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Modelling and Structural Analysis of Camshaft of Locomotives

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ABSTRACT:

Camshaft is used in the engine for transfers motion to inlet & exhaust valve. Iftransfer of motion is not proper then the strokes of the engine will not do in proper way. It also effects on performance of engine. To make work of camshaft in precise way, it is require in order designing a good mechanism linkage of camshaft.In four strokes engine one of the most important component is camshaft, such a important part and that over the years subject of extensive research. In this study, Design of Camshaft is done as per power stroke and suction stroke and its model is done in CATIA and Static and Modal Analysis is carried in ANSYS. By varying Materials like Gray Cast Iron & Nickel chromium molybdenum steel and find out which is best material Suits for design.

Introduction to Cam:

A camis a rotating or sliding piece in a mechanical linkage used especially in transforming rotary motion into linear motion or vice versa. It is often a part of a rotating wheel (e.g. an eccentric wheel) or shaft (e.g. a cylinder with an irregular shape) that strikes a lever at one or more points on its circular path. The cam can be a simple tooth, as it is used to deliver pulses of power to a steam hammer, for example, an eccentric disc or other shape that produces a smooth reciprocating (back and forth) motion in the follower, which is a lever making contact with the cam. The cam can be seen as a device that translates from circular to reciprocating (or sometimes oscillating) motion.

A common example is the camshaft of an automobile, which takes the rotary motion of the engine and translates it into the reciprocating motion necessary to operate the intake and exhaust valves of the cylinders. The opposite operation, translation of reciprocating motion to circular motion, is done by a crank. An example is the crankshaft of a car, which takes the reciprocating motion of the pistons and translates it into the rotary motion necessary to operate the wheels. Cams can also be viewed as information-storing and transmitting devices. Examples are the cam-drums that direct the notes of a music box or the movements of a screw machine's various tools and chucks. These diagrams relate angular position to the radial displacement experienced at that position. Several key terms are relevant in such a construction of plate cams: base circle, prime circle (with radius equal to the sum of the follower radius and the base circle radius), pitch curve which is the radial curve traced out by applying the radial displacements away from the prime circle across all angles, and the lobe separation angle (LSA - the angle between two adjacent intake and exhaust cam lobes). Displacement diagrams are traditionally presented as graphs with non-negative values. A camshaft is a shaft to which a cam is fastened or of which a cam forms an integral part. A shaft with cam lobes(bumps) which is driven by gears, a belt, or a chain from the crankshaft. The lobes push on the valve lifters to cause the valves to open and close. The camshaft turns at half the speed of the crankshaft.

Cam is a versatile, specially shaped part of a machine that is always in contact with a member a called the follower. The name cam should not be confused with the common abbreviation cam for camera and camcorder, both used in the fields of photography and video, nor with the acronym CAM applied to computer applied to computer-aided manufacturing, which utilizes computational facilities for machinery fabrication of all kinds. Many different types of cam profile are designed andmanufactured depending on a machine's requirements (P.W Jensen, 1987). Cam is a part of a rotating wheel or shaft that strikes a lever at one or more points on its circular path. The cam is in most cases merely a flat piece of metal that has had an unusual shaped or profile machined onto it. Many studies on the cam mechanisms concern the problem of vibrations. As machine speed increases the problem of vibrations of the cam mechanism has the more significant importance. The vibration level has the influence on the wear rate, noise level and service life of the cam actuated machines and devices and also to the precision operation of machines. Because of that it is important to understand the cause of vibrations and provide means to control or to minimize unwanted vibrations so that desirable system response characteristics maybe predicted and obtained.Cam follower mechanism are found in almost all mechanical device and machine for example in agriculture, transportation equipment, textiles, packaging, machine tools, printing press, automobile internal combustion engines, food processing machines, switches, ejection molds, and control systems, and more recently in micro machines such as micro electromechanical system[MEMS].

LITERATURE REVIEW

S.G.THORAT, NITESH DUBEY, ARVIND SHINDE, PUSHKAR FULPAGARE, MANISH SURYAVANSHI did a study on DESIGN & ANALYSIS OF CAMSHAFT. Camshaft is one of the key parts or components in the engines of automobile and other vehicles.

The goal of the project is to design cam shaft analytically, its modeling and analysis under FEM. In FEM, behaviour of cam shaft is obtained by analysing the collective behaviour of the elements to make the cam shaft robust at all possible load cases. This analysis is an important step for fixing an optimum size of a camshaft and knowing the dynamic behaviours of the camshaft. Initially the model is created by the basic needs of an engine with the available background data such as power to be transmitted, forces acting over the camshaft by means of valve train while running at maximum speed.

Karri Anil, DVSRBM Subhramanyam Sharma did a study on STRUCTURAL AND MODEL ANALYSIS OF CAMSHAFT The cam shaft and its related parts control the opening and closing of the two valves. It comprises of a cylindrical bar running over the length of the cylinder with a number of rectangle sections expanded from it, one for every valve. The cam projections make the valves open by pushing on the valve, or on some moderate component as they turn. This shaft additionally gives the drive to the ignition system. The camshaft is driven by the crankshaft over timing gears cams are made as indispensable parts of the camshaft and are designed in such an approach to open the valves at the right timing and to keep them open for the important span. An example is the camshaft of the vehicles, which takes the revolving movement of the engine and translates it in to the responding movement important to work the suction and exhaust valves of the cylinders.

Material properties, lubrication system, system operating, and the mechanical contact stress are the factor influences the camshaft and its follower performance. The main aim of this work is to find the cam stress, strain and total deformation values. Then with the use of CATIA three-dimensional model of the cam shaft is obtained. Once the CAD model is obtained, modal analysis is performed on CAM SHAFT by applying Cast Iron material, Aluminium Alloy and Billet steel material.

In this work, a camshaft is designed for multi cylinder engine and 3D-model of the camshaft is demonstrating using modeling software CATIA V5 R18. The model created in CATIA V5 R18 is transported in to ANSYS 14.5.

A.S.Dhavale,V.R.Muttagi's review is about the "Study of Modeling and Fracture Analysis of Camshaft".Camshaft is used in the engine for transfers' motion to inlet & exhaust valve. If transfer of motion is not proper then the strokes of the engine will not done in proper way. It also effects on performance of engine. To make work of camshaft in precise way, it is require in order to design a good mechanism linkage of camshaft. To design good mechanism linkages the dynamic behavior of the components must be considered, this includes the mathematical behavior of physical model . In this case, introduction of two mass, single degree of freedom and multiple degree of freedom dynamic models of cam follower systems are studied. In four strokes engine one of the most important component is camshaft, such a important part and that over the years subject of extensive research. In this study, causes of fracture of camshaft are discuses. By using scanning electron microscopy and finite element analysis methods are used for fracture analysis of camshaft.

DESIGN AND ANALYSIS OF CAMSHAFT

3.1CALCULATIONS:

Calculations for camshaft:

Diameter of bore (Dbore) = 49mm = 0.049 m.

Length of stroke (L) =52mm =0.052m

For continuity equation,

A × V = C

Ac = π/4(Db2),

where Ac = Area of cylinder

Ac = π/4 (0.049)2

Ac = 1.8857×10^{-3} m2

V = 2LN/60 where N = Speed of piston

= 2 × 0.052 × 8000/60

V= 13.866 m/s

Q = Ac × V = C

Q = 1.8857 × 10-3 × 13.866

= 0.0261 m3/sec

Inlet valve:

Velocity = 85 m/s

π/4 dip2 × Vip = Ac× V

π/4 dip2 × 85 = 0.0261

Where Vip = velocity of inlet port , dip = diameter of inlet port.

dip2 = 0.0261 × 4/(π × 85)

= 3.9095 × 10-4

dip = 0.0197 m.

Lift of valve hip = dip/(4cosα) + 1mm

= 0.01975/ (4cos45)+1×10-3 [∝ =45]

= 7.9907×10^{-3}m.

Exhaust valve:

Velocity = 95 m/s

π/4dep2 ×Vep = Ac ×V where

Vep= velocity of exhaust port.

π/4dep2 × 95 = 0.0261

dep2 = 0.0261 × 4/ (95 × π)

= 3.4980 × 10-4

dep = 0.0187 m

Lift of valvehep = dep/(4cosα) +1mm

hep = $0.0187/(4\cos 45) + 1\times10^{-3}$

= $6.6114 \times 10^{-3} + 1\times10^{-3}$

= 7.6114×10^{-3} m.

Angle of ascent, ϕa = 58°

Angle of descent, ϕd = 58°

Design of Camshaft:

From empirical relation,

Diameter of camshaft = (0.16×Dbore) + 12.7

= $(0.16 \times 0.049) + 12.7 \times 10^{-3}$

= 0.02054 m

= 0.02054×10^{3}mm

= 20.54mm (Approximately 21mm)

Base circle diameter:

Dbase circle = Dcamshaft+ 3mm

= 21+3

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= 24 mm

Width of cam:

(Wc) = (0.09 × Dbore) + 6 $\times 10^{-3}$

= (0.09 × 0.049) + 6 $\times 10^{-3}$

Wcam = 10.41mm

Forces:

Force (F)=Ffollower + Rrocker arm

Forces on inlet cam:

Frockerarm = Fs+ Fa + Ff

Fs = $\pi/4\ d_{iv}^{2} \times$ ps

Fs= spring force.

div = dip+ 2(0.05 dip to 0.07 dip)

= 0.0197 + 2(0.05 × 0.0197)

= 0.0220 m.

dv = Valve diameter.

Ps = maximum suction pressure < atmospheric pressure

= $0.01 N/mm^2$

Fs = $\pi/4\ (0.0220)^2 \times (0.01)$

Fs= $3.38013 \times 10^{-6} N/mm^2$

Fva = mv× av.

mv = 8grms.

Speed of camshaft (N) = 8000/2= 4000rpm.

In degrees per sec = 4000/60 × 360˚

= 24000˚/sec.

t = 58˚ /24000˚

= 2.4166×10-3 sec.

Acceleration:

hv = ut + ½ avt2 where [u=0]

$7.99 \times 10^{-3} = (0)\ (2.4166 \times 10^{-3}) + 0.5 \times av \times (2.4166 \times 10^{-3})^2$

$7.99 \times 10^{-3} = 0 + 2.9210 \times 10^{-6} av$

av = $(7.99 \times 10\text{-}3)/(2.9201 \times 10^{-6})$

av = 2736.1712 m/s2

Fva = 8×2736.1712

Fva = 21.889 N

Where Fa= acceleration force.

Ff = Inertia force

= mf × af

=40×af

af= hf× ϖ 2/ ϕ a2×4

ϖ =2×π×N/60

=2×π×4000/60

=418.87rad/sec

ϕ a=58˚

=58×π/180

=1.0122rad

af=$(7.99 \times 10^{-3}) \times (418.87/1.0122)^2 \times 4$

= $(7.99 \times 10^{-3}) \times 171248.1339 \times 4$

= 5473.090 m/sec2.

Ff = 40×af

= 40×5473.09

= 218923.6143

= 218.923 N.

Ft = Fs + Fa + Ff

= 3.8013 + 21.889 + 218.923

= 244.6133 N.

Force on Exhaust Cam:

Fe = Fs + Fa + Fg + Ff

Fs = $\pi/4 dev^2 \times$ Ps

dev = dep + 2 × (0.05 depto 0.07 dep)

= 0.0187 + 2 × 0.06 ×0.0187

dev= 0.0209 m.

Ps = 0.01 N/mm2

Fs = π/4 × (0.0209)2×0.01

= 3.4306 ×10-6

Fs= 3.4306 N

Fa = mv×av

mv = 8 gms

N = 8000/2

= 4000rpm

In degrees per second = 4000/60 ×360˚

= 24000˚/sec

t = 58/24000

= 2.4166 ×10-3 sec

Acceleration:

hv = ½ $\times av \times t^2$

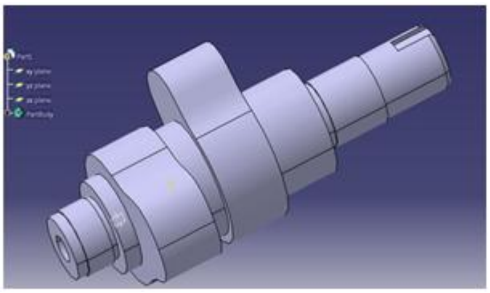
7.6114 ×10-3 = 0.5 ×av× (2.4166×10^{-3})

av = $(7.6114 \times 10^{-3})/(2.9201 \times 10^{-6})$

= 2606.5545m/sec2

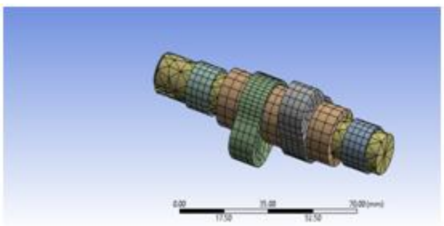
$F_a = m_v \times a_v$
$= 8 \times 2606.5545$
$= 20852.4365$
$= 20.8524$ N.
$F_f = m_f \times a_f$
$m_f = 40$gms
$a_f = h_v \times (\varpi^2 / \phi a^2) \times 4$
$= 7.6114 \times 10^{-3} \times (418.887/1.0122)2 \times 4$
$a_f = 5213.7521$ m/sec^2
$F_f = 40 \times 5213.7521$
$= 208550.0874$
$F_f = 208.5500874$ N
$F_g = \pi/4 \times d_v^2 \times P_{max}$
$P_{max} = 5.25$ kw
I.P = PmLAN/60
$5.25 \times 10^3 = P_{max} \times 0.0521 \times \pi/4 \times (0.049)^2 \times 4000/60$
$P_{max} = 5.25 \times 103/6.5372 \times 10^{-3}$
$= 803091.7738$ N/m2
$F_g = \pi/4 \times dev2 \times P_{max}$
$= \pi/4 \times (0.0209)2 \times 803.091$
$= 275.516$ N
$F_e = 3.4306 + 208.550 + 20.8524 + 275.516$
$F_e = 508.349$ N.

CATIA DESIGNING

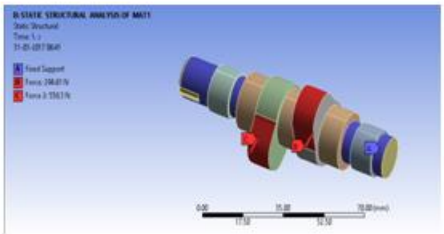


Structural Analysis of Camshaft Using Nickel chromium molybdenum steel

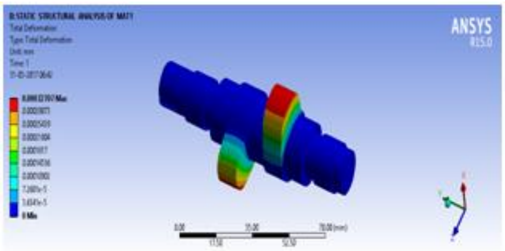
Meshed Model



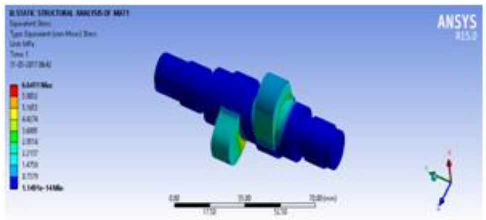
Boundary conditions on3D Model of Camshaft in Ansys



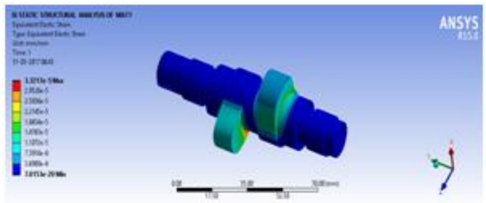
Displacement vector sum:



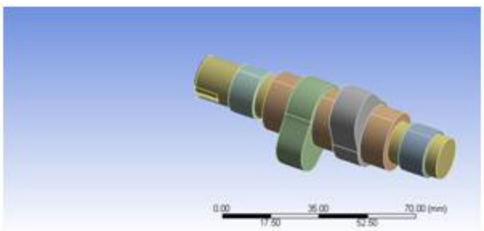
Von Mises stress:



Strain



Modal Analysis Of Camshaft Using Nickel chromium molybdenum steel



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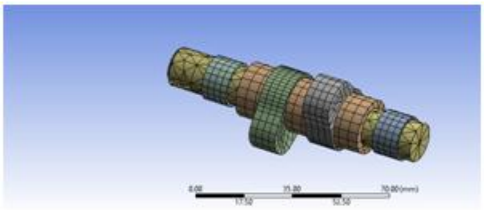
Meshed Model



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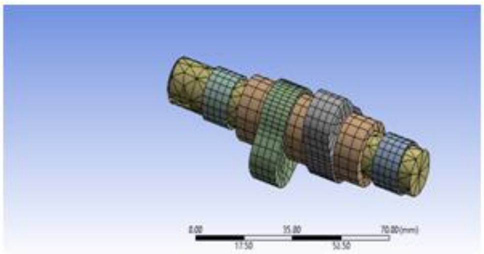
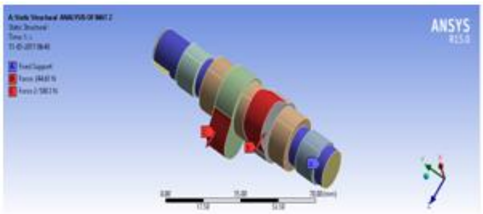
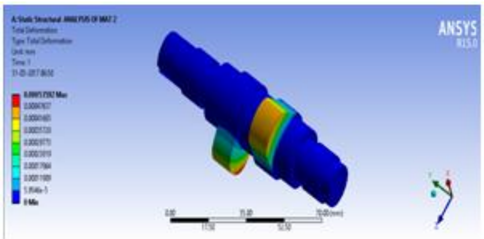


Structural Analysis Of Camshaft Using Gray Cast Iron

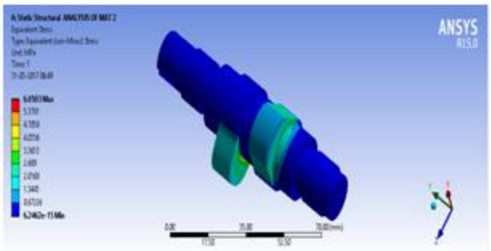
Boundary Conditions



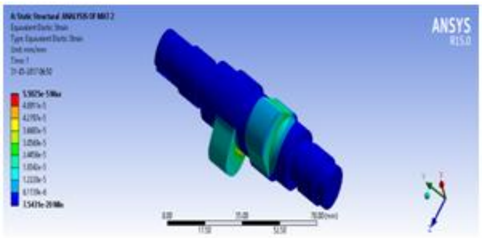
Displacement Vector Sum:



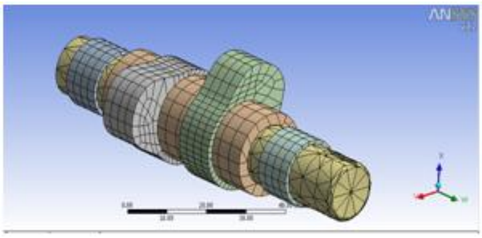
Vonmises Stress:



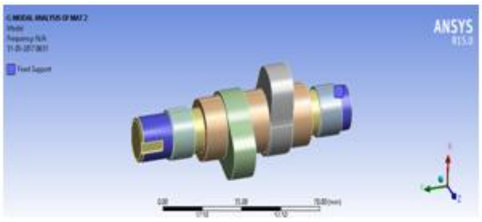
Strain



Modal Analysis Of Camshaft Using Gray cast iron



Apply Loads



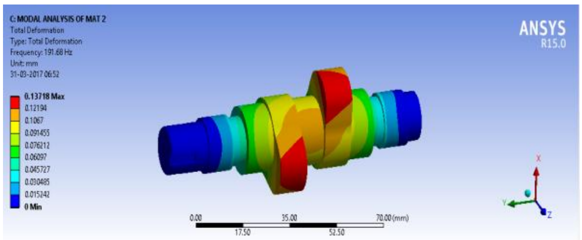
RESULT AND DISCUSSION

Structural analysis results of nickel chromium molybdenum steel camshaft:

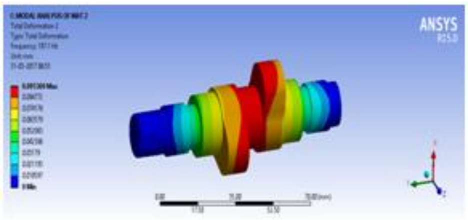
Materil Name	Displacement(mm)	Stress (Mpa)
Nickelchromium molybdenum steel	0.32e-3	6.6411

Modal analysis resultsof nickel chromium molybdenum steel camshaft:

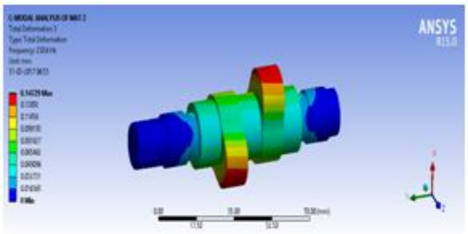
MODEL-1



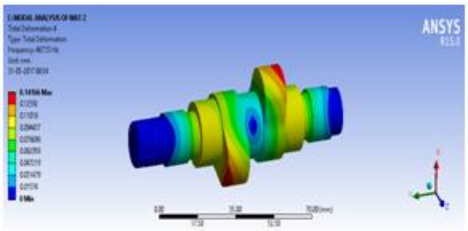
MODEL-2



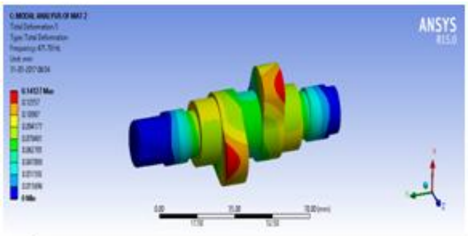
MODEL-3



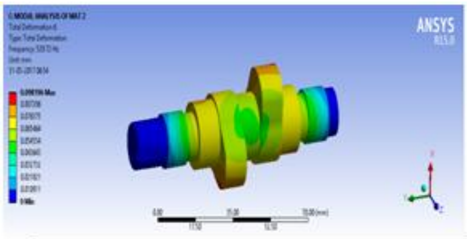
MODEL-4



MODEL-5



MODEL-6



Modal Analysis Results Table

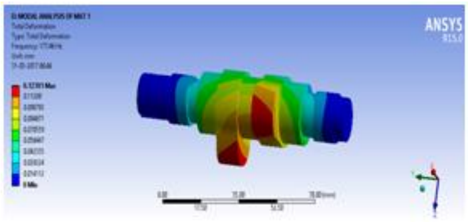
MODE	FERQUENCY(hz)
1	191.68
2	197.1
3	230.6
4	467.55
5	471.78
6	529.72

Structural analysis results of Gray cast iron camshaft

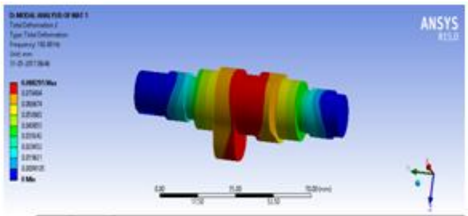
Material Name	Displacement(mm)	Stress (Mpa)
Gray Cast iron	0.53e-3	6.0503

Modal analysis results of gray cast iron camshaft

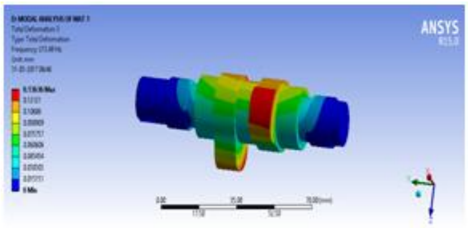
MODEL-1



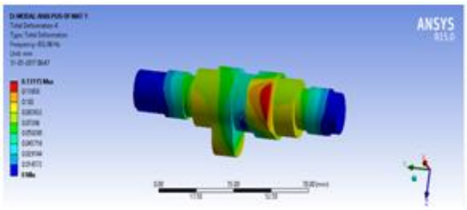
MODEL-2



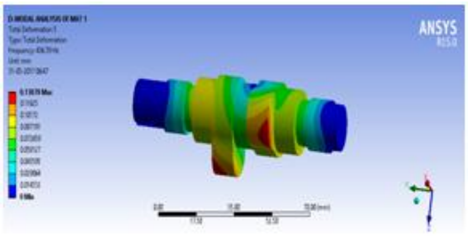
MODEL-3



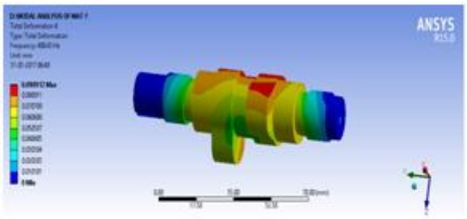
MODEL-4



MODEL-5



MODEL-6



Modal Analysis Results Table

MODE	FREQUENCY(Hz)
1	177.46
2	182.48
3	213.49
4	432.86
5	436.78
6	490.43

COMPARISION RESULTS OF BOTH MATERIALS:

On performing structural analysis and modal analysis of camshaft using both the materials, the following results were obtained.

- From structural analysis, the displacement and stress values of camshaft using gray cast iron and nickel chromium molybdenum steel are as follows:

Material	Displacement(mm)	Stress (Mpa)
Nickel chromium molybdenum steel	0.32e-3	6.6411
Gray Cast iron	0.53e-3	6.0503

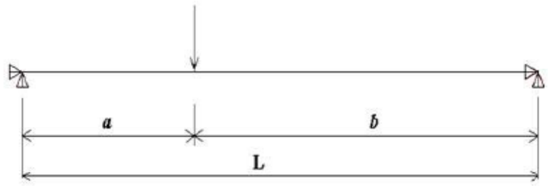
- From the above table, it is clear that camshaft displaces less in case of nickel chromium steel when compared to Gray cast iron.
- From modal analysis, the modal frequency of camshaft using Gray cast iron and nickel chromium molybdenum steel are as follows:
-

Frequency	Nickel chromium molybdenum steel(hz)	Gray Cast iron (hz)
1	191.68	177.46
2	197.1	182.48
3	230.6	213.49
4	467.55	432.86
5	471.78	436.78
6	529.72	490.43

- From the above table, as the modal frequencies for camshaft using nickel chromium molybdenum steel is more compared to cast iron.
- On comparing all the above results, camshaft made of nickel chromium molybdenum steel is preferred.

ANALYTICAL CALCULATIONS OF CAM SHAFT

Deflection of Camshaft:



$$Y = 0.8 \times Fmax \times a^2 \times b^2/[E \times (L(dc^2 - \delta c^4]$$

Where,

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Fmax = total force on camshaft = 1057.693 N

a = Distance of exhaust cam from the journal end =40.5 mm

b = Distance of exhaust cam from the journal end =92.95 mm

E = Modulus of elasticity of C45 = 2.2 * 105 MPa

L = Distance between the two journals per cylinder =133.45 mm

dc = Outer diameter of camshaft = 28.85 mm

δc = Inner diameter of camshaft = 0 mm

y= 0.00039 mm (Nickel chromium molybdenum steel)

y = 0.00056 mm (gray Cast iron)

Bending stresses:

$$\frac{M}{Y} = \frac{F}{Y} = \frac{E}{R}$$

$$\sigma b = \left[\frac{Mbmax}{Wb}\right] = \frac{[F_{max} \times b \times a \times 32] \times E}{\left[\pi \times {d_c}^3 \times \left(1 - \left(\frac{{\delta_c}^4}{{d_c}^4}\right)\right) \times l\right]}$$

σb=6.54 N/mm^2 (Nickel chromium molybdenum steel)

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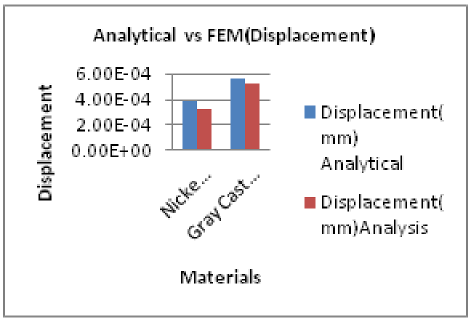
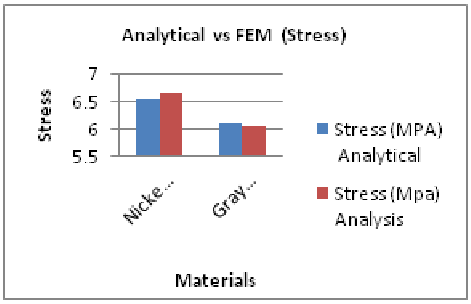
σb= 6.105 N/mm^2 (Gray Cast iron)

ANALYTICAL RESULTS CAMSHAFT:

Material	Stress (MPA) Analytical
Nickel chromium molybdenum steel	6.54
Gray cast iron	6.105

COMPARISION OF FEM ANALYSIS AND ANALYTICAL RESULTS OF CAMSHAFT:





	Cast Iron	Nickel Chromium Molybdenum Steel
Factor of Safety	3.738	11.432

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Materials	Displacement (mm) Analytical	Displacement(mm) Analysis	Stress (MPA) Analytical	Stress (Mpa)
Nickel chromium molybdenum steel	0.39E-3	0.32E-3	6.54	6.6411
Gray Cast iron	0.56E-3	0.53e-3	6.105	6.0503

CONCLUSION

- In this project Design and Modal Analysis of camshaft is done by using CATIA and ANSYS software. By using ANSYS the modal analysis is done to find out the natural frequencies of Cam. The displacement and stress are calculated.
- The design of the cam is done by using CATIA software. The design is done by using cam profile at inlet and outlet (exhaust). The Cam have knife edge follower.
- The structural analysis is used to find the stress and displacement values in Cam. The modal analysis is used to find the natural frequencies of the camshaft and the safety of factor is also considered.
- In this project the preferred material for Cam is selected at it's working environment. The material selection is done by considering stress, displacement and natural frequencies of the materials.
- The material selection for Cam is done by using ANSYS software. In this the two materials are compared. The stress and displacements are calculated at inlet and outlet of Cam. Finally the nickel chromium molybdenum steel is preferred.
- From the analytical results,it is observed that displacement and stress values of both materials that are nickel chromium molybdenum steel and gray cast iron was approximately equal to the displacement and stress values obtained from finite element method by using ANSYS is software so that the analysis of these materials is correct so nickel chromium molybdenum steel is best suitable material.

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