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PARAMETRIC DESIGN OF A JIG & FIXTURE USING CAE AND FEM ANALYSIS OF POSITIONERS AND CLAMPING

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ABSTRACT

Use of Jigs and fixtures can guarantee the proper fixation and positioning of cutting tools with respect to work piece during the entire manufacturing process, helping in manufacturing of identical parts at required accuracy and production speed. In this paper, parametric modelling of a jig and fixture for drilling a cylindrical part, with mounting surface perpendicular to the cutting tool, has been carried out in CAE. The stability condition of the work piece during the drilling process has been evaluated by studying the forces due to the cutting tool and the clamp on the work piece, using the built-in FEM tools. The plastic deformation of the work piece must be prevented, and the elastic deformation should be such that it does not cause separation of the work piece from the positioner. Results show the high potential of the software in such design and modelling practices. A static analysis of the work piece secured in a jig and fixture has been performed to obtain the applied loads accurately and quickly. This helps prevent the extra cost incurred due to improper design.

Keywords*:* Jig and fixture, Positioning, Clamping, Finite element.

INTRODUCTION

The process of design of a set of jig and fixture is one in which a design is evaluated, and a technique is developed for increased efficiency and productivity. With the help of jig and fixture technology various industries can manufacture special tools required for the mass production with high degree of accuracy. For increased reliability in the process of designing a set of jig and fixture, the following prerequisites must be fulfilled[1,2]:

1. Accurate understanding of the requirements (both quality and quantity with a knowledge of main purpose of the design)
2. Study and understanding of various methods for obtaining an optimum set (understanding the components and calculation procedures)
3. Prior experience in performing the design process (trial and error in previous designs)
4. Appropriate knowledge of testing methods and the related procedures (error analysis, margins, etc.)

The role of jig and fixture as an important tool in manufacturing shall be determined after the specification of the production process. Therefore, the designer should pay attention to the following basic parameters when designing a jig and fixture set:

1. Make it possible for an operator to attain his/her maximum efficiency, through the use of jig and fixture set,
2. Produce parts with the minimum cost,
3. Continuously produce identical high quality products, with the help of the jig and fixture set, or in other words the production be under the operator's control,
4. The design should be such that it guarantees an errorless process, or in other words, it should be impossible for the operator to make any error, and operator safety is also taken care of,
5. The materials of the tools and methods of production should not result in high cost, and the tools should have suitable operating life[3].

Extensive research has been done to optimize the clamping force, and to model the interaction between the work piece and the clamping components. Wang *et al.*[4] have provided analytical methods and techniques for development of Intelligent Fixture Systems (IFS).

Based on Newton-Euler Equations, Melkote[5] proposed an algorithm for optimization of clamping force and fixture arrangement for a work piece during machining process.

Jeng *et al.*[6] introduced an algorithm which was based on the assumption that the center of gravity (CG) does not move at the clamping surfaces.

Hamidi *et al.*[7] have used finite element method (FEM) for analysis of clamping system for a work piece. They have also studied the friction between the work piece and the clamps.

Any work piece, which is not fixed in space, is free to move in all the 12 directions (it has 6 degrees of freedom). That means the object can move linearly along the coordinate axes (in both the +ve and –ve directions) and rotate along the same axes in either direction. For the accurate positioning and securing of the work piece in the jig and fixture, these degrees of freedom must be restrained.

In order to restrain the movement of the work piece in a jig and fixture and support it against the machining forces, positioners and clamps are used. Positioners restrain some degrees of freedom, and the other degrees of freedom of the work piece are restrained by the application of appropriate clamping force[3]. Traditionally, experience has played the main role in determination of the clamping forces, and often as a measure of increased reliability, a bigger force is applied. Application of this additional force, for the case of close tolerances of the work piece, results in loss of dimensional accuracy. On the other hand, an insufficient clamping force will allow movement of the work piece during the machining process, which eventually results in a complete loss of dimensional accuracy[3]. Therefore, application of an optimum clamping force for securing the work piece is very essential. However, these forces should not cause plastic deformation in the work piece, and at the same time the elastic deformation should not cause separation of the work piece from the positioners[6].

The new CAE software has excellent design and modelling facilities, which provide a good opportunity for the designer to implement his/her ideas. It is also possible to obtain the fabrication engineering drawings at the end of design process easily. The other possibility is a preliminary static analysis that can be done using FEM, which will help in determining the design performance against the acting forces[8,9].

The Designed Jig and Fixture

The work piece and the jig and fixture set for drilling the work piece have been modelled in *Unigraphics NX* software[10]. The cylindrical work piece is as shown in Fig. - 1. It is presumed that the internal and external turning processes have been already carried out, and that now a hole of 10 mm diameter is to be made in the lateral surface (Fig. - 2). To perform this operation, it is necessary to rest the work piece on the drilling machine bed, and that its axis of symmetry is perpendicular to the drilling machine axis. Therefore, we use the internal cylindrical surface of the work piece for positioning the 10 mm hole with respect to the cutting tool. This makes it easier and speedier to put and remove the work piece from the jig.

After securing the mounting surface perpendicular to the cutting tool axis, a jig with right angle construction must be used. The jig body will be made up of construction steel St37-2[11] (Fig.- 3).

If we position with the cylindrical axis, it will be possible to restrain 9 out of 12 movements associated with an unrestrained work piece. It will have 3 remaining movements, which allow it to move in the positive x-direction and rotate in clockwise and anticlockwise directions around the axis (Fig. - 4). The cylindrical axis will be made up of alloy steel C45 of standard number 1.0535[11]. The remaining degrees of freedom can be eliminated, by the addition of the screw type fixture at the end of the cylindrical axis of the positioner and applying a standard torque for tightening the screw.

In order to avoid taking the nut off the axis screw completely every time the work piece is opened or closed, a special screw is considered at the end of positioner axis with a corresponding nut diameter smaller than the work piece cylindrical hole diameter. Therefore, M8 screw and nut combination has been used for this purpose.

Now to fasten the work piece, a C shape washer is used between the nut and the work piece

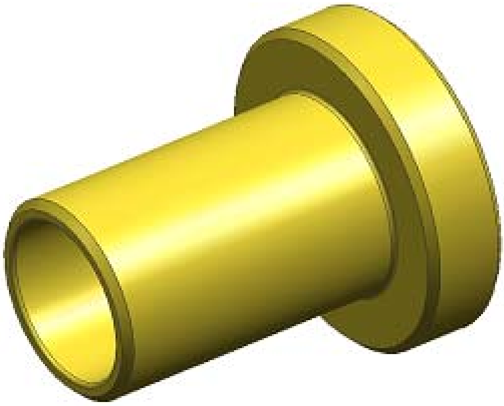

Fig. - 1: The work piece prior to drilling

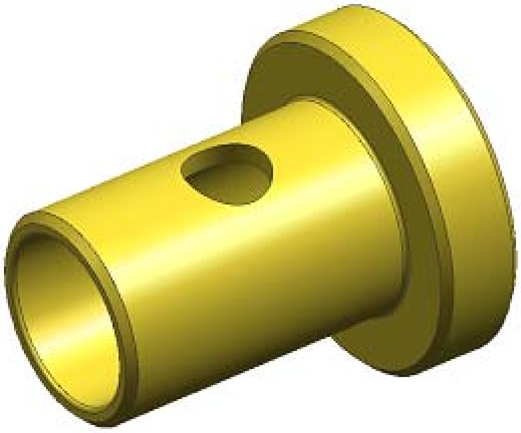

Fig. - 2: The work piece after drilling

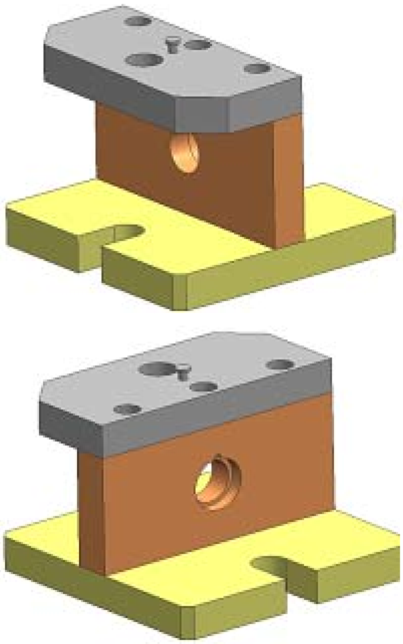

Fig. - 3: The jig and fixture construction

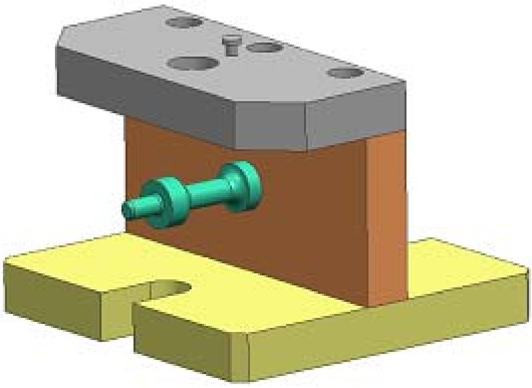

Fig. - 4: The axial positioner

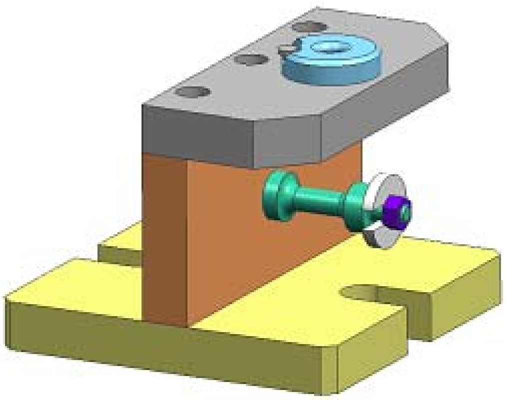

Fig. - 5: The clamping nut and washer and bush

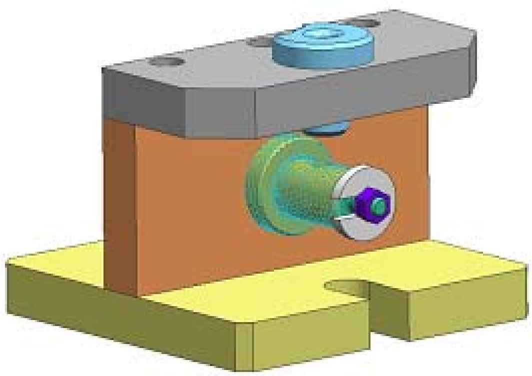

Fig. - 6: The complete model of jig and fixture and the work piece

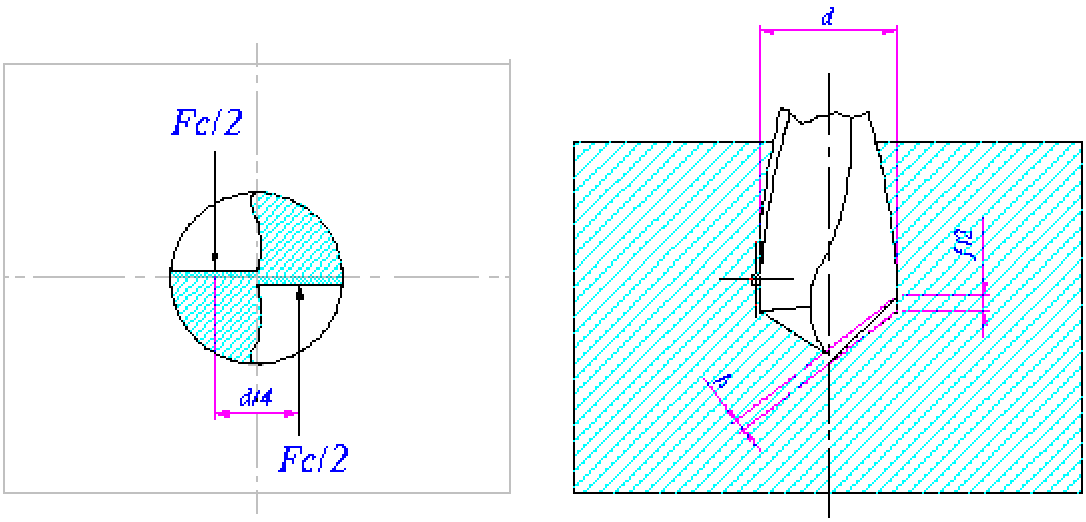

Fig. - 7: Drilling forces in the drilling process

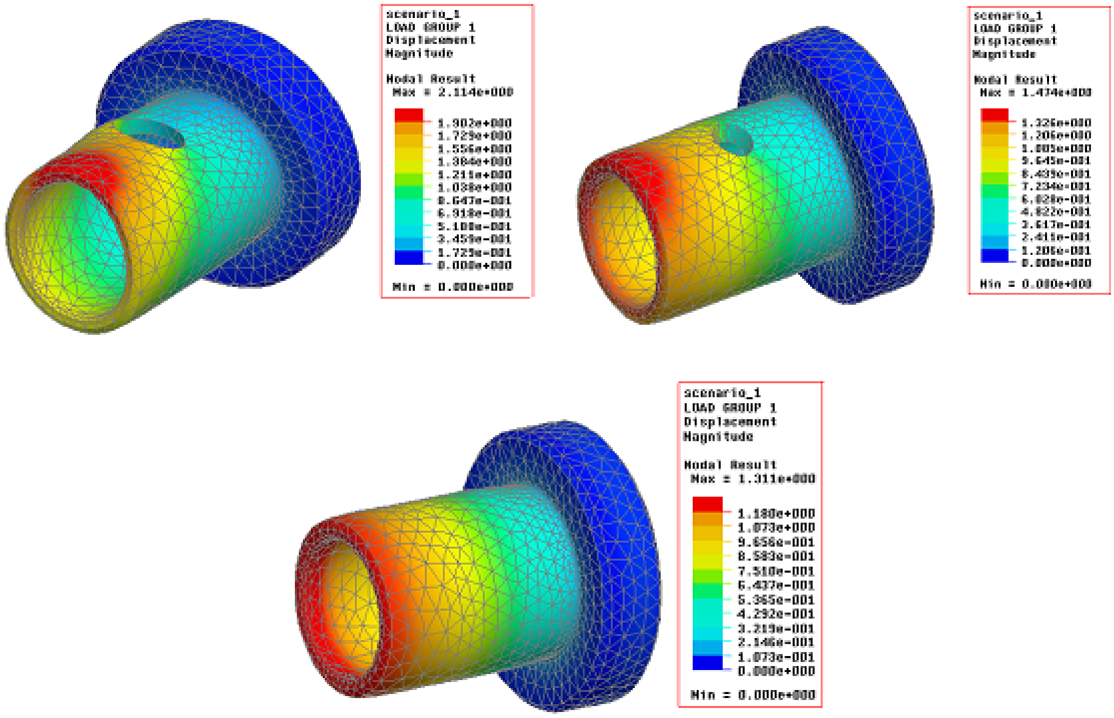

Fig. - 8: Stage 1 - first, second and third deformation case

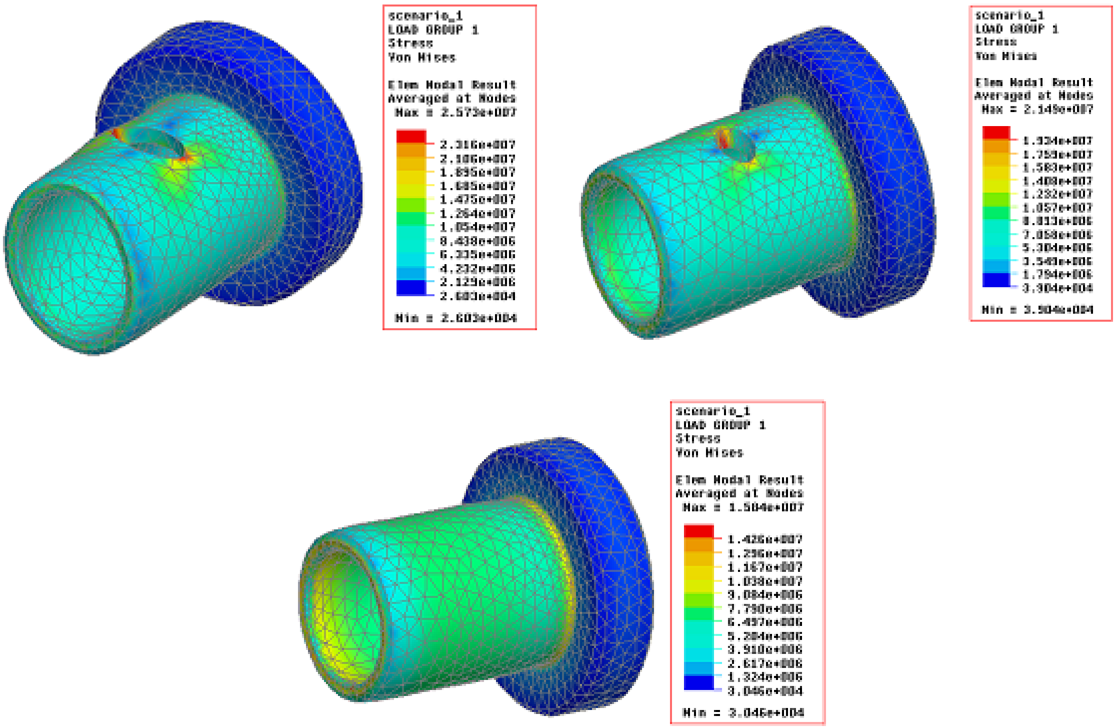

Fig. - 9: Von Mises stresses for the first, second and third case

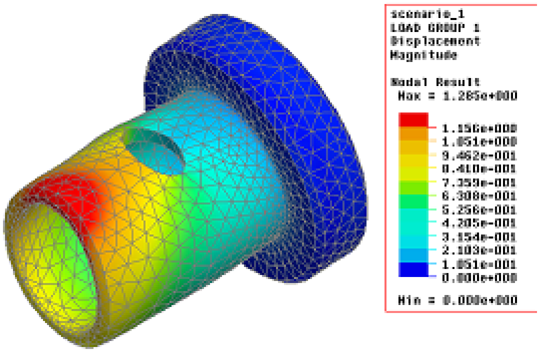

Fig. - 10: Stage 2 - first, second and third deformation cases

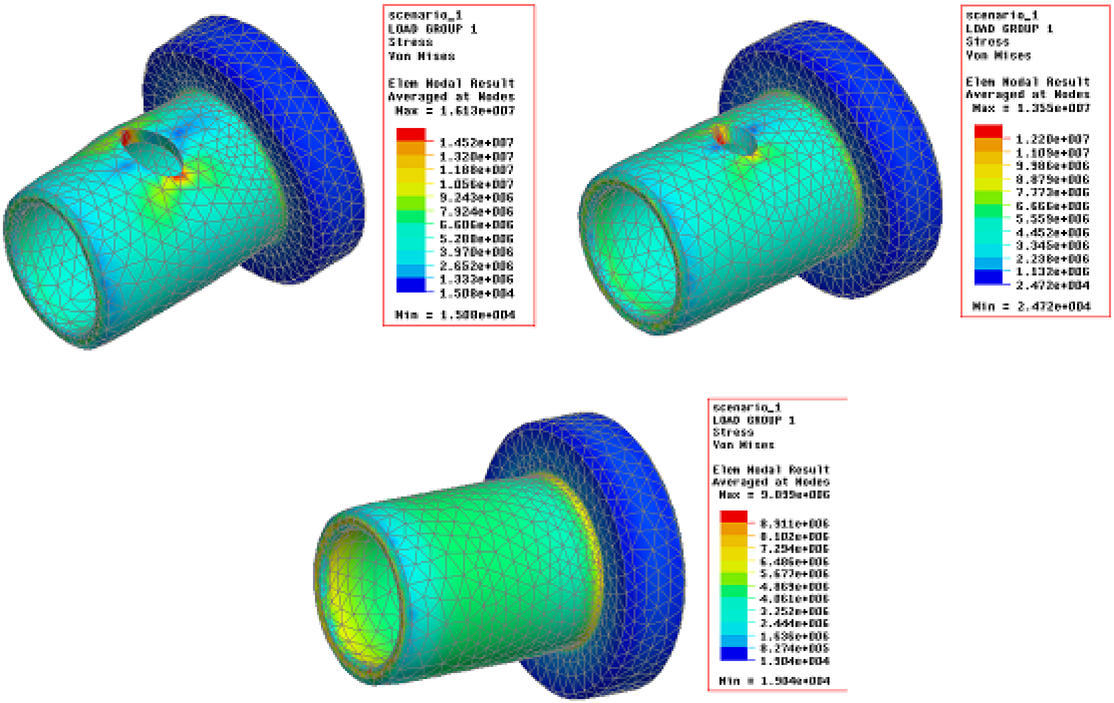

Fig. - 11: Von Mises stresses for the first, second and third case

(Fig. - 4). On slight loosening of the nut it is possible to free the washer and take out the work piece easily.

After drilling the hole in the work piece, the cutting tool will strike the positioner axis. Therefore, in order to prevent this interference and the possibility of egress of the chip, the middle portion of the positioner has a reduced diameter, and to prevent the rotation of the positioner axis, a small pin has been considered.

For the guidance of the cutting tool, a replaceable rotating bush made of nitrated steel with good heat and wear resistance and standard number 1.8507, is placed on the guide place, as shown in Fig. - 5. The complete jig and fixture model with the attached work piece is shown in Figure 6.

Drilling Force Theory

In the drilling process, the drilling operation is performed by a two-edge cutting tool (drill bit). On the basis of cutting wedge angle, the drilling bits are classified into three types; N, H and W. Two opposing forces from the drilling bit wedge act on the work piece, which create a torque, as shown in Fig. - 7. The following relations are used for estimation of the force and the drilling torque:

$$F_c = A.k_c \tag{1}$$

$$M_c = \frac{F_c.d}{4} \tag{2}$$

where,

d = diameter of the cutting tool

A = cutting bit cross section, given as:

$$A = \frac{d.f}{2} \tag{3}$$

f, which is the feed in one revolution, can be used for estimation of cutting bit thickness (h), with the following relation:

$$h = 0.43f \tag{4}$$

k_c, is the specific drilling force, which is determined using the following relation:

$$k_c = kC_1C_2 \tag{5}$$

The correction factors C_1 and C_2 are obtained from Table - 1. Constant *k* is the specific drilling force, whose magnitude is expressed in tabular form, and is defined on the basis of drilling speed and the material[12].

Finite Element Analysis

With the help of Unigraphics NX software, a static analysis using FEM has been carried out:

1. To study the forces from the cutting tool and those due to the clamping, on the work piece,
2. To evaluate the stability condition of the work piece during the drilling operation,
3. To determine if the work piece has deformed plastically, and
4. To ascertain if the elastic deformation is at a level that does not cause separation of the work piece from the positioner.

Table - 1: Correction factors

Correction Factor C_1	Drilling Speed (RPM)
1.3	10 to 30
1.1	31 to 80
1.0	81 to 400
0.9	> 400
Correction Factor C_2	**Manufacturing Method**
0.8	Milling
1.0	Lathe machine
1.2	Drilling

The *Unigraphics NX* software can also help determine the extent of deformation and Von Mises stresses in the work piece. Table - 2, presents the mechanical properties of the work piece[11, 13, 14].

To position the drilling place and to fasten the work piece, the positioner axis and its end screw is used. Clamping with the screw exerts a compressive force. According to screw standard, the maximum preliminary clamping force and the maximum torque for tightening the M8 screws of (8.8), and assuming a coefficient of friction, μ, between the washer and nut to be 0.15 (for a good

Table - 2: Mechanical Properties of the work piece

Mechanical Property	Value
Density	7.829e-6 kg/mm^3
Yielding Stress	137 MPa
Modulus of Elasticity	206 MPa
Poisson Ratio	0.3

dry surface condition), are:

$$F_v = 16 \quad kN \,;\; M_A = 25 \quad N.m$$

On the other hand, a drilling force acts on the work piece. According to Equations (1) and (2), and assuming a machining speed of 30 RPM and a feed of 0.2 mm per revolution, this drilling force and its torque are:

$$F_c = 4492.8 \quad N \,;\, M_c = 11.232 \quad N.m$$

The work piece is compressed against the back of the jig's perpendicular surface, and is supported by the cylindrical surfaces at the beginning and at the end of the axial hole. Therefore, these surfaces have been considered as the supports.

The meshing of the work piece has been done using the *Tetra10* element. There are 2190 elements and 4149 nodes.

The analysis has been done in two stages, and each stage consists of 3 cases. The optimization of machining conditions and clamping force has been carried out in the second stage of the analysis.

The three cases are:

1. Assuming that clamping force is applied to the work piece prior to drilling,
2. Assuming that claming and drilling forces are applied during the drilling, and
3. The cutting tool is leaving the work piece, and assuming that clamping force is applied to the drilled work piece after the completion of drilling.

First stage analysis

In this stage, loading is done on the basis of the forces and torques. The maximum values of deformations and the maximum Von Mises stresses were determined using the software.

Table - 3: Maximum Deformations

First Stage Analysis	Maximum Deformation (mm)
First Condition	1.311
Second Condition	1.474
Third Condition	2.114

These values are presented in Tables - 3 and 4, and are shown in Figs. - 9 and 10, respectively. The deformation in the first case, i.e., assuming that clamping force is applied to the work piece prior to drilling is low, but increases to the final value, when the clamping force increases and the work piece is drilled. The analysis of the stresses shows that the deformation in the work piece is not plastic, nevertheless, this amount of deformation causes some problems in the stability of the drilling process.

Table - 4: Maximum Von Mises Stresses

First Stage Analysis	Maximum Von Mises Stresses (MPa)
First Condition	15.84
Second Condition	21.49
Third Condition	25.74

Second stage analysis

In the second stage, the cross section area of the cutting bit and the correction factors are reduced, by increasing machining speed (85 RPM) and reducing the feed in one revolution (0.1 mm). The values of machining speed and feed are directly related to the drilling force, and the magnitude of force and drilling torque will change to the following values:

$$F_c = 1572.8 \quad N \,;\; M_c = 3.933 \quad N.m$$

On the other hand, the clamping force which is the torque and force for tightening the screw can be reduced to the following values if the friction between the parts in contact is increased.

$$F_v = 10 \quad kN \,;\, M_A = 20 \quad N.m$$

As in the previous stage, after the loading and determination of the boundary conditions, the maximum values of deformations and the maximum Von Mises stresses were determined using the software. These values are presented in Tables - 5 and 6, and are shown in Figures 10 and 11, respectively. Here also, the deformation for the first case, i.e., when hole has been drilled and no drilling force is applied, increases to the final value. However, the magnitude of these deformations stresses has decreased considerably. The magnitude of stresses shows that the deformation in the work piece is not plastic. But, still the stability

Table - 5: Maximum Deformations

Second Stage Analysis	Maximum Deformation (mm)
First Condition	0.8196
Second Condition	0.923
Third Condition	1.285

Table - 6: Maximum Von Mises Stresses

Second Stage Analysis	Maximum Von Mises Stresses (MPa)
First Condition	9.899
Second Condition	13.55
Third Condition	16.13

of the process can not be guaranteed. It is evident that no major optimization has been carried out, and that for further evaluation of the clamping and positioners, it is possible to include some changes in the design. However, what can clearly be seen are the capabilities of the new CAE software, which along with modelling, designing and production of engineering drawing capabilities also present some facilities for performing finite element analysis. Using this capability, the designer can identify and solve the problems in his design before the actual fabrication. In the traditional methods, determination of clamping force and the positioning locations are done on the basis of experience, and the results so determined, usually present higher values. It may be possible that this conservative method does not produce any side effects, and even satisfy the operators, but the residual stresses in the work piece due to higher values of clamping force and positioning errors will certainly introduce damaging effects. Therefore, application of the design and modelling software is the need of the day, and being a kind of support for the designers, it can guarantee the quality of the parts so produced.

RESULTS AND DISCUSSION

The parametric modelling and design of drilling jig and fixture has been done, using CAE software. The designer can evaluate different designs and study the three dimensional views of his/her designs. This capability is very useful in designing jig and fixtures with the aim of increasing ease of work, production speed and reducing manufacturing errors.

The static analysis on the work piece and the designed jig and fixture has been carried out using FEM tools.

Assuming the location of the positioner and clamping is fixed, the clamping force as opposed to the force exerted during the machining process has been optimized so that, the maximum deformation produced in the work piece is minimized. In addition to ensuring the stability of the work piece, stress in no point has been allowed to exceed the maximum permissible value.

The analysis is needed to arrive at an optimum design in terms of clamping and machining forces acting on the work force. This way, application of higher forces based on experience, which may cause plastic deformation, can be avoided.

Overall, the procedure presented in this paper can be used for designing drilling jigs and fixtures, which can result in savings in manufacturing cost and time.

REFERENCES

1. Henriksen, E.K.: *Jig and Fixture Design Manual,* (1973)
2. Hoffman, E.G., *Jig and Fixture Design,* (2003)
3. Joshi, P.H.: *Jigs and Fixtures*', McGraw-Hill, (1990)
4. Wang, Y.F., Wong, Y.S. and Fuh, J.Y.H., "Off-line Modeling and Planning of Optimal Clamping Forces for an Intelligent Fixture System", *Int. J. Mach. Tools Manuf.,* **39,** (1999)
5. Melkote, S.N. and Li. B., ''Optimal Fixture Design Accounting for the Effect of Work piece Dynamics'', *Int. J. Adv. Manf. Technol.,* **18,** (2001)
6. Jeng, S.H.L, Chen, L.G. and Chieng, W.H., ''Analysis of Minimum Clamping Force", Tool Manufacturing, *Int. J. Mach. Tool Manufact.,* **35,** (1995)

7. Hamidi, M., Rogers, R.J., Nadkarni, G.R. and Bonham, “On Realistic Modeling of Work Pieces Fixture Interaction”, University of New Brunswick, N.B., Canada.
8. Kalpakjian, S.: *Manufacturing Processes for Engineering Materials*, 3rd ed., (1997)
9. Rong, Y. and Zhu, Y.: Computer-Aided Fixture Design, (1999)
10. Unigraphics NX Documentation, (2002)
11. Steel Website: http://www.matweb.com
12. Oberg, E. *et al.: Machinery Hand book*, New York, Industrial press INC., (1984)
13. Lyman, T.: *Metals Hand Book: Forming,* **4,** (1969)
14. Applied Finite Element Analysis, John Wiley & Sons, (1984)