Preliminary vibration testing and analysis for automotive electronic control units

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ABSTRACT. The general trend for the mounting location of powertrain electronics reflects a migration from the traditional passenger and engine compartments to on the engine and transmission. Because of high level for accurate and secure working of electronic control units (ECU), producers established appropriate criteria which must be satisfied during different testing procedures. One criteria is allowed vibration level. In this paper, measurement technique and analysis of vibration level of ECU for passenger car equipped with an up to date diesel engine, is shown. Existing universal measurement equipment is used. For analysis and signal processing, according to methodology and criteria by ECU producer, appropriate software is developed. Also, in this paper, some testing results are given. It is shown, that in prototype design, this way for getting preliminary results of ECU vibration levels is very reliable, fast and not too much expansive.

KEYWORDS. ECU; Vibration; Testing; Measurement; Analysis.

INTRODUCTION

For the first generation of automotive Engine Control Modules (ECM) in the late 1970s, the passenger compartment was the logical mounting location. Containing relatively limited functionality and input/output (I/O), these electronic control units (ECU) were typically located either in or below the dashboard. As powertrain control system complexity and control module functional content grew, it became more difficult to find acceptable locations within the passenger compartment. Additionally, the routing of the ECU wire harness from the passenger compartment through the bulkhead to the engine compartment became increasingly problematic. With its bulky connector(s), large number of wires, higher current levels, and overall length, the ECU wire harness created vehicle level assembly issues and increased the potential for electromagnetic and radio frequency interference (EMI/RFI) related problems. Consequently, by the late 1980's, the mounting location for engine and powertrain ECUs began to move from the relatively benign and protected passenger compartment to the much harsher underhood environment of the engine compartment.

VIBRATION REQUIREMENTS

While the transition from the passenger to the engine compartment did not significantly change the level of ECU vibration exposure, the move to on-engine substantially increases this requirement. For on-engine and on-transmission locations, the lower frequency energy level (less than 500 Hz) is dominated by the periodic motion of the engine and powertrain components. Consequently, the input energy follows engine RPM and its harmonics, generally exhibiting sinusoidal behavior. Additionally, during periods of extended driving at constant RPM (e.g. highway travel), the input energy will effectively dwell at a fixed frequency. Higher frequency energy vibration (up to 2 kHz) is dominated by the response behavior of the powertrain and its structural elements (transmission housings, valve covers, etc.) and generally exhibits random behavior.

Typical vibration test requirements for on-engine and on transmission ECU mounting locations have a lower frequency sinusoidal sweep component with acceleration levels of 30 Gs and a higher frequency random component with acceleration levels of 10 Grms. Specific test level and duration should be evaluated and verified on a case by case basis with actual on-engine measurements.

Given the severity of these requirements, the mechanical design of the ECU and its mounting hardware or features (brackets, bosses, etc.) must provide sufficient integrity to avoid vibration failures. As a general rule, the vibration resonant response frequencies of the various mechanical systems should be above the low frequency component (above 500 Hz) and not coincident with one another. For example, Fig. 1 shows an ECU and its mounting bracket oscillating model. The desired separation of the resonant frequencies for the mounting bracket, ECU enclosure, and internal structure are shown in Fig. 2. Ideally, these resonant frequencies should be well above 500 Hz and separated by one octave.

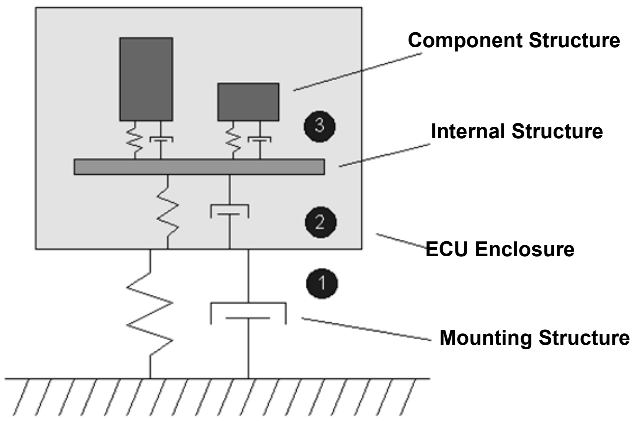

Figure 1: ECU and mounting bracket oscillating model

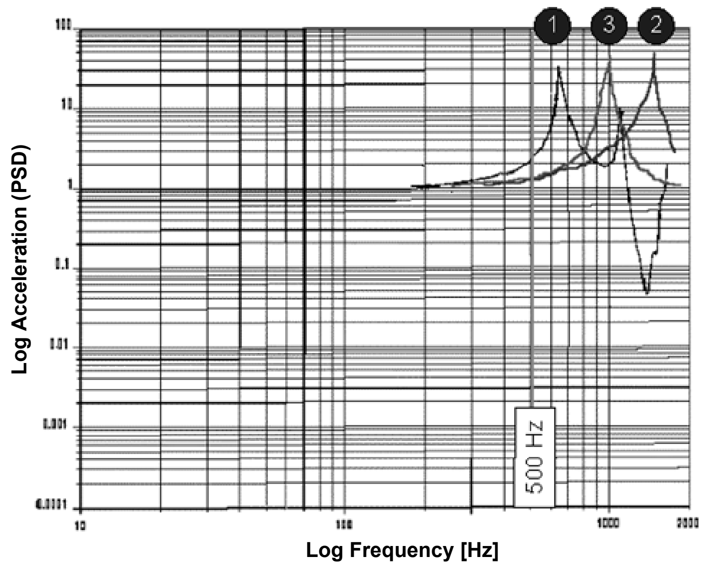

Figure 2: Resonant frequencies of ECU and mounting bracket

MANUFACTURER VIBRATION CRITERIA

ECU manufacturers are always defining adequate criteria which must be satisfied during ECU vibration testing. These criteria are depending on the ECU type and sort. Testing procedures are done by ECU manufacturer, on special road conditions and using well defined measuring equipment and methodology.

To obtain permission for assembling one up to date diesel engine in passenger car, ECU manufacturer defined special criteria and methodology for vibration testing. Three axis acceleration sensors are mounted to:

- ✓ central processing unit inside the ECU,
- ✓ ECU enclosure (housing),
- ✓ ECU bracket, and
- ✓ car-chassis.

Acceleration sensors mounted on the ECU enclosure are shown in Fig. 3.

Test is done in the specific road conditions, on the washboard track at manufacturer's testing polygon, driving with constant speed at 30 km/h and 40 km/h, in the 2nd gear ratio. Sampling frequency is 4096Hz, with resolution of 2Hz, and valuable results are up to 2kHz. Measuring results are processed and analized using power spectral density which must satisfy required criteria.

Figure 3: Vibration measurement by pieso transducers (Ver.1)

The most critical testing results, Z-direction accelerations with speed of 40km/h, are shown in Fig. 4. Ordinate is power spectral density [$(m/s^2)^2/Hz$], and abscissa is frequency [Hz]. Criteria is clearly drown bold broken stright line.

At the frequency of 100Hz, all measured points are outside of criteria. The whole range from about 50Hz to 200Hz is critical.

Finally, this solution for ECU bracket and mounting structure (Ver.1) is without approval for serial production. The vibration amplitudes on the ECU exceed the validated levels and therfore are not permissible for a release of the ECU. The too high elasticity of the ECU bracket is the main cause of the vibration levels. Consequently it must be hardened or another point of fixation must be defined in order to flatten the frequencies amplitudes around 100Hz.

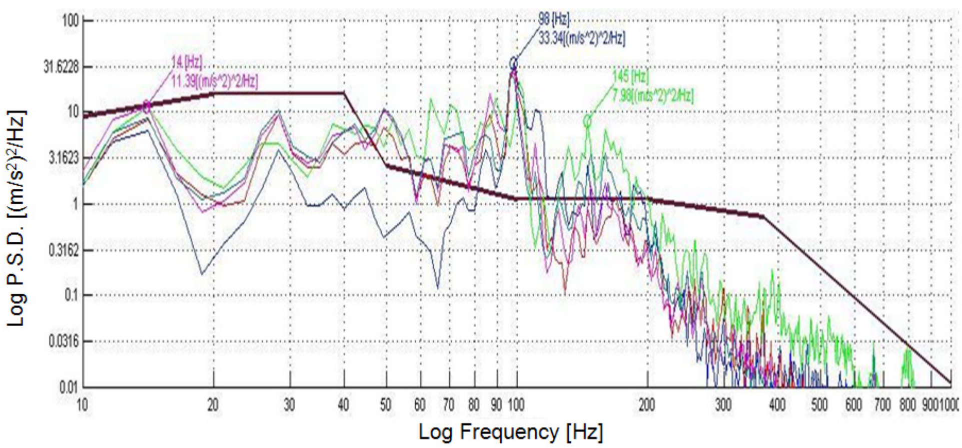

Figure 4: Vibration measuring by three-axis pieso sensors (Ver.1)

METHODOLOGY FOR PRELIMINARY VIBRATION TESTING

Vibration measurements and testing on the ECU done on the polygon at ECU manufacturer, are expensive and take some time for realization. To save a money and shorten time for launching new vehicle design in serial production, own methodology for preliminary ECU vibration testing is developed. One axis inductive acceleration sensors, HBM type B12/500, are used. It is shown in Fig.5 how these sensors are mounted in the Z and X direction. This ECU bracket is called Version 1. One axis acceleration sensors are mounted to:

- ✓ ECU enclosure (housing),
- ✓ ECU bracket, and
- ✓ car-chassis.

First test and analysies are done for pulse excitation in all three axis by rubber hammer. In this way eigen frequency values are obtained and eventualy significant change in system response can be detected as well as critical frequency range.
Polygon testing is done on the flat asphalt track with parallel wooden boards (dimension 1x0.1x0.04m, free space is 0.9m), driving with constant speed at 30, 40 and 50 km/h, in the 2nd gear ratio. This type for polygon testing is chosen after large number of tests with different tracks, because results are comparable with official. Data acquisition is done by measuring device HBM Spider8, and sampling frequency is 9600Hz. Measuring results are processed and analized using specialy developed software application based on Matlab from MathWorkd, which includes calculation of power spectral density of acceleration signals and vibration criteria required by ECU manufacturer.

Figure 5: Vibration measurement by one-axis inductive sensors (Ver.1)

RESULTS FOR PRELIMINARY VIBRATION TESTING

Processed results of preliminary vibration testing for Z and X direction accelerations on the ECU enclosure (housing), driving at constant speed of 40km/h, in the 2nd gear ratio, are shown in Fig.6. This construction of ECU bracket (Version 1), means rigid and hard connection between car chassis and ECU bracket on the front right wheelbox. This results are quite comparable with official measurements and results, see Fig.4, and reasonable preliminary testing is validated.

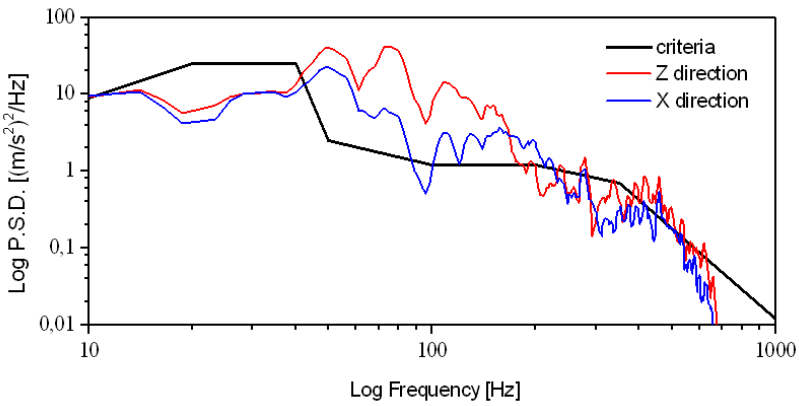

Figure 6: Results of vibration measurement by one-axis inductive sensors (Ver.1)

So, the results are showing that it is necessary to change the construction of ECU bracket or connecting point with car chassis. After that, preliminary testing procedure should be repeated.

The another construction and solution for ECU bracket, Version 2, is shown in Fig. 7. Metal spikes are maden on the car chassis, and ECU bracket is mounted with rubber rings. The third connecting point between ECU bracket and car chassis (below the bracket) remains rigid.

Processed measurement results for Z and X direction accelerations on the ECU enclosure, driving with constant speed of 40 km/h, in the 2nd gear ratio, shown in Fig. 8, pointed out improvements only regarding to the level of allowed vibrations, comparing with Version 1, but critical frequency range remains the same.

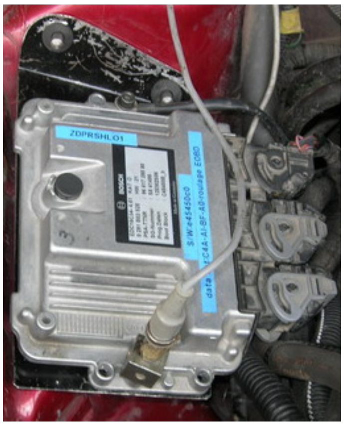

Figure 7: ECU bracket, Ver. 2.

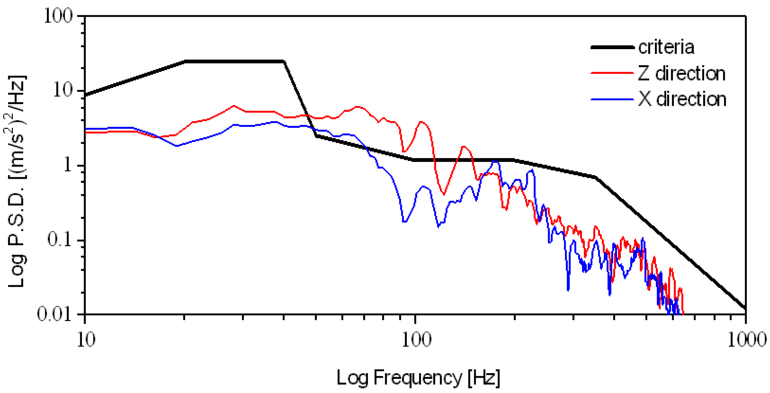

Figure 8: Results of preliminary vibration measurement (Ver.2)

To move down resonant frequency, below 50Hz, and to reduce much more vibration level, new reconstruction of ECU bracket was done. Small rubber bracket with metal ring is mounted on the third connecting point between ECU bracket and car chassis, Version 3, see Fig. 9. Processed results for vibration measurements with this solution, for Z and X direction accelerations on the ECU enclosure, driving with constant speed of 40 km/h, in the 2nd gear ratio are shown in Fig.10. Improvements with this solution are clear, distinguishable and acceptable for vibration level in the whole frequency spectrum.

Figure 9: ECU bracket, Ver. 3.

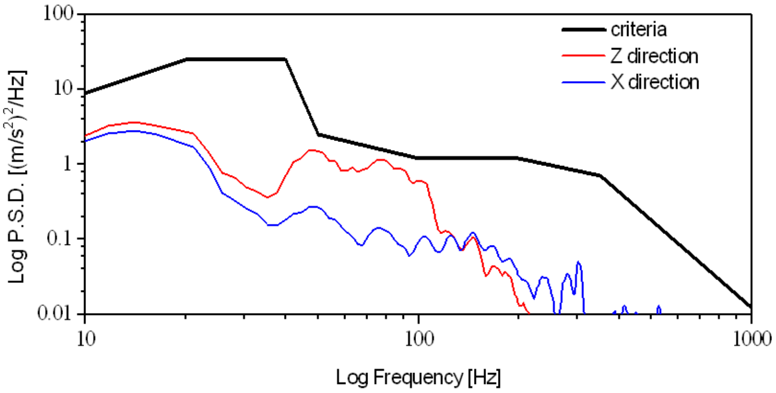

Figure 10: Results of preliminary vibration measurement (Ver.3)

CONCLUSION

Methodology, measurement technique and analysis of measurement results for acceleration signals, to identify ECU vibration level is shown in this paper. This methodology is based and verified with official testing by ECU manufacturer, but it is adjusted with existing measurement equipment and testing polygon.

Appropriate software for measurement results processing is developed. By this, it is possible to reliably validate different constructions.

Because enough good software for ECU vibration level calculation in the construction design phase is inaccessible, this way to obtain preliminary results of ECU vibration level is reliable, rapid and acceptable regarding to total costs.

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