

# Comparative Study and Analysis of Drive Cone Safety to the Engine Drive Gear's Overhang on the Camshaft's Drive Cone

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**Abstract:** - A camshaft is a shaft that has a cam attached to it. The camshaft provides the follower, another element, with the preset, specified motion. The camshaft and its follower play crucial roles in engine operation in the automotive industry. Numerous analyses have been conducted on component failure because the system operates at high speeds and heavy loads. FEM-experimentation is used for the analysis. An approximation of the component failure is the outcome of the finite element analysis. This research is to ascertain the drive cone's safety in light of the engine drive gear's overhanging impacts on the shaft's drive cone. The components' stress concentration is found using design software. The computations make use of the drive torque and forces delivered by the engine drive gear. The finite element analysis result indicated that the outermost fiber of the camshaft's driving cone was the site of the largest stress concentration, which ultimately led to failure.

**Index Terms** -Camshaft, valve mechanism and Timing belt

## 1. Introduction

The drive cone failure is one of the main issues with the camshaft. The overhang effects of the engine drive gear assembly on the camshaft's driving cone resulted in a significant number of cone breakages. The stresses and safety aspects in the camshaft's drive cone region were examined under limiting settings, which included injection pressures of 900 bar and a range of overhang lengths. The overhang lengths of 20, 44, and 62 mm were taken into consideration. There are five cams on the cam shaft. The eccentric cam that operates the lift pump is the first one. The purpose of the remaining four is to power the pump's plungers. The cams are positioned so that pumping elements distribute gasoline at the precise moment in the engine's operating cycle and in the firing order. Fluid is supplied to the injector pump elements' intake by the lift pump. The governor assembly, delivery valve, and cam-driven plunger make up each component of the pump. The governor's job is to regulate the amount of gasoline that the plunger delivers to a cylinder. To get, turn the plunger in relation to the spill orifice using the helical groove. Engine fuel is supplied at a specific pressure by a fuel injection pump. The pump creates the necessary pressure and delivers the appropriate amount of gasoline at the appropriate time. A high pressure line carries the pressurized gasoline to the nozzle. Fuel is injected into the combustion chamber by the nozzle. A subset of conditions needs to be fulfilled by an in-line pump, including: Timing and

duration of fuel injection; the total volume of fuel to be injected; the amount of pressure to be created. The aluminum pump housing houses the integrated camshaft of each engine cylinder, whereas the in-line injection pumps have their own camshaft. To obtain the power needed for spinning, it is connected to the diesel engine. The necessary amount of fuel is compressed by the cam lobes on the cam shaft, which then transforms the rotational action of the camshaft to the reciprocating motion of the plunger. Injectors then transfer this pressurized fuel to the combustion chamber.

### Evolution of high pressure fuel injection in line pump

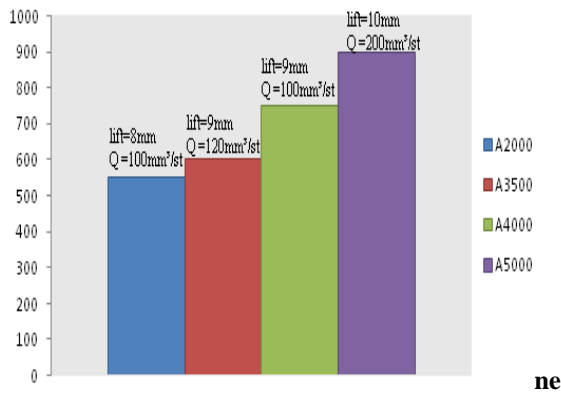
Model: A5000 fuel injection pump is being developed to meet the new and more stringent BS-4 emissions norms. This pump runs at injection pressures of 900 bar resulting in high stresses and deformations in camshaft. Till now the variant available which is capable of delivering the fuel at max of 750 bar.

### Need for A5000 Fuel injection Pump

The present a pump was designed to meet CPCBI norms and has reached its technical design limitations due to which it is not meeting the need for higher power generation. This led to the development of A5000 fuel injection pump. A5000 Inline Fuel Injection pump is being developed to meet the new CPCBII emission norms for power rate up to

200kVA

Figure 1: Advance of Inli



### Fuel Injection pump

Objectives:

- Analysis of Engine Gear Assembly drive Cone Breakage
- Analysis of Camshaft bending due to loads acting on the roller
- Analysis of Camshaft twisting due to Torsion Loads

Applications	: Genset Applications
Power	: up to200 kVA
Pump End Pressure	: 850 bar
Pump speed	: 750 rpm
Fuel Delivery	: 200mm <sup>3</sup> /st

## 2. Literature Review

An in-line injection pump incorporates the camshaft, and a plunger-and-barrel assembly for each engine cylinder. Camshaft is integrated in the aluminum pump housing. It is connected to the diesel engine either through a timing device, through a coupling element or directly [1]. A roller tappet with spring seat is located above each camshaft cam. The spring seat provides a positive-drive connection between pump plunger and roller tappet. The pump plunger moves up and down in the pump barrel [2]. In cam design it is important to reduce the cam and tappet wear to correlate the cam profile design with the curvature radius and the Hertz stresses level and it is recommends that the material for the cam and tappet to be steel with material hardness to be around 60 HRC [3]. The factors influencing the endurance limit to improve the design of shaft dimensions and through stress analysis done using Ansys it shown

that the maximum value of stress occurs at the vicinity of change in cross section of the shaft where a relief groove is present [4]. The working of camshaft and tappet assemblies in the inline fuel injection, these operate in conjunction with the plunger return springs to provide the reciprocating motion for the pumping elements. The camshaft is supported by heavy-duty rolling bearings, ball or opposed tapered rollers, and is of rugged proportions to withstand without deflection the heavy loads imposed upon it. Either or both ends may have standard tapers with keyways which provide connections for a driving coupling or gear and the governor [7]. Each spring returned pump plunger is lifted by its cam through a tappet assembly, incorporating a roller, bush and pin to ensure smooth rolling contact with the cam [8]. Fuel injection pump cams are subjected to high unit stresses and sudden impact loading and must therefore possess hard surface to resist the wear and galling and a tough softer core to support the hard surface. Carburized steels have higher wear resistant cam surfaces because of the higher carbon content in the carburized surface produces iron carbide with exceptional wear resistance and tougher with soft core. Since the fuel injection equipment requires high plunger velocities with short injection durations the suitable cam are the fast cams that is tangent cams [9]. To predict the elasticity at each contact as well as the pressure distribution across each contact patch. Hertzian contact theory is probably the most widely used analytical contact model and variations of this model are used [10]. Design methods based on strength considerations for sizing shafts and axles to withstand both steady and fluctuating loads [11]. The effects of combined bending torsion and axial loads are considered along with many application factors that are known to influence the fatigue strength of shafting materials. Methods are presented to account for variable amplitude loading histories and their influence on limited life designs [12]

## 3. Modeling and Analysis of Camshaft

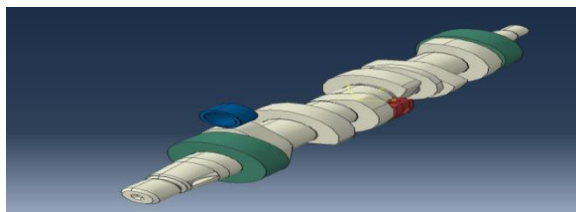
### Modeling

A 3D geometry of the camshaft was modeled with the minimum diameter of the shaft is 27.5mm. The lobes were placed at a phase difference of 60 degrees from each other to take care of the firing order sequence. The roller was positioned appropriately on the respective camshaft lobe to represent its position in the maximum injection pressure condition [5].

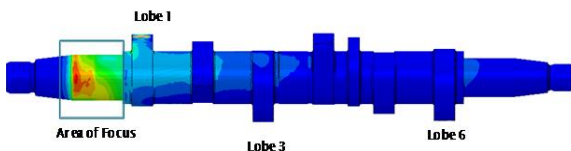
The bearings were modeled as simple cylinders and placed in the respective positions to the camshaft surfaces. The center bearing was modeled as a semi-cylindrical piece. A clearance of 0.052 mm is prescribed relative to the relevant camshaft surface.

**Analysis**

To analyze the model for the induced stresses, strains and deflections, using the Finite Element Method, one needs to discretize the geometry into simpler shapes. The purpose of the discretization is twofold. The first is to capture the underlying geometry of the component accurately. The second is to capture the deformations and the underlying strain distributions. Features like fillets, notches and keyways need a higher level of discretization. This is because the strain distributions in these features have very high strain and deformation gradients. The above two tasks are accomplished by using nodes and elements [6].



**Figure 2: CAD Model of Camshaft**



**Figure 3: Von Mises Stress distribution**

**Stress Analysis**

Both bending loads and Torsion moments are applied to the reference point which is transmitted to the camshaft. The details of the loads have been mentioned; Constraint: Coupling constraint (Constraint applied at reference point to the outer surface of the drive cone) Contacts constraints are imposed between the camshaft and the two bearings respectively.

*Assumptions and Boundary conditions:*

Strains are small We are operating under the proportional limit.	Reference point: Constrained along the X direction.
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Since we are operating under isothermal conditions the stresses are not a function of temperature and we are also eliminating the time dependent strain effects like creep, viscous elasticity etc.	Roller ID : Roller completely constrained.
	Right Bearing : Bearing OD Completely Constrained.
	Left Bearing : Bearing OD Completely Constrained.
	Centre Bearing : Completely Constrained.

In this case we have chosen a combination of tetrahedral and hexahedral elements. Hexahedral are used where feasible. The tetrahedral elements are used to model complex features and transitions between simple or complex features

**Table 1: Forces acting under injection pressure at 900bar**

Injection pressure operating at Lobe	From Cone End (mm)	Drive Torque (Nm)	Radial force (N)	Tangential force (N)
Case-1 at Lobe:1-3-6	20-44-62	153.3	830.5	2144.1
Case-2 at Lobe:1-3-6	20-44-62	185.1	1002.7	2588.9

**Table 2: Various overhang length for injection pressure 900bar**

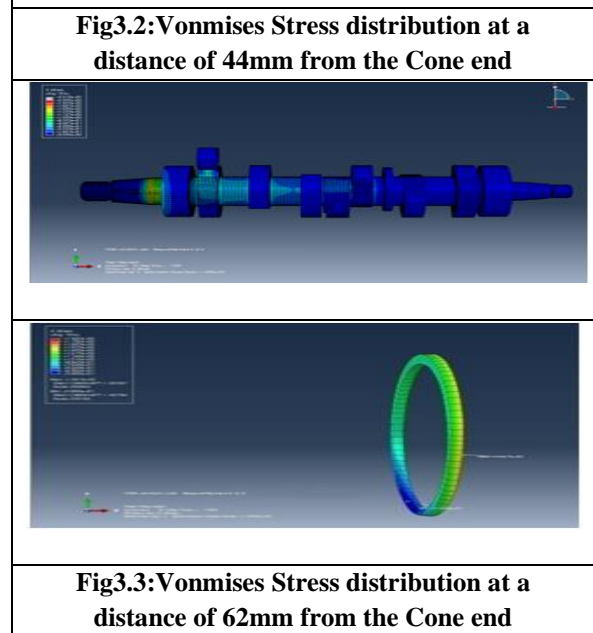
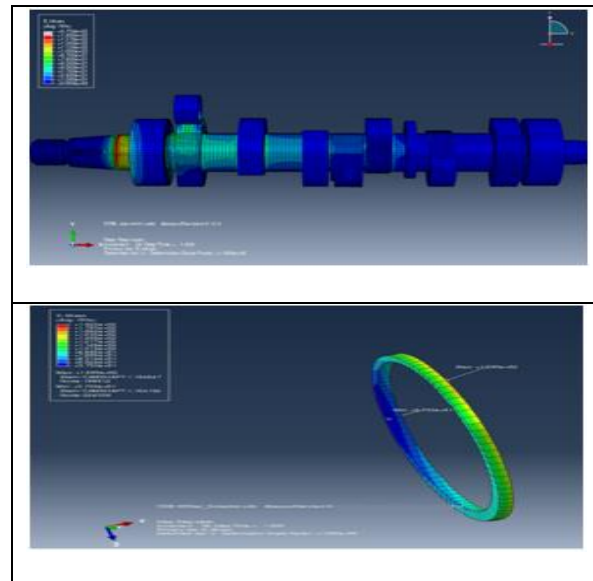
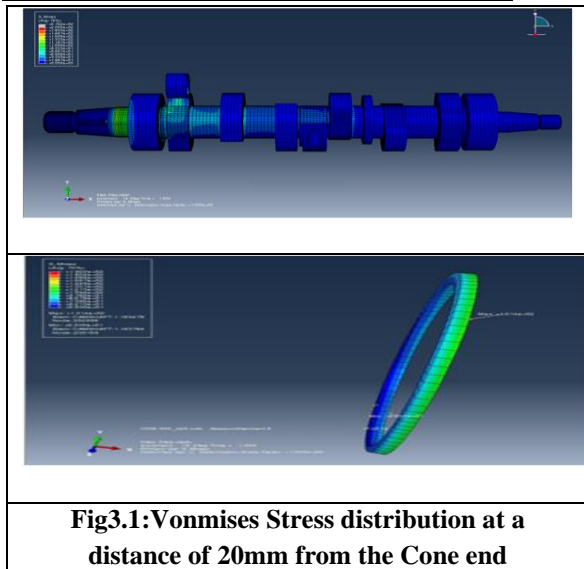
Dimensi ons	Equival ent Stress (N/mm2 )	Permissi ble Stress (N/mm2)	Deflecti on (mm)	Fact or of Safe ty
20	94.58	244.86	-0.0473 (Lobe:1 )	2.56
44	120.625	215.24	-0.147 (Lobe:2 )	1.7
62	146.65	200	-0.047 (Lobe:3 )	1.3

The coefficient of friction at all interfaces is assumed

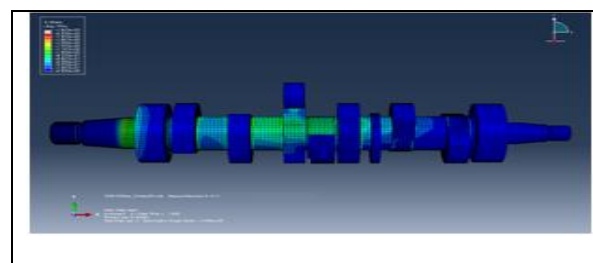
to be a conservative value of 0.12. Additionally, a contact constraint is defined between the centre bearing and the camshaft .In the event of the camshaft deflecting excessively and coming into contact with the bearing, this contact would be invoked. Similarly, the roller-camshaft interaction is defined using contact [13].The stresses developed at this contact should balance the external torque, thus keeping the shaft in a state of static equilibrium (A very necessary conditions for the static stresses to develop in the camshaft). The innovations that established the brand in engine manufacturing and design were technologically advanced for the time [14]. Concepts like lubrication, the use of aluminum components, and positioning the camshaft on the head proved to be precursors to modern vehicle manufacturing techniques, with many of these solutions being deemed truly essential. The engine's ease of assembly and manufacture was due to its simplicity. Because of the current low level of automation, the manufacturing times were substantially longer [15]. Furthermore, the methods of manufacturing and assembly relied solely on skilled workers, meaning that the absence of one may halt output entirely. This idea served as the foundation for the effects the factory experienced during the strike.

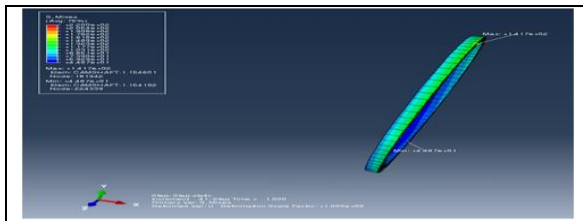
**Case-1**

**Injection pressure operating at FIRST Lobe:**

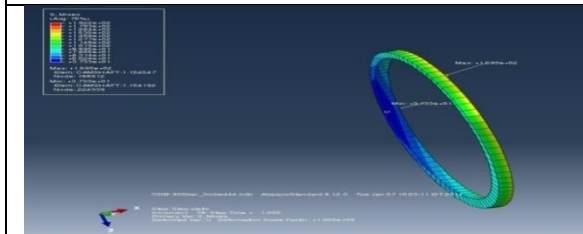
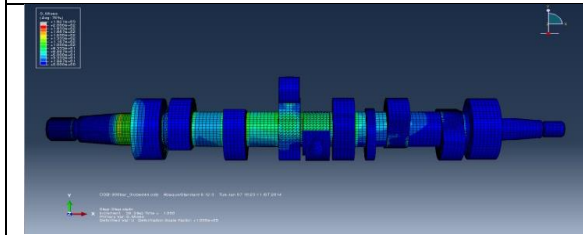


**Injection pressure operating at THIRD Lobe:**

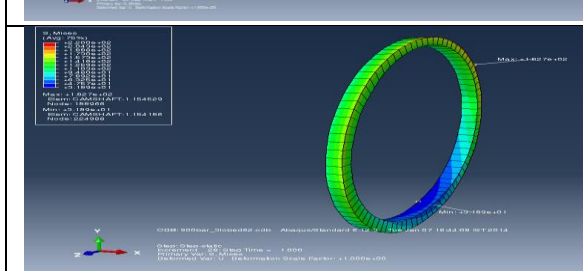
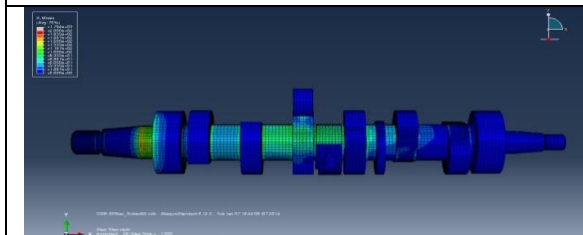




**Fig3.4:Vonmises Stress distribution at a distance of20mm from the Cone end**

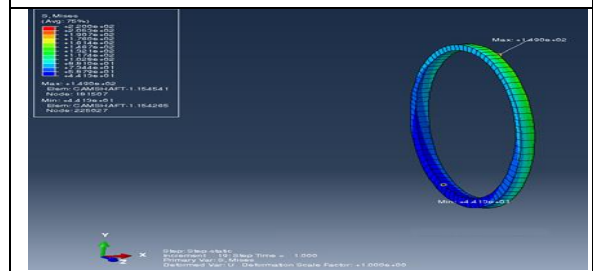
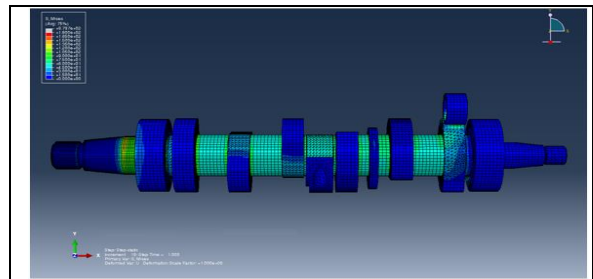


**Fig3.5:Vonmises Stress distribution at a distance of 44mm from the Cone end**

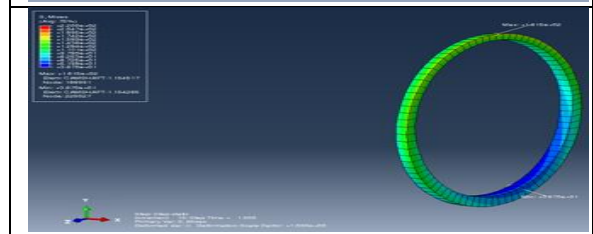
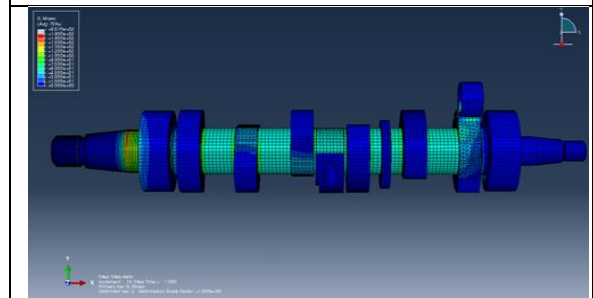


**Fig3.6:Vonmises Stress distribution at a distance of 62mm from the Cone end**

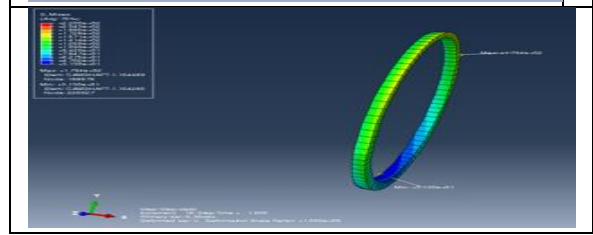
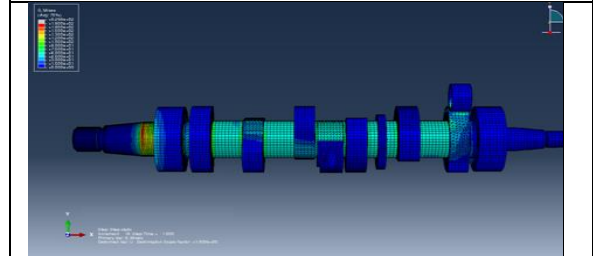
**Injection pressure operating at SIXTH Lobe:**



**Fig3.7:Vonmises Stress distribution at a distance of20mm from the Cone end**



**Fig3.8:Vonmises Stress distribution at a distance of 44mm from the Cone end**



**Fig3.9: Vonmises Stress distribution at a distance of 62mm from the Cone end**

The figure 3.1-3.9 represents the general von mises stress distribution in the camshaft. The adjacent figure represents the von mises stress distribution in the vicinity of the node with the max value of stress in the drive cone region. These conditions are realized by assuming that the material is isotropic and homogenous and that no internal voids etc are present. These ensure that the matter can be considered as continuous, thus allowing us to use the scalar calculus of functions (differentiability, inerrability). Both bending loads and Torsional moments are applied to the reference point which is transmitted to the camshaft.

The production of standard emissions, particles, and combustion stability were all significantly impacted by the design of the injector nozzle head. When compared to nozzle heads with bigger fissures, multi-hole nozzle heads demonstrated slightly greater NOx emissions and improved CO<sub>2</sub>, CO and total PN emissions. When the injection pressure is increased, the SOI for some nozzle designs may be delayed more than for other injector head designs, but the engine performance—including power output, emissions formation, and combustion stability—must still be maintained.

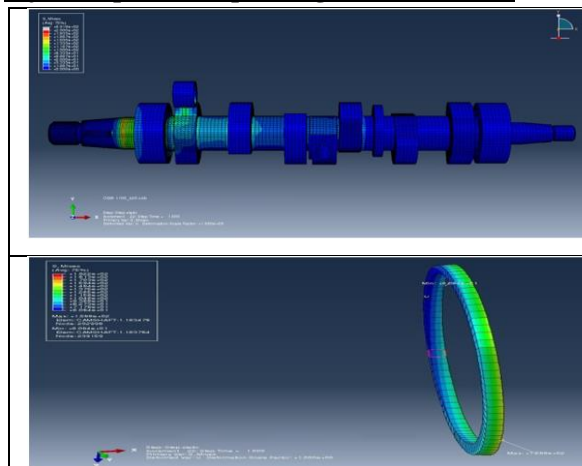
Derived from technological innovation, the industry performance generated much reliability so that engines designed by the brand were widely used in the aeronautical industry, fully complying with the requirements to be used as aircraft power plant. However, the automotive production division was moderate, as this brand was bound to produce to a well-defined social sector, with high purchasing power [16]. Its line was luxury vehicles having similarities with the current Rolls Royce. In addition, each car was unique, there was complexity everywhere, especially in the composition of the car chassis.

A steel roller "timing chain" or a toothed rubber "timing belt" are the two most common methods of driving the camshaft [17] . The camshaft has also occasionally been driven by gears. The distributor, oil pump, gasoline pump, and occasionally the power steering pump are all driven by the camshaft in certain configurations. The engine's crankshaft powers the camshaft through a set of gears known as timing and

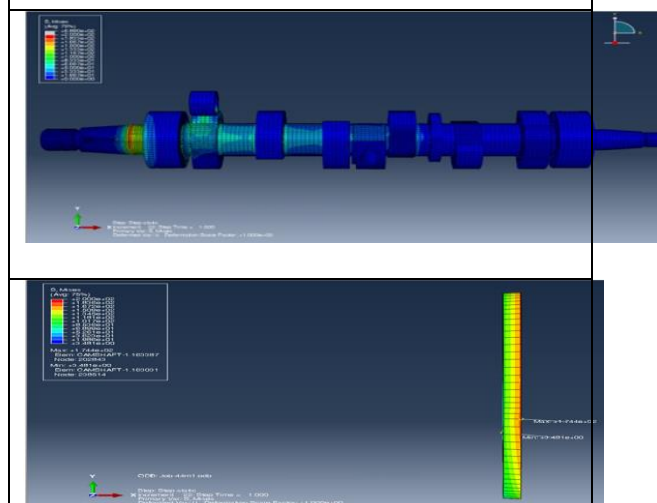
idler gears. The gears facilitate the camshaft's rotation to match the crankshaft's rotation.

**Case-2**

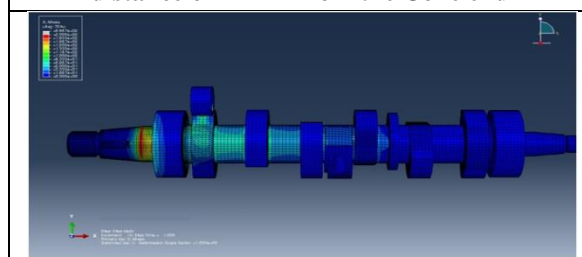
**Injection pressure operating at FIRST Lobe:**



**Fig3.10: Vonmises Stress distribution at a distance of 20mm from the Cone end**



**Fig3.11: Vonmises Stress distribution at a distance of 44mm from the Cone end**



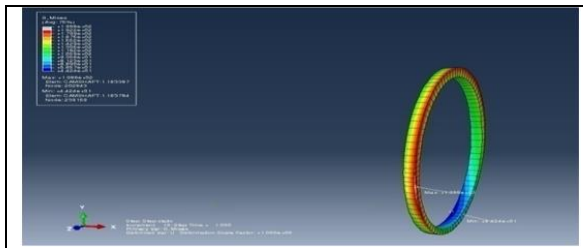


Fig3.12: Vonmises Stress distribution at a distance of 62mm from the Cone end

**Injection pressure operating at THIRD Lobe:**

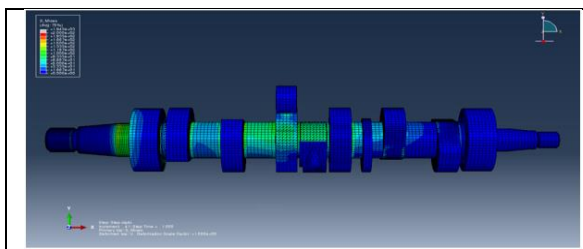


Fig3.13: Vonmises Stress distribution at a distance of 20mm from the Cone end

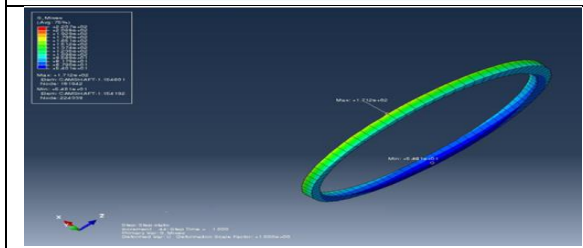


Fig3.13: Vonmises Stress distribution at a distance of 20mm from the Cone end

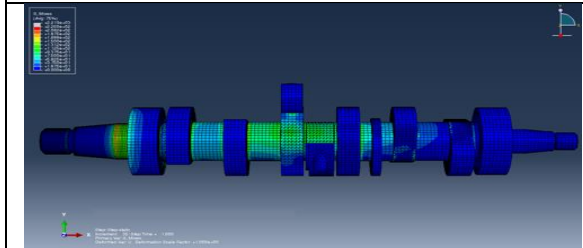


Fig3.14: Vonmises Stress distribution at a distance of 44mm from the Cone end

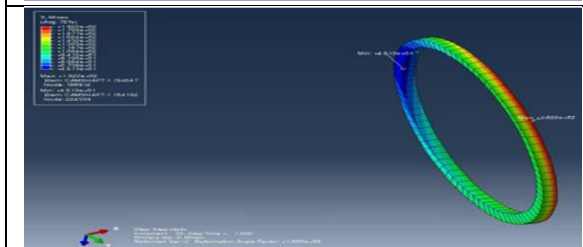


Fig3.14: Vonmises Stress distribution at a distance of 44mm from the Cone end

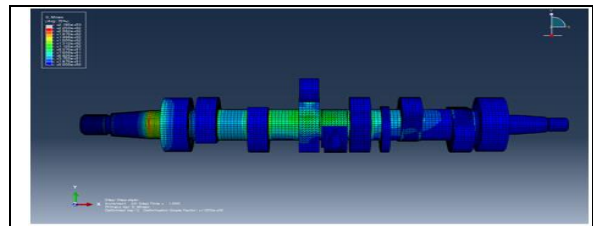
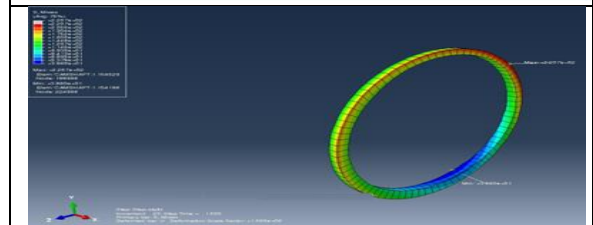


Fig3.15: Vonmises Stress distribution at a distance of 62mm from the Cone end



**Injection pressure operating at SIXTH Lobe:**

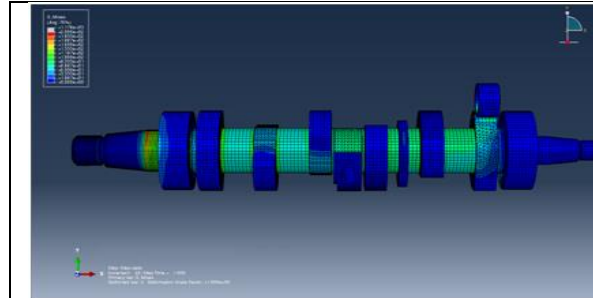
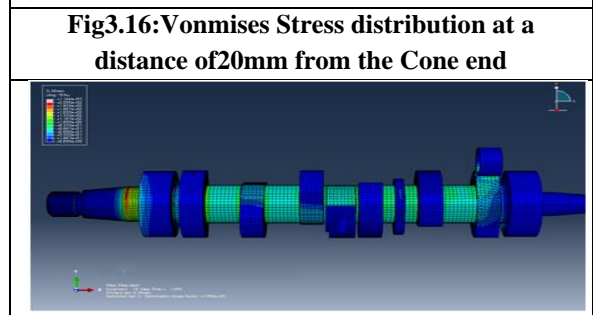
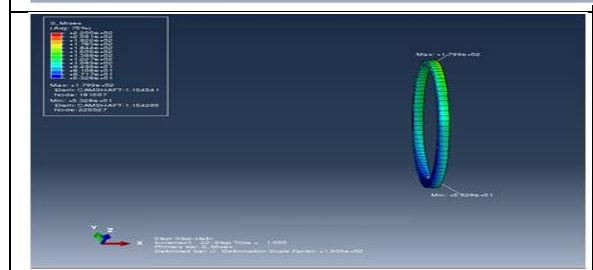
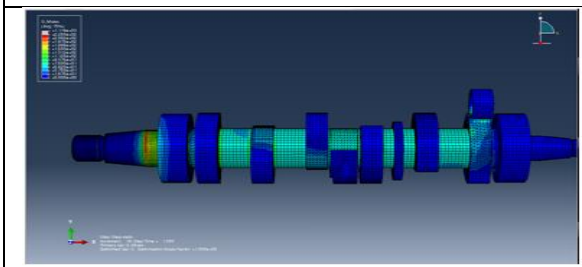


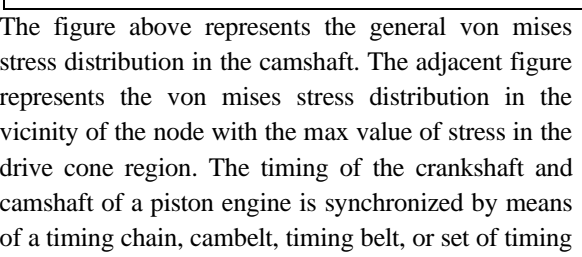
Fig3.16: Vonmises Stress distribution at a distance of 20mm from the Cone end



**Fig3.17: Vonmises Stress distribution at a distance of 44mm from the Cone end**



**Fig3.18: Vonmises Stress distribution at a distance of 62mm from the Cone end**



The figure above represents the general von mises stress distribution in the camshaft. The adjacent figure represents the von mises stress distribution in the vicinity of the node with the max value of stress in the drive cone region. The timing of the crankshaft and camshaft of a piston engine is synchronized by means of a timing chain, cambelt, timing belt, or set of timing gears. By synchronizing, the engine's valves operate according to the pistons' positions, opening and closing at the appropriate moments. A chain drives the sprockets of the timing gears. This drive is known as a sprocket drive as a result.

The crankshaft and camshaft rotate in the same direction. When there is greater space between the crankshaft and camshaft, it is utilized. The camshaft's purpose is to regulate the timing and motion of the valves, and the engine's behavior is entirely dependent on the way those valves are coordinated. Every time a camshaft is applied incorrectly, disappointment results, but when cam selection is done correctly, an engine will frequently provides you more than you could anticipate. Each bank of the cylinder head of an engine with double overhead cams, dual overhead cams, or twin cams has two camshafts: one for the intake valves and another for the exhaust valves. As a result, a straight engine has two camshafts, whereas a V or flat engine has four camshafts total [1].

It is advisable to withdraw from driving your car if your camshaft is broken. You want to prevent any more expensive damage because engine problems are

among the most expensive to repair. The form of the lobes on camshafts can have a significant impact on a vehicle's performance at various engine speeds. By being aware of their functions and the various varieties that are available, you can get the most out of your four-stroke engine. While a cam chain is made of metal and resembles a bicycle chain in shape, it fulfills the same function as a cambelt. Usually, it is protected by a metal engine cover that is sealed. Usually, cam chains are run "wet," which means they function in the oil to help with lubrication and efficiency.

#### 4. Results and Discussion

The configuration with 20mm overhang length is safe from the consideration of stress in the part. The above decision was based on the computed factors of safety for both static and dynamic conditions and the values are

##### Static Conditions

The acceptable factor of safety for infinite life is 1.3 for static conditions, here we, observe, from the tables above, that the FOS for the 44 mm overhang is also above 1.6. However considering various uncertainties in the load calculations, overstressing and deficiencies in material processing, the factor of safety may dip to below the required 1.6

**Table 3: Static FOS for injection pressure of 900bar**

Dimension	Equivalent Stress	Permissible Stress	FOS
20	94.58	244.86	2.56
44	120.625	215.24	1.7
62	146.65	200	1.3

##### Dynamic Conditions

As we know the minimum acceptable factor of safety for infinite life is 1.6 and 1.51 for static and dynamic conditions respectively, we, observe, from the tables above, that the FOS for the 44 mm overhang is also above 1.6. However considering various uncertainties in the load calculations, overstressing and deficiencies in material processing, the factor of safety may dip to below the required 1.6

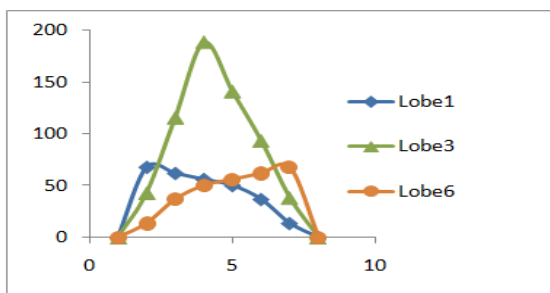
**Table 4: Dynamic FOS for injection pressure of 900bar**

L	Di	F	L	Di	F	L	Dim	F
O	m	OS	O	m	O	O	"a"	O

B E N o	“ a”		B E N o	“ a”		S	B E N o	S	
1	20	2.6	3	20	2.4	6	20	2.3	9
	44	2.3		44	2.1		44	2.1	
	62	1.9		62	1.8		62	1.8	

As we know the minimum acceptable factor of safety for infinite life is 1.6 and 1.51 for static and dynamic conditions respectively, we, observe, from the tables above, that the FOS for the 44 mm overhang is also above 1.6. However considering various uncertainties in the load calculations, overstressing and deficiencies in material processing, the factor of safety may dip to below the required 1.6

CASE-1



CASE-2

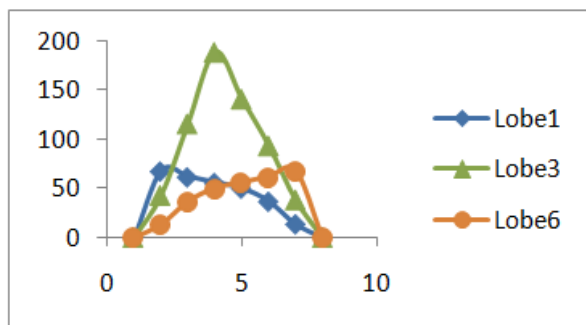


Figure 4-1: Bending moment during 1-3-6 cylinders

5. Conclusions

The configuration with 20mm overhang length is safe from the consideration of stress in the part. The above decision was based on the computed factors of safety for both static and dynamic conditions. For

infinite life, the minimum acceptable factor of safety is 1.6 and 2 for static and dynamic conditions respectively, we, observe, from the tables above, that the FOS for the 44 mm overhang is also above 1.6. However considering various uncertainties in the load calculations, overstressing and deficiencies in material processing, the factor of safety may dip to below the required 1.6. Hence it is recommended to limit the design up to 44mm overhang. It was found that deflection is beyond the permissible limit of 0.052mm when the third lobe is subjected to the injection pressure. This confirms the presence of centre bearing. However, the centre bearing intermittent contact with the shaft may lead to excessive wear of the shaft. The angle of twist from the maximum torque condition was calculated earlier and found to be 1.009 deg. From the results it is evident that the angle of twist is without any criticality and acceptable. The values output by FEA and the values calculated match to a good level of accuracy.

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