Design and Analysis of Self Centering Steady Rest for CNC Turning Machine

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Abstract: *In the present scenario Automation plays a vital role in carrying on the production processes effectively in the production shop. Especially while carrying on machining operations the automation is very much essential. In most of the industries they are facing the problems such as vibration and other effects like deflection on work piece while carrying on machining operations on Axis centered CNC lathe or else on a normal lathe. Good surface finish also will not be obtained when proper support is not given on the slender work piece in performing machining operations. Hence in order to overcome the problems of deflection and vibration effects on slender work pieces we tend to utilize the Self centering steady rest. The self-centering steady rest will be arranged such that it will be placed between the rollers to give support to the work piece. The input to that device is given by hydraulic pressure. We can say that by means of facilitating the self-centering steady rest we can increase the productivity by reducing cycle time, obtain higher accuracy and good surface finish and also overcomes the deflection and vibrationproblems.*

Keywords: *steady rest, work holder, cutting tool, deflection, vibration effect, lead time*

1. INTRODUCTION

Now a day's the rapid growth of technology as well as the utilization of CNC machine in industries are increased. In the past, known steady rests have been designed only for use in contacting the outer periphery of the work piece. The most common application is to support a work piece during turning or milling and, increasingly, during secondary operations such as ID drilling, boring and producing end face.

Steady rests have been used for many years in connection with machining operations. Steady rests are supplementary intermediate, supports, used in turning long slender work to prevent it from being bent by the action of the cutting forces. Steady rest hold, locate and support the work piece held by a chuck. Figure 1 shows a turning operation with the work piece held by a chuck. The steady rest supports the bar to be turned while three adjustable shoes center and support the bar. This support absorbs most of the bending forces. Figure 1 shows a turning operation within a steady rest and Centre support. The cutting forces should be applied as close as possible to the bed, table, face plate and the spindle bearings. Figure 1 shows a chuck and a long work piece to be turned.

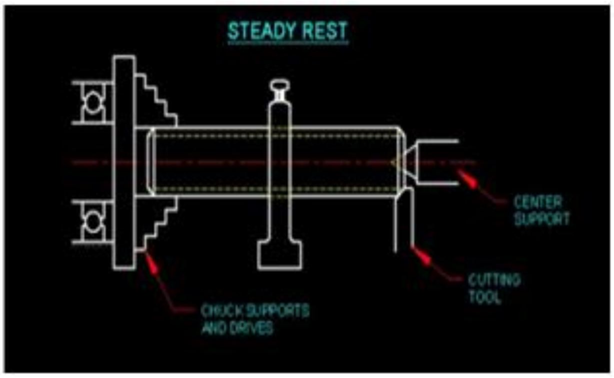


Figure1: Turning Operations within a Steady Rest and Centre Support

1.1. Problem Statement

The problem is about the clamping of large camshafts on the machine which takes more time for machining. For the clamping purpose self-centering steady rest is used. It takes more time for the machining of large camshafts by successive clamping and declamping.

1.2. Objectives

- To design the suitable clamping system using steady rest for the camshaft machiningon CNC turning machine.
- To design the proper hydraulic circuit based on the application of thesystem.
- To analysis the designed system using CAD and CAEtools.

2. METHODOLOGY

- **Mechanism Layout of Steady Rest**

This includes study of various clamping/gripping mechanisms used for the clamping purpose. Also, it includes study of different mechanisms used for the steady rest operation. The proper mechanism for the proper working of steady rest is determined.

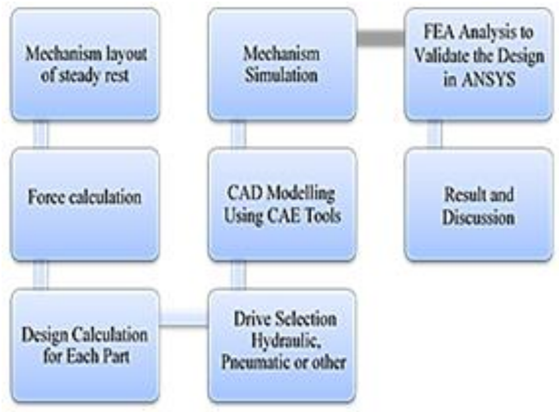


Figure2: Methodology

- **Force Calculation**

This includes calculation of clamping force of steady rest.

- **Design Calculation for Each Part**

Design of various components of steady rest based on the clamping force required. It consists of design of arms, design of cam for the steady rest's operation and design of rollers or the steady rest.

- **Drive Selection Hydraulic, Pneumatic or Other**

Depending upon the force requirement, speed of clamping, compatibility with the system and application, proper drive selection for the operation of steady rest is obtained.

- **CAD Modelling Using CAE Tools**

With the help of CAE tools, the CAD model of the steady rest is done. For that purpose, CAD software are used. In this, CAD model of the operating mechanism, components of steady and assembly of the steady rest is done.

- **Mechanism Simulation**

Simulation of the mechanism is done with the help of CAD software to ensure the proper working of mechanism.

- **FEA Analysis to Validate the Design in ANSYS**

Analysis of the CAD model using ANSYS for the validation of the design will be done.

- **Result and Discussion**

After the design and analysis, results are recorded based on analysis and suitable material will be selected for the steady rest manufacturing.

3. DESIGN CONSIDERATION OF STEADY REST

Arms self-cantering steady rests are specially designed to get the optimum result in automatic holding of cylindrical jobs. Arms steady rests provide best cantering accuracy& repeatability in microns. Arms self-cantering steady rests can be used as replacement of any other models of self-cantering steady rests due to interchange ability in mounting dimensions. Arms steady rests are hydraulically operated and can be interfaced with the CNC system, save the setting time and give better productivity. The special rollers used in Arms steady rests help for running the job in high rpm and give best surface finish

Figure3: Steady Rest for CNC Turning

3.1. Working Principle

The steady rest consists of 3 arms assembled in a steel body with rollers at the arms for holding the work piece. The Centre one brings the other two arms in a circular movement to hold the center of the work piece. This helps to get the repeatability and consistency in getting the centering accuracy. The Centre arm is operated by a hydraulic cylinder. The job holding rollers are lubricated through centralized lubricating system.

3.2. Technical Specifications

- Min.job dia.: - 20 mm
- Max.job dia.: - 165 mm
- Max. axial opening:-173 mm
- Standard operating pressure: - 8-50 bar
- Max.operating pressure: - 60 bars
- Clamp. Pressure/roller at 8 bars: -130 dan
- Max. Clamp. Pressure/roller: -1000 dan
- Centering accuracy over the over the whole
- clamping range: -0.04 mm
- Repeatable accuracy: -0.007 mm
- Max.peripheral roller speed: -725 m/min
- Max. Peripheral roller speed at half max. clamp
- pressure: - 875 m/min
- Centralized lube Port connection: - 1/8" BSP,1 no.
- Hyd. Port connection: - ¼" BSP
- Cylinder bore: - 80 mm
- Weight (approx.): -40 kg

3.3. List of Spares

- Piston seal: - PT0300800 T46N, Busak make 1 no.
- Piston rod seal: -RU3000 250-Z20, Busak make 1 no.
- Rollers: -20 × 47 × 25 nos.
- Wiper: - Henning AB-1 type, 4 nos.
- O ring: -ID 85 × 2, 1 no.
- O ring: -ID 17 × 2, 1 no.
- Pull back plate: -FRU3. 1- 01- 008- 4, 2 nos.
- Piston wear ring: - GP65 00800 T47, Busak make, 1 no.
- Proximity switch: -EGL 12×02 AP 024-SEM-LK, Technic Euchner make, 2nos.
- Connecting plug: -SWLF3AP -5000P, Technic Euchner make, 2nos

3.4. Proposed Drawing

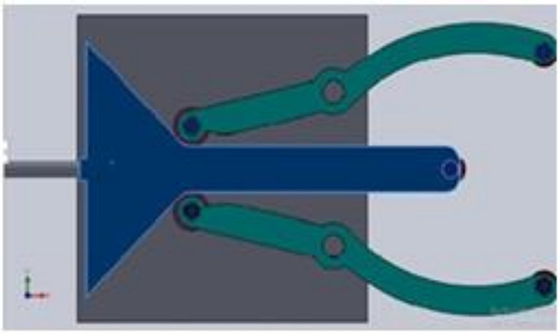


Figure4: Clamping Mechanism for Steady Rest

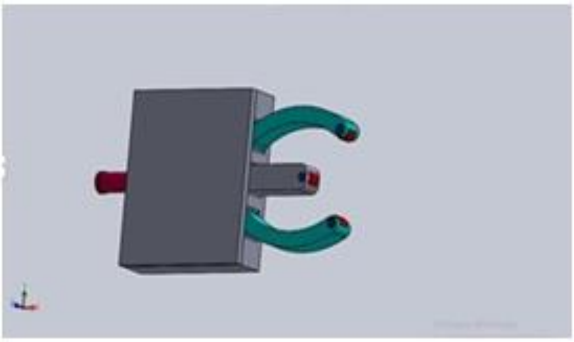


Figure5: Steady Rest with Casing

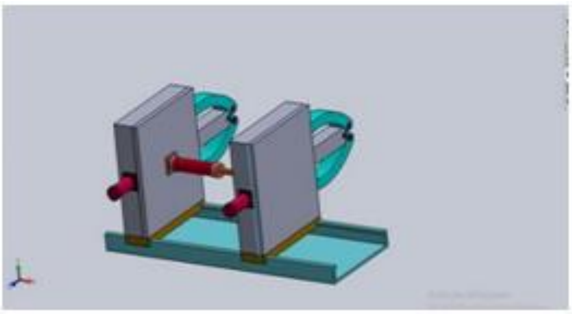


Figure6: Proposed Concept (Double Steady)

3.5. Design Calculation

- Force exerted by hydraulic oil on the cam

Bore of hydraulic cylinder = 80mm

Operating pressure = 15kg/cm^2

1kg/cm^2 = 0.098 MPa

Therefore,

15 kg/cm^2 = 1.47 MPa = 1.47 N/mm^2

Now,

Pressure = Force / Area

Force = Pressure * Area

Force = 7389.025 N

- Design of Arms for Steady Rests

Force acting on arm 1 = 7389.025 / 2

= 3694.51 N

Material selected for arm = 16MnCr5

Let Syt = 950 N/mm^2

Assuming factor of safety = 1.5

Allowable bending stress = 950 / 1.5

=633.33N/mm^2

Arm act as a leaver

Effort (P) = 3694.51 N

l_1 = 100 mm

l_2 = 124 mm

Therefore,

$F = P^* (l_1 / l_2)$

= 2979.44 N

- Maximum bending moment is at fulcrum

$Mb = F * (l_2 - d_1)$

= 309862.129 N.mm

- Bending stress is given by

$\sigma_b = Mb * Y / I$

y= h/2 and I= bh^3/12 ……. (for rectangular cross section)

Taking b= 45mm

$\sigma_b = (Mb * h) / 2(bh^3 / 12)$

h = 14.75 mm

h = 40 mm

As available standard roller size 20*47*25 mm, hence selecting height of arm h= 40mm is considered.

- Checking stress in the arm,

  b = 45mm and h= 40mm

  Bending stress is given by

  σ_b= (Mb * y) / I

  = (6 * Mb) / bh^2

  = 25.82 N/mm^2

  $\sigma_b < \sigma_{b\ allowable}$, hence design is safe.

- Cutting Force Calculation

  Maximum diameter of job = 79 mm

  Turning speed = 1000 rpm

  Grooving speed = 650 rpm

  Feed (F) = 0.5 mm/rev

  Depth of cut (ap) = 1.5 mm

  Kc= specific cutting force = 2500 to 3000 MPa for steel

- Cutting speed

  For turning

  Vc = π*Dm*n / 1000

  = 248.185 m/min

  For grooving

  Vc = π*Dm*n / 1000

  = 161.32 m/min

- Cutting Force

  Fc = (Kc*ap*F) / 1000

  = 2250 N

- Power Required

  For turning

  P = (Vc*F*ap*Kc) / (60*10^3*n)

  = 10.34 KW

  = 13.786 H.P.

  For grooving

  P = (Vc*F*ap*Kc) / (60*10^3*n)

  = 6.72 KW

  = 8.96 H.P.

  Camshaft material = Mild Steel

  Tool material = Carbide

  Nose Radius (R) = 0.4 mm to 1.2 mm

  Depth of cut (t) = 1.5 mm

  Chip thickness (tc) = 1.75 mm (by assuming)

  Cutting force (Fc) = 2250 N

  Thrust force (Ft) = 900 N (by assuming)

- Chip thickness ratio (rc) = t / tc = 0.857
- Frictional force

  F = Fc sinα + Ft cosα …… (α=rake angle)

  = 1130.26 N

- Normal force

  N = Fc cosα – Ft sinα

  = 2143.60 N

- Kinetic coefficient of friction

  μ = F / N

  = 0.5273

- Frictional angle

  $\beta = \tan^{-1}\mu$

  = 28^0

- tanϕ = (rc*cosα) / (1-rc sinα)

  ϕ = 43.11^0

- Shear angle (ψ)

  tanψ = (rc*cosα) / (1-rc sinα)

  ψ = 43.11^0

- Shear force

  Fs = Fc cosψ – Ft sinψ

  = 1027.53 N

- Normal force (Fn)

  Fn = Fc sinψ + Ft cosψ

  = 2194.69 N

4. 3D MODELING AND DETAILED DRAWING OF STEADY REST

Software used for 3D modeling: SolidWorks

Solid Works software is a multi-platform software suite for computer-aided design (CAD), computer-aided engineering (CAE), developed by the French company Dassault Systems.

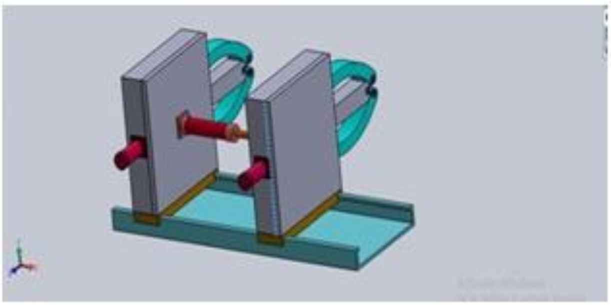


Figure7: 3D modeling using Solid Works Software

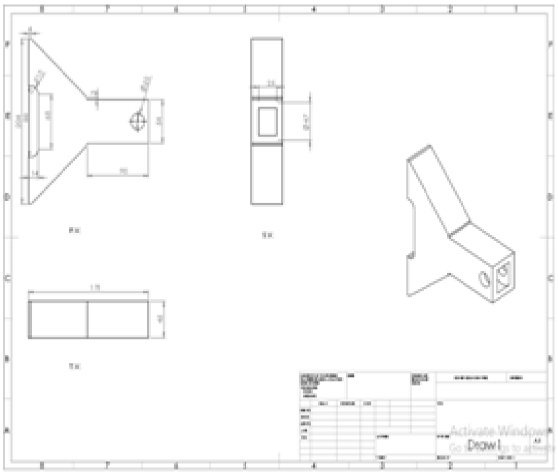


Figure8: Detailed Drawing of Steady Rest

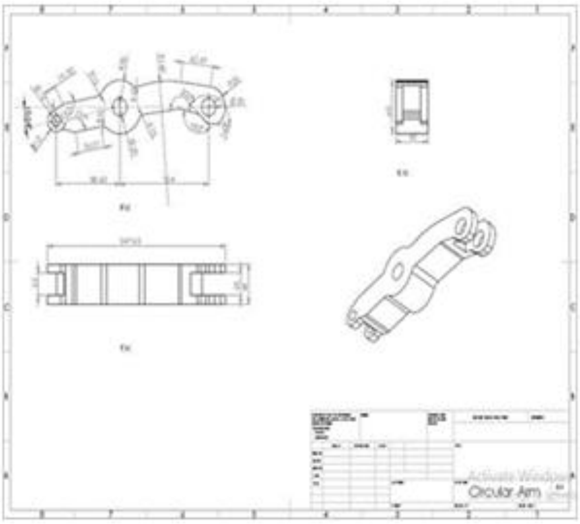


Figure9: Detailed Drawing of Steady Rest

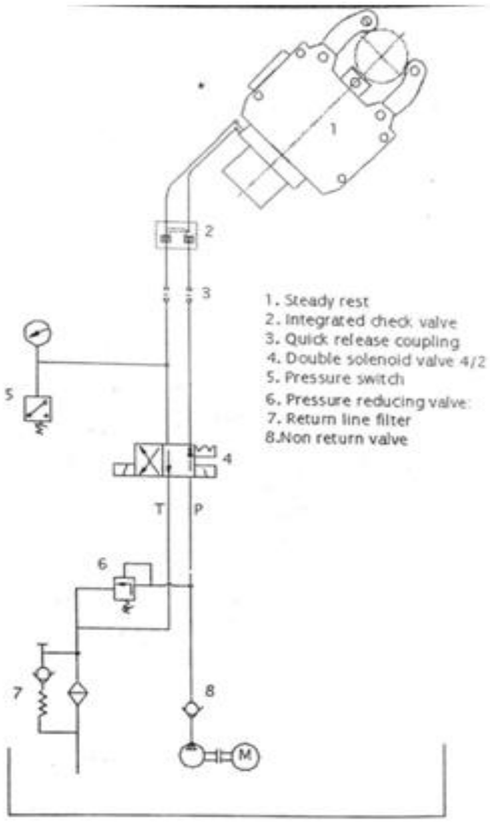


Figure10: Present Hydraulic Circuit for Single Steady Rest Clamping System

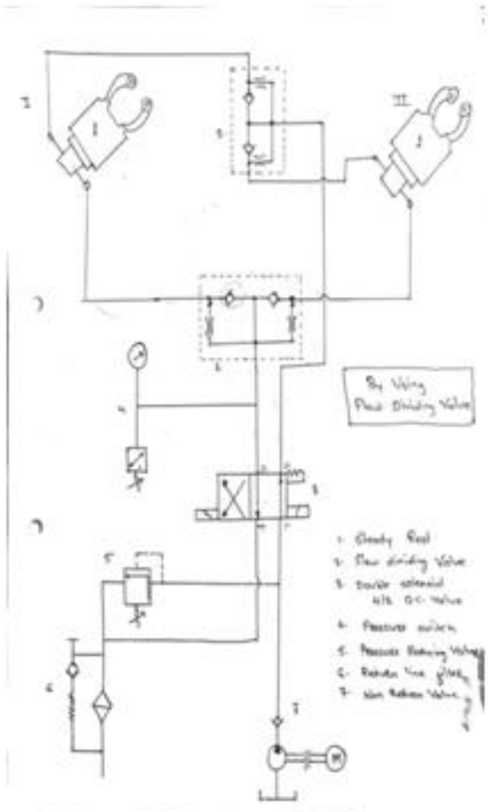


Figure11: Proposed hydraulic Circuit for Proposed Clamping System (Synchronous circuit)

5. PROPOSED HYDRAULIC CIRCUITS FOR STEADY REST AND ITS SELECTION

5.1. Design Calculation of Hydraulic System

Force exerted by hydraulic oil on the cam

Bore of hydraulic cylinder = 80mm

Operating pressure = 15kg/cm^2

$1 kg/cm^2 = 0.098$ MPa

Therefore,

$15\ kg/cm^2 = 1.47$ MPa $= 1.47\ N/mm^2$

Now,

Pressure = Force / Area

Force = Pressure * Area

Force = 7389.025 N

This force is distributed to the outer arms of the steady rests.

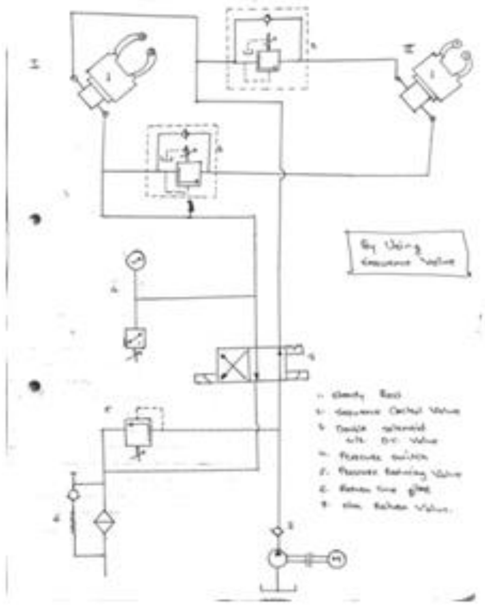


Figure12: Proposed hydraulic Circuit for Proposed Clamping System (Sequencing circuit)

Figure No.10 shows the available hydraulic circuit for the existing steady rest. The circuit is only for the single steady operation.

For the two steady operations, we need different types of hydraulic circuit.

Figure No.11 and Figure No.12 shows the hydraulic circuit for the operations of two steady rests.

Figure No.11: Synchronizing Circuit

Figure No.12: Sequencing Circuit

A) Sequencing Circuit:

- Figure No. 8.2 shows the sequencing circuit for two steady rest system.
- Hydraulic cylinder in steady rest can be operated sequentially using a sequence valve.
- Figure No.8.2 shows two sequence valves are used to sequence the operation of two double acting cylinder (steady rests).
- Steady rest 1, first clamp the wok piece and after achieving set pressure the second steady rest operates and clamp the work piece.
- This sequence of cylinder operation is controlled by sequence valve.

B) Synchronizing Circuit:

- Figure No. 8.3 shows the Synchronizing Circuit for two steady restsystem.
- Hydraulic cylinder in steady rest can be operated synchronously using flow dividing valves.
- Figure No. 8.3 shows the hydraulic circuit in which two cylinders is arranged in parallel.
- When two cylinders are identical, the load on the cylinders is identical and then extension and retraction are synchronized.
- This Synchronization of cylinder operation is controlled by flow dividing valves.

Selection of Circuit

From the proposed circuits we are selecting synchronous circuit, because

- At a time Clamping and De-clamping of each steady rest is possible which reduces time than the sequence circuit.
- The Synchronizing Circuit is easy to design.
- It is easy to use and handle over the sequence circuit.

6. FEA ANALYSIS OF STEADY REST

The Finite Element Analysis (FEA) is the simulation of any given physical phenomenon using the numerical technique called Finite Element Method (FEM).

Most of these processes are described using Partial Differential Equations (PDEs). Differential equations not only describe natural phenomena but also physical phenomena encountered in engineering mechanics. These partial differential equations (PDEs) are complicated equations that need to be solved in order to compute relevant quantities of a structure (like stresses (ϵ), strains (ϵ), etc.) in order to estimate the structural behavior under a given load. It is important to know that FEA only gives an approximate solution to the problem and is a numerical approach to get the real result of these partial differential equations. Simplified, FEA is a numerical method used for the prediction of how a part or assembly behaves under given conditions. It is used as the basis for modern simulation software and helps engineers to find weak spots, areas of tension, etc. in their designs.

6.1. Selection of Material

For the analysis purpose of the designed steady rest different materials are considered. This is done for the better and comparative analysis results. The materials which are used for the analysis purpose are as follows:

- 16MnCr5
- EN8
- Aluminium Alloy

The analysis is done using CAE software i.e. Ansys. For the analysis various input parameters such as hydraulic pressure, cutting force, speed of the rotating shaft is considered. These parameters are constant for every material. The input parameter values are given below.

Table1: Selection of Material

Material	Hydraulic Force (N)	Cutting Force (N)	Speed of Shaft (rpm)
16MnCr5	7389	2250	650
EN8	7389	2250	650
Aluminium Alloy	7389	2250	650

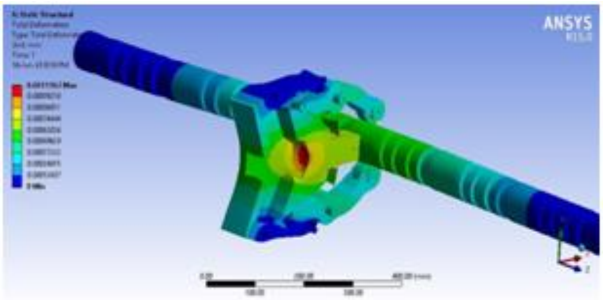
According to the above input parameters the analysis for each material is done. The analysis is done to check the equivalent stress and total deformation produced in designed steady rest for each material. The analysis is done for both single steady rest and double steady rest and the results are noted down.

6.2. Analysis of Single Steady Rest

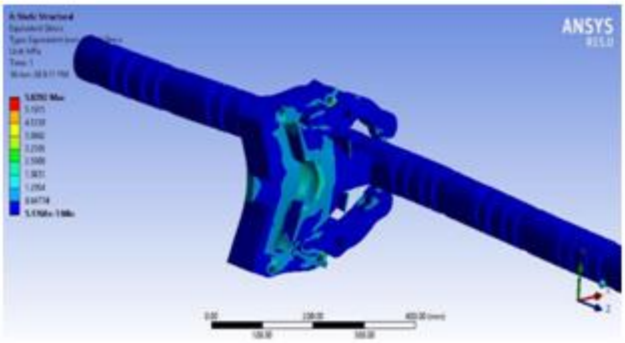
Analysis of the single steady rest for each material is shown. (Total Deformation and Equivalent Stress).

Material: - EN8

Total Deformation

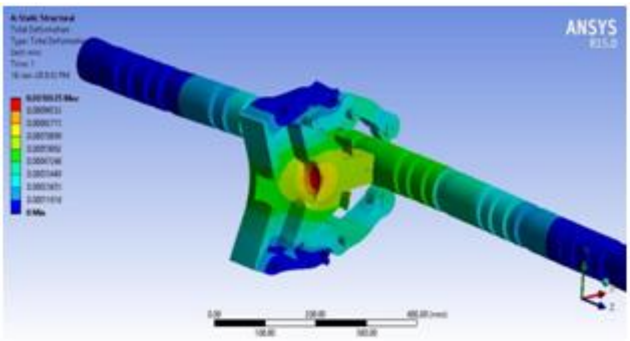


Equivalent Stress

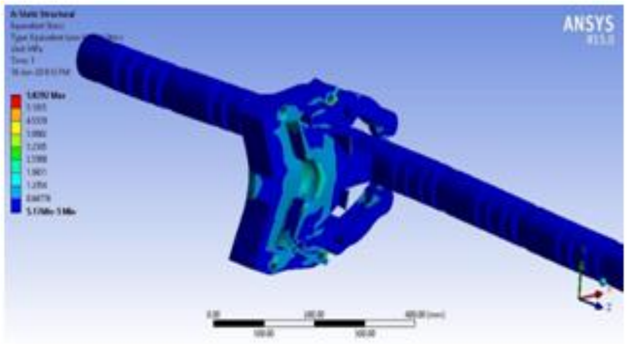


Material: - 16MnCr5

Total Deformation

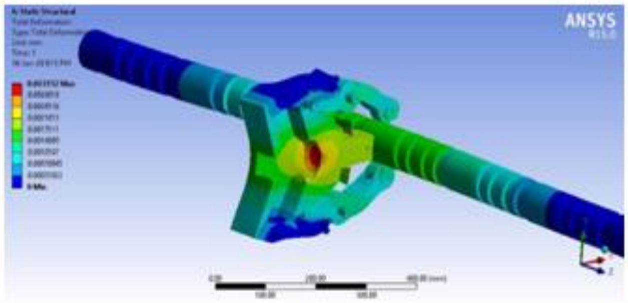


Equivalent Stress

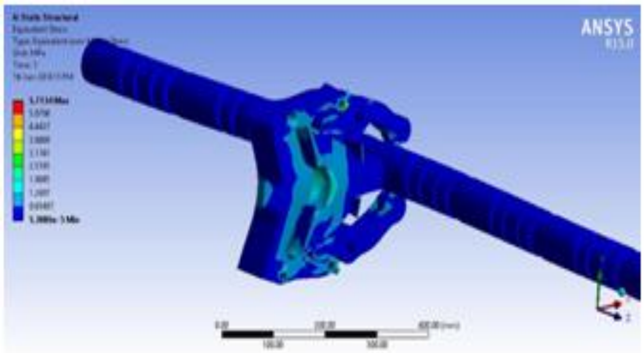


Material: - Aluminum Alloy

Total Deformation



Equivalent Stress

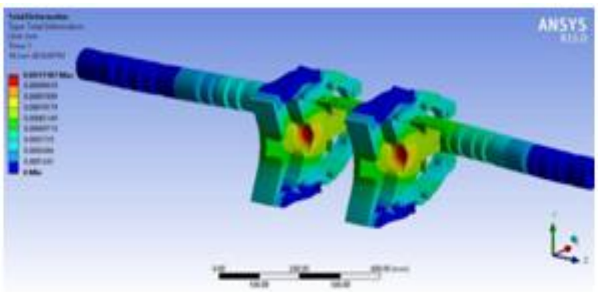


6.3. Analysis of Double Steady Rest

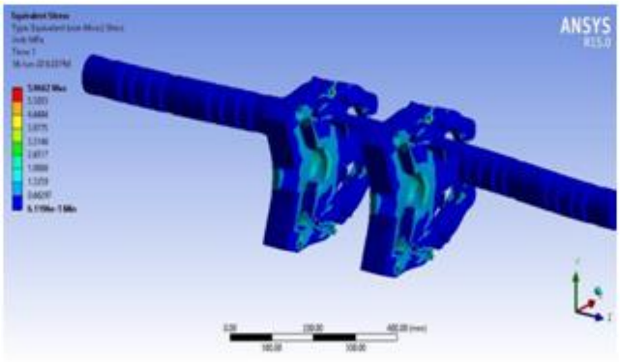
Analysis of the double steady rest for each material is shown. (Total Deformation and Equivalent Stress).

Material: - EN8

Total Deformation

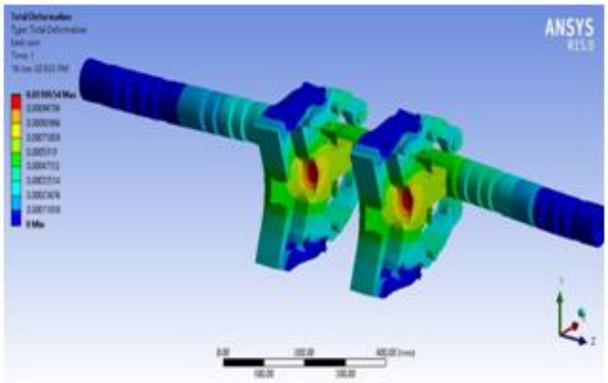


Equivalent Stress

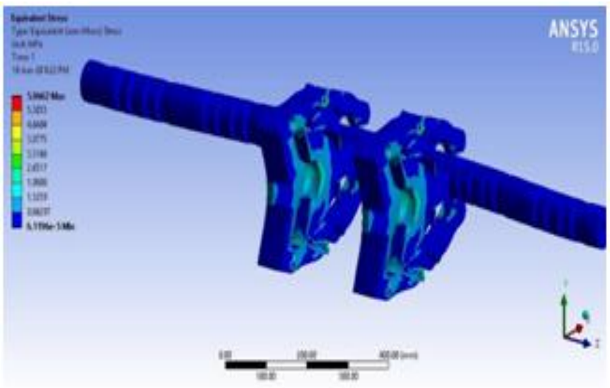


Material: - 16MnCr5

Total Deformation

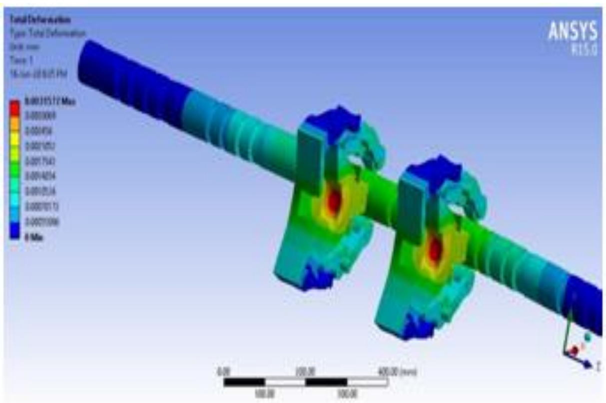


Equivalent Stress

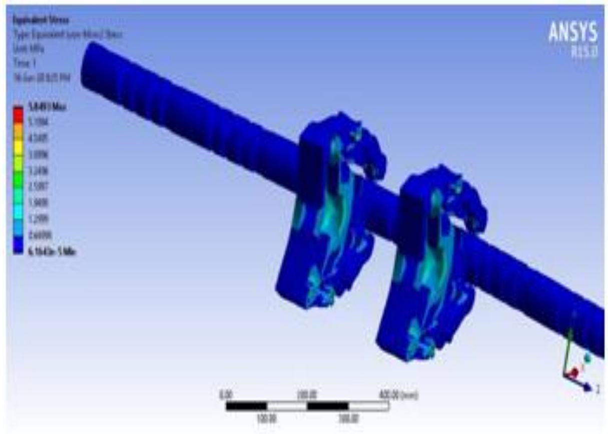


Material: - Aluminum Alloy

Total Deformation



Equivalent Stress



7. RESULT AND DISCUSSION

7.1. Ansys Results

The analysis is done and output parameters are noted down. (Equivalent Stress and Total Deformation).

Table2: Ansys Results

Material	Equivalent Stress (MPa)		Total Deformation (mm)	
	Single Steady	Double Steady	Single Steady	Double Steady
16MnCr5	5.829	5.966	0.0011	0.0010
EN8	5.829	5.966	0.0011	0.0010
Aluminium Alloy	5.713	5.849	0.0031	0.0031

7.2. Cycle Time Results

From the cycle time calculation, the following results are obtained.

Table3: Cycle Time Results

Parameter	Single Steady	Double Steady
Time for 1 job	42 min 36 sec	41 min 51 sec
Jobs Completed in 1 shift (8 hrs.)	11	11
Jobs completed in 1 day (24 hrs.)	33	34
Jobs completed in 1 week (6 days)	202	206
Jobs completed in 1 month (24 days)	811	825

Material selected for steady rest is 16MnCr5. Because,16MnCr5 steels are alloyed case hardly engineering steels for parts which require core tensile strength of 800 to 1100 N/mm^2 and good wearing resistance. It is an engineering material typically used to manufacture Piston, Bolts, Cam shafts, Leavers and other vehicle and mechanical engineering components.

8. CONCLUSION

- After multiple iteration of FEA analysis of steady rest with different parameters it is concluded that 16MnCr5 is suitable. Because equivalent stress from the analysis is less than that of the allowable stress (equivalent stress = 5.966 MPa < allowable stress = 633.33 MPa). Therefore, design is safe.
- After observing the overall process in industry (GMT, Ichalkaranji) and relevant calculation of cycle time, it is observed that the production of job (camshaft) can be increased by 14 no. per month after adopting the double steady rest instead of single steady rest.

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