International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Finite Element Analysis and Optimization of Machine Fixture

SD.Ruksar Begum†, T.Sita Ram Babu† and M.JagadeeswaraRao†

†Balaji Institute of Engineering and Sciences, Warangal, Hyderabad, Telangana, India.
†Design for Manufacture, University College of Engineering, O.U, Hyderabad, Telangana, India.

Accepted 13 Aug 2015, Available online 20 Aug 2015, **Vol.5, No.4 (Aug 2015)**

Abstract

During machining operation, fixtures are used to locate and constrain a work piece. In any manufacturing operation, a certain amount of deformation will occur in the work piece due to clamping and machining forces. So the dimensional and form errors will occur in the work piece. A good fixture design minimizes work piece geometric and machining errors by limiting the work piece elastic deformation. An ideal fixture design exhibits minimal deformation while machining and it consists of optimal fixture layout, optimum clamping forces and optimum number of fixturing elements such as locators and clamps. Hence, in this research work, the machining fixture layout, clamping forces and number of fixturing elements optimization problems are considered with an objective of minimizing the work piece elastic deformation caused during machining. In this machining fixture layout optimization problem, the work piece is treated as elastic model and fixture elements are treated as rigid to predict the work piece elastic deformation, which influences the dimensional and form errors of the work piece. In this research work, Finite element solver ANSYS has been used to determine the work piece elastic deformation caused due to machining and clamping forces.

Keywords: *Fixtures, Optimization.*

1. Introduction

In a manufacturing industry, every product should undergo processes such as turning, facing, milling etc. On the completion of the process, the product at times, comes out with certain imperfections. These imperfections might or might not be within the acceptable range. These imperfections cause the machined Work piece to deviate from their ideal designed geometry which creates part errors. A considerable amount of these deviations occurring in any part will bring about high rejection rates. Hence poor quality and high rejection rates caused due to part errors remain major problems in the industries.

Dimensional and form errors of a work piece altogether form part error (Lange 1985). Dimensional error is defined as the deviation of the actual dimension from the desired value and shape or form error can be described as the deviation of the geometrical form of a part. These errors occur mainly because of work piece elastic deformations and constitute part error (Abdullah et al 2011). As all the materials are deformable in nature, deformations induced by cutting and clamping forces are inevitable.

If the dimensional and form errors seriously violate he dimensional tolerance, the machining process will lead to waste products. Therefore, reliable machining technologies should be employed to obtain consistent part shapes and machining accuracy (Wan Min et al 2005).In the machining process, the fixtures are used for the orientation and clamping of the work piece to be machined. Fixture is a work holding device, and is a fundamental part of almost every manufacturing operation from machining to assembly. Machining fixture is a precision device meant for locating and constraining the work piece during machining. It is used to establish and maintain the required position and orientation of a work piece, so that cutting operations can be performed on the work piece.

A typical machining fixture consists of number of locators and clamps. Locators are inactive fixture elements used to position the work piece while clamps are active fixture elements that are actuated mechanically, hydraulically, or pneumatically to apply clamping forces onto the work piece in order to resist external forces generated by the machining operation. In most of the cases, the clamping, locating positions and clamping force are selected based on experience and method of trial-and-error. To avoid slip, very high clamping forces may be applied arbitrarily on the component. A poor selection of the positions of the fixture elements and clamping forces can lead to undesirable work piece deformation, low dimensional and form accuracy of the work piece (Wang et al 2005).

2. Work piece geometry and machining parameters

The geometry and features of the work piece are shown in Figure 3.1. The material of the work piece is

*Corresponding author **SD.Ruksar Begum and T.Sita Ram Babu** are working as Assistant Professor

Aluminium 7075-T6 with a Poisson ratio of 0.33, Young's modulus of 72 GPa and the density of 2795 kg/m^3. Because of its low weight and more elongation, Aluminium deserves more attention in the literature related to part accuracy (Li and Melkote 2001) and behavior (Mahadevan et al 2006). The outline dimensions of the work piece are 127 mm × 127 mm × 38.1 mm. The end milling of a 25.4 mm slot is simulated, with the cut starting at 101.6 mm, 34.29 mm, 127 mm and ending at 101.6 mm, 34.29 mm, 0 mm respectively. The end milling operation is carried out on the work piece. The machining parameters of the end milling operation are given in Table 3.1. The entire tool path is discretized into 5 load steps and cutting force directions are determined by the cutter position.

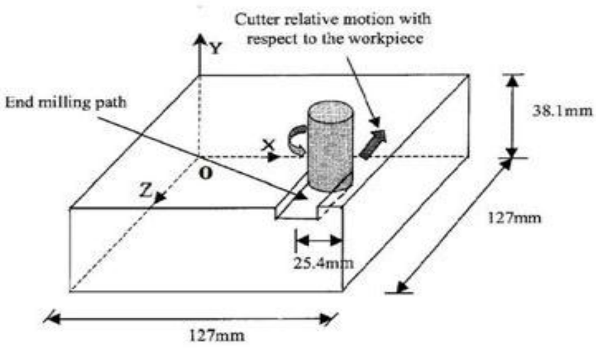

Fig. 1 A Prismatic Work Piece and End Milling Path

Table 1 Machining parameters

Machining parameters	
Cutter diameter	25.4 mm
Number of flutes	4
Spindle speed	660 rpm
Feed	0.2032 mm/tooth
Radial depth	25.4 mm
Axial depth	3.81 mm
Helix angle	45^0
Radial rake angle	10^0
Projection length	92.08 mm
Machining forces	F_X=1105.67 N; F_Y=442.10 N; F_Z=283.56 N
Clamping forces	$C^F{}_1$=738.5 N; $C^F{}_2$=341.1 N; $C^F{}_3$=1026.8 N

2.1 Machining fixture plan

The fixture plan for holding the work piece in the machining operation is shown in Figure 3.2. The 3-2-1 locator principle (Li and Melkote 2001) 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 (Nee et al 2004). The other degrees of freedom are constrained by clamp elements. Here three clamps are used to restrain the work piece.

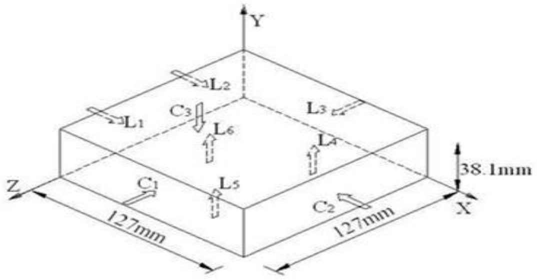

Fig. 2 Work Piece-Fixture Configuration

In the fixture layout, six locators and three clamps are used to constrain the work piece. Each fixturing element has three coordinate values. So the number of variables is twenty seven. In all cases, one variable in each element remains always constant and one more variable is also assumed to be constant. Hence the numbers of design variables which are reduced from 27 into nine are as follows:

The position of L_1 varies only along the Z direction.
The position of L_2 varies only along the Z direction.
The position of L_3 varies only along the X direction.
The position of L_4 varies only along the X direction.
The position of L_5 varies only along the X direction.
The position of L_6 varies only along the X direction.
The position of C_1 varies only along the X direction.
The position of C_2 varies only along the Z direction.

Table 2 Fixturing elements and coordinate values

Fixturing Elements	Coordinate values (mm)		
	Constant		Variable
Locator 1 (L_1)	X = 0;	Y = 19.05	Z = 73.5 to 117
Locator 2 (L_2)	X = 0;	Y = 19.05	Z = 10 to 53.5
Locator 3 (L_3)	Y = 19.05;	Z = 0	X = 10 to 117
Locator 4 (L_4)	Y = 0;	Z = 14.941	X = 73.5 to 122
Locator 5 (L_5)	Y=0;	Z = 112.06	X = 73.5 to 122
Locator 6 (L_6)	Y=0;	Z = 63.5	X = 10 to 53.5
Clamp 1 (C_1)	Y = 19.05;	Z = 127	X = 10 to 117
Clamp 2 (C_2)	X = 127;	Y = 19.05	Z = 10 to 117
Clamp 3 (C_3)	Y = 38.1;	Z = 63.5	X = 10 to 78.9

3. Finite element modelling of the work piece-fixture system

In this work, FEM software ANSYS has been used for FE modelling and analysis. Figure 3.3 shows FEM flow chart and Figure 3.4 shows the finite element model of the work piece-fixture system. For discretization, hexahedral elements are chosen because of their usage in fixture design problems (Liu et al 2007) and more number of nodes per elements.

3.1 Boundary conditions made for the finite element modelling

Work piece is an elastic body whereas the fixturing elements are rigid body.

Work piece is discretized into the hexahedral element. The number of degrees of freedom per node is three. Locators are modelled as displacement constraints that prevent work piece translation in the normal direction. The clamping forces are modelled as a point force acting over the work piece-clamp contact point. Machining forces are considered as harmonic forces.

Type of Element = solid 45.
Type of mesh = Mapped mesh.

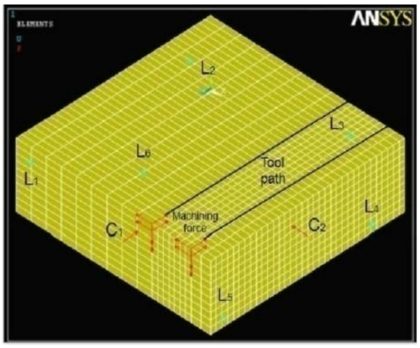

Fig. 3 Finite Element Model of work piece-Fixture System

Harmonic analysis is carried out to simulate the work piece-fixture system under machining conditions. Initially, the modal analysis is conducted to find out the natural frequency of the system. It ensures that the excitation frequency is not equal to the natural frequency of the system in order to avoid resonance. The induced frequency of the work piece-fixture system is determined by using the cutter speed and the number of flutes in the tool. Then, harmonic analysis is conducted to find out the response of the system with respect to the harmonic frequency.

3.2 Excitation Frequency of the Work piece-Fixture System

The excitation frequency of the work piece-fixture system is found out by using the values of cutter speed and the number of flutes in the tool.

Spindle speed = 660rpm
No. of flute = 4
Spindle Speed = 660/60 = 11 revolutions per sec
Time taken for ¼ revolution = one cycle (since no. of flute is four)
So time taken for one cycle is = 1/(11*4)
= 1/44 sec
It is known that
Frequency =1/T = 44 Hz.
So the excitation frequency of the work piece-fixture system is 44 Hz.

3.3 Modal Analysis on Work piece-Fixture System

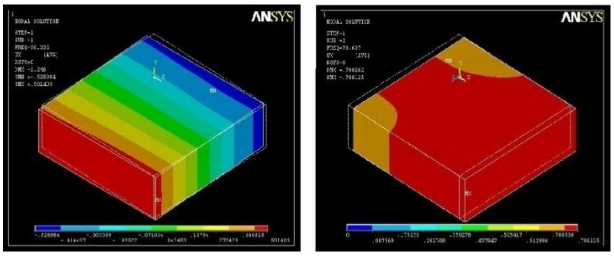

Fig. 4 Mode 1: 56.332 Hz and Mode 2: 73.637 Hz

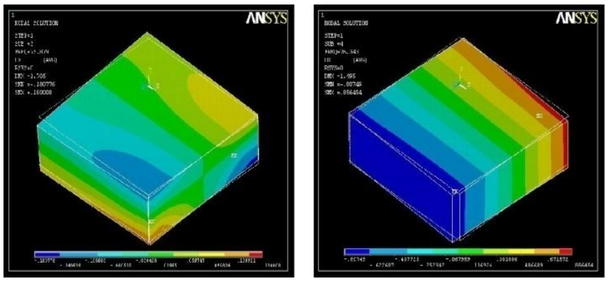

Fig. 5 Mode 3: 75.879 Hz and Mode 4: 76.343 Hz

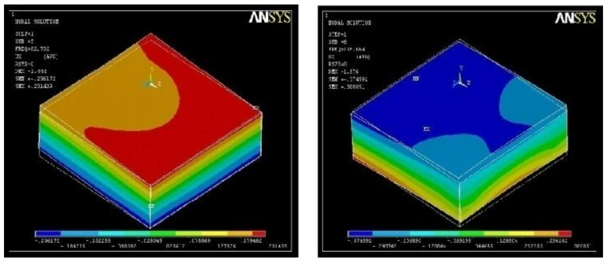

Fig. 6 Mode 5: 82.732 Hz and Mode 6: 116.664 Hz

3.4 Harmonic Analysis of Work piece-Fixture System

In harmonic analysis, the system response is simulated with regard to the harmonic frequency. In milling operation, the machining forces which are exerted on the work piece are periodical forces. So it would be more suitable to represent the milling forces as harmonic forces. The excitation frequency of the work piece-fixture system is determined by using the cutter speed and the number of flutes in the tool. The excitation frequency is 44 Hz.

The harmonic frequency is defined in the range of 0 to 44 Hz. Eleven sub steps are taken up within the load step. The clamping forces acting on the system are static forces. So, Static analysis is carried out first, by considering the clamping forces and the displacement constraints then a prestressed harmonic analysis is carried out by considering the machining forces and the harmonic frequency. It is indeed important to consider the material removal effects for achieving accurate realistic results in the dynamic analysis. By using element death technique in ANSYS, simulation of the material removal effect in the dynamic analysis is done. Here, the entire tool path is discretized into five load steps.

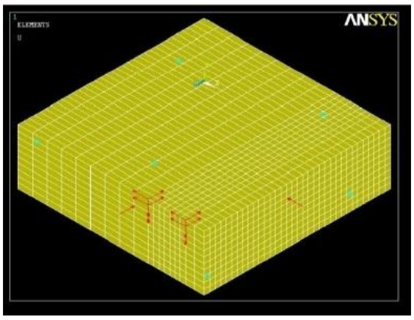

Fig. 7 Load step 1

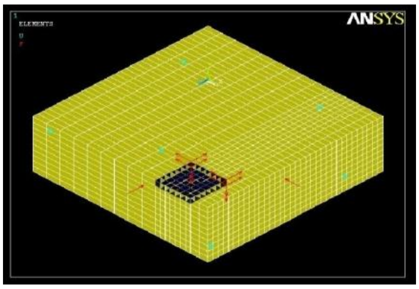

Fig. 8 Load step 2

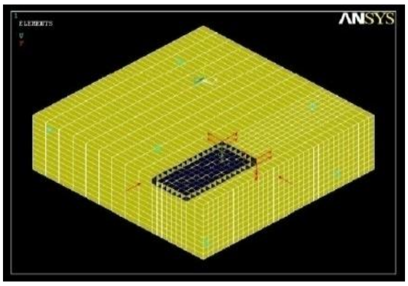

Fig. 9 Load step 3

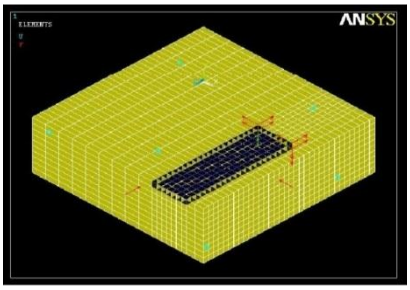

Fig. 10 Load step 4

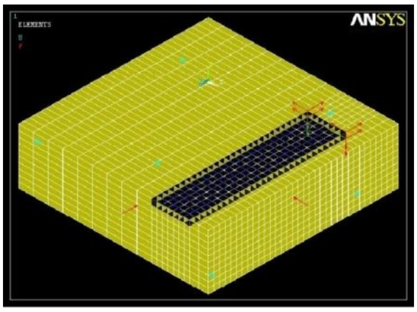

Fig. 11 Load step 5

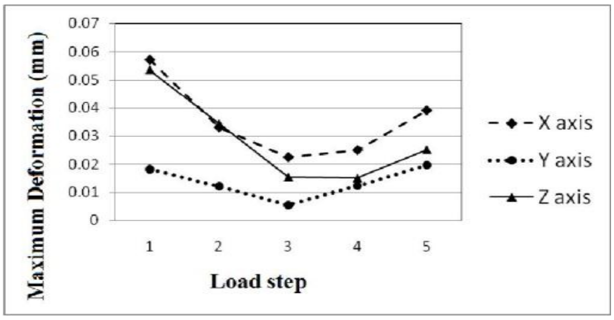

Fig. 12 Maximum Deformation Vs Load Step

The results of the harmonic analysis, in which the maximum deformation along the X, Y and Z axes for the five load steps, are plotted. It shows that the work piece undergoes more deformation in X axis with the load step 1, i.e. the direction at which tangential force of the cutting tool acts. The deformation is very less in the Y axis, compared to the other two axes. More deformation occurs along X axis because of more amount of cutting force is acting along X axis. During load step 1 the cutting forces are acting at the extreme outer portion of the work piece and are nearer to free edges of the work piece to have more deformation.

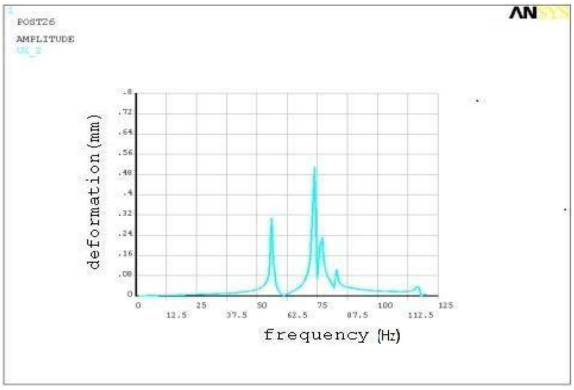

Fig. 13 Work Piece Deformation versus Frequency

The amplitude values are maximum when excitation frequency matches with natural frequency of the work piece-fixture system.

In the FE analysis of the work piece-fixture system for milling operation, the machining forces which are exerted on the work piece are periodical forces. So the milling forces are treated as harmonic forces. The clamping forces acting on the system are static forces. So initially, static analysis is carried out by considering the locators as displacement constraints and the clamping forces. After the static analysis, a Pre-stressed harmonic analysis is carried out by considering the machining forces and the harmonic frequency. In the Pre-stressed harmonic analysis, the stress due to the clamping is taken into account. So the FE analysis of the work piece-fixture system simulates the system response and gives work piece deformation with respect to the harmonic and clamping forces.

4. Design and optimization of machining fixture layout

Table 3 Deformation for different layouts

Layout	Deformation
1	0.1602
2	0.1022
3	0.2675
4	0.1393
5	0.0704
6	0.1718
7	0.1190
8	0.0999
9	0.0580
10	0.1130
11	0.1103
12	0.0999
13	0.1665
14	0.2087

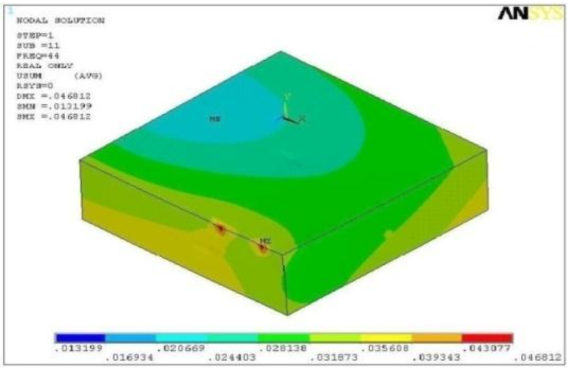

Fig. 14 Deformation distributions for optimum layout

Refining of optimum layout

To improve the results, the optimized layout by ANN is further fine-tuned with the variation of deformation values for various positions of locators and clamps. As mentioned in Section 4.3.3, the new locations for all the locators and clamps have been found based on the work piece deformation. A minimum deformation of 0.04493 mm occurs when the position of L_1 is at 85.91 mm and 0.04492 mm deformation is obtained when L_2 is at 44.82 mm along Z axis.

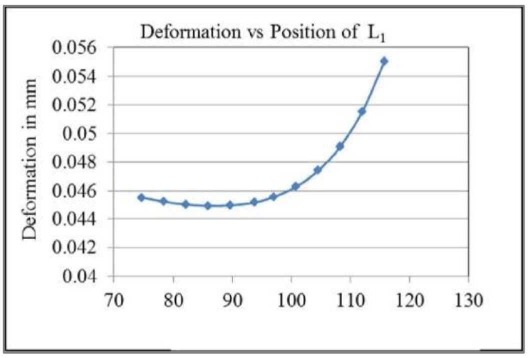

Fig. 15 Position of Locator L_1vs Work piece Deformation

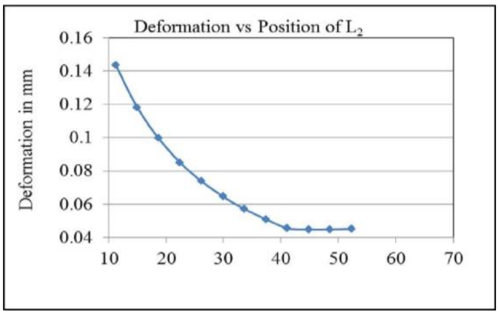

Fig. 16 Position of Locator L_2vs Work piece Deformation

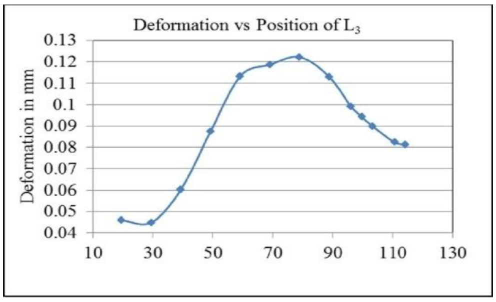

Fig. 17 Position of Locator L_3 vs. Work piece Deformation

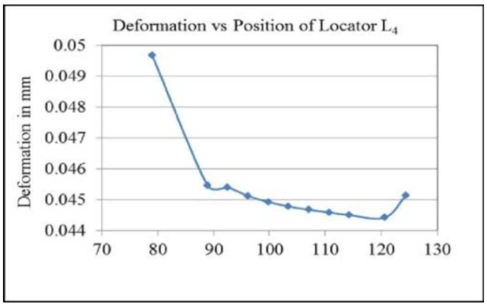

Fig. 18 Position of Locator L_4 vs. Work piece Deformation

For both locators L_5 and L_6, the minimum deformation occurs when the locators are near the initial position and deformation is further reduced with the refined positions of L_5 and L_6. Figure 5.2(e) and 5.2(f). For the refined position of $L_{5,}$ the deformation is 0.0438 mm and for $L_{6,}$ it is 0.0435 mm.

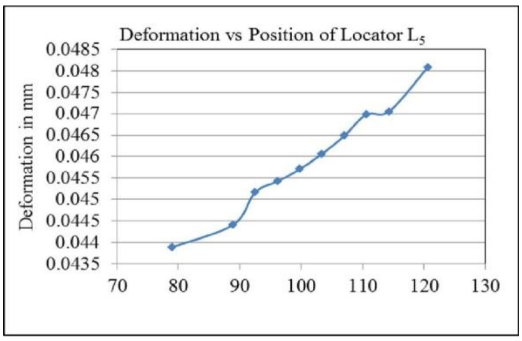

Fig. 19 Position of Locator L_5vs Work piece Deformation

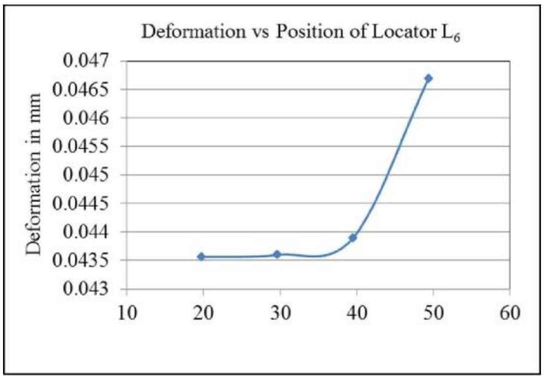

Fig. 20 Position of Locator L_6vs Work piece Deformation

The changes in work piece deformation for various clamping positions and indicate that deformation decreases when the position of C_1 increases along X axis. Related to the position of $C_{2,}$ the deformation is minimum when C_2 lies in the middle of its range and near the initial position of $C_{3,}$ the work piece deformation is minimum. Refined positions of C_1, C_2 and C_3 give least deformations of 0.0434 mm, 0.042811 mm and 0.042805 mm respectively. The work piece deformations vary with different positions of individual fixture elements and for particular position of a fixture element the work piece deformations are less because of less imbalanced moment.

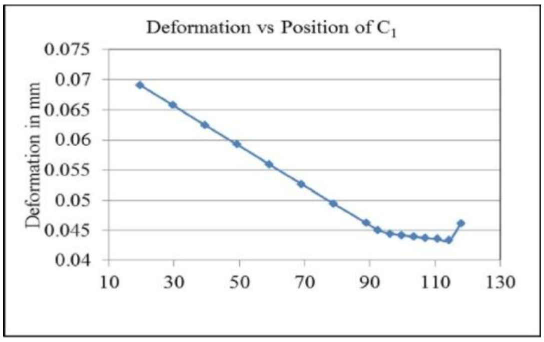

Fig. 21 Position of Clamp C_1vs Work piece Deformation

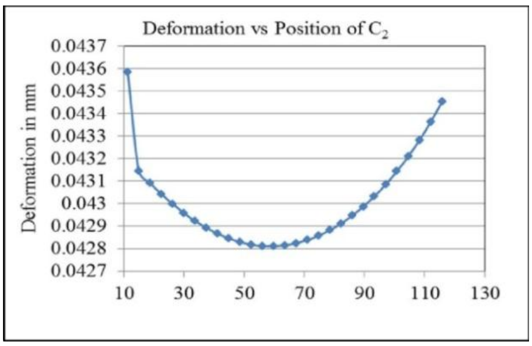

Fig. 22 Position of Clamp C_2 vs Work piece Deformation

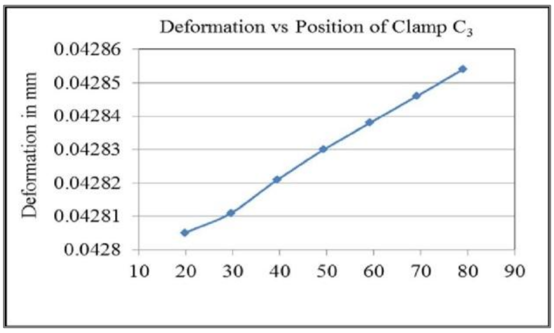

Fig. 23 Position of Clamp C_3vs Work piece Deformation

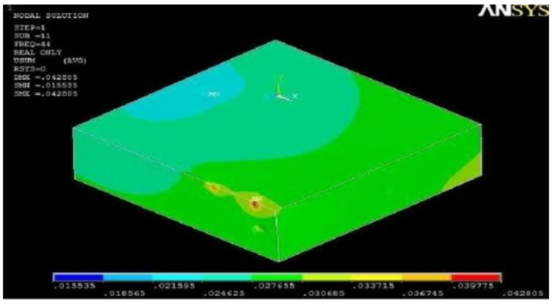

Fig. 24 Work piece Deformations for the Refined Optimum Layout

Conclusions

1. Minimizing work piece deformation due to clamping and cutting forces is essential to ensure accuracy and production quality in the machining operation.

2. To make sure that a work piece is manufactured according to required dimensions and tolerances, it should be appropriately positioned and clamped.

3. In the number of fixture elements optimization, the addition of one more locator produces more work piece deformation when it is simply added with the optimal machining fixture layout.

4. At the same time, the totally rearranged overall optimum layout including the newly added locator produces less work piece deformation.

5. In this work, machining fixture layout optimization methods have been applied in the case studies and consequently, the optimal fixture layouts and their work piece deformation values have been obtained.

6. Optimization of number of fixture elements, positions of fixture elements and magnitude of clamping forces are necessary to minimize work piece deformation due to clamping and cutting forces.

7. In the FE analysis of the work piece-fixture system for milling operation, the machining forces which are exerted on the work piece are periodical forces. So the milling forces are treated as harmonic forces.

8. The clamping forces acting on the system are static forces. So initially, static analysis is carried out by considering the locators as displacement constraints and the clamping forces.

9. After the static analysis, a prestressed harmonic analysis is carried out by considering the machining forces and the harmonic frequency.

10. In the prestressed harmonic analysis, the stress due to the clamping is taken into account. So the FE analysis of the work piece-fixture system simulates the system response and gives work piece deformation with respect to the harmonic and clamping forces.

11. Fixture layout is optimized with an objective of minimizing the overall elastic deformation of the work piece, which influences the dimensional and form errors

12. The number of fixturing elements is also optimized for minimum work piece deformation.

References

J.B.Humphreys, (1961), Effect of composition on the liquidus and eutectic temperature and on the eutectic point of cast irons, *BCRIAJ*,19,609-621.

S. Vallapuzha, E.C. De Meter, S. Choudhuri and R.P. Khetan, (2002) "An investigation into the use of spatial coordinates for the genetic algorithm based solution of the fixture layout optimization problem", *International Journal of Machine Tools and Manufacture 265–275*.

K. Krishna kumar and S.N. Melkote, (2000) "Machining fixture layout optimization", *International Journal of Machine Tools and Manufacture 40 579– 598.*

Wang MY, 2001 "A full-kinematic model of fixtures for precision locating applications" in IEEE/RSJ *International conference on intelligent robots and systems, Maui (HI USA). p. 1135–40.*

B. Li and B.W. Shiu, (2001) "Principle and simulation of fixture configuration design for sheet metal assembly with laser welding. Part 2. Optimal configuration design with the genetic algorithm", *International Journal of Advanced Manufacturing Technology 18 276–284.*