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Research Article

Analysis of Fuel Filter Head and Modifications for Weight Reduction

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Abstract

A fuel filter head is used to remove contaminants from fuel to protect engine from damage. Fuel filter head is an important part of fuel filter system which support whole filter assembly. It is tightened to the body of engine by means of bolted joints. The tightening action induces pretension load in filter head. It is necessary to determine the stress developed due to bolt preload and g load. This work aims to analyze for stress and propose low weight alternative material for filter head. Initially existing fuel filter head is analyzed for stresses by using various load conditions. A new material and modified structure are proposed for filter head and analyzed for stresses under similar conditions used for analyzing existing model. The modal scaling factor, yield strength and design margin concept are used to validate filter head for safe design. The modified filter head reveals lower stress level, weight and cost as compared to existing model. This study helps to reduce weight which results in lower fuel consumption.

Keywords: FEA; Fuel filter head; Material testing; Modal analysis; Static structural analysis; Weight reduction

Introduction

The function of fuel filter is to remove dirt and rust particles from fuel. Presence of these contaminants can cause wear to the engine parts, it can also lower the fuel burning efficiency and increases knocking, at large extent these contaminates can cause bursting of engine. Thus, the purpose of capturing contaminated dirt particles is to protect the components like fuel pump, fuel injector. Hence, fuel filter serves a vital function in today's engine fuel system. Main parts of fuel filter system are fuel filter, filter head, bolted joint, filter paper. Function of filter head is to protect and tighten the whole filter system. It does not allow the leakage of fuel from fuel filter. There are different techniques for weight reduction incorporated in industries to modify the structure depending on the required end result [1]. Some of the techniques consist of topology optimization; shape optimization, material substitution etc. Material replacement is trending technique used for weight reduction. Engine performance could also be improved by using lightweight materials. Hence, now a day's application of light weight material is a trending concept used in engine pats to reduce its weight. Apart from technological advancement, still excessive stress development in fuel filter head is found. Due to vibration of cylinder block, it is necessary to determine the fuel filter vibrating frequency. The finite element approach makes it easy to simulate within a short time span. The application of light weight material in automotive industries are discussed based on cost, applications, limitations and percentage wise use in vehicles [2]. The diesel fuel filter of Euro 6 version of 1.61 diesel engines is designed using nylon 66 with 30% glass reinforced fiber. The comparison is discussed between nylon 66 and 30% glass reinforced fiber nylon 66 [3,4]. Engine weight is reduced by 70% and reciprocating mass is reduced by 90% with the help of fiber reinforced composites [5-7]. Non-linear large deflection contact analysis for fuel filter system is performed to predict the maximum stresses generated on fuel filter head [1]. An intensive research on analysis of fuel filter, weight reduction, and use of lightweight materials in automobiles has been done in large amount. Authors recommend using lightweight materials in automobile system. Lot of research is presented on replacing metal by plastic material. Plastic material is recommended in automobile components of which simulation-based analysis of filter head is not paid under more attention. This paper deals with the modeling and analysis of filter head by considering alternative material. An alternative material is proposed for the filter head for reducing weight. The modal and static structural analysis on the fuel filter head is performed using ANSYS software. The proposed alternative material is tested by using universal testing machine.

Methodology

Analysis of existing fuel filter head

CAD modeling of existing fuel filter head has been done with the help of modeling software CREO parametric. The CAD geometry of fuel filter system consists of two fuel filter canister, filter head, cylinder block and bolts. Filter head is connected to cylinder block by bolts. Fuel filters are attached to the filter head. Existing CAD model of filter head is shown in Figure 1. Fuel filter head commonly made up of aluminum. Material properties of aluminum filter head are given in Table 1.

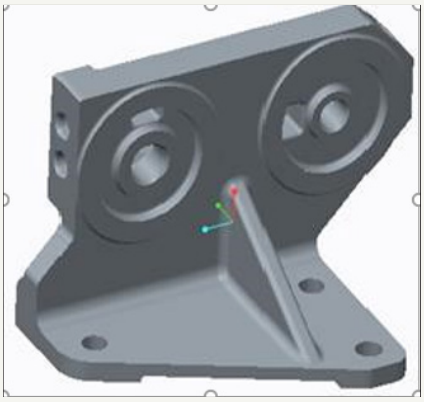

Figure 1: Existing fuel filter head CAD model.

Table 1: Material properties of existing fuel filter head.

Parameter	Values	Units
Density	2713	Kg/m^3
Young's Modulus	7.2	GPa
Poisson's Ratio	0.33	-
Yield Tensile Strength (YTS)	124	MPa
Weight	1.37	Kg

Mesh parameter

Meshing method used was patch conforming tetrahedron. The Figure 2 shows the meshed model of existing fuel filter head. Each contact and filter head were fine meshed of 1mm and 2mm using face and body sizing. Bonded contacts are given to define the behavior of components. The contacts are checks for initial behavior and re-meshing is done whenever required.

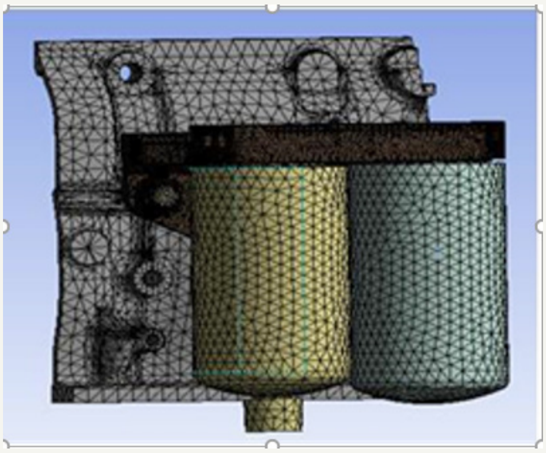

Figure 2: Meshed model of existing filter head.

Boundary condition

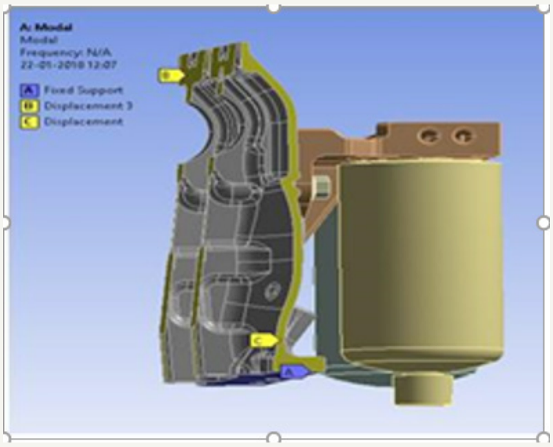

Figure 3: Boundary conditions.

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Filter head is attached to the cylinder block with the help of bolts. Cylinder block is fixed at the base. Also cylinder block is constrained in X and Z direction. Cylinder block is fixed and constrained in all directions to prevent any rigid body motion of the system. Boundary condition for modal and static structural analysis is shown in Figure 3.

Modal analysis

Existing fuel filter head need to be analyzed for modal analysis to check the design criteria (natural frequency). If it satisfying the acceptance criteria of design then it can be modify for weight reduction. Modal analysis is used to find the natural frequency and respective mode shapes. By doing modal analysis, it is possible to find those vibration frequencies of system which avoid the critical frequencies. The acceptance criteria for modal analysis are that first natural frequency should be greater than the primary frequency.

Target Frequency = (Number of Cylinder/2) × [(RPM/60)] × 1.1

Resonance condition occurs when the primary frequency is greater than natural frequency.

Static structural analysis

Static structural analysis is used to determine the effect of load on components. It calculates the stresses and deformation generated due to thermal and mechanical load. Static analysis consists of different load cases. Load cases required for on-highway general vehicles are used for filter head static structural analysis. There are seven load cases applied on filter head in which first load case is load application due to bolt pretension. Fuel filter head is attached to the cylinder block and it is subjected to mechanical load by means of bolt pretension. Bolt preload values can change due to properties like temperature, wear etc. So, the bolt preload values can be calculated by the torque generated in the component for cylinder block joints. The bolt preload are applied on each bolt of the filter head. Due to application of preload more stresses are generated on filter head [5]. Maximum and minimum principal stresses are calculated for 7 load cases. The load cases are shown in Table 2. The maximum stress generated should be below the yield strengths limit of filter head material. Design margin is the ratio of fatigue strength of material to the operating stress at that location. Design margin should be greater than one for safe design.

Table 2: Load cases for static structural analysis.

Load Case No.	Description
1	Bolt Preload (Pb)
2	Pb+6g load in upward direction
3	Pb+4g load in downward direction
4	Pb+4g load in fore direction
5	Pb+4g load in aft direction
6	Pb+2g load in left direction
7	Pb+2g load in right direction

Modal scaling

Modal scaling is used to calculate the scaling factor. With the help of these scaling factors, scald stress plots are generated. From scaled stress plots it is determined that whether the stress occurred is less than equivalent fully reverse stress material limit or not. If the scaled stress is within the limit then it can satisfy the design criteria. Modal scaling technique is used when the generated natural frequency are less than the primary frequency. Scaling factor is calculated by using this formula shown below. The values for frequency “f” and displacement “D1” are taken directly from the total deformation plot.

Scaling Factor = (Assumed G load/(X ×D_1)

By using this scaling factor, scaled stress plots are generated. From the scaled analysis plot, maximum scaled stress is calculated. If maximum scaled stress is within the limit then the modified design is considered as safe.

Analysis of modified fuel filter head

Drawbacks of aluminum material are it is heavy and it requires high initial cost. It also tends to get more brittle with exposure to heat. Hence an alternative material is selected for weight and cost reduction of fuel filter head. The new selected material of fuel filter head is tested using universal testing machine to check the yield strength of material. The procedure for fuel filter head analysis and material testing are discussed in following section. Selection of an appropriate best material for particular component is one of the main tasks. Material selection is based on different factors like strength, heat distortion ability, dimensional stability etc. Cost of material is also considered as main factor. For fuel filter head weight reduction new plastic material nylon 66+30% glass reinforced fiber is selected. As addition of 30% glass fiber increases its tensile strength, dimensional stability, heat distortion ability etc. [3]. Material properties of Nylon 66 with 30% glass reinforced fiber are given in Table 3.

Table 3: Material properties of modified filter head.

Parameter	Values	Units
Density	1360	Kg/m^3
Young’s Modulus	4.2	GPa
Poisson’s Ratio	0.39	-
Yield Tensile Strength (YTS)	100	MPa
Weight	0.7	Kg

CAD model of modified filter head is shown in Figure 4. In modified filter head ribs are provided on front and back side of the filter head. Addition of ribs increases stiffness and helps the part to resist warpage. It also helps to increase strength of plastic material. Fillets are provided to reduce stress concentration at sharp corners Red color shows the presence of inserts in filter head. Inserts helps to increase the strength of plastic part, improve wear resistance, enhances design flexibility. Meshing method used is same as used for existing filter head. Fine meshing of 1-2mm is given at each contact and fillets. Also plastic filter head is required fine meshing as it is the main part under consideration which can have more stress concentration. Body sizing is given to the filter head. At fillet and each contact location face sizing of 1mm is given. Modified filter head has more number of nodes and elements as compared to baseline filter head.

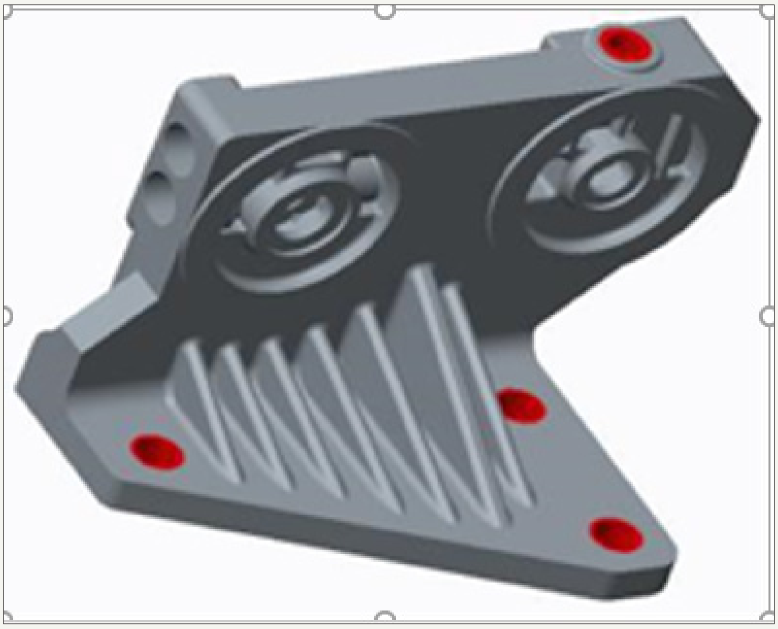

Figure 4: Meshed model of existing filter head.

Boundary condition for modal and static structural analysis of modified filter head are used same as for existing filter head. Modal analysis, modal scaling and static structural analysis are performed. Same loading conditions shown in Table 2 are used for modified static structural analysis.

Result and Discussion

Table 4: Natural frequency and mode shape result.

Mode No.	Natural Frequency		Mode Shape
	Existing Filter Head	Modified Filter Head	
1	174	51.50	Bending about Vertical axis
2	254	79.33	Bending about horizontal axis
3	509	146.76	Mixed Mode
4	560	169.63	Mixed Mode

Modal analysis is performed to check response of structure at resonance condition. The calculated frequencies and respective mode shapes for existing and modified filter head are given in Table 4. Four natural frequencies and mode shapes are calculated. This shows that all calculated frequencies are greater than the primary frequency.

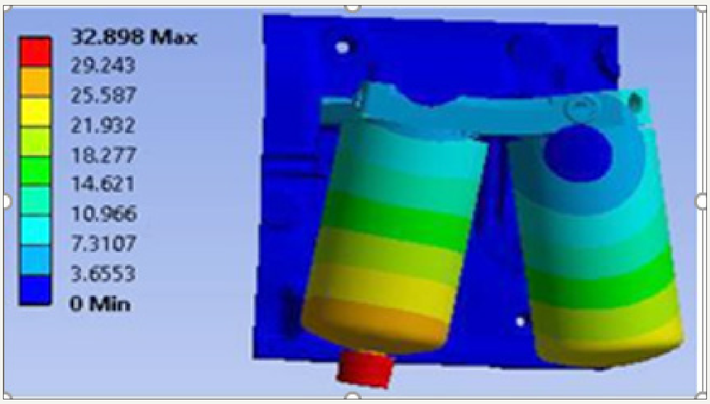

Figure 5: Natural frequency at third mode of modified fuel filter head.

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The Figure 5 shows the natural frequency plot at third mode for modified filter head. The natural frequency of 146.76Hz with mixed mode shape is generated at third mode. The Figure 6 shows the natural frequency for existing and modified filter head. It is seen from Figure 6 that all modified natural frequencies are less than existing natural frequency. First and second frequency of modified filter head does not satisfy the criteria. It is required to perform the modal scaling for first and second natural frequency of modified filter head.

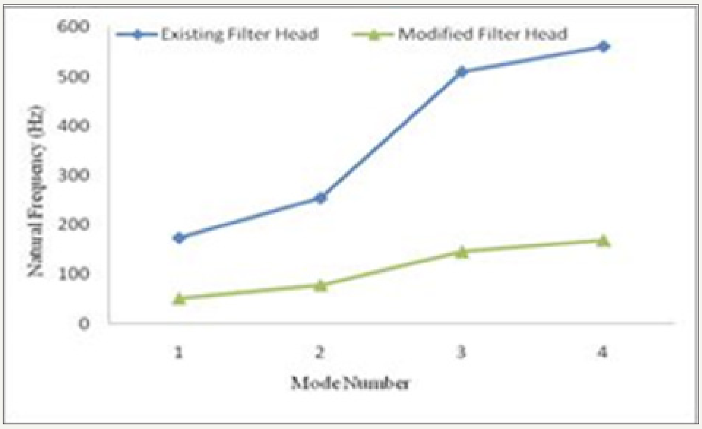

Figure 6: Natural frequency of existing and modified filter head.

Modal analysis of existing filter head satisfies the acceptance criteria because all frequency generated are greater than the primary frequency. It is seen that, for modified filter head, first and second frequency are below the acceptance criteria of modal analysis. Hence, it is necessary to perform the modal scaling.

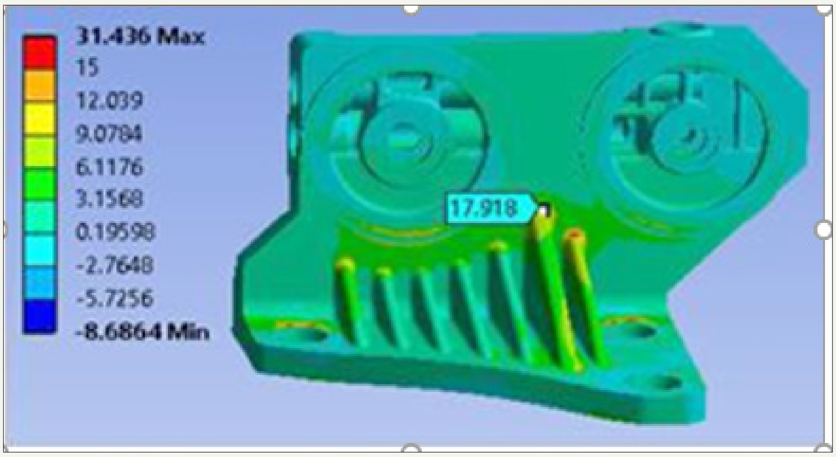

Figure 7: Scaled maximum stress plot for modified filter head.

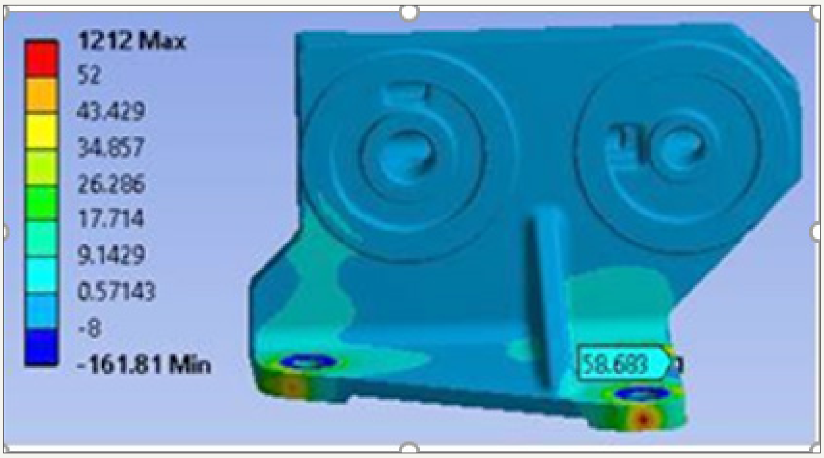

Figure 8: Maximum stress on existing filter head.

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Modal scaled stress plot for mode one is shown in Figure 7. The maximum stress occurred in modified filter head at first mode after scaling is 17.918MPa. Maximum principal scaled stress for first mode is less than the equivalent fully reversed stress limit. Hence after modal scaling it is satisfying the design criteria. Structural analysis of existing and modified filter head is carried out to calculate the maximum principal stresses occurred on filter head due to bolt preload and g load. Critical areas of maximum stresses are finding out on filter head. Maximum and minimum principal stresses for existing and modified filter head are calculated for seven load cases of on-highway general vehicles. Static structural plot for maximum principal stress of existing filter head during load case 2 is shown in Figure 8. Maximum stress in modified filter head is generated during load case 2. Maximum stresses generated in modified filter head are less than stress occurred on existing filter head. The location of maximum stress on modified filter head is shown in Figure 9.

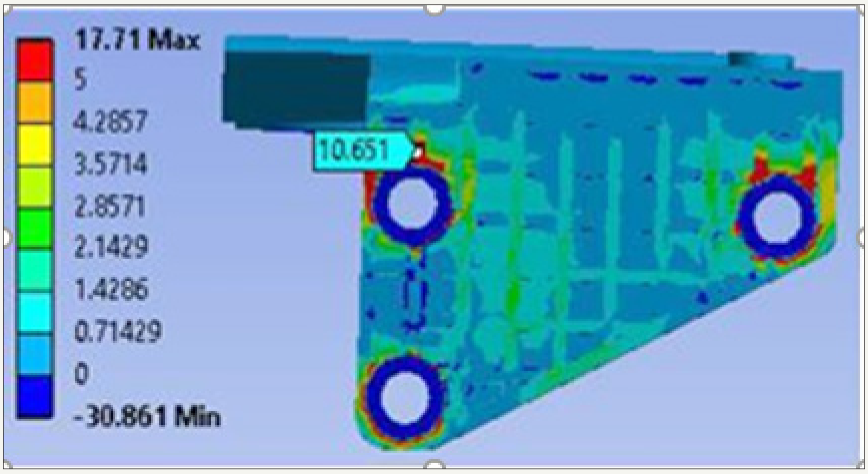

Figure 9: Maximum stress on modified filter head.

Maximum stresses generated in modified filter head are less than stress occurred on existing filter head. Hence, modified design for maximum principal stress is within the safe limits. Table 5 gives the calculated values of maximum and minimum principal stress for existing and modified fuel filter head. Here, minimum and maximum principal stresses generated in existing as well as in modified filter head are below the yield limit of material. Design margin is greater than one hence the design for existing and modified filter head is safe.

Table 5: Stress generated on existing and modified filter head.

Load Case No.	Existing Filter Head		Modified Filter Head	
	Maximum Principal Stress	Minimum Principal Stress	Maximum Principal Stress	Minimum Principal Stress
1	58.49	13.13	9.50	5.40
2	58.69	13.74	9.93	10.65
3	58.32	12.73	9.47	5.74
4	58.43	12.71	9.62	5.39
5	58.25	13.48	9.60	5.38
6	58.54	13.37	9.64	5.21
7	57.94	12.77	9.31	5.53
Design Margin	124/58.69=2.11	124/13.74=9.02	100/9.9=10.10	100/10.65=9.38

Table 6: Result of tensile testing.

Parameters	Generated Value
Load at Peak (N)	1827.04
Elongation at Peak (mm)	8.50
% Elongation at Peak	17.00
Break Strength (MPa)	67.32

Tensile testing of nylon 66+30% glass reinforced fiber material is performed as per standard ASTM D638. The results of tensile tests are used in selecting materials for engineering applications. The strength of a material is a primary concern. The tensile testing results of nylon 66+30% GF material, the results are given in Table 6. The Figure 10 revels that peak strength is 188.60MPa. The resulted young's modulus is 4.42. It is seen that generated value of young's modulus is close to those which is used for finite element static structural and modal analysis. As weight reduction is the most cost-effective means to reduce the fuel consumption. Presented work satisfies all the static structural and modal analysis design criteria.

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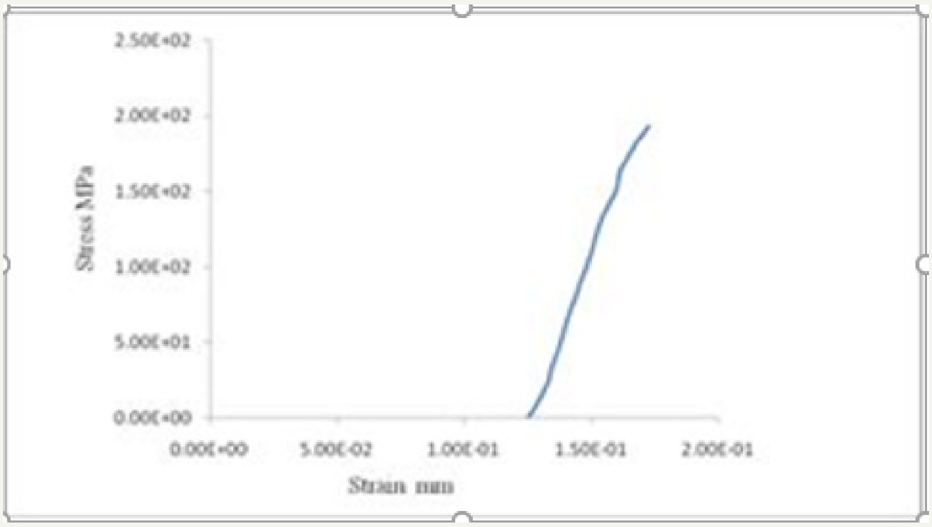

Figure 10: Stress strain curve of Nylon 66+30% glass reinforced fiber material.

Aluminum filter head weighs 1.37Kg while modified filter head weighs 0.7Kg. Material cost of aluminum per Kg is Rs 150. Aluminum filter head are available in market at Rs 648. As compared to aluminum, material cost of nylon 66+30% glass fiber is 90Rs/Kg. The product cost of nylon 66+30% fuel filter head is 390 Rs. It is seen that, by using plastic fuel filter head there is 39.81% cost saving without loss of strength and stiffness. Nylon 66 is easily available in market. Economic advantages like recycling of material for weight reduction of vehicles by replacing aluminum by nylon 66 with lightweight materials are also considered. Also one of the main important things regarding to nylon 66 material of filter head is that the material can be 100% recycled.

Conclusion

Finite element modal and static structural analysis is performed for existing filter head. For weight, cost and stress reduction, an alternative material is selected. For the particular material filter head geometry is modified according to material design and modeling criteria.

1. According to maximum yield stress criteria, maximum principal stress should be greater than one hence, modified filter head satisfies the acceptance criteria. Also the calculated design margin is greater than one for safe design. Hence according to yield strength criteria, modified filter head is safe.
2. According to acceptance criteria, in existing filter head, first frequency is 174Hz which is greater than acceptance criteria.
3. After modal scaling it is seen that modified filter head satisfies all the acceptance criteria of filter head.
4. After the tensile testing of nylon 66+30% glass fiber material, the calculated yield strength is close to the properties used in FE static structural analysis. This shows that the material is safe at particular yield strength limit.

Nylon 66 offers weight reduction of 48.90% over aluminum for equal strength and stiffness. By using plastic material of nylon 66 with 30% glass fiber there is 39.81% of cost saving. Hence modified fuel filter head can be successfully implemented in engine as it satisfies all the acceptance criteria.

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