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Original Research Article

Vibrational Durability Test Methodology for an EGR Cooler

Savci, İ. Hakkı[1]; Uluk, Berç[1]; Kutlu, Mustafa[1]

[1] Ford Otosan, Product Development Department, 34885, Istanbul, Turkey

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Abstract

EGR Cooler is one of the key automotive components which use coolant to reduce exhaust gas during discharge through the air induction system. These automotive components are exposed to different types of vibrations such as simple sinusoidal or random excitations.
This work presents vibration durability test methodology which is used for the EGR cooler of Heavy Duty Vehicle. Test set-up and procedures are developed to assess durability performance of the EGR on the electrodynamic shaker. Sine, random and sine on random test profiles are compared to show their effect of the EGR durability. In addition effect of the excessive test profiles are observed on the EGR in this work.

Key Words: Exhaust Gas Recirculation; Electro Dynamic Shaker; Heavy Duty, PSD (Power Spectrum Density)

Nomenclature

EGR	Exhaust Gas Recirculation
SOR	Sinus on random
PSD	Power Spectrum Density
EDS	Electro Dynamic Shaker
HD	Heavy Duty

*Corresponding author:
E-mail: ihsavci@gmail.com
Tel: +90 505 6810573

1. Introduction

Several technologies have been developed to reduce diesel emissions especially NO_x reduction systems in last decades [1]. The emissions are restricted by legislations [2].

The most promising NO_x emission reduction technologies are exhaust gas recirculation (EGR) system to reduce peak cylinder temperature that reduces NO_x form caused by combustion [3].

EGR cooler, EGR valve and EGR mixer are the main components of the EGR system. EGR Cooler cool down the exhaust gas before exhaust gases are returned into the intake manifold to reduce NO_x values [4].

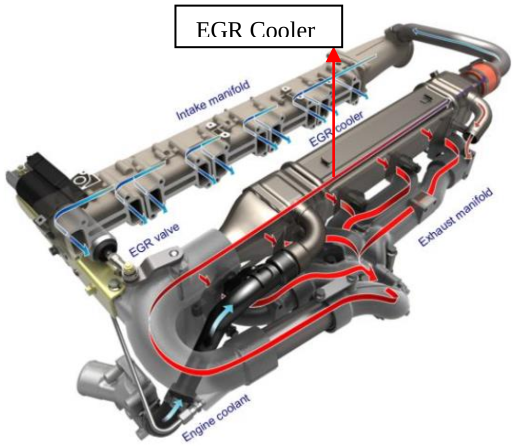

Figure 1. EGR System Euro IV Engines [5]

Vibration may cause components failure as a result of long term exposure to time varying loads. The engine components must pass rig based vibration durability test without any failure (microscopic cracks etc.) prior to serial production. Test time is accelerated by scaling the input load to a replicate one which gives the same fatigue damage over the real life. So, development time and cost can be decreased. The input load must not be scaled excessively that might alter the failure mechanism [6,7,8].

The engine excitations are the main loading input for engine mounted components. Torsional vibration due to combustion process and unbalanced centrifugal and reciprocating inertial forces cause these engine loads. Vibrational loads are measured by tri-axial engine accelerometers with idle speed to the maximum engine speed. The accelerometers are installed on engine block since that location indicates the engine excitations [9,10,11].

Customer can prefer to use either sinusoidal sweep or random vibration profile as vibration test specification of an automotive part. For the given test duration and reliability parameters, both vibration test specifications will have an equivalent durability damage level [12].

The objective of this study is to establish the procedures affecting the vibrational durability of the EGR Cooler using different test profiles such as sin, random and sin on random. The critical output that is studied here are the macroscopic cracks on the EGR Cooler at the points of the fins and the damage of the system at the surface of the EGR Cooler.

In the first step of this study shows the vibration data effect on the engine component durability. Sinus and random test profiles were applied on two EGR cooler. Due to weight limitation of the shaker, third EGR Cooler was tested separately and sin on random test profile was applied.

In the second step, two different test profiles effect were carried out and results are presented in this paper. Excessive test profiles effects were investigated in terms of the macroscopic cracks.

2. Materials and Methods

EGR cooler vibration test spectra was generated by EGR cooler supplier as Sine Sweep and Random. Engine raw data for the spectra was collected by Ford Otosan. Rig test was performed in Ford Otosan. The cooler was subjected to the Resonance Sweep and the General Vibration Durability tests respectively.

Engine vibration raw data was collected in engine dynamometer with sampling rate 10 kHz by Ford Otosan. Accelerometer positions on engine block and EGR coolers are shown in Figure 2, 3 and 4.

Raw data was collected during full-load sweeps between 600-2100 RPM with 60 seconds ramp up and 60 seconds ramp down in all 3 axis of each sensor.

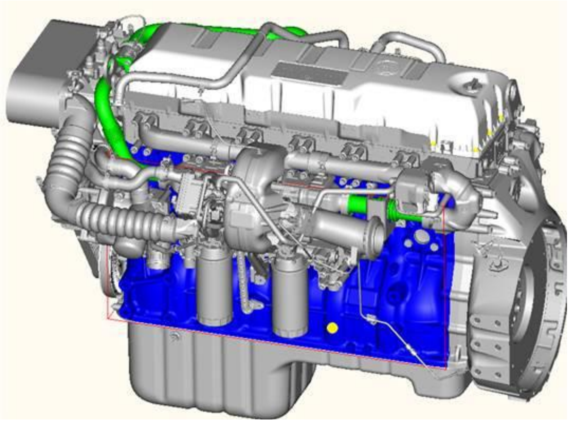

Figure 2. Accelerometer Position on Engine Block

Figure 3. Front Accelerometer Position on EGR Cooler

Figure 4. Rear Accelerometer Position on EGR Cooler

Waterfall diagrams were prepared to indicate acceleration change as per engine rpm and frequency for each accelerometer and directions which allows detecting natural frequencies. Figure 5 shows the data for front accelerometer in X direction [13].

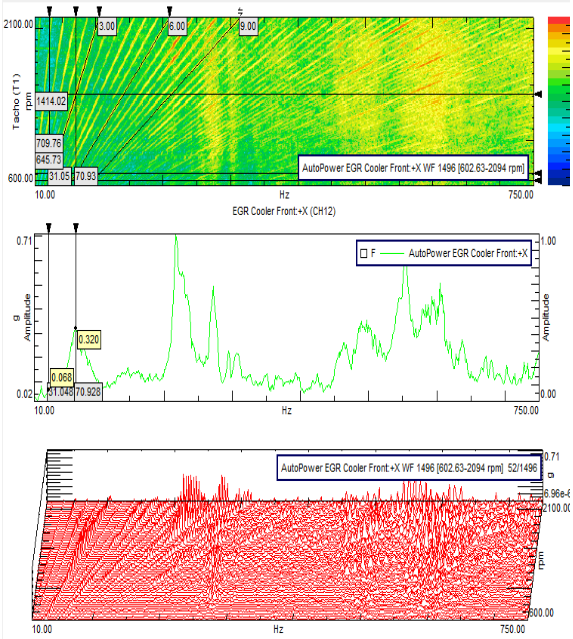

Figure 5. Waterfall Diagram of EGR Cooler Front Accelerometer + X

Test Setup

Electrodynamic Shaker was used to perform vibration durability test for EGR cooler. EGR coolers were filled with water at 3 bar abs pressure during the test.

Sample size is defined as 3. Sample 1 and 2 was tested together with sine and random profile. Sample 3 was tested separately with sine on random (SOR) test profile. Two different test profiles were compared in terms of the durability of the EGR cooler.

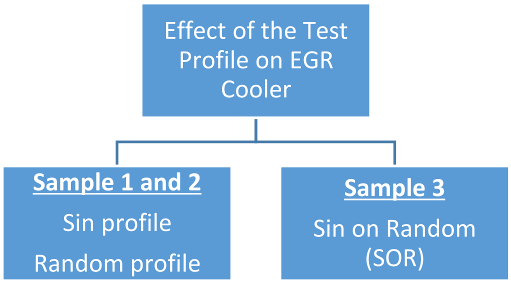

Figure 6. Test Profile

The EGR coolers were assembled in the same orientation as installed in the engine using the assembly torque specifications and tested at room temperature (20°C) in accordance with test spectrums generated.

Figure 7 shows orientation of Sample 1 & 2 and accelerometer positions. Overview test load is measured as ~229kg for this set-up.

- 2 EGR parts: ~18kg
- Fixture: ~70kg
- Armature: 48kg
- Small head expander: 93kg

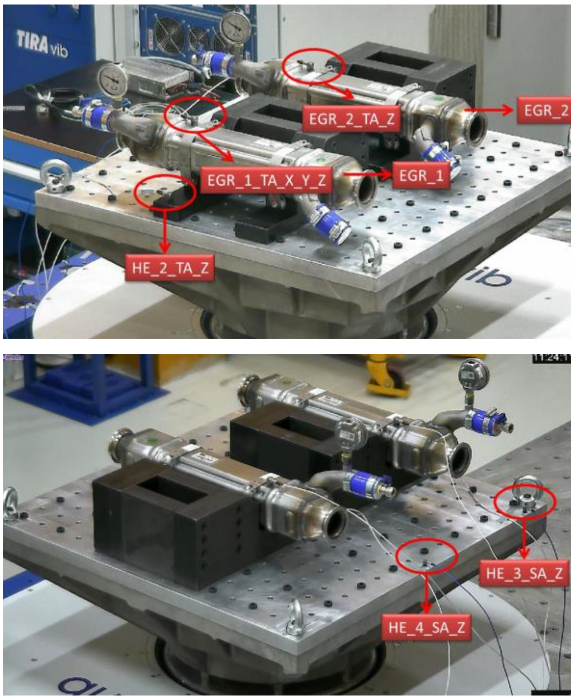

Figure 7. Accelerometer Position on EGR Cooler 1&2

Figure 8 shows orientation of Sample 3 and accelerometer positions. Overview test load is measured as ~220kg for Sample 3 test set-up. Three EGR cooler could not installed on the fixture due to payload. Sample 3 was tested separately and applied by SOR test profile. Two test approaches can give detailed information about the effects of the sin, random test and sinus on random test.

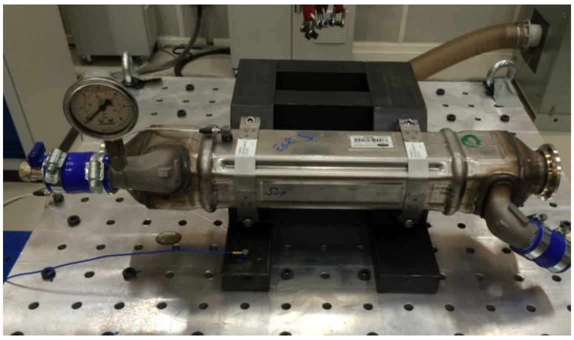

Figure 8. Accelerometer Position on EGR Cooler 3 on rig

Test Procedure

Resonance Sweep Check was performed for each sample to detect natural frequencies of the cooler before Vibration Durability test.
FREQUENCY SWEEP TEST - The response of the EGR cooler to vibration excitation must be checked first from 25 Hz to 500 Hz with an input 1g if there is any resonance which occurs below the highest significant excitation frequency or not [5]. The highest significant order for engine is 3 and maximum engine speed is 2600rpm. So, highest significant excitation frequency is calculated as 130Hz. 200Hz was taken into account with safety factor 1.5.

$$\text{Highest Significant Excitation Frequency} = \frac{\text{Maximum Engine Speed (RPM)}}{60} \cdot \text{Highest Significant Order}$$

Sweep Range	:25 to 500 Hz
Sweep Rate	:1 Hz/sec
Input Acceleration	:1 g

If natural frequencies are found below 200Hz, assembly of the EGR Cooler (the bracket, contact surfaces, straps, strap bolts etc.) would be updated to increase natural frequency of EGR cooler in assembled condition [14].
VIBRATION DURABILITY TEST- EGR cooler is tested for infinite lifetime ($1x10^7$ cycles) by considering it is exposed to vibrations over a wide range of frequencies on the engine. Random test for broad band vibration (10 – 2000 Hz) and Sine sweep test for range of significant engine orders are applied. Random and Sine spectrums are applied simultaneously which is called SOR (Sine on Random). They can also be applied respectively if the shaker is not capable to perform SOR [15,16].
SOR is performed for 20 hours in each direction with 1.0 Oct/min. If Sine and Random signals are applied respectively, each spectrum must be applied 20 hrs. individually.
Sine and Random vibration test spectra

generated is shown in Figure 8-10.

- Test duration: 20h / axis in space
- Random: 20 – 2000 Hz
- Sine sweep: 30 – 245 Hz, 1 Oct/min

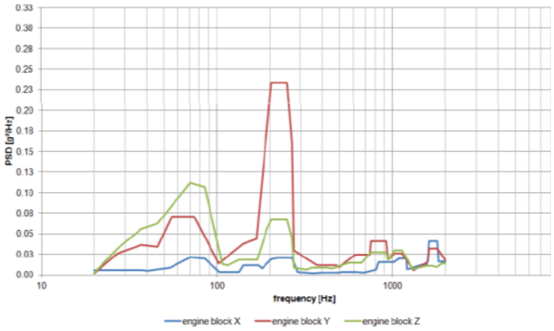

Figure 9. Random Test Spectra – Engine Block

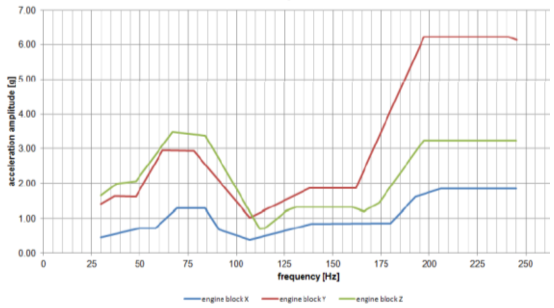

Figure 10. Sine Sweep Test Spectra – Engine Block

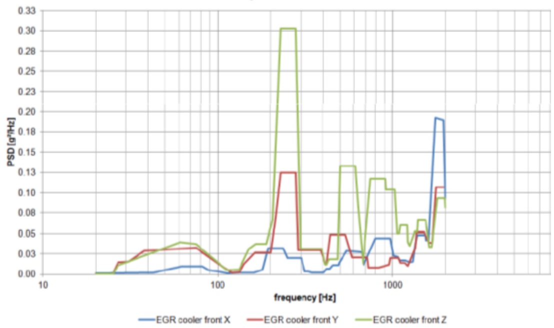

Figure 11. Random Test Spectra – EGR Cooler Front

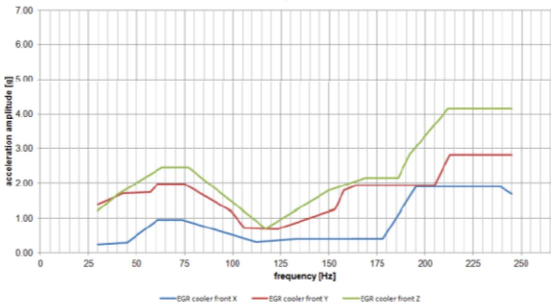

Figure 12. Sine Sweep Test Spectra – EGR Cooler Front

3. Results and Discussion

Frequency sweep test performed first for Sample 1&2 and then Sample 3. Durability test of Sample 1 and 2 was performed by using Sine and Random test spectrums respectively. Sample 3 was tested with SOR i.e. Sine and Random test spectrum simultaneously.

FREQUENCY SWEEP TEST – Any resonance that occurs below the highest significant excitation frequency was not detected. Fig 12 shows that any frequency below 200Hz was not measured during frequency sweep test.

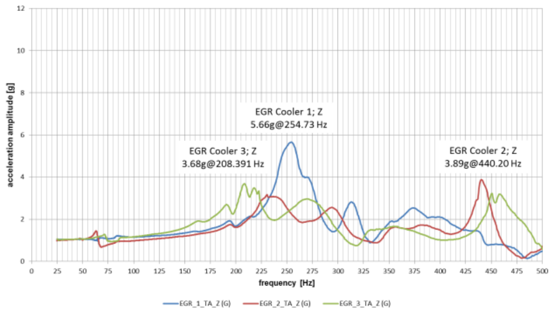

Figure 13. Sine Sweep Test Results, Z Axis

GENERAL VIBRATION DURABILITY TEST - General Vibration Durability Test was performed by using Sine, Random and Sine on Random spectra.

First, shaker table was checked with input data and confirmed resonance did not occur. Then, the spectra of the “EGR cooler front“ was used to check the response amplitudes of the cooler on the shaker were not found as lower than the spectra. Even, higher output values compared to the “EGR cooler front” was measured on some test points but shaker input was not reduced manually. Sweep measurements are presented in Figure 13-17.

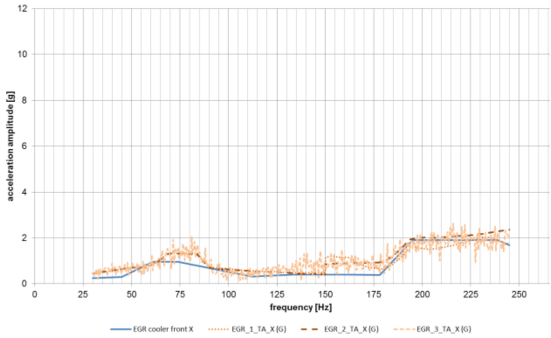

Figure 14. Sine Test - Response of EGR Coolers, X Axis

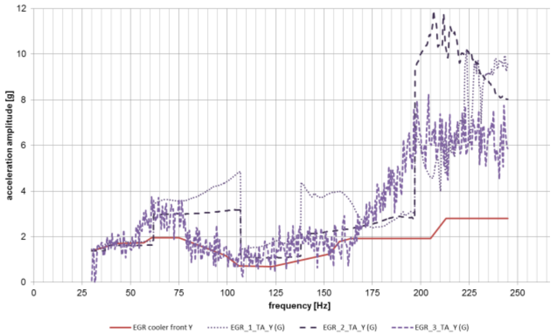

Figure 15. Sine Test - Response of EGR Coolers, Y Axis

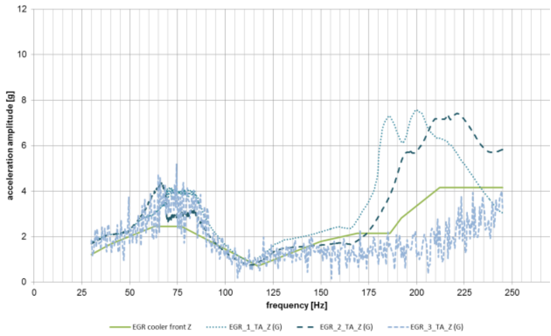

Figure 16. Sine Test - Response of EGR Coolers, Z Axis

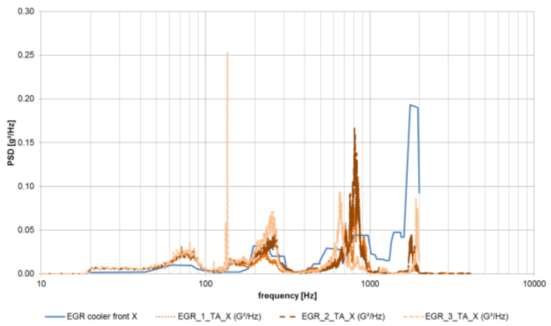

Figure 17. Random Test - Response of EGR Coolers, X Axis

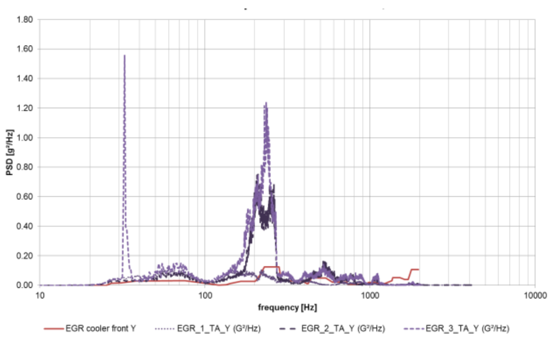

Figure 18. Random Test - Response of EGR Coolers, Y Axis

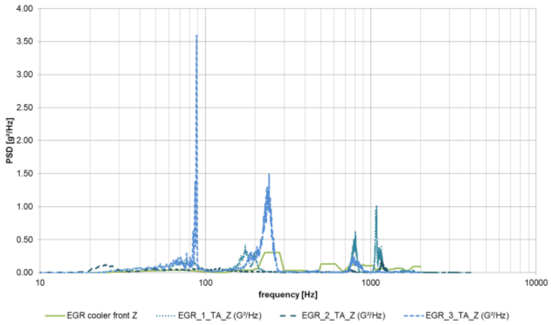

Figure 19. Random Test - Response of EGR Coolers, Z Axis

4. Conclusion

New methodology has been developed to estimate vibrational durability performance for EGR coolers in this work.

Several vibrational tests were performed with a wide variety of prototypes to assess durability of the EGR cooler. EGR Cooler vibration tests were conducted by using sine, random and sine on random vibration test spectra, which was prepared by in Ford Otosan. These two test approach did not show significant difference in terms of the EGR durability assessment.

Any natural frequency below 200Hz was not detected during sine sweep test.

Initial leakage check and visual check after durability test were performed by Ford Otosan with no peculiarities and leakage issue.

Figure 20. Initial Leak Check Setup

Detailed microscopic investigation is completed and cracks were observed at the inner edge of the EGR cooler. Figure 20 and 21 show the crack location in details.
Higher output values of EGR cooler on the shaker compared to the test spectra may cause micro cracks due to excessive high dynamic tensile and bending loads during the test. After detailed investigation of the supplier, the test might be repeated with reduced input test spectra so that the response of the EGR cooler on the test bench will be similar to the expected response from the engine measurement [17].

Figure 21. Outlet header overview

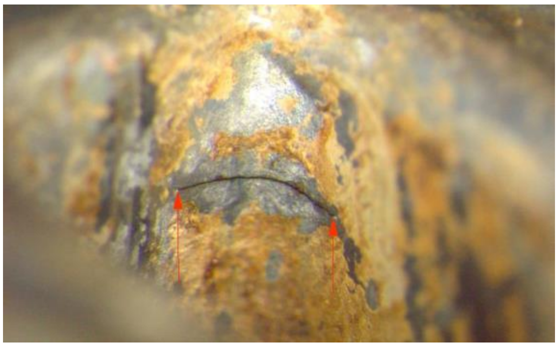

Figure 22. Crack location found at the 1

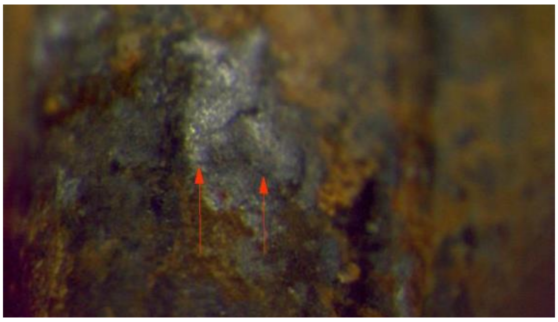

Figure 23. Crack location found at the 2

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