X	Y	Z
L_1	0	19.05	97.1
L_2	0	19.05	33.6
L_3	19.7	19.05	0
L_4	120.6	0	14.94
L_5	79.0	0	112.06
L_6	19.7	0	63.5
L_7	0	19.05	42 to 84
C_1	114.3	19.05	127
C_2	127	19.05	29.8
C_3	39.5	38.1	63.5
C_4	127	19.05	50 to 100
C^F_1=738.5 N	C^F_2=170.55 N	C^F_3=1026.8 N	C^F_4= 170.55 N

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Table 1.9 Fixture layouts for 3-3-1 configuration with additional clamp

Position of fixture elements along particular axis (mm)											D_{max} (mm)
L_1	L_2	L_3	L_4	L_5	L_6	L_7	C_1	C_2	C_3	C_4	
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	56.02	0.0641
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	59.74	0.0641
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	63.5	0.0641
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	67.23	0.0641
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	71.13	0.0641
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	75.02	0.0641
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	78.93	0.0642
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	82.78	0.0642
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	86.52	0.0642
97.1	33.6	19.7	120.6	79.0	19.7	112.0	114.3	29.8	39.5	90.37	0.0642

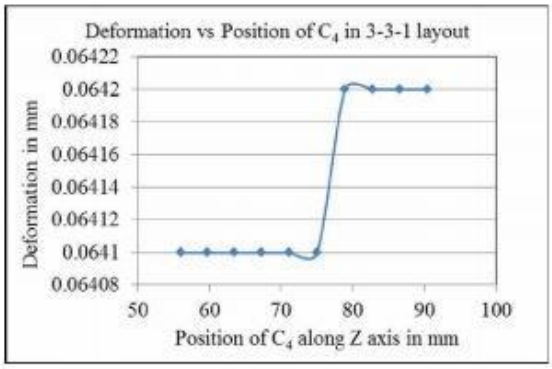

Figure 1.12 Position of clamp C_4 in 3-3-1 layout vs workpiece deformation

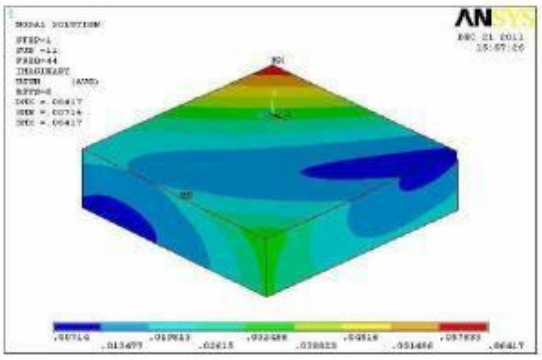

Figure 1.13 Workpiece deformation for the better layout of 3-3-1 configuration with additional clamp

Selection of Optimal Number of Fixture Elements Theoptimal number of fixture elements is fixed by comparing the deformation values of all fixturing schemes and is shown in Table 1.10. The 3-3-1 locating scheme gives the minimum deformation compared to 3-2-2 scheme. The influence of addition of clamps on workpiece deformation is not significant as shown in Table 1.10

Table 1.10 Comparison of deformation values

S.No.	Locating schemes	Maximum Deformation (mm)
1	3-2-2	0.06537
2	3-3-1	0.06417
3	3-2-2 Clamp added	0.06536
4	3-3-1 Clamp added	0.06426

1.3 ILLUSTATION OF FIXTURE LAYOUT OPTIMIZATION BY GA WITH OPTIMUM NUMBER OF FIXTURE ELEMENTS

Basedon workpiece deformation, 3-3-1 locating scheme is selected as optimal one for the considered workpiece-fixture system and the optimal fixture configuration has seven locators and three clamps. eIn this section, GA based optimization is presented for the optimal positions of seven locators and three clamps.

1.3.1 Objective Function of GA

The minimization of moment is the basic objective so as to minimize the workpiece deformation. So ten sets of moment equations are formulated to obtain the moment values at locator and clamp contact points as given in Equations (1.1) to (1.10).These equations are framed with the basic rule that the moment equals the product of force and the distance from

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which it is applied. The moment about locator L1 due to machining, clamping and reaction forces at locator contact points is described in Equation (1.1) by multiplying the force values with the corresponding perpendicular distances with respect to locator position L1.Similarly Equations (1.2) to (1.10) are developed to calculate moments about other six locators and three clamps.The following equations are given as inputs in the form of program to the MATLAB software and the new set of layouts and moment values are obtained.The crossover and mutation probabilities quoted in the Section 7.4 are used during the MATLAB software programming.

Number of iteration (Nmax): 150 Population size (Ps) : 30

Crossover probability (Pc) : 60% Mutation probability (Pm) : 4%

$$\sum_{ML1} = \begin{bmatrix} -[(ZL_1 - ZL_2)R_2] - [(XL_3 - XL_1)R_3] \\ +[(ZL_1 - ZL_4)R_4] + [(XL_4 - XL_1)R_4] \\ +[(XL_5 - XL_1)R_5] + [(XL_6 - XL_1)R_6] \\ +[(ZL_1 - ZL_6)R_6] - [(ZL_1 - ZL_7)R_7] \\ +[(XC_1 - XL_1)C_1^F] + [(ZC_1 - ZC_2)C_2^F] \\ -[(ZL_1 - ZC_3)C_3^F] - [(XC_3 - XL_1)C_3^F] \\ -[(Z_F - ZL_1)F_X] - [(X_F - XL_1)F_Y] \\ -[(Z_F - ZL_1)F_Y] + [(X_F - XL_1)F_Z] \end{bmatrix} \quad (1.1)$$

$$\sum ML_2 = \begin{bmatrix} [(ZL_1 - ZL_2)R_1] - [(XL_3 - XL_2)R_3] \\ +[(XL_4 - XL_2)R_4] + [(ZL_4 - ZL_2)R_4] \\ +[(XL_5 - XL_2)R_5] - [(ZL_5 - ZL_2)R_5] \\ +[(XL_6 - XL_2)R_6] - [(ZL_6 - ZL_2)R_6] \\ +[(ZL_{-} - ZL_{-})R_{-}] + [(XC_{-} - XL_{-})C^F] \\ -[(ZC_2 - ZL_2)C_2^F] - [(XC_3 - XL_2)C_3^F] \\ +[(ZC_{-} - ZL_{-})C^F] - [(Z_{-} - ZL_{-})F_X] \\ -[(X_F - XL_2)F_Y] - [(Z_F - ZL_2)F_Y] \\ +[(X_{-} -)_{XL_2}F_Z] \end{bmatrix} \quad (1.2)$$

$$\sum_{ML3} = \begin{bmatrix} [(ZL_1 - ZL_3)R_1] + [(ZL_2 - ZL_3)R_2] \\ +[(XL_4 - XL_3)R_4] - [(ZL_3 - ZL_4)R_4] \\ +[(XL_5 - XL_3)R_5] - [(ZL_5 - ZL_3)R_5] \\ -[(XL_3 - XL_6)R_6] - [(ZL_6 - ZL_3)R_6] \\ +[(ZL_7 - ZL_3)R_7] - [(ZC_2 - ZL_3)C_2^F] \\ +[(XL_3 - XC_3)C_3^F] + [(ZC_3 - ZL_3)C_3^F] \\ +[(Z_F - ZL_3)F_X] - [(X_F - XL_3)F_Y] \\ +[(Z_F - ZL_3)F_Y] + [(X_F - XL_3)F_Z] \end{bmatrix} \quad (1.3)$$

$$\sum ML_4 = \begin{bmatrix} [(ZL_1 - ZL_4)R_1] + [(XL_4 - XL_3)R_3] \\ -[(ZL_5 - ZL_4)R_5] - [(XL_4 - XL_6)R_4] \\ -[(ZL_6 - ZL_4)R_6] + [(XL_4 - XL_7)R_7] \\ -[(XL_{-} - XC_{-})C^F] - [(ZC_{-} - ZL_{-})C^F] \\ +[(XL_4 - XC_3)C_3^F] + [(ZC_1 - ZL_4)C_3^F] \\ -[(Z_F - ZL_4)F_X] + [(Z_F - ZL_4)F_Y] \\ +[(X_{-} -)_{XL_4}F_Z] \end{bmatrix} \quad (1.4)$$

$$\sum ML_5 = \begin{bmatrix} -[(ZL_5 - ZL_2)R_2] + [(XL_5 - XL_3)R_3] \\ +[(ZL_5 - ZL_4)R_4] - [(XL_5 - XL_6)R_5] \\ -[(ZL_5 - ZL_6)R_6] + [(XL_5 - XL_7)R_7] \\ -[(XL_{-} - XC_{-})C^F] + [(ZL_{-} - ZC_{-})C^F] \\ +[(XL_{-} - XC_{-})C^F] - [(ZL_{-} - ZC_{-})C^F] \\ -[(Z_F - ZL_5)F_X] + [(Z_F - ZL_5)F_Y] \\ +[(X_F - XL_5)F_Z] \end{bmatrix} \quad (1.5)$$

$$\sum ML_6 = \begin{bmatrix} [(ZL_1 - ZL_6)R] - [(ZL_6 - ZL_2)R] \\ -[(XL_3 - XL_6)R_3] + [(KL_4 - XL_6)R_4] \\ +[(ZL_6 - ZL_4)R_4] + [(XL_5 - XL_6)R_5] \\ -[(ZL_6 - ZL_5)R_5] + [(XL_6 - XL_7)R_7] \\ +[(XC_{-} - XL_{-})C^F] - [(ZC_{-} - ZL_{-})C^F] \\ -[(Z_F - ZL_6)F_X] + [(X_F - XL_6)F_Y] \\ +[(Z_F - ZL_6)F_Y] + [(X_F - XL_6)F_Z] \end{bmatrix} \quad (1.6)$$

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$$\sum ML_1 = \begin{bmatrix} [(ZL_1 - ZL_7)R_1] - [(ZL_7 - ZL_2)R_2] \\ -[(XL_1 - XL_7)R_3] + [(XL_4 - XL_7)R_4] \\ +[(ZL_7 - ZL_4)R_4] + [(XL_5 - XL_7)R_5] \\ -[(ZL_5 - ZL_7)R_5] + [(XL_6 - XL_7)R_6] \\ +[(ZL_1 - ZL_7)R_6] + [(XC_1 - XL_7)C^F] \\ +[(ZC_2 - ZL_7)C_2^F] - [(ZC_3 - ZL_7)C_3^F] \\ +[(XC_1 - XL_7)C^F] - [(Z_F - ZL_7)F] \\ -[(X_F - XL_7)F_Y] - [(Z_F - ZL_7)F_Y] \\ +[(X_F - XL_7)F_Z] \end{bmatrix} \quad (1.7)$$

$$\sum MC_1 = \begin{bmatrix} -[(ZC_1 - ZL_1)R_1] - [(ZC_1 - ZL_2)R_2] \\ +[(XL_4 - XC_1)R_4] + [(ZC_1 - ZL_4)R_4] \\ +[(ZC_1 - ZL_5)R_5] - [(XC_1 - XL_5)R_5] \\ +[(ZC_1 - ZL_6)R_6] - [(ZC_1 - ZL_7)R_7] \\ +[(ZC_1 - ZC_2)C_2^F] + [(XC_1 - XC_3)C_3^F] \\ -[(ZC_1 - ZC_3)F_Y] - [(X_F - XC_1)F_Y] \\ -[(ZC_1 - Z_F)F_Y] + [(XC_1 - X_F)F_Z] \end{bmatrix} \quad (1.8)$$

$$\sum MC_2 = \begin{bmatrix} [(ZL_1 - ZC_2)R_1] - [(ZC_2 - ZL_2)R_2] \\ +[(XC_1 - XL_1)R_3] - [(XC_2 - XL_4)R_4] \\ +[(ZC_2 - ZL_4)R_4] - [(XC_2 - XL_5)R_5] \\ -[(XC_1 - XL_6)R_6] + [(ZC_2 - ZL_7)R_7] \\ -[(XC_1 - XC_3)C_3^F] + [(XC_1 - XC_2)C_2^F] \\ -[(Z_F - ZC_2)F_X] + [(XC_2 - X_F)F_Y] \\ +[(Z_F - ZC_2)F_Y] - [(XC_2 - X_F)F_Z] \end{bmatrix} \quad (1.9)$$

$$\sum MC_3 = \begin{bmatrix} [(ZL_1 - ZC_3)R_1] - [(ZC_3 - ZL_2)R_2] \\ -[(XL_1 - XC_3)R_3] + [(XL_4 - XC_3)R_4] \\ +[(ZC_3 - ZL_4)R_4] + [(XL_5 - XC_3)R_5] \\ -[(ZL_5 - ZC_3)R_5] - [(XL_6 - XC_3)R_6] \\ +[(ZC_1 - ZL_6)R_6] + [(ZC_3 - ZL_7)R_7] \\ +[(XC_1 - XC_2)C_2^F] - [(Z_F - ZC_3)F_X] \\ +[(X_F - XC_3)F_Y] + [(Z_F - ZC_3)F_Y] \\ +[(X_F - XC_3)F_Z] \end{bmatrix} \quad (1.10)$$

After150 iterations, fixture layouts for minimum moment values are selected. The layouts for minimum moment values are shown in Table 1.11. Table 1.12 shows the optimal layout obtained from GA for minimum deformation of the workpiece

Position of fixture elements along particular axis (mm)										Moment
L_1	L_2	L_3	L_4	L_5	L_6	L_7	C_1	C_2	C_3	(Nmm)
12.6	5.30	22.0	107.9	55.8	90.25	11.6	23.0	27.1	59.2	1.5754
10.5	16.6	20.2	76.0	27.5	109.3	78.5	29.9	31.2	99.3	73.2711
26.9	9.81	29.4	102.1	27.5	49.26	23.5	13.7	32.4	22.8	68.7484
104.5	33.6	19.7	120.6	79.0	63.5	70.7	114.3	29.8	63.5	0.08646
29.2	18.7	28.5	70.8	53.7	13.77	47.6	28.6	27.2	55.1	17.4049

Table 1.12 Optimum layout with 3-3-1 locators

Position of fixture elements along particular axis (mm)										D_{max}
L_1	L_2	L_3	L_4	L_5	L_6	L_7	C_1	C_2	C_3	(mm)
104.58	33.6	19.7	120.06	79.0	49.39	70.79	114.3	29.8	63.5	0.038894

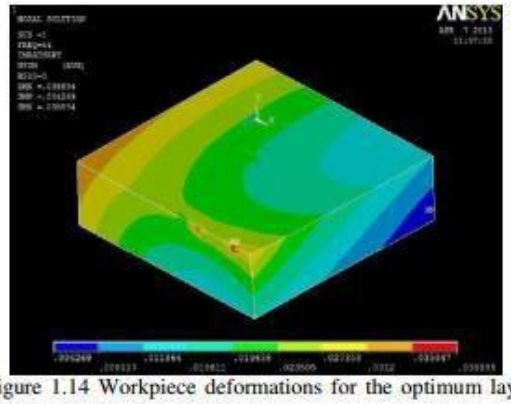

Figure 1.14 Workpiece deformations for the optimum layout with 3-3-1 locating scheme

Figure1.14 shows the diagrammatical representation of the workpiece deformations for the 3-3-1 optimum layout. Workpiece deformations report a maximum deformation of 0.038894 mm, which shows 9.9% of reduction in workpiece elastic deformation compared with the maximum deformation of 3-2-1 optimum layout.

1.4 FINETUNING OF 3-3-1 OPTIMUM LAYOUT Thefollowing graphs in Figures 1.15(a) to 1.15(j) demonstrate the variations of deformation values for various positions of locators and clamps and the new coordinate values of fixture elements are selected for least workpiece deformation. As the locator L7 was inserted between locators

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L1 and L2, the finetuning of locator L7 is considered after the positioning refinement of locators L1 and L2. Here, the position of locator L5 has more influence on minimizing workpiece deformation than other fixture elements. Table 1.13 presents the refined optimum layout of 3-3-1configuration. Figure 1.16 shows workpiece deformations for the refined optimum layout after finetuning and it reports that the maximum deformation is 0.035932 mm. This shows 7.6% reduction in maximum workpiece deformation compared to deformation of optimum layout before finetuning.

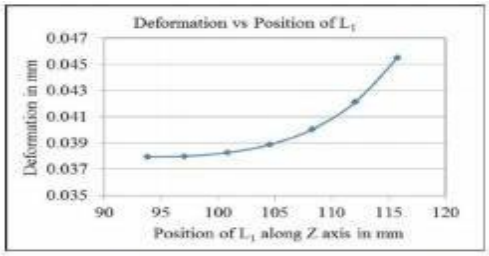

Figure 1.15(a) Position of Locator L_1 Vs Workpiece deformation

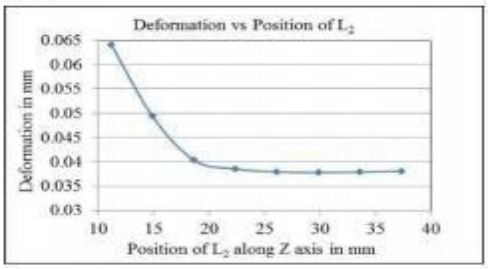

Figure 1.15(b) Position of Locator L_2 Vs Workpiece deformation

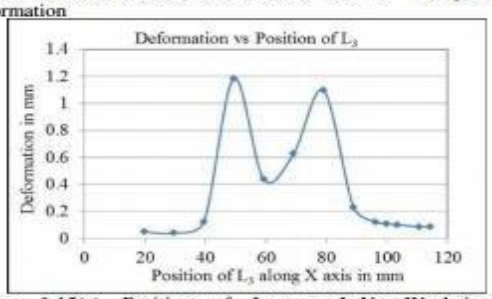

Figure 1.15(c) Position of Locator L_3Vs Workpiece deformation

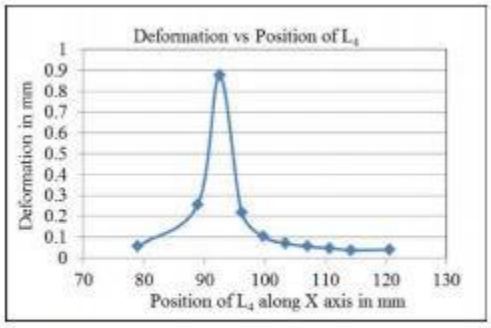

Figure 1.15(d) Position of Locator L_4 Vs Workpiece deformation

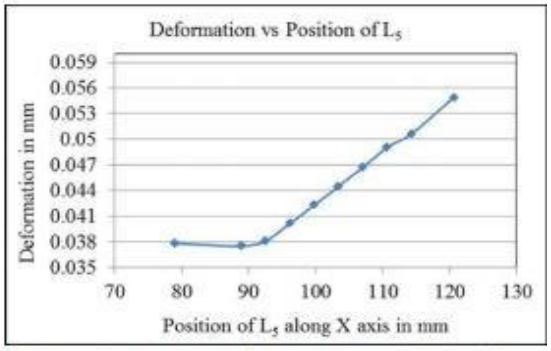

Figure 1.15(e) Position of Locator L_5 Vs Workpiece deformation

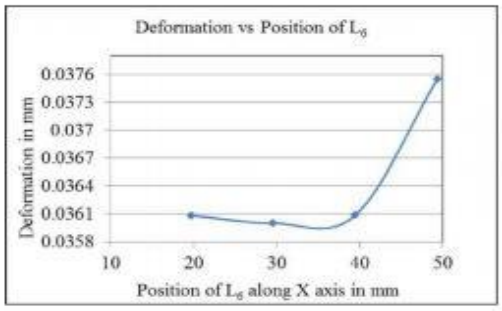

Figure 1.15(f) Position of Locator L_6 Vs Workpiece deformation

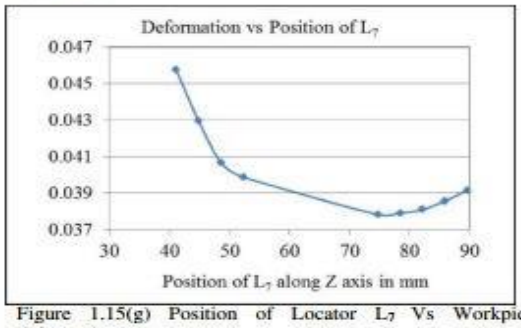

Figure 1.15(g) Position of Locator L_7 Vs Workpiece deformation

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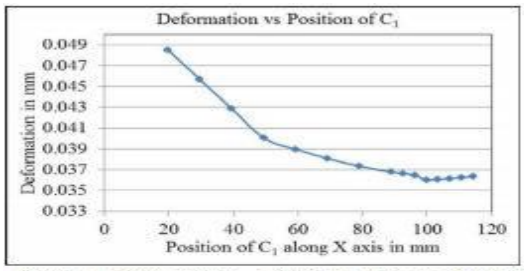

Figure 1.15(h) Position of Clamp C_1 Vs Workpiece deformation

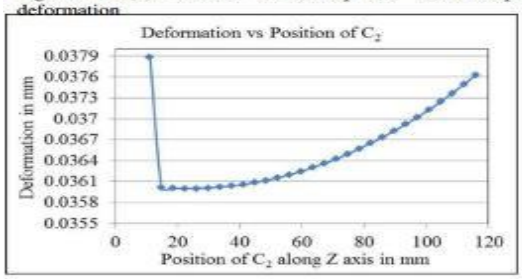

Figure 1.15(h) Position of Clamp C_2Vs Workpiece deformation

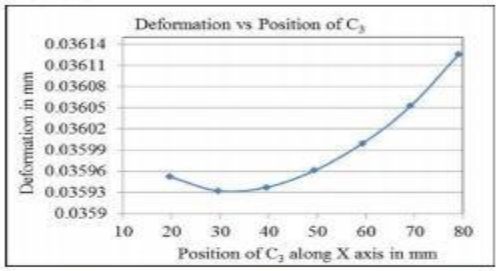

Figure 1.15(i) Position of Clamp C_3 Vs Workpiece deformation

Table 1.13 Refined optimum layout with 3-3-1 locators

Position of fixture elements along particular axis (mm)										D (mm)
L_1	L_2	L_3	L_4	L_5	L_6	L_7	C_1	C_2	C_3	
93.83	29.88	29.63	114.30	88.90	29.63	74.71	99.78	26.15	29.63	0.035932

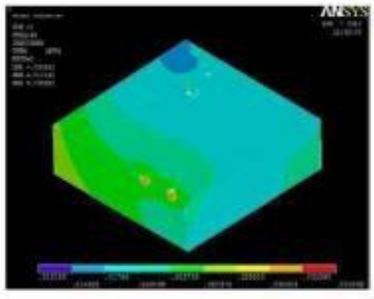

Figure 1.16 Workpiece deformations for the refined optimum layout with 3-3-1 locating scheme

CONCLUSION

MinimizingCompared with 3-2-1 locating scheme 7.4% of reduction in workpiece elastic deformation is achieved by using 3-3-1 locating scheme for the considered workpiece-fixture system. So the dimensional and form errors of the workpiece can be reduced more with 3-3-1 scheme than with 3-2-1 locating scheme. As 3-3-1 locating scheme is more suitable than 3-2-1 locating scheme for constraining the movement of prismatic components while machining, more accurate components can be achieved by using the 3-3-1 locating scheme.

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