Fracture, Fatigue Growth Rate And Vibration Analysis Of Camshaft In Railways

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Abstract - The cam shaft is the device regulates the opening and closing of the two valves. The connected parts are push rods, rocker arms, valve springs and tappets. It had number of lobes protruding over a cylindrical shaft, one for each valve. The cam lobes force the valves to open by or on some intermediate mechanism as they rotate. Also, this same rotation of the shaft offers the drive to the ignition system. Camshafts are made from steel and sit below the cylinders and pistons in the engine block. At present, camshafts are being manufactured in railways by rolled steel bars and machined by turning and excessive removal of material. We are replaced with aluminum alloy 6061, forged steel & cast iron. For checking, 3D-model of the camshaft is created using modeling software CREO parametric software and analysis done in ANSYS with different materials aluminum alloy, forged steel & cast iron. In this paper, the static analysis and Modal analysis done to conclude the deformation, stresses, strains and the deformation with respect to frequencies at different mode shapes and fatigue analysis is to estimate the life of the component.

Keywords - Cam shaft, FEA, CAE tools, fatigue analysis, ANSYS

INTRODUCTION TO CAMSHAFT

The cam can be seen as a device that translates from circular to reciprocating (or sometimes oscillating) motion. The diesel locomotive trail engine camshaft which takes the rotary motion of the shaft and converts into the reciprocating motion to operate the intake and exhaust valves of the cylinders.

Cam is fastened to camshaft to form as an integral part. Displacement diagrams of Cams can reflect the varying position a roller follower would make as the cam rotates about an axis. These diagrams relate angular position to the radial displacement experienced at that position. Numerous vital terms are important in a construction of cams: base circle, prime circle (with radius equal to the sum of the follower radius and the base circle radius), pitch curve is the radial curve drawn 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 or graphs are generally presented with non-negative values.

And most importantly it is redefining the P-V diagram wherein peak firing pressures have been reduced while increasing the Mean Effective Pressure in the engine. It has been accomplished by delaying the fuel injection (from 25.5 º bTDC to 22° bTDC) and injecting it at higher air compression pressures. As a result, combustion is delayed and peak firing pressures are reduced because by that time return stroke (power delivery stroke) of piston starts. But at the same time power, is delivered for a longer duration and at higher mean pressures. This higher mean pressure has led to changes in the engine camshaft where stress levels have increased.

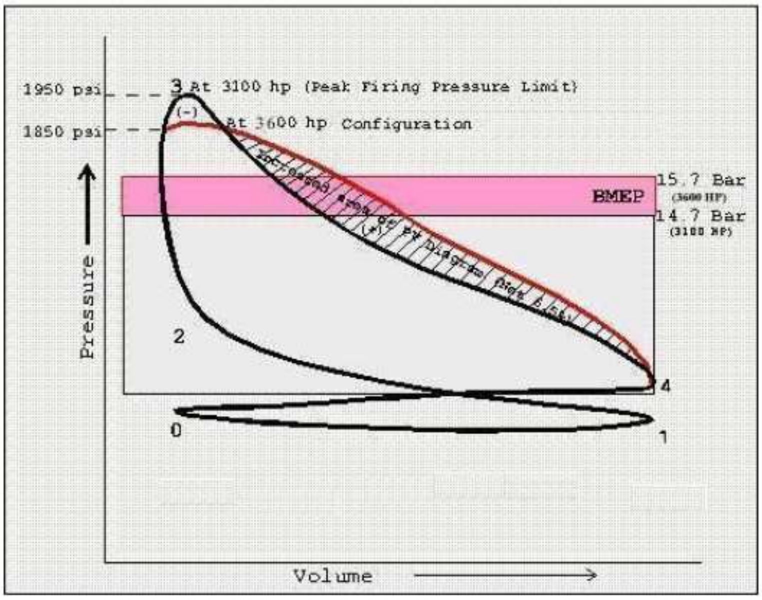


Fig-1: Modified Indicator Diagram for 3600 HP Upgraded Engines

This paper is mainly focused on the replacing rolled steel with aluminum alloy, forged steel & cast iron materials to reduce stresses, strains and the deformation with respect to frequencies at different mode shapes and fatigue analysis is to estimate the life of the component. Fortunately, Finite Element Analysis tools available today are quite helpful in handling complicated designs, but it is not easy to deploy them in all situations. Moreover it is important to know, what factors have significant impact on the Stress Concentration Factor in similar geometries and how can these be resolved.
In this Paper, a camshaft is designed for Railway engine and 3D-model of the camshaft is created using modeling software pro/Engineer. The model created in pro/E is imported in to ANSYS. After finishing of assigning the element properties, meshing and constraints the loads are applied on camshaft for three different materials namely aluminum alloy 6061, forged steel & cast iron. For that condition the results have been taken has displacement values and von misses stresses for the static state of the camshaft. After taking the results of static analysis, the model analysis and harmonic analysis are done one by one. Finally, comparing the three different materials the best suitable material is selected for the construction of camshaft.

SPECIFICATION OF ROLLED STEEL MATERIAL:
The material used for rolled camshafts was equivalent to AISI E 1070 grade High Carbon Steel which is suitable for induction hardening of camshaft lobes. This material was selected by DMW after lot of experimentation, so initially the same grade material was adopted for forgings also. The Mechanical and Chemical properties for this material are tabulated below:

Table - 1: Mechanical Properties of Magnaflux Quality AISI E 1070 Grade Hot Rolled, Normalized and Tempered Steel suitable for Induction Hardening (3)

Sr.	Parameter	Specified Values
1	Tensile Strength (Min)	670 MPa
2	Yield Strength (Min)	350 MPa
3	% Age Elongation (Min)	17
4	% Age Reduction in Area (Min)	40
5	Hardness	190-230 BHN

SELECTION OF MODIFIED MATERIALS
The rolled material used in railways can exhibit more strength but not fatigue and damping due to shock loading condition. Hence this lead to modification of present rolled steel material. The high fatigue strength of Forged steel, moderate for Cast iron and lowest for aluminum considered for fatigue analysis. The vibrational analysis also done to get the damping factors of modified material camshafts. The modified materials mechanical properties are given as follows:

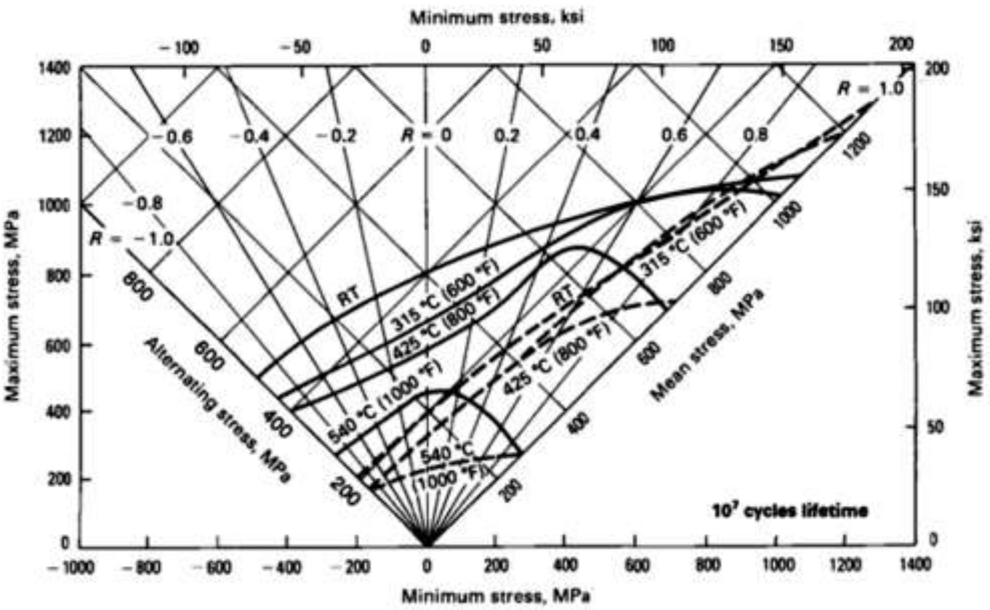
Table -2: Mechanical Properties of aluminum alloy 6061, forged steel & cast iron

Properties	Aluminum 6061	Forged Steel[4]	Cast Iron[4]
Hardness	120	219	97
Ultimate Tensile Strength	310 MPa	655 MPa	658 MPa
Modulus of Elasticity	68.9 GPa	210 GPa	178 GPa
Bearing Yield Strength	386 MPa	440 MPa	410 Mpa
Poisson's Ratio	0.33	0.3	0.33
Fatigue Strength	96.5 MPa	1124 MPa	927 MPa
Fracture Toughness	290 MPa	980 MPa	658 MPa

A locomotive working on Indian Railways undergoes a typical duty cycle as tabulated below;

Table: Duty Cycle of Locomotives[2]

Notch	8	7	6	5	4	3	2	1	Idle
RPM	1100	980	860	740	640	580	510	450	350
Duty Cycle %age									
Passenger Service	22	6	4	8	4	8	5	6	38
Freight Service	22	7	5	3.5	3.5	3.5	3	1.5	51



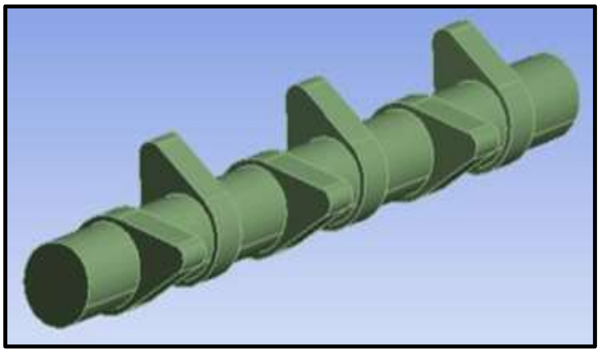
Constant-lifetime Fatigue Diagram for Alloy Steel (UTS: 1035 MPa)*1
#Solid lines- Unnotched, Dashed Lines- Notched Specimens, in 107 cycles

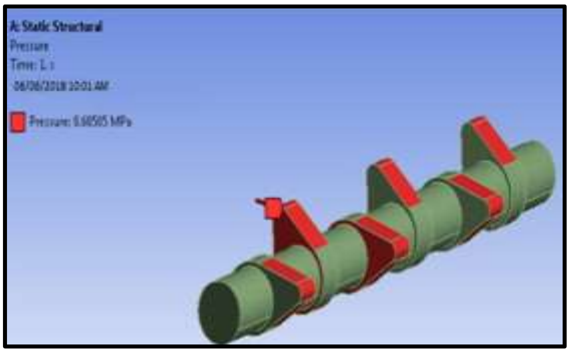
Manufactured Cam Shaft and Machined Cam Shaft

MODELING & FINITE ELEMENT ANALYSIS

A CAD model design with conventional and composite materials of CamShaft is created in Creo 4.0. It has special tools in generating surface design to construct typical surfaces, which are later converted into solid models. Solid model of all parts of the structures are then assembled to make a complete structure.

The CAD model of Camshaft with conventional and composite materials used for FE Analysis during assembly is shown in figure-2 &3. The Camshaft model imported in ANSYS-14 workbench. A stress-deflection analysis is performed using finite element analysis (FEA). The complete procedure of analysis has been done using ANSYS-14 Workbench. Generally to conduct finite element analysis process is divided into three main phase’s preprocessor, solution and postprocessor. The preprocessor is a program that processes the input data to produce the output that is used as input to the subsequent phase (solution). Solution phase is completely automatic. The FEA software generates the element matrices, computes nodal values and derivatives, and stores the result data in files. These files are further used by the subsequent phase (postprocessor) to review and analyze the results through the graphic display and tabular listings. The output from the solution phase is in the numerical form and consists of nodal values of the field variable and its derivatives. For example, in structural analysis, the output is nodal displacement and stress in the elements. The postprocessor processes results data and displays them in graphical form to check or analyze the result. The graphical output gives the detailed information about the required result data. The boundary conditions of the Camshaft in preprocessor stage are shown below.


3d model of cam shaft


Boundary Condition of Cam Shaft

RESULTS AND CONCLUSION

Structural Analysis Results

Material	Deformation (mm)	Stress (N/mm^2)	Strain
Forged steel	0.028264	15.931	7.9928e-5
Cast iron	0.0851499	15.841	0.0001448
Aluminum alloy	0.079318	14.782	0.00020896

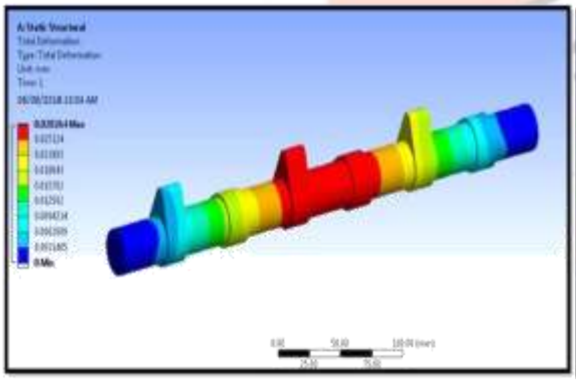
Modal analysis results

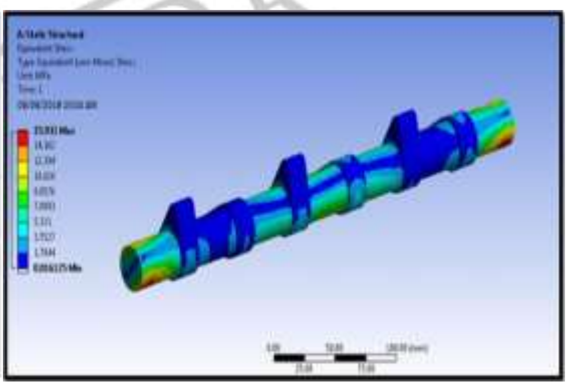
Material	Deformation Mode-1 (mm)	Frequency (Hz)	Deformation Mode-2 (mm)	Frequency (Hz)	Deformation Mode-3 (mm)	Frequency (Hz)
Forged steel	31.772	798.02	31.955	798.37	30.694	2126.4
Cast iron	33151	608.45	33.317	608.71	31.956	1622.9
Aluminum alloy	53.487	790.61	53.794	790.95	51.692	2106.6

Fatigue analysis results

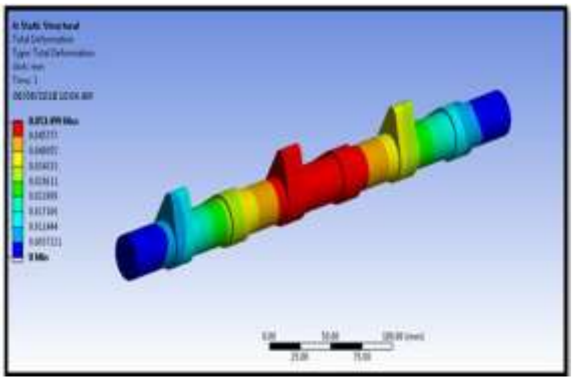
Material	Life	Damage	Safety factor	
			Min	Max
Forged steel	1e9	11122	0.05831	15
Cast iron	1e9	10728	0059214	15
Aluminum alloy	1e9	8592	0.06487	15

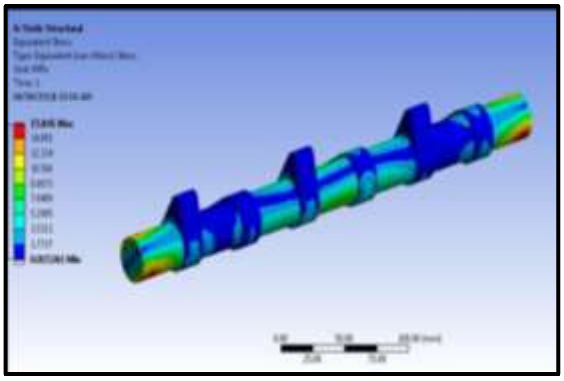
Materials – Forged steel


Total deformation

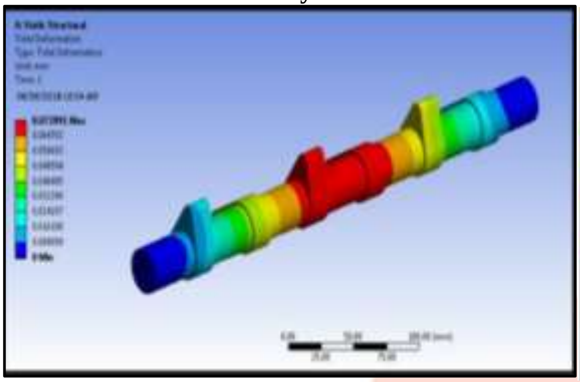

Von-Misses Stress

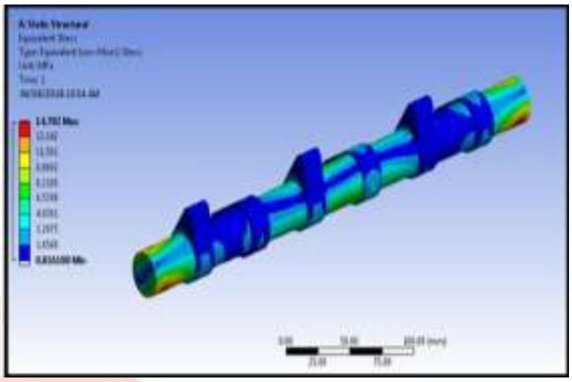
Materials - Cast iron


Total deformation

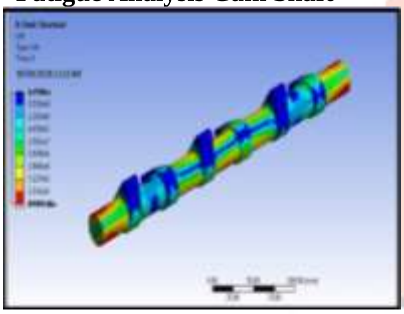

Von-Misses Stress

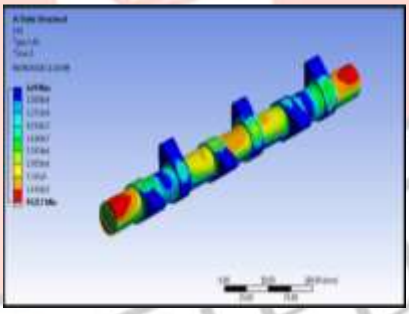
Materials - Aluminum Alloy 6061

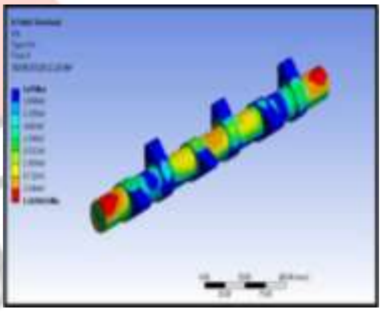

Total deformation


Von-Misses Stress

Fatigue Analysis Cam Shaft


Forged Steel


Cast Iron


Aluminum Alloy

The camshaft is driven by the crankshaft over timing gears cams are made as integral parts of the camshaft and are designed in such a way to open and close the valves at the right timing and to keep them open for the required duration. By observing the static analysis, the stress values are less for aluminum alloy 6061 compare with forged steel and cast iron. By observing the modal analysis, the deformation and frequency values are more for aluminum alloy. By observing the fatigue analysis, the safety factor values are more for aluminum alloy. So, it can be concluding the aluminum alloy is better material for cam shaft. The Cam Shafts can be modeled in composites to absorb shock load for future scope.

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