Journal of Namibian Studies, 34 S2(2023): 1592–1610 ISSN: 2197-5523 (online)

Comparative Analysis of Broaching Machine Structure Frame for Performance Evaluation

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Abstract

Broaching is a typical manufacturing process to machine components. Based on the type of broach being used, this process can generate circular, hexagonal, irregular shapes or keyway slots. Broaching is highly specialized manufacturing process with good precision. Amount of material removal is effected in one stroke. The structure frame is very important component of broaching machine. Hence it is necessary that design & analysis of this element of the machine is properly done. Present paper deals with analysis of said element with different considerations & comparative analysis of it. The modeling of the frame structure is done and after analysis of structure frame with different considerations, comparative results are derived and interpreted.

Keywords: Broaching, Slot, Stroke, Structure frame.

Introduction

Broaching is a typical manufacturing process to machine typical parts. Based on the type of broach being used, the process can generate circular, horizontal, irregular shapes or keyway slots. Broaching is highly specialized manufacturing process with good precision. Total material removal takes place in one stroke of the broach.[1] [2]

Depending upon the type of material and its orientation, broaching machines are classified as,

1. Horizontal broaching machines

2. Vertical broaching machines

3. Surface broaching machines

4. Continuous broaching machines

Broaching tools are specially designed for each job depending upon the profile to cut. Type of broaching is dependent on dimension and thickness. Also it is influenced by the height of broach and weight of broach.

Features of different type of broaching machines and briefed in next paragraph.

Horizontal Broaching Machine

Horizontal broaching machines are generally of pull nature. They are used for external and internal profiles, most of the times they are most suited for internal profiles.

Base of the machine is generally twice of the length of the tool. It consists of pull head and tool support adapter for guiding the tool through path. It is shown in fig.1 As shown in figure they are generally of pull type.

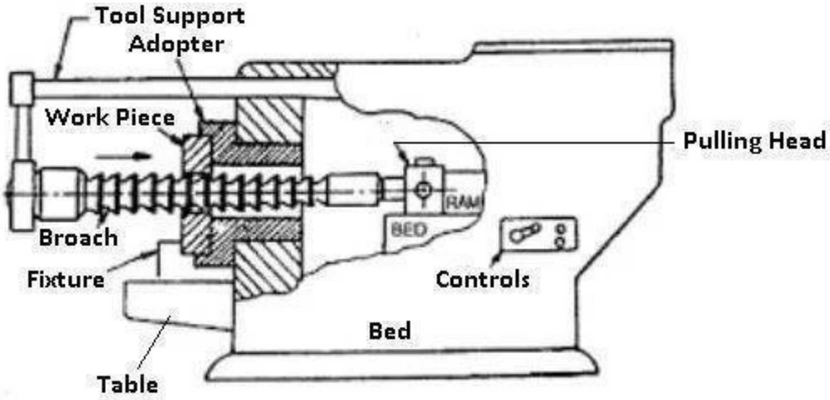

Figure 1: Horizontal broaching machine schematic

Horizontal machines have an advantage of carrying long broaching tools while at the same time they can occupy more floor space which leads to a disturbing the economy of production. They are used for spline, keyways and slots.

Vertical Broaching Machine

These machines can be made both in pull and push type but as press machines are of push nature, they are most popular in push mode. It is shown in fig.2

These machines are widely used because of advantage of easy pass of work. In this type also work can be stationery and tool can be push or pull type. Vertical machines require high shed heights or pit is needed to accommodate the tool length. These machines take up less floor area than horizontal machines hence are economical.

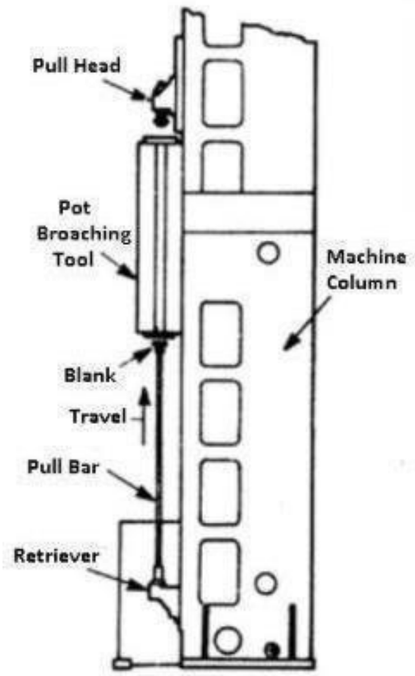

Figure 2: Vertical broaching machine schematic

Both Electro mechanical and hydraulic drives are possible in vertical broaching machine. But hydraulic type is most popular because of its smoothness and cost.

Surface Broaching Machine

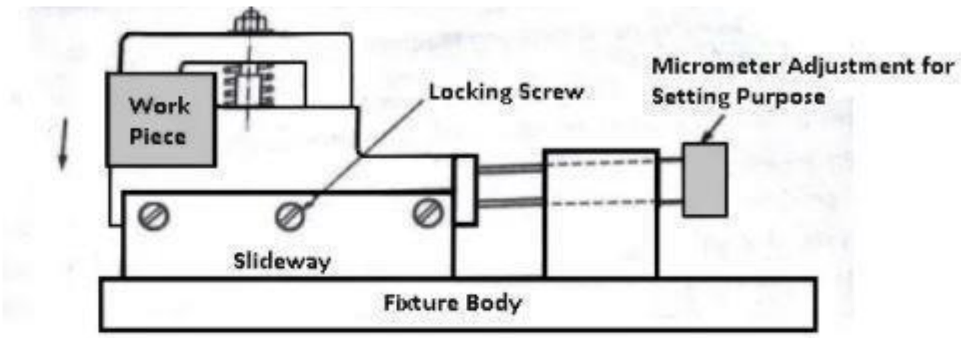

Figure 3: Surface broaching machine schematic

These machines can be either horizontal or vertical. In these machines broach tool is fixed to the ram and ram moves horizontally or vertically and performs the cutting operation on fixed workpiece. As name suggests they are generally used for surface machining of job. Here more than two rams can also be used depending on the shape of job required. These are called as duplex broaching machines. It is shown in fig.3 above.

Continuous Broaching Machine

Continuous machine is of horizontal or rotary type. In rotary machine work is fed to machine through guide and tool is kept stationary which continuously performs the machining of respective job and finished job is received from output port. It is generally in the form of table.

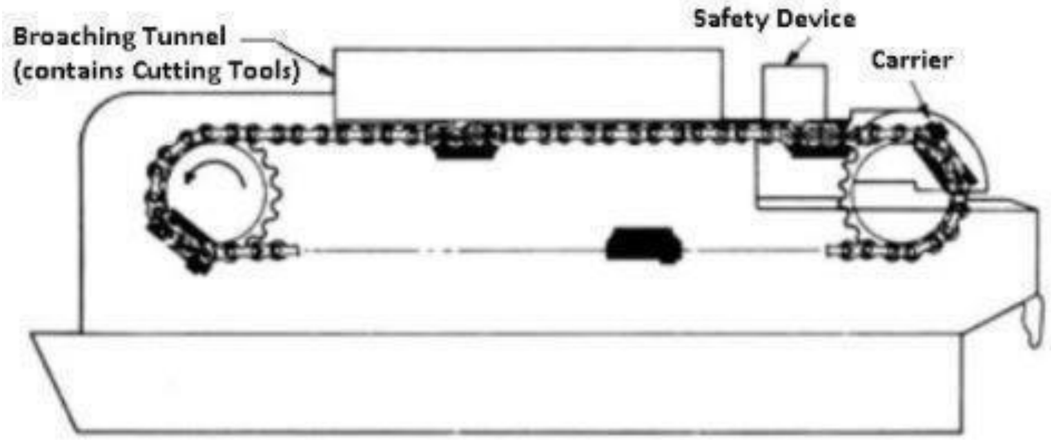

Figure 4: Continuous broaching machine schematic

In horizontal type work moves along the endless chain and tool is kept stationary. Holding fixture is designed on that chain itself. Continuous machines are generally used for small parts only, cannot be used for large parts.5

Basic Modeling and Design of Machine

Basic Concept Design

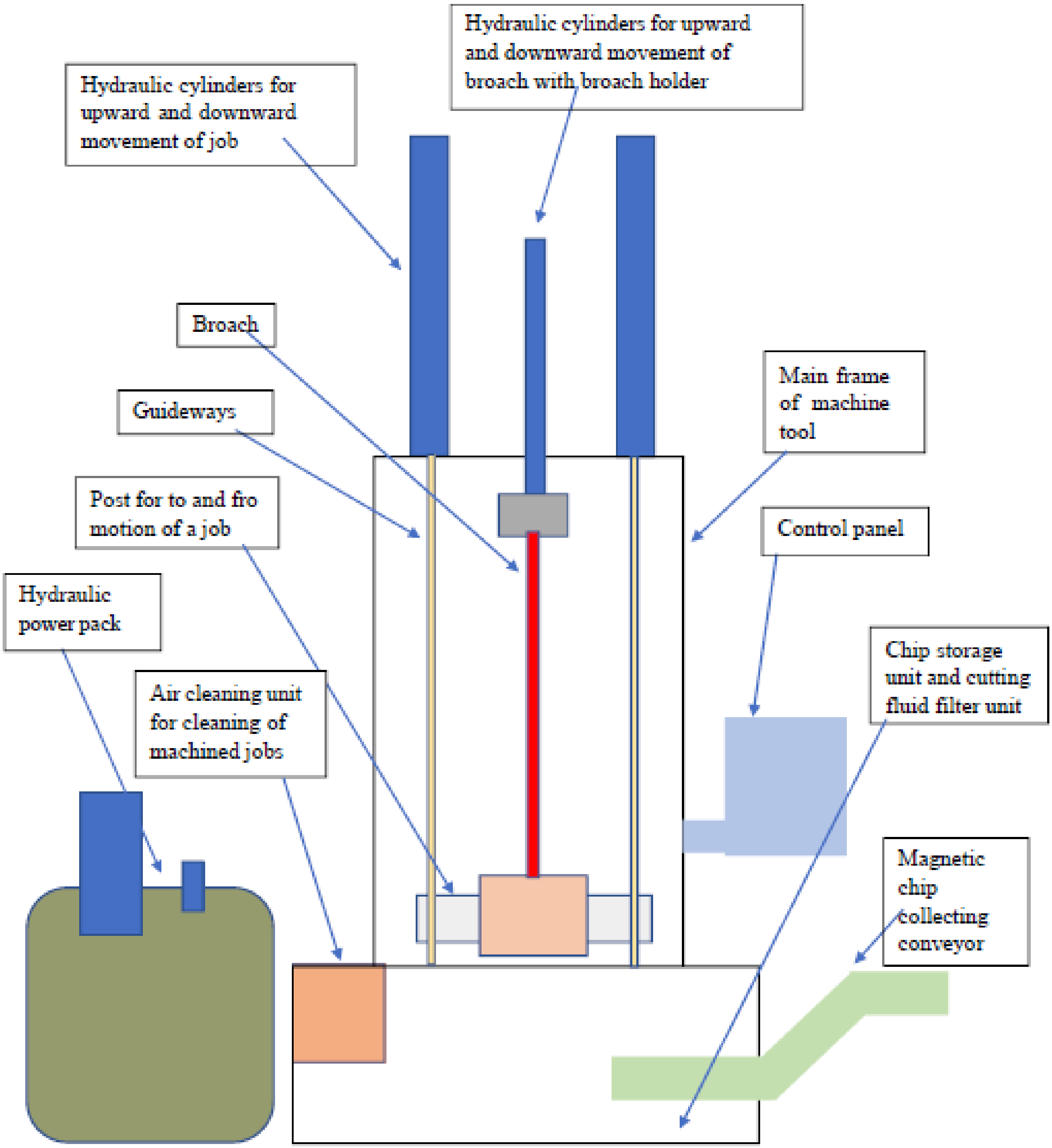

Figure 5: Basic concept design

Above fig.5 gives basic idea about essential components of machine tool. Machine[3] [4] [5] [6] frame is base of all the components which allows fixing of all the components on it and it is a stationary body. In order to facilitate the cutting operation there is need of relative motion between workpiece and tool and this is obtained with help of hydraulic actuators and the collets. Main hydraulic actuators are used for the movement of workpiece. And auxiliary actuator is used to facilitate the upward and downward movement of broach tool. Collets are used for holding the broach stationary. Cross guide attached with actuators are used to provide transverse motion of workpiece. To give hydraulic power to circuit hydraulic power pack is used. Air cleaning unit and chip collection units are extra accessories provided with the machine.

From above basic concept design, 3D model has been made for the basic understanding of the operations and the parts. By using this sequence of operation is decided.

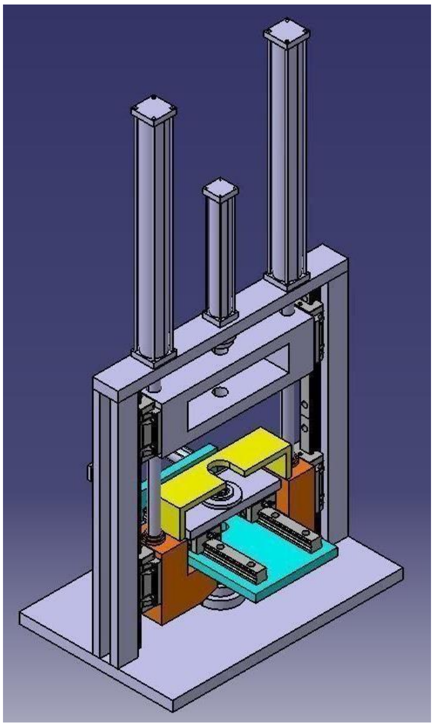

Figure 6: Isometric View of 3D Concept Layout.

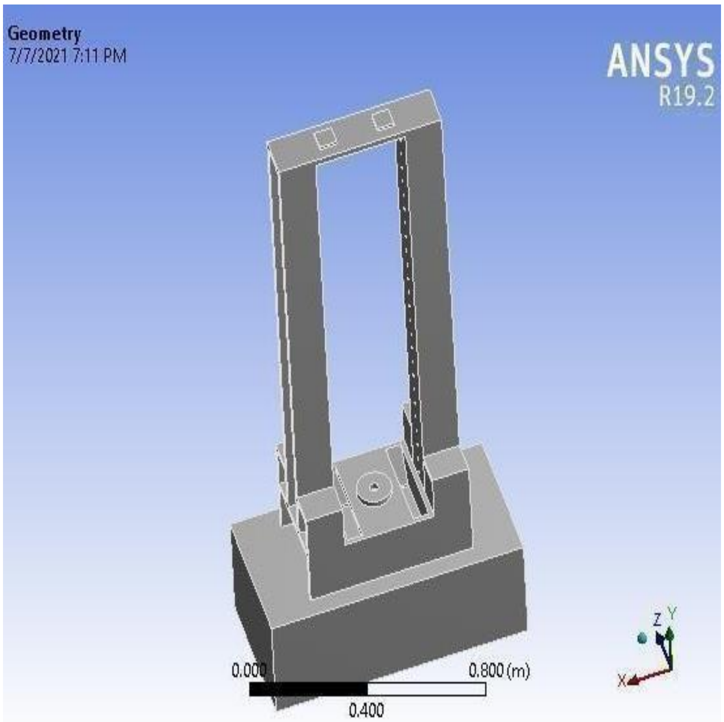

Figure 7: Model for Analysis

Concept Layout.

From this 3D layout shown in Fig.6 and 7, basic components of machine tool can be well understood.

Structure Validation and Its Analysis

Basic layout of structure is made and tested in ANSYS then results are observed [7] [8] [9] [10] and required changes have been made. Those ANSYS results are as follows:

Above fig.7 shows the cad model of the structure whose analysis had been carried out. CATIA software is used for making the model. Structure frame analysis is carried out in ANSYS R19.2. The frame section dimensions were with thickness of 25 mm, having width of 75 mm with C section of height one metre, designed after analysis.

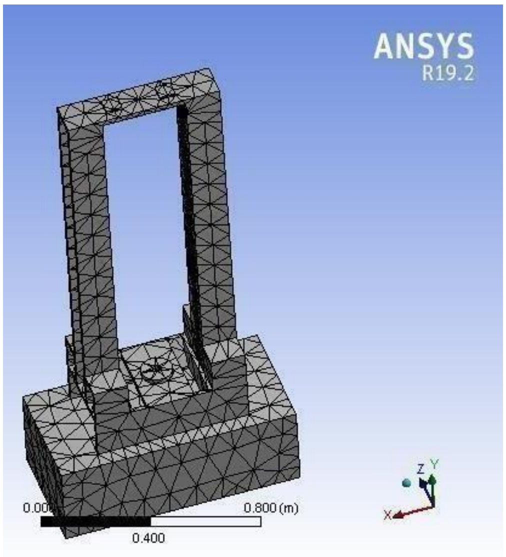

Figure 8: Meshing output

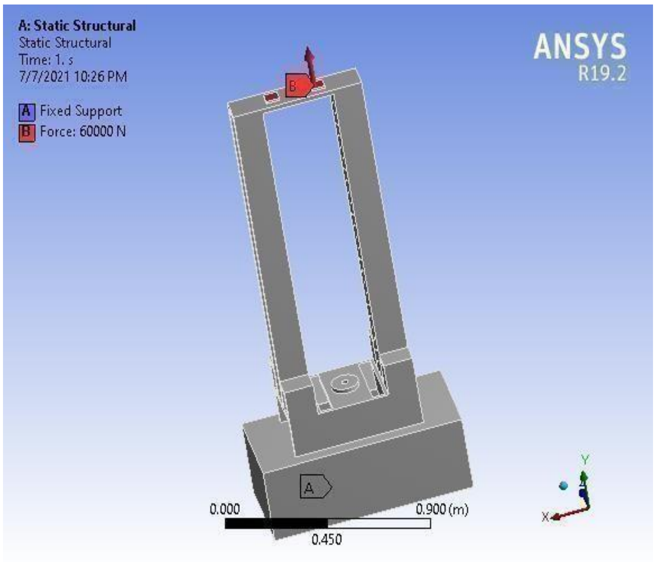

Figure 9: Geometrical constraints and loading condition.

Above fig.8 and 9 shows the final output after the meshing is done [11] [12] [13] on the model and also the geometrical constraints and the force applied. Here base plate of structure is fixed and force of 6,000 Kg is applied on both the cylinder mounting positions. Let's check only for these conditions because they are the extreme cases of loading and failure. Material applied here is a structural steel with Syt = 250 MPa, Sut

= 460MPa and density = 7850 Kg/m3. Material used for structure is ductile in nature so while analyzing the stress results, appropriate theory of failure must be used. List of theories of failures is given below:

1. Maximum Principal stress theory (Rankine's Theory) (M.P.S.T.)
2. Maximum shear stress theory (Guest and Tresca's theory) (M.S.S.T.)
3. Maximum distortion energy theory (Von mise's theory) (M.D.E.T.)
4. Total strain energy theory (Haigh's theory) (T.S.E.T.)
5. Maximum principal strain theory (Saint Venant's theory) (M.P.S.T.)

Here state of stress is triaxial so, theories of failure are must to analyze the structure [14] [15] [16]. But because of ductile material, total strain energy theory and maximum principal strain theory are not applicable so try to analyze the structure with help of remaining theories. So, let's analyze the structure with help of remaining theories of failure which are more appropriate. Following are the results for all possible theories of failure.

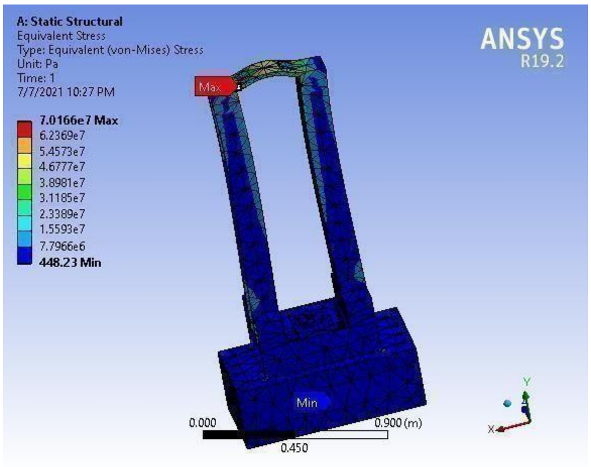

Figure 10: Stress results of von mises theory

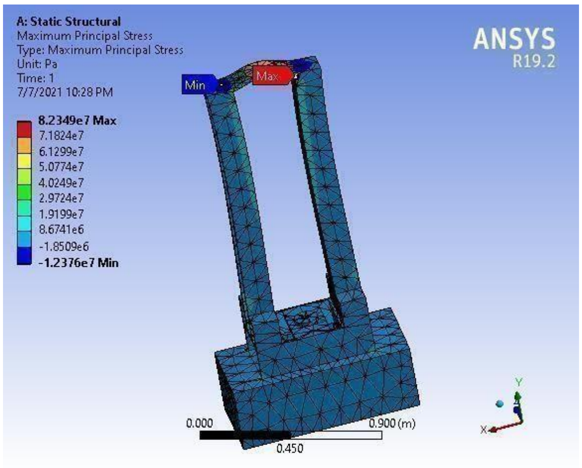

Figure 11: Stress results of maximum principal stress theory

Above fig.10 gives the stress results as per von mises theory. Von mises theory is also called as Total Distortion Energy theory. As per distortion energy theory material is said to be failed when total distortion energy at critical point exceeds the total distortion energy at the time of failure of tensile test.

Total distortion energy is given by following formula:

$((1+\mu) / 6E) \surd (\sigma1- \sigma2)^2 + (\sigma2- \sigma3)^2 + (\sigma3- \sigma1)^2$

Von mises theory is the most appropriate theory of failure for ductile material.

Maximum principal stress theory is actually used for brittle nature materials or for the tri-axial state of stress of ductile material where principal stresses are same in nature. This theory gives over safe results. So, sometimes this theory with less factor of safety leads to a failure. In above fig.11, maximum and minimum stress points are shown. Maximum stress here is 82.34 MPa tensile while 12.37 MPa compressive.

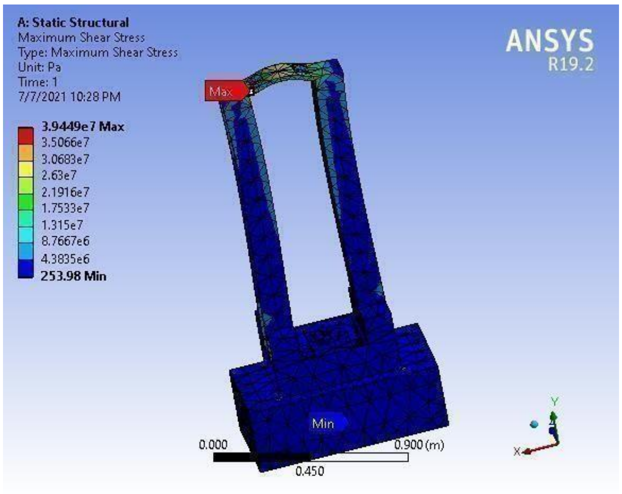

Figure 12: Stress results of maximum shear stress theory

Maximum shear stress theory is most conservative theory for ductile materials and this gives under safe results, which leads to increased dimensions of components and simultaneously the increased cost of material. Shear stress theory is not applicable to brittle materials. In above fig.12 maximum and minimum shear stress points are given which are 39.44 MPa and 253.98 Pa resp. All above results are tabulated in below table. Deformation results are also observed in ANSYS which are discussed below.

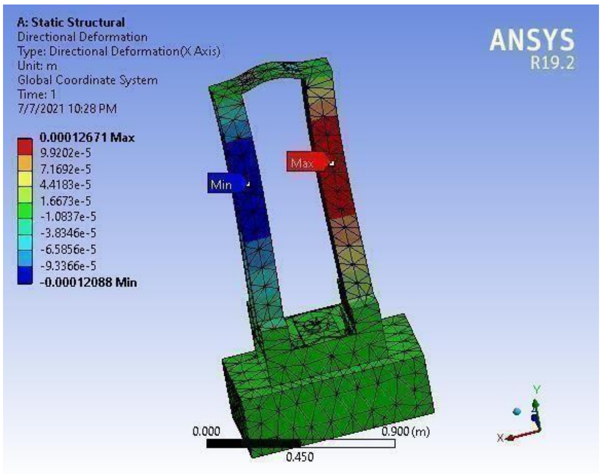

Figure 13: Directional deformation results

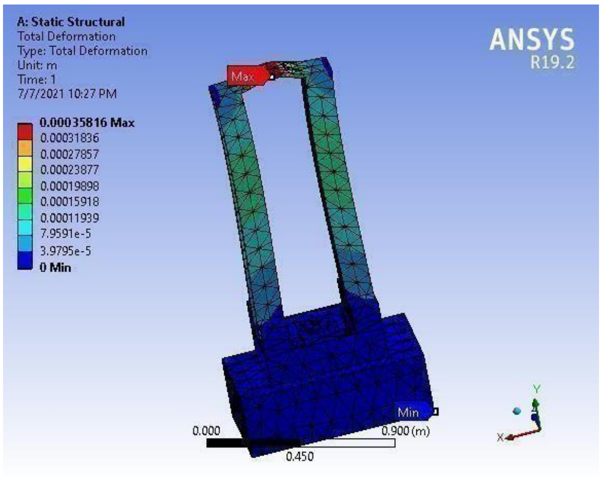

Figure 14: Total Deformation results

In above fig.13 & 14 directional and total deformation is observed respectively. Total deformation is vector sum of all the directional deformations. This is important to understand the deformations in structure which are going to affect our final machining tolerances.

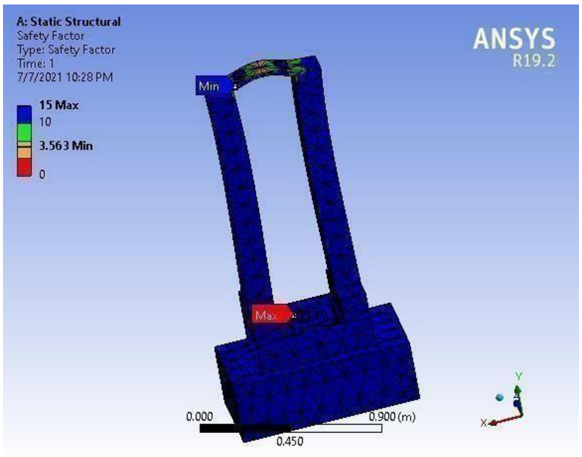

Figure 15: Factor of safety using von mises theory

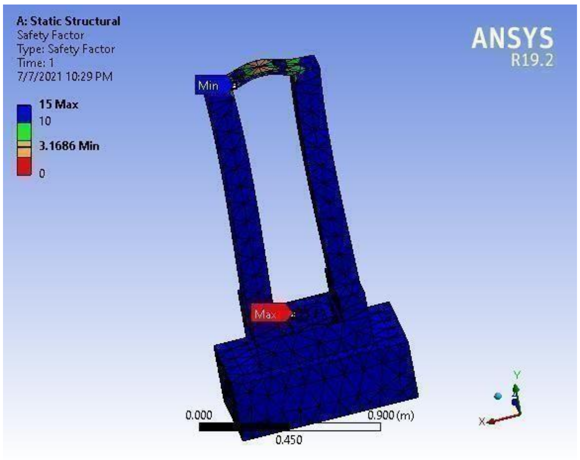

Figure 16: Factor of safety for shear stress theory

Above fig.15 & 16 gives allowed factor of safety with respective theories of failures. And these factors of safeties give us the idea about extent of safety of frame structure. Factor of safety is calculated as Permissible stress / Actual maximum stress.

In next discussion only loading conditions are changed, same force is applied at the place of bottom collet. All rest remains same. Results for stress, deformation and factor of safety are also observed.

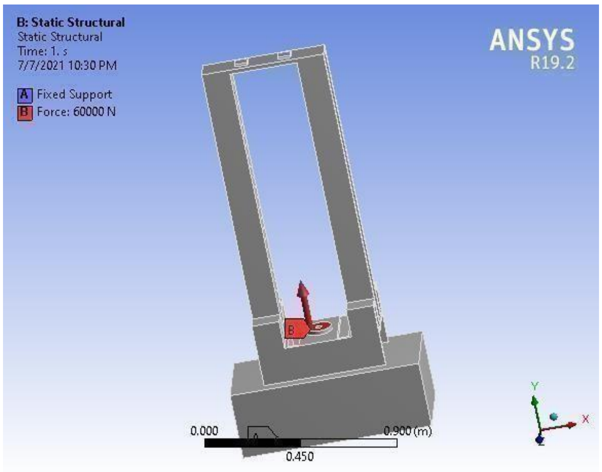

Figure 17: Geometrical constraint & loading Condition

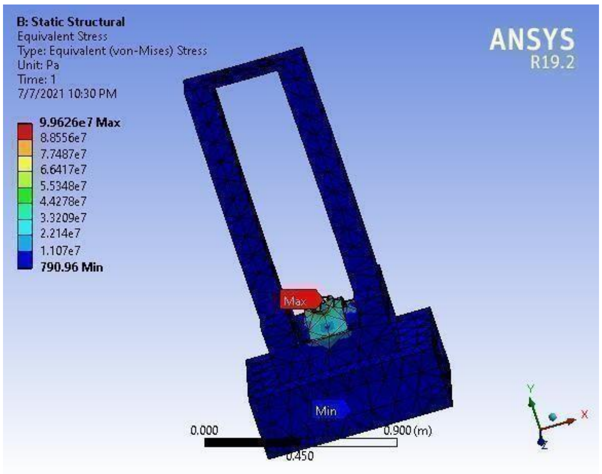

Figure 18: Stress results of von mises theory

Material applied here is a Structural steel with Syt = 250 MPa, Sut = 460MPa and density =7850 Kg/m3

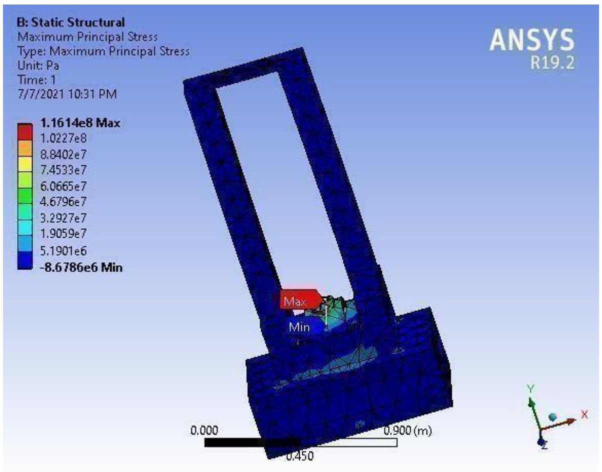

Figure 19: Stress results of maximum principal stress theory

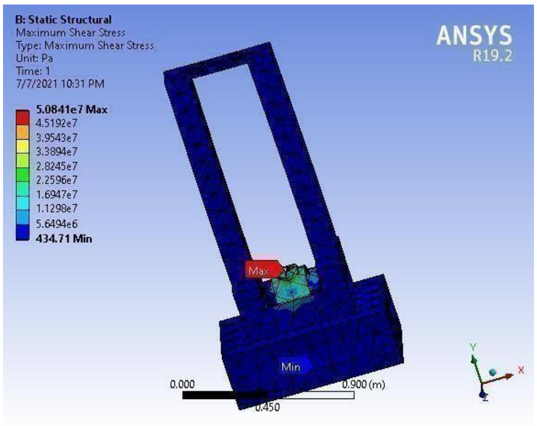

Figure 20: Stress results of maximum shear stress theory

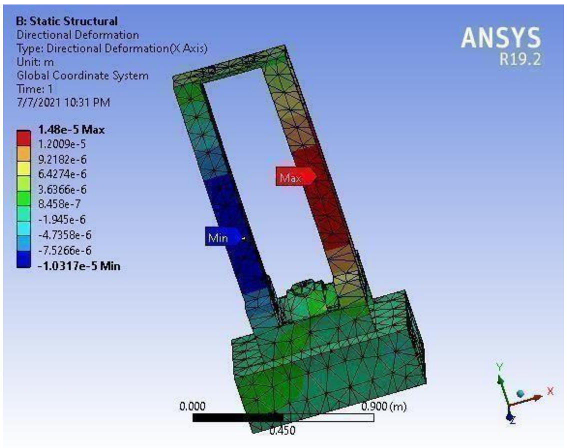

Figure 21: Directional deformation results

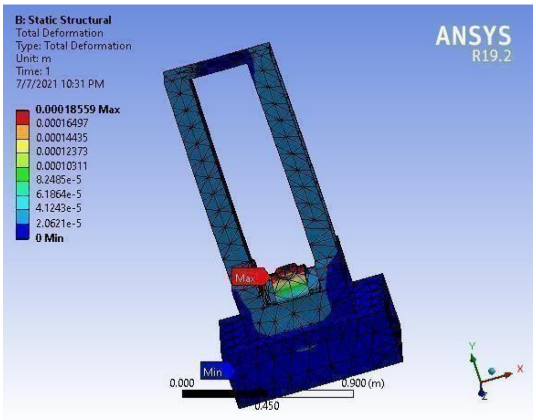

Figure 22: Total deformation results

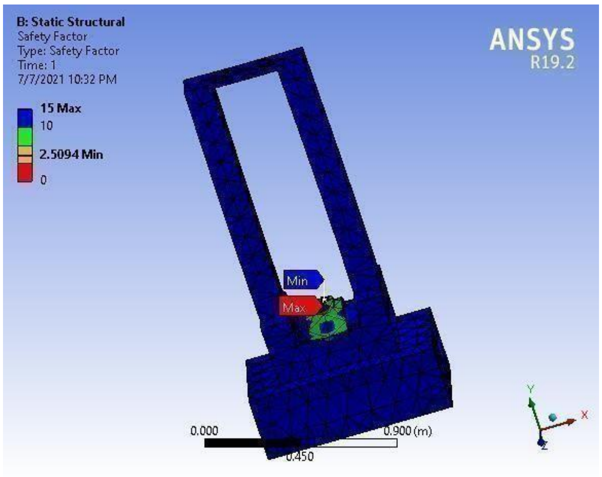

Figure 23: Factor of safety for von mises theory.

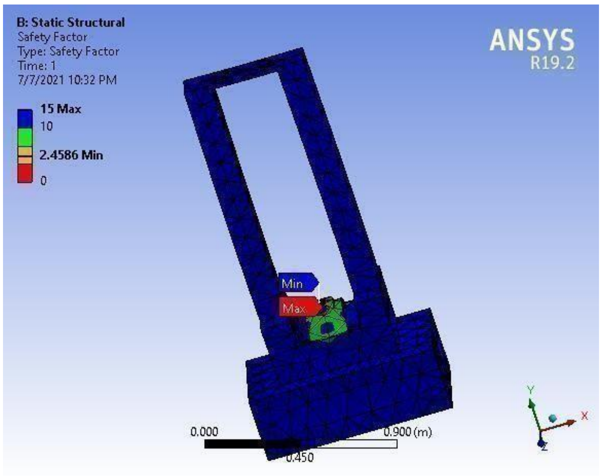

Figure 24: Factor of safety for maximum maximum shear stress theory

Results for loading condition 1 and 2 are tabulated below. Results observed are von mises stress, Shear stress, Maximum principal stress, Factor of safety for maximum shear stress theory and von mises theory, Directional deformation and total deformation. In stress, deformation and factor of safety results, maximum stress and minimum stress points are highlighted.

Results and Discussions

Table 1: Observation of various results obtained using ANSYS

Sr. No.	Results	Loading Condition 1		Loading Condition 2	
		Max	Min	Max	Min
1.	Stress by M.D.E.T.	70.16 MPa	$448.23*10^{-6}$ MPa	99.62 MPa	$790.96*10^{-6}$ MPa
2.	Stress by M.P.S.T.	82.34 MPa	-12.37 MPa	116.14MPa	-8.67 MPa
3.	Stress by M.S.S.T.	39.44 MPa	$253.98*10^{-6}$ MPa	50.08 MPa	$434.71*10^{-6}$ MPa
4.	Directional Deformation	0.1267 mm	-0.1208 mm	$1.48*10^{-2}$ mm	$-1.03*10^{-2}$ mm
5.	Total Deformation	0.3581 mm	0 mm	0.1855 mm	0 mm
6.	Factor of safety using M.D.E.T.	15	3.563	15	2.5094
7.	Factor of safety using M.S.S.T	15	1.686	15	2.4586

From above analysis results in Table1 minimum factor of safety observed are 2.4586 which are considerably good. This indicates design can sustain the loads acting on it without failure.

1) Loading Condition 2 exhibit higher maximum stress inducement in all the theories of failure considered, this is due to the reduction in the maximum total deformation with change in same force application location.

2) Factor of safety is almost consistent regardless of the theory of failure under consideration. This indicates that despite of the theory of failure used for the analysis the factor of safety is varying in very narrow margin.

3) For the same force applied on the geometry, under consideration change in location is responsible for variation in total deformation.

Conclusion

For a broaching machine frame structure, finite element analysis was carried out. Various theories of failure were applied and results were compared; keeping other conditions constant. The trend of variation of maximum stress, factor of safety and total deformation were studied and analyzed.

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