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Structural Integrity Analysis of the Charging Air Tube Support for a Diesel Engine of Commercial Vehicle

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ABSTRACT

The study is carried out through numerical and experimental methods. The finite element method is used to simulate the support mechanical behavior via modal analysis, and for the evaluation of stress concentration regions through pressure and thermoelastic static analyses, and dynamic analysis. The fatigue life is calculated for the presented stresses.

Stress, acceleration and temperature data were obtained through dynamic test. For material evaluation, chemical analysis, hardness and metallographic analysis were carried out. For thoroughness, a failed support fractography will be presented.

The objective of this study is to correlate the data obtained by numerical method with experimental data, and as a result, the support failure mechanism was identified. A modified support is presented to avoid the failure for the determined loads.

The support within the proposed modifications reduces the current maximum stress in 41% and improved the fatigue life in 4.99e5 cycles.

INTRODUCTION

In a diesel engine development process, the focuses are performance, economy and ecological responsibility. In the current economic condition and country growth, the commercial vehicles manufacturers seek to meet the high demand with dynamism and applicability for different power requirements in the same engine, changing some components such as turbine, air tubes, and air cooling system, among others. However, with increasing engine power, the loads on the support are amplified. This contributes to shortening the support life. Avoiding failure due to the new working conditions motivates the structural components study.

The diesel engine charging air tube support has a important structural function and it failure affects parts that precludes the engine operation.

THE CHARGING AIR TUBE SUPPORT

The diesel engine charging air tube support, produced from hot rolled steel, has the important structural function of supporting the charging air tube, fixed on the turbine and the intercooler. The tube or turbine failure precludes the engine operation. The support also has the function of reducing the displacements imposed on the turbine by engine vibrations that may damage the structure of the mentioned assembly.

The Figure 1 illustrates the studied support. The Figure 2 presents the support position in the engine.

Figure 1 – Charging Air Tube Support.

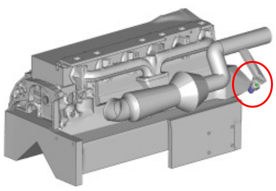

Figure 2 – Charging Air Tube Support Position in the engine.

The material used to manufacture the support should follow the DIN EN 10149-3 1.0971 [1] (S260NC) standard chemical composition, which was confirmed by testing.

The Table 1 shows the chemical composition obtained. The material mechanical properties are shown in Table 2. E is the elasticity modulus, ν is the Poisson Ratio, ρ is the density, σ_{Rup} is the rupture limit, σ_{Yield} is the yield limit and σ_{Fat} is the fatigue limit.

Table 1 –Material chemical composition.

C %	Mn %	Si %	P %	S %	Al %	Nb %	V %	Ti %
0,16	1,20	0,50	0,025	0,020	0,015	0,09	0,10	0,15

Table 2 – Material standard mechanical properties.

E **[N/mm^2]**	ν	**ρ** **[ton/mm³]**	**σ_{Rup}** **[N/mm^2]**	**σ_{Yield}** **[N/mm^2]**	**σ_{Fat}** **[N/mm^2]**
210000	0.30	7.85x10^{-9}	340	240	127

The material fatigue limit was calculated considering the Marin`s endurance limit equation coefficients [2].

$$\sigma_{Fat} = k_a.k_b.k_c.k_d.k_e.k_f.(\sigma_{Yield}/*.5)$$

Marin's endurance limit equation for steel materials.

Where:
k_a = surface condition modification factor;
k_b = size modification factor;
k_c = load modification factor;
k_d = temperature modification factor;
k_e = reliability factor;
k_f = miscellaneous-effects modification factor;
σ_{Fat} = Fatigue limit at the critical location of a machine part in the geometry and condition of use;

The laboratory tests showed that the Rockwell B hardness is 78 HRB, which is according to the expected material hardness. The metallographic analysis presented ferritic microstructure with pearlite scattered islands as presented in Figure 3 [3].This microstructure is typical of hypo-eutectoid carbon steels [4]. The low carbon percentage evidences the material ferritic structure, which explains the low hardness.

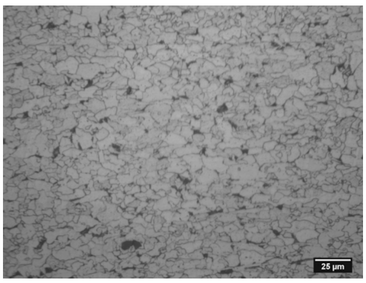

Figure 3: ZE260 Material micrography

METHODOLOGY

The charging air tube support was modeled with solid elements (HEXA). The exhaust tube was modeled with shell elements (QUAD4).The bolts were modeled with bar elements (BAR). The other components were modeled with solid elements (TETRA4). The alternator pulleys were modeled with mass element (CONM2). The static analyses considered the motor and transmission rubber mounting, which were modeled with spring elements (CBUSH). Contact between the charging air tube support, spacer washers and charging air tube were considered.

Figure 4 shows the model assembly boundary conditions for modal and static analyses and Figure 5 shows the model assembly boundary conditions for the dynamic analysis.

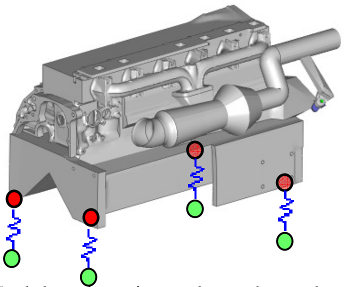
Figure 4 – Modal and static analyses boundary conditions.

Clamp: Restrictions in directions 1, 2, 3, 4, 5 and 6 for the modal analysis.

Clamp: Restrictions in directions 1, 2, 3, 4, 5 and 6 for pressure at the tube socket and thermoelastic analyses.

Engine and Transmission rubber mountings for static analysis.

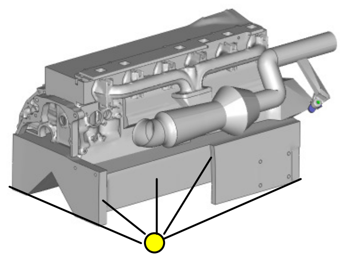
Figure 5 – Dynamic analysis boundary conditions.

Large Mass, where Acceleration x Time loads, in the X, Y and Z directions were applied.

SOFTWARE TOOLS

For the charging air tube support evaluation, the following software tools were used:

- Medina Pre-processor - version 8.2, for finite element modeling;
- MD.NASTRAN Solver - version 2010.1.0, for the modal and static calculations;

- PERMAS Solver - version 13.00.216, for the dynamic calculations;
- Medina Pos-processor - version 8.2, for results analysis.

LOADS & CRITERIA

For the modal analysis the frequency range used was 0 to 300 [Hz].

For the static analysis the pressure at the tube socket used was 2.1 [bar] which was measured in the vehicle engine. For the thermoelastic analysis, a components temperature variation list was obtained experimentally. Table 3 and Figure 6 shows the temperature gradient imposed.

For the dynamic analysis, Acceleration x Time loads, in the X, Y and Z directions were applied. The loads were measured at the critical frequency range of 1541-1547 [rpm]. Figure 7 shows engine dynamic load graph.

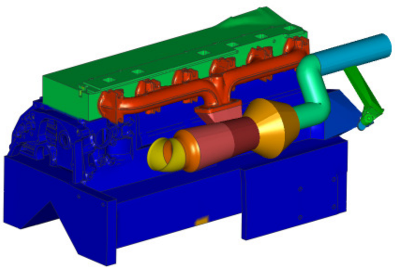

Figure 6 – Thermoelastic static loads.

Table 3: Thermoelastic static loads.

Regions	Part	Initial Temp.[ºC]	Final Temp. [ºC]
Region	Exhaust Brake	26.5	470.9
Region	Exhaust Collector Tube	26.5	459.3
Region	Turbine Housing (hot)	26.5	232.1
Region	Turbine Housing (cold)	26.5	174.0
Region	Charging Air Tube	26.5	124.6
Region	Cylinder Head	26.5	120.5
Region	Charging Air Tube	26.5	124.6
Region	Charging Air Tube Support	26.5	100.0
Region	Crankcase	26.5	97.3
Region	Water Tube	26.5	93.9

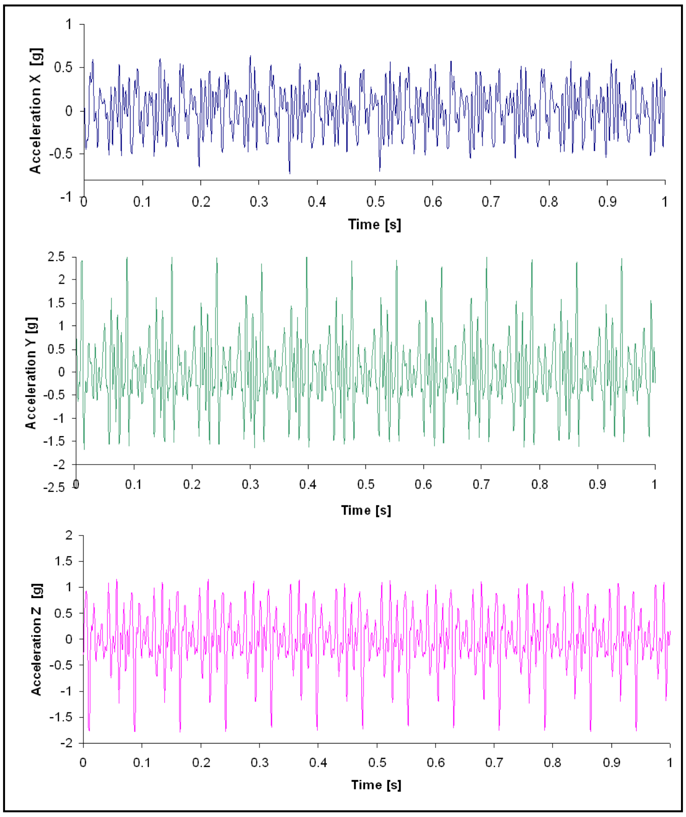

Figure 7: Dynamic load graphs.

CRITERIA

In modal analysis, the first assembly natural frequency should be equal to or greater than 182.00 [Hz], which is the 4 ½ order frequency of the 6 cylinder engine, for a maximum of 2200 [rpm] with a 10% safety factor, according to Campbell Diagram [5].
In the pressure at the tube socket and thermoelastic static analyses and in the dynamic analysis, the stresses in the support must not exceed the material fatigue limit [6].

RESULTS

The engine assembly presented their first natural frequencies at 157.21 [Hz]. Figure 8 shows the modal analysis results.

1st Mode f1 = 157.21 [Hz]
Maximum displacement versor
x = -0.62; y = 0.49; z = 0,61

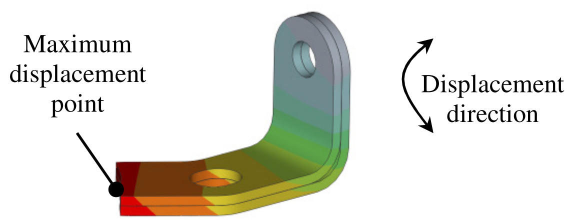

Figure 8 - Modal analysis results.

The pressure at the air tube socket and thermoelastic static analyses and dynamic analysis results are shown in Figure 9, 10 and 11 respectively. Values within a red frame are above material fatigue limit. Table 4 shows the static and dynamic analyses summary results.

The *von Mises* stresses are presented as a percentage of the materials fatigue limits. The values presented in red are above the material fatigue limit.

Table 4 - Static and dynamic analyses summary results.

Analyses	Support σ_{fat} = 127 [N/mm²]
Pressure	143%
Thermoeslastic	55%
Dynamic	98%

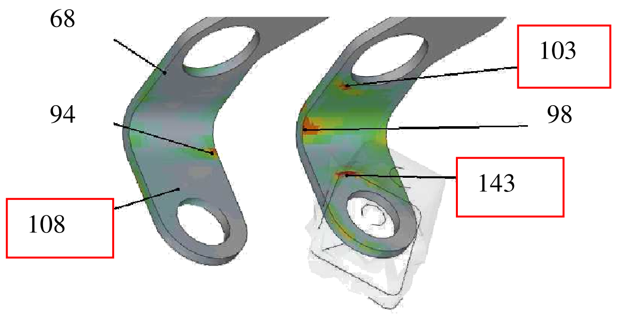

Figure 9: Static analysis results - Pressure at the Tube Socket.

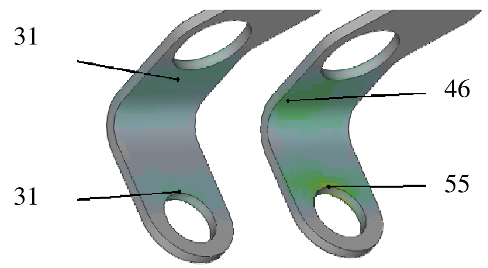

Figure 10: Static analysis results – Thermoelastic.

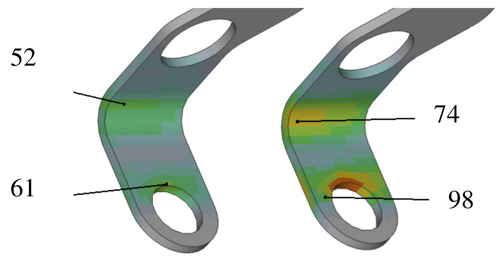

Figure 11: Dynamic analysis results.

FRACTOGRAPHY

A failed support fractography was made to further investigate the failure cause. The aim was examine the origin of cracking to reveal the cause of crack initiation. As a result of the fractography, geometry modifications in the parts in contact with the support were made in order to minimize its effects in the crack initiation. The failed support presented the crack initiation in the same maximum *von Mises* stresses calculated region, showing that the mathematical model is consistently modeled.

Figure 12 shows the support failure region. Figure 13 shows the beach marks and suggests fatigue failure. Figure 14 shows the ratchet marks which suggests the crack initiation point according to the identified stress concentration region in the mathematical model.

Figure 12: Support failure region.

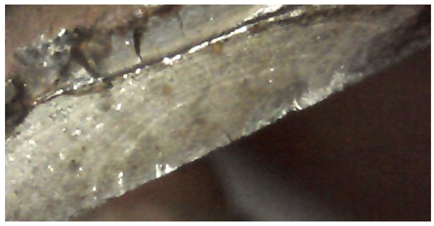

Figure 13 Beachmarks.

Figure 14: Ratchetmarks.

FATIGUE LIFE STRESS CYCLES

A verification of the fatigue life stress cycles to failure (Nf) were performed. For the studied support , the number of cycles were calculated considering maximum *von Mises* stresses obtained in the pressure at the Charging air tube socket and the S260NC material fatigue limits, which is the current material used in the support (σ_{fat} = 127 [N/mm^2]). The S700MC which follows the DIN EN 10149-2 1.8974 [7] standard, is the proposed material in order to avoid the support failure, plus a geometry modification in the Water Tube contact region within the support from sharp to round edges. The fatigue limit calculated for the S700MC is σ_{fat} = 159 [N/mm^2].

Table 5 –Proposed material standard mechanical properties.

E [N/mm^2]	ν	ρ [ton/mm³]	σ_{Rup} [N/mm^2]	σ_{Yield} [N/mm^2]	σ_{Fat} [N/mm^2]
210000	0.30	7.85x10^{-9}	750	700	159

The Shigley´s equations were used to calculate the fatigue number of cycles-to-failure (N_f) [8]:

$$N_f=10^6*(\sigma_{max} / \sigma_{fat})^{1/b}$$

Where:

σ_{max} = Maximum *von Mises* stress calculated in the pressure at the charging air tube socket analysis;
σ_{Fat} = Fatigue limit at the critical location of a machine part in the geometry and condition of use;
b = 1/3 (log (0,9*σ_{Rup} / σ_{fat}).

Table 6 shows the fatigue life stress cycles calculated for the current and proposed modifications. *Von Mises* stresses presented as a percentage of the material fatigue limits.

Table 6: Fatigue life stress cycles to failure calculated.

Part	Material	*Von Mises* Stresses	Fatigue life Nf [cycles]
"L" Support	S260NC	154 %	3.30 e4
	S700MC	113 %	5.32 e5

SUMMARY/CONCLUSIONS

For the modal analysis, the first natural frequency is 157.21[Hz]. Although the engine support is excited below the 6 cylinders engines fourth and a half frequency order, not meeting the established the criteria, the analyzed support presented stresses below the fatigue limits in the dynamic analysis, suggesting that vibration is not the assembly issue.

For the pressure at the tube socket static analysis, the engine presented stresses above the fatigue limit at the support. For the thermoelastic analysis, the support presented stresses below the fatigue limit.

The engine charging air tube support is not according the established criteria, which confirms the failure in the vehicle due to pressure issues.

The current and with the proposed modifications supports are not according the established criteria. The fatigue life stress cycles to failure (Nf) of the supports were calculated. The current support Nf shows a low cicle fatigue life, which confirms the failures in the vehicle. The support within the proposed modifications reduces the current maximum stress in 41% and improved the fatigue life in 4.99e5 cycles.

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DEFINITIONS/ABBREVIATIONS

MEDINA: Finite Element Pre and Post-processor from T-Systems.

σ_{Fat}: Material Fatigue Stress Limit.

σ_{Rup}: Material Rupture Stress Limit.

σ_{Yield}: Material Yield Stress Limit.

Nf: Fatigue life stress cycles to failure.