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Design and Structural Optimization of Oil Pan

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Abstract:

The control of noise and vibration is essential in the design process of an automobile, since it contributes to the comfort, efficiency and safety. In order to reduce radiated noise and vibration in power train assembly, one of the most critical components is an oil pan. The aim of this study is the development of a methodology to increase the oil pan stiffness starting from a sketch of the component and adding material where it is needed and to reduce structure born radiation. The model is created starting from the geometry of an actual oil pan. A series of iterative optimizations are carried out with finite element software. In this study, the design method based on accounting for the coupling effects of the static load and the dynamic load. For this a structural static analysis will be done by applying the operating loads and design optimization shall be done to minimize the deflection. A vibration analysis will be done on the oil pan to calculate frequencies and mode shapes and also the component behavior at different frequencies due to operating loads. The current work explores the effects of pre-stress forces on modal parameters of oil pan. The harmonic response analysis of pre-stressed oil pan is one of the key objectives in this project. To increase the stiffness of the actual oil pan rib type structures are added to geometry where it is needed. Then again, structural static analysis will be done on stiffened oil pan and the results will be evaluated.

Keywords:

oil pan, modal analysis, harmonic analysis, strengthening, resonance.

I.INTRODUCTION:

While it is known as an oil pan in the U.S., other parts of the world may call it an oil sump. In automotive and other similar applications, the bottom side of four-stroke internal combustion engines are sealed by a large metal pan mounted called oil pan. It holds engine oil and acts as an oil reservoir.

During engine operation, oil pump draws oil from the pan and circulate it through the engine, after the oil has passed through the engine, it is allowed to return to the oil pan. It's a spot for the oil to collect if the engine isn't running. It also is where the oil cools as air passes over the surface of the pan. It's a place for impurities in the oil to settle and it has a drain to allow for removal of old oil. Use of a sump requires the engine to be mounted slightly higher to make space for it. Often though, oil in the sump can surge during hard cornering starving the oil pump. For these reasons racing and piston aircraft engines are "dry sumped" using scavenge pumps and a swirl tank to separate oil from air which is also sucked up by the pumps.

Oil pans are detachable mechanisms made out of thin steel and bolted to the bottom of the crankcase. To maximize its function, it is molded into a deeper section and mounted at the bottom of the crankcase to serve as an oil reservoir. When an oil pan is removed, some components revealed usually include the crankshaft, oil pickup, and the bottom end of the dipstick. Some oil pans will also contain one or more magnets that are designed to capture small pieces of metal before they can plug the oil filter or damage the engine.

II.LITERATURE SURVEY:

Bart Peeters [1] presented a two vibration-based approaches which can detect damage and yield updated experimental models of the structure. A first approach is based on (operational) modal analysis. Based on vibration measurements, the modal parameters of the structure are estimated. The idea is now to automate this process so that, without human intervention, a representative dynamic model of the structure is always available. The second uses multiple-model estimation in the case when the state-space models have different state dimensions. Andreas Veiz and Johannes discussed the possibility to optimize an oilpan with the new method of a parametric optimization [2]. A bidirectional interface for direct modification of CAD Parameters by the optimization tool optiSLang was used.

A modal analysis was performed to determine the first eigen frequencies which are critical in some cases and therefore it has to be increased. Development of 'draw' component and the changes made in product design due to manufacturing and assembly reasons considering the design intent and also the advantages of using various CAE software used in designing draw tools were discussed by Y. N. Dhulugade, P. N. Gore [3]. It helped for reducing the complete product development cycle as compared to what happens with conventional methods. A smart car oil pan with surface-attached piezoelectric actuators for active noise and vibration reduction using numerical simulations was designed by S. Ringwelski, T. Luft, U. Gabbert [4]. FEM is applied to model the structural behavior of the oil pan as well as the surface-attached piezoelectric actuators. Possible high cycle fatigue (HCF) failure modes causing the cracking of a turbine spacer in a gas turbine engine are determined by M. Attia and J Hou by using FEA. The effects of prestress forces on modal parameters of concrete beams were explained by Marco Breccolotti [6].

Concerning the twofold purpose aspect, it is still not clarified whether prestress forces should be included or not in standard identification-model-updating frameworks Fixed modal analysis and harmonic frequency response function (FRF) analysis were performed on an existing Ford 1.3L Endura E petrol engine aluminum oil pan [7]. Acoustic Control (ASAC) method to reduce noise provided proof that vibration induced noise from the oil pan has the potential to be reduced significantly [8].Complete product design of integrated breather valve cover with optimal solution of all the available techniques in every aspect of design, development and real time production of valve cover were discussed [9]. Stress and flow analysis of the critical component of gate valve was done using FEA and its stress and flow analysis validation is supported by classical mechanics [10].The aim of the present study is to design an oil pan from the existing model to with structural stability to avoid failure of oil pan due to resonance at various operating speeds, where similar studies are not available in the literature.

III.PROBLEM DEFINITION AND METHODOLOGY:

Oil pan has been designed and optimized for Structural behavior for vibration control. The design method based on accounting for the coupling effects of the static load, and the dynamic load which are necessary and important.

In the present work, the effects of pre-stress forces on modal parameters of oil pan are considered. The harmonic response analysis of pre-stressed oil pan is carried out. Most dominant mode shapes are enumerated up to 1200 Hz, Then harmonic analysis is completed using full harmonic method. CREO 3.0 software is used to design the oil pan and ANSYS software is used to do finite element analysis.

IV.Design of Oil Pan:

Oil pan model was designed by using 3D modeling software (CREO3.0). Oil pan has been designed for operating pressures loading and vibrations. The 3D model of actual oil pan is shown in fig1.

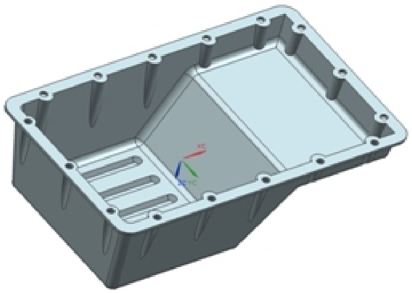

Fig.1 Solid model of Oil pan

The prepared model of the oil pan is exported to ANSYS. All the components of the Oil pan are assigned as per the below Aluminium alloy material properties.

Young's Modulus : 72GPa
Yield Strength : 414 MPa
Tensile Strength : 483 MPa
Density : 2800 kg/m^3
Poison ratio : 0.3

Static analysis was done to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Modal analysis determines the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed.

Modal analysis was carried out on the prestressed oil pan to determine the natural frequencies and mode shapes of a structure up to 1300 Hz. The bolting locations are Fixed in all dof. Internal pressure 0.035MPa is applied on Oil pan. The boundary conditions and loading applied for static analysis are shown in fig2.

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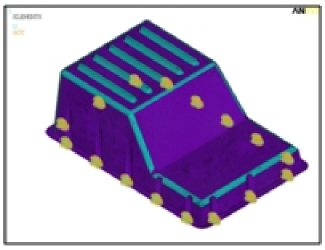

Fig2 Meshed oil pan with boundary conditions

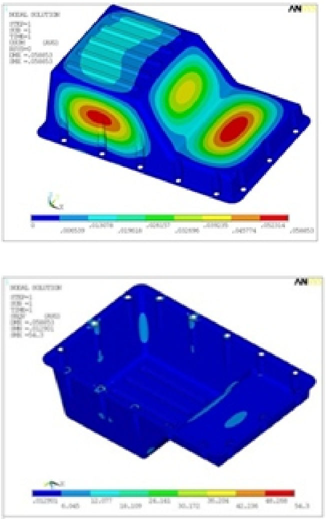

Fig3a, 3b. Total Deflection & VonMises stress for pre stress analysis

From the prestress analysis, it is observed that the maximum deflection of 0.05mm is at top plate and side plates of oil pan and VonMises stress of 54 MPa is observed at bolting locations of oil pan. Modal analysis to obtain the natural frequencies and mode shapes is conducted on this prestressed oil pan.

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DYNAMIC ANALYSIS OF OIL PAN:

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. Modal analysis was carried out on Oil pan to determine the natural frequencies and mode shapes of a structure up to 1300 Hz. Various mode shapes of these frequencies are shown in fig4.

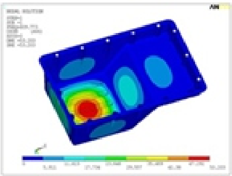

Fig 4a Mode shape 1

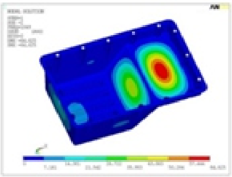

Fig 4b Mode shape 2

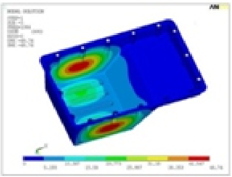

Fig 4c Mode shape 3

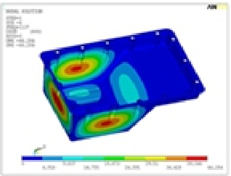

Fig 4d Mode shape 4

Table1 Frequencies in the range of 0-1200Hz.

MODE. NO	FREQUENCY (Hz)	Occurrence Location
1	809	Bottom side
2	1049	Front bottom
3	1064	Side walls
4	1137	Side walls

After conducting modal analysis various modes of natural frequencies and appearance their location are shown in table 1. To check the magnitude values of deflections and stresses at the above mentioned natural frequencies due to the operating loads, harmonic analysis is carried out on the prestressed oil pan.

HARMONIC RESPONSE ANALYSIS:

Harmonic response analysis gives the ability to predict the sustained dynamic behaviour of structures. It is used to verify whether or not your designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations. In the harmonic analysis, structure responses at these natural frequencies are recorded. Graphs are plotted between amplitude in mm in Y-axis and Frequency in Hz in X-axis in the frequency range of 0-1300 Hz. The graphs are shown in fig 5. The amplitude of vibration at various natural frequencies are read from table 2.

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The maximum amplitude of vibrations is occurring at 1049 Hz frequency and it is calculated as 5.6mm at the top plate location.

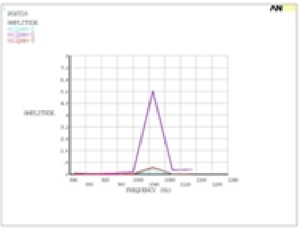


Fig5a. Harmonic response top plate

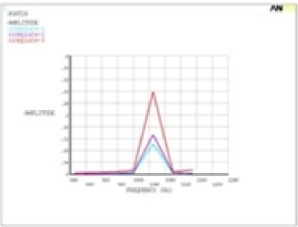


Fig 5b. Harmonic response side plates

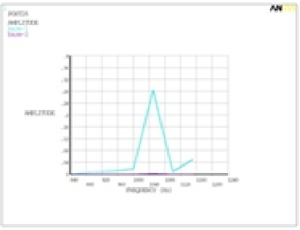
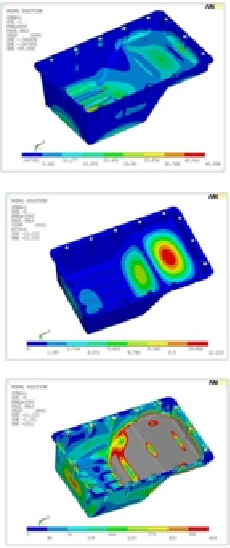


Fig 5c. Harmonic response base plate

Table2. Harmonic response Analysis Frequency vs. Amplitude



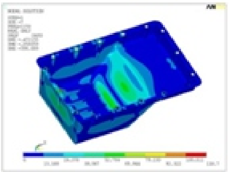


Fig 6a, 6b, 6c and 6d.
VonMises stresses at various frequencies

Table 3. Deflections and VonMises stresses at various frequencies:

S.no	FREQUENCY(Hz)	DEFLECTIONS (mm)	VON MISES STRESS (MPa)
1	850	0.3	46
2	1050	12.2	2811
3	1150	0.47	396

The deflections and VonMises stresses at various modes of natural frequencies are shown in table3. From the results, it is observed that maximum stress is 2811MPa and it is more than the yield strength of the material 414MPa. Hence the design of oil pan is not safe for the above operating loading conditions as per VonMises theory.

DESIGN OF MODIFIED OIL PAN:

To keep the oil pan safe operating, the stiffness of oil pan has to be increased. For this reason, the actual oil pan is to be modified and rib type structures are added at the locations where high stresses will occur. Rib type structural elements are added at top plates where the supposed failure may occur. The oil pan is modified as shown in fig7. Then, structural analysis, modal analysis, harmonic analysis are done on the modified oil pan to evaluate results in the same working conditions.

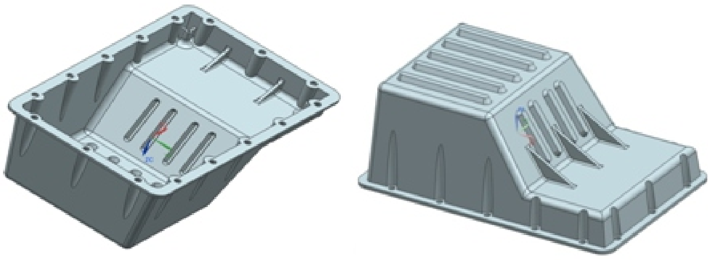


Fig7. 3D Modified Oil pan

PRE-STRESS ANALYSIS OF MODIFIED OIL PAN:

The model is designed in CREO 3.0 modeling software. The boundary conditions and loading applied for static analysis are shown below

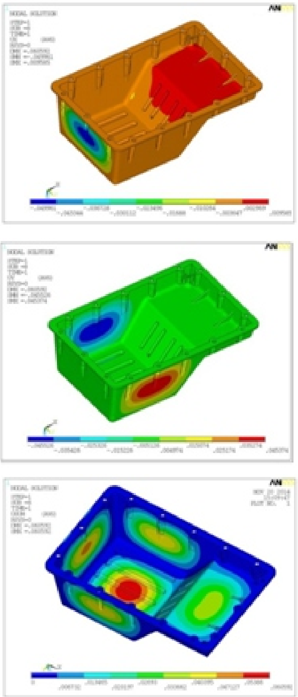


Fig8a, 8b, 8c. Deflections in X, Y, Z directions of modified oil pan for pre stress analysis.

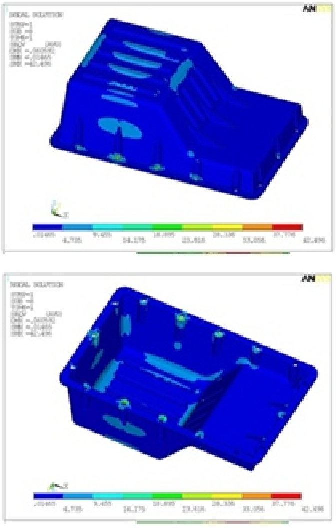


Fig9. Von Mises stress for pre stress analysis.

From the prestress analysis of the modified oil pan, it is observed thattotal deflection and VonMises stresses are0.06mm and 42MPa respectively in pre stress analysis. The maximum stress is observed on the bolting locations of the Modified oil pan. The yield strength of the material is 414Mpa.

MODAL ANALYSIS OF MODIFIED OIL PAN:

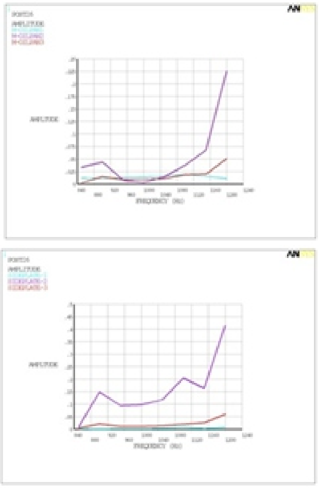
Modal analysis was carried out on Modified Oil pan to determine the natural frequencies and mode shapes of a structure in the frequency range of 0 -1300 Hz. From the modal analysis, a total of 3 natural frequencies are observed in the frequency range of 0-1300 Hz. The total weight of the Modified Oil pan is 6.0kg. The mode shapes of these frequencies are shown in table4.

Table4.Natural Frequencies of modified oil pan:

Mode no	1	2	3
Frequency Hz	879	1064	1113

HARMONIC RESPONSE ANALYSIS:

In harmonic analysis, natural frequencies obtained from the modal analysis are used to study the structure response at these natural frequencies. This is done to check, the structure behavior for resonance condition. Because, resonance occurs when natural frequency coincides with operating frequency.Empirical value of pressure under the hood of valve cover is recorded to 30 - 35KPa. Hence the valve cover has to with stand 35Kpa of pressure on a worst case scenario. The bolting locations are Fixed in all dof. Internal pressure 0.035MPa is applied on Modified Oil pan. Graphs are plotted between amplitude in mm in Y-axis and Frequency in Hz in X-axis in the frequency range of 0-1300 Hz. The graphs are shown in fig10.



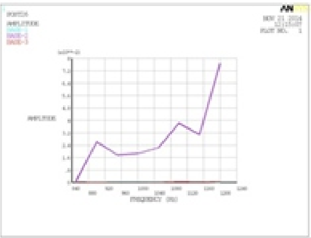


Fig10a, 10b, 10c. Harmonic response at locations on Modified Oil pan top plate, side plates, base respectively.

Table5. Harmonic response Analysis Frequency vs. Amplitude for modified oil pan

SNo	Location	Frequency Hz	Amplitude mm
1	Top Plate	900	0.04
		1200	0.225
2	Side Plate	900	0.15
		1100	0.2
		1200	0.43
3	Base plate	900	2.6
		1100	3.9
		1200	7.5

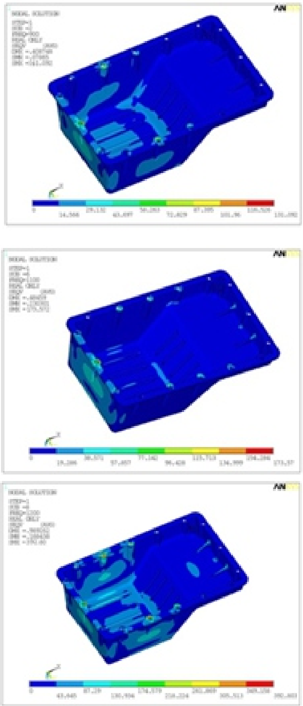


Fig11a, 11b, 11c. Maximum deflections and VonMises stress of Modified Oil pan at critical frequencies.

Table6: Deflections and VonMises stress for critical frequencies

S.no	FREQUENCY(Hz)	DEFLECTIONS (mm)	VON MISES STRESS (MPa)
1	900	0.4	141
2	1100	0.48	173
3	1200	0.98	392

V.RESULTS AND DISCUSSION:

From the above results it is observed that the critical frequencies 900Hz, 1100Hz, and 1200Hz are having stresses of 141MPa, 173MPa and 392MPa respectively. The yield strength of the material used for Modified Oil pan is 414MPa.

According to the VonMises Stress Theory, the VonMises stress of Modified Oil pan at frequencies 900Hz, 1100Hz, and 1200Hz are having stresses less than the yield strength of the material.

Hence the design of Modified Oil pan is safe to work for the mentioned operating loading conditions.

VI.CONCLUSION:

In this project a truck oil pan was designed and analyzed for vibration reduction. Finite element analysis was done to model the structural behavior of oil pan. Both static and dynamic loads were considered for the analysis. In this project the effects of pre-stress forces on modal parameters of oil pan and harmonic response analysis of pre-stressed oil pan using ANSYS has been performed. First pre-stress modal analysis was performed using block lanczo's method on the oil pan and then harmonic analysis of the pre-stressed oil pan was done using full harmonic method. Based on the results obtained, it was observed that the original oil pan was not safe for the operating loads. Later design changes were implemented to increase the stiffness of the oil pan. From the FE simulation results of the modified oil pan, it is concluded that the modified oil pan is safe for the mentioned operating loads.

VII.FUTURE SCOPE:

Presently, the oil pans are made of Steel and Aluminium considering the weight and stiffness and type of automobile for which it is being used. There may be a scope in future for replacement of metal oil pan with a composite material. Oil pans are used for not only holding the engine oil but they can also be used to cool the engine oil. A thermal analysis can be conducted on the oil pan.

VIII.ACKNOWLEDGEMENT:

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