McNair Scholars Research Journal

Volume 3 | Article 2

2016

EcoCAR3 COMPONENT TEST PROCEDURE AND DEFINITION: An Evaluation of the Impact of Mechanical Vibration Tests on the Performance on a Plug-in Hybrid Electric Vehicle

Lesley E. Ngwe Neh
Embry-Riddle Aeronautical University, ekuel@my.erau.edu

EcoCAR3 COMPONENT TEST PROCEDURE AND DEFINITION.

An Evaluation of the Impact of Mechanical Vibration Tests on the Performance on a Plug-in Hybrid Electric Vehicle

Presented to

Dr. Ilteris Dermikiran

Embry Riddle Aeronautical University

Daytona Beach, FL

In Partial Fulfillment of the Requirements for

The Ronald E. McNair Post Baccalaureate Achievement Program

By

Lesley E. Ngwe Neh

ekuel@my.erau.edu

Abstract

The purpose of this paper is to examine the impact the effect of mechanical vibration tests on the performance on the EcoCAR3 which is a Plug-in Hybrid Electric Vehicle (PHEV). PHEVs require new control and energy management algorithms that are crucial for vehicle performance. In this paper the creation of a test plan, procedures, and the actual vibration tests are considered. Similar models such as the EcoCAR2 have been developed to evaluate vehicle performance for conventional and hybrid architectures. However, the inclusion of a vibration test on the EcoCAR3 is expected to boost its performance. Various standards as well as test procedures and definitions are used in this analysis. The paper provides quantitative and qualitative analysis of the control algorithms to analyze their effects vibration on the performance of EcoCAR3; these results are compared with the results of the models developed before EcoCAR3. Some important advantages of performing mechanical vibration tests on vehicle or automotive components are shown and can be useful in the design of the optimal control algorithms for PHEVs. As shown in the results, the performance problem for PHEVs is not limited to vibrations, but it also involves external factors, such as price of electricity, energy market and regulations, charging - availability, battery life issues, etc.

INTRODUCTION

Foreign oil dependence, increased cost of fuel, pollution, global warming are buzz words of today's era. Automobiles have a large impact on increasing energy demand, pollution and related issues. Most transportation systems in the world rely heavily on oil for about 94 percent of delivered energy with no substitutes currently available at scale. This complete dependence on a single fuel has its origins in a time when oil was an inexpensive and exclusively domestic resource, but over time, it has created serious economic and national security vulnerabilities most countries. In addition to highly volatile and economically damaging prices, petroleum fuels carry high environmental costs. In the U.S. for example, nearly 50 percent of supplies deriving from foreign producers, high oil prices have also contributed heavily to an expanding trade deficit and national security concerns. As a consequence, many efforts are being concentrated on innovative systems for transportation that could replace petroleum with cleaner fuel, i.e. electricity from the power grid. Electrification of the transportation system with plug-in hybrid electric vehicles (PHEVs) such as the EcoCAR3 have the potential to decrease the world's dependence on oil and the risks associated with its production and use. The use of PHEVs can become a very important change in this direction, since such vehicles could benefit from the increasing availability of renewable energy**.** Using electricity as a fuel also has benefits for the average consumer, as it is less expensive than gasoline, and electricity prices are less volatile than gasoline prices.

EcoCAR3 is the latest U.S. Department of Energy (DOE) Advanced Vehicle Technology Competition (AVTC) series and is North America's premier collegiate automotive engineering competition. The EcoCAR3 will be a redesign of a Chevrolet Camaro into a hybrid-electric car that will reduce environmental impact, while maintaining the muscle and performance expected from this iconic American car. While the model is the most technologically advanced Camaro in the vehicle's history, EcoCAR3 teams will be tasked to incorporate innovative ideas, solve complex engineering challenges, and apply the latest cutting-edge technologies. Teams have four years (2014-2018), to harness those ideas into energy to meet engineering, environmental and economic goals. The Camaro will keep its iconic body design, while student teams develop and implement eco-power and performance under the hood, retain safety and meet high consumer standards. The teams also will focus on developing technology that will lower emissions by incorporating alternative fuels. This paper gives a broad overview of PHEV deployment, with an eye towards mechanical vibration tests performed on the various components of the EcoCAR3. The vibration test comprises of three main sections: The test plan, the conformity flowchart/test procedures, and the test run.

METHOD

THE TEST PLAN

The test plan is a document detailing the objectives, target market, internal beta team, and processes for a specific beta test for a software or hardware product. The plan typically contains a detailed understanding of the eventual workflow. It typically documents the strategy that will be used to verify and ensure that the vehicle meets its design specifications and other requirements. This test plan was prepared by or with significant input from the test team.

ERAU EcoCAR3 Vibration Test

Some type of unique company generated a number to identify this test plan, its level and the level of software that it is related to. Preferably the test plan level will be the same as the related software level. The number may also identify whether the test plan is a master plan, a level plan, an integration plan or whichever plan level it represents. This is to assist in coordinating software and testware versions within configuration management.

- Unique "short" name for the test plan
- Version date and version number of procedure
- Version author and contact information
- Revision history

Keep in mind that test plans are like other software documentation, they are dynamic in nature and must be kept up to date. Therefore, they will have revision numbers. You may want to include author and contact information including the revision history information as part of either the identifier section of as part of the introduction.

The Plan's Purpose

State the purpose of the Plan, possibly identifying the level of the plan (master etc.). This is essentially the executive summary part of the plan. You may want to include any references to other plans, documents or items that contain information relevant to this project/process. If preferable, you can create a references section to contain all reference documents.

- Project authorization
- Project plan
- Quality assurance plan
- Configuration management plan
- Relevant policies and standards
- For lower level plans, reference higher level plan(s)

Identify the scope of the plan in relation to the software project plan that it relates to. Other items may include, resource and budget constraints, scope of the testing effort, how testing relates to other evaluation activities (Analysis & Reviews), and possible the process to be used for change control and communication and coordination of key activities. As this is the "Executive Summary" keep information brief and to the point.

Test Items

These are things you intend to test within the scope of this test plan. Essentially a list of what is to be tested. This can be developed from the software application test objectives inventories as well as other sources of documentation and information such as:

- Requirements specifications
- Design specifications
- Users guides
- Operations manuals or guides
- Installation manuals or procedures

This can be controlled and defined by your local Configuration Management (CM) process if you have one. This information includes version numbers, configuration requirements where needed, (especially if multiple versions of the product are supported). It may also include key delivery schedule issues for critical elements. Identify any critical steps required before testing can begin as well, such as how to obtain the required item. This section can be oriented to the level of the test plan. For higher levels it may be by application or functional area, for lower levels it may be by program, unit, module or build. References to existing incident reports or enhancement requests should also be included. This section can also indicate items that will be excluded from testing

Features To Be Tested

This is a listing of what is to be tested from the USERS viewpoint of what the system does. This is not a technical description of the software but a USERS view of the functions. It is recommended to identify the test design specification associated with each feature or set of features. Set the level of risk for each feature. Use a simple rating scale such as (H, M, L); High, Medium and Low. These types of levels are understandable to a user. You should be prepared to discuss why a particular level was chosen. This is another place where the test objectives inventories can to use to help identify the sets of objectives to be tested together, (this takes advantage of the hierarchy of test objectives). Depending on the level of test plan, specific attributes (objectives) of a feature or set of features may be identified.

Features Not to be Tested

This is a listing of what is NOT to be tested from both the users viewpoint of what the system does and a configuration management/version control view. This is not a technical description of the software but a USERS view of the functions.

- Identify WHY the feature is not to be tested, there can be any number of reasons.
    - Not to be included in this release of the Software.
    - Low risk, has been used before and is considered stable.
    - Will be released but not tested or documented as a functional part of the release of this version of the software.

Approach

This is your overall test strategy for this test plan; it should be appropriate to the level of the plan (master, acceptance, etc.) and should be in agreement with all higher and lower levels of plans. Overall rules and processes should be identified.

- Are any special tools to be used and what are they?
    - Will the tool require special training?
- What metrics will be collected?
    - At which level is each metric collected?
- How is Configuration Management handled?
- How many different configurations will be tested?
    - Hardware
    - Software
    - Combinations of HW, SW and other vendor packages
- What are the regression test rules? How much will be done and how much at each test level.
    - Will regression testing be based on severity of defects detected?
- How will elements in the requirements and design that do not make sense or are untestable be processed?

- If this is a master test plan the overall project testing approach and coverage requirements must also be identified.
- Specify if there are special requirements for the testing.
- Only the full component will be tested.
  - A specified segment of grouping of features/components must be tested together.
- Other information that may be useful in setting the approach are:
- MTBF, Mean Time Between Failures - if this is a valid measurement for the test involved and if the data is available.
- SRE, Software Reliability Engineering - if this methodology is in use and if the information is available.
- How will meetings and other organizational processes be handled.
- Are there any significant constraints to testing?
  - Resource availability
  - Deadlines
- Are there any recommended testing techniques that should be used, if so why?

Item Pass/Fail Criteria

What are the completion criteria for this plan? This is a critical aspect of any test plan and should be appropriate to the level of the plan. The goal is to identify whether or not a test item has passed the test process.

- At the unit test level this could be items such as:
  - All test cases completed.
    - A specified percentage of cases completed with a percentage containing some number of minor defects.

        - Code coverage tool indicates all code covered.
- At the master test plan level this could be items such as:
    - All lower level plans completed.
        - A specified number of plans completed without errors and a percentage with minor defects.
- This could be an individual test case level criterion or a unit level plan or it can be general functional requirements for higher level plans.
- What is the number and severity of defects located?
- Is it possible to compare this to the total number of defects? This may be impossible, as some defects are never detected.
- A defect is something that **may** cause a failure, and may be acceptable to leave in the application.
    - A failure is the result of a defect as seen by the User, the system crashes, etc.

Suspension Criteria and Resumption Requirements

Know when to pause in a series of tests or possibly terminate a set of tests. Once testing is suspended, how is it resumed and what are the potential impacts, (i.e. regression tests)? If the number or type of defects reaches a point where the follow on testing has no value, it makes no sense to continue the test; you are just wasting resources.

- Specify what constitutes stoppage for a test or series of tests and what is the acceptable level of defects that will allow the testing to proceed past the defects.
- Testing after a truly fatal error will generate conditions that may be identified as defects but are in fact ghost errors caused by the earlier defects that were ignored.

Test Deliverables

What was delivered as part of this plan?

- Test plan
- Test design specifications.
- Test case specifications
- Test procedure specifications
- Test item transmittal reports
- Test logs
- Test incident reports
- Test summary reports
- Test incident reports

Test data was also considered a deliverable as well as possible test tools to aid in the testing process. One thing that is not a test deliverable is the software; that is listed under test items and is delivered by development. These items need to be identified in the overall project plan as deliverables (milestones) and should have the appropriate resources assigned to them in the project tracking system. This will ensure that the test process has visibility within the overall project tracking process and that the test tasks to create these deliverables are started at the appropriate time. Any dependencies between these deliverables and their related software deliverable should be identified. If the predecessor document is incomplete or unstable the test products will suffer as well.

Test Tasks

There should be tasks identified for each test deliverable. Include all inter-task dependencies, skill levels, etc. These tasks should also have corresponding tasks and milestones in the overall project tracking process (tool). If this is a multi-phase process or if the application is to be released in increments, there may be parts of the application that this plan does not address. These areas need to be identified to avoid any confusion should defects be reported back on those future functions. This will also allow the users and testers to avoid incomplete functions and prevent waste of resources chasing non-defects. If the project is being developed as a multi-party process this plan may only cover a portion of the total functions/features. This needs to be identified so that those other areas have plans developed for them and to avoid wasting resources tracking defects that do not relate to this plan. When a third party is developing the software, this section may contain descriptions of those test tasks belonging to both the internal groups and the external groups.

Environmental Needs

Are there any special requirements for this test plan, such as:

- Special hardware such as simulators, static generators etc.
- How will test data be provided? Are there special collection requirements or specific ranges of data that must be provided?
- How much testing will be done on each component of a multi-part feature?
- Special power requirements.
- Specific versions of other supporting software.
- Restricted use of the system during testing.
- Tools (both purchased and created).
- Communications

    Web

    Client/Server

    Network

Topology

External

Internal

Bridges/Routers

Security

Responsibilities

Who is in charge? There should be a responsible person for each aspect of the testing and the test process. Each test task identified should also have a responsible person assigned. This includes all areas of the plan, here are some examples.

- Setting risks.
- Selecting features to be tested and not tested.
- Setting overall strategy for this level of plan.
- Ensuring all required elements are in place for testing.
- Providing for resolution of scheduling conflicts, especially if testing is done on the production system.
- Who provides the required training?
- Who makes the critical go/no go decisions for items not covered in the test plans?
- Who delivers each item in the test items section?

Staffing and Training Needs

Identify all critical training requirements and concerns.

- Training on the product.
- Training for any test tools to be used.

Schedule

Should be based on realistic and validated estimates. If the estimates for the development of the application are inaccurate the entire project plan will slip and the testing is part of the overall project plan. The first area of a project plan to get cut when it comes to crunch time at the end of a project is the testing. It usually comes down to the decision, ‘Let’s put something out even if it does not really work all that well’. And as we all know this is usually the worst possible decision.

- How slippage in the schedule will to be handled should also be addressed here.
- If the users know in advance that a slippage in the development will cause a slippage in the test and the overall delivery of the system, they just may be a little more tolerant if they know it’s in their interest to get a better tested application.
- By spelling out the effects here you have a chance to discuss them in advance of their actual occurrence. You may even get the users to agree to a few defects in advance if the schedule slips.
- At this point, all relevant milestones should be identified with their relationship to the development process identified. This will also help in identifying and tracking potential slippage in the schedule caused by the test process.
- It is always best to tie all test dates directly to their related development activity dates. This prevents the test team from being perceived as the cause of a delay. For example: if system testing is to begin after delivery of the final build then system testing begins the day after delivery. If the delivery is late system testing starts from the day of delivery, not on a specific date.

There are many elements to be considered for estimating the effort required for testing. It is critical that as much information as possible goes into the estimate as soon as possible in order to allow for accurate test planning.

Risks and Contingencies

What are the overall risks to the project with an emphasis on the testing process?

- Lack of personnel resources when testing is to begin.
- Lack of availability of required hardware, software, data or tools.
- Late delivery of the software, hardware or tools.
- Delays in training on the application and/or tools.

THE CONFORMITY FLOWCHART/TEST PROCEDURES

These are standard operating procedures which outline the requirements and processes involved in conducting, coordinating and documenting the vibration tests on the vehicle and its components. These procedures describe minimum requirements for the tests to be successfully conducted and in a timely manner. The test team leader is in charge of ensuring every requirement has been met before any testing can begin. Failure to meet these requirements will result in serious delays. The triangles represent tollgates which are simply checkpoints to confirm that a requirement has been met.

THE TEST RUN

An engineering test run is defined as nothing more than the initial run that mimics the formal, current good manufacturing practice. This process involves carrying out precautions and testing to ensure good quality products. In this case, the test run comprised of various mechanical vibration tests conducted on the vehicle and its components to qualify it for safety public use. The purpose of a vibration test is to determine if the item being tested is likely to survive the vibration environment in which it will work. The reproduction of in service conditions of each component is possible thanks to an electrodynamics vibrator. The simplest form of mechanical vibration to consider is that based on a linear theory. This means that displacement, velocity and acceleration satisfy a proportional relationship to each other and to the mechanical stiffness of the system. Each device under test has been assumed to have three degrees of freedom. This activity was safely carried out by the test team who have been trained to perform this kind of an engineering process. A vibration test system was used to conduct the tests. This system involves all of the components, equipment and tools that will be used in conducting the vibration tests. The picture below shows what a typically vibration system will include.

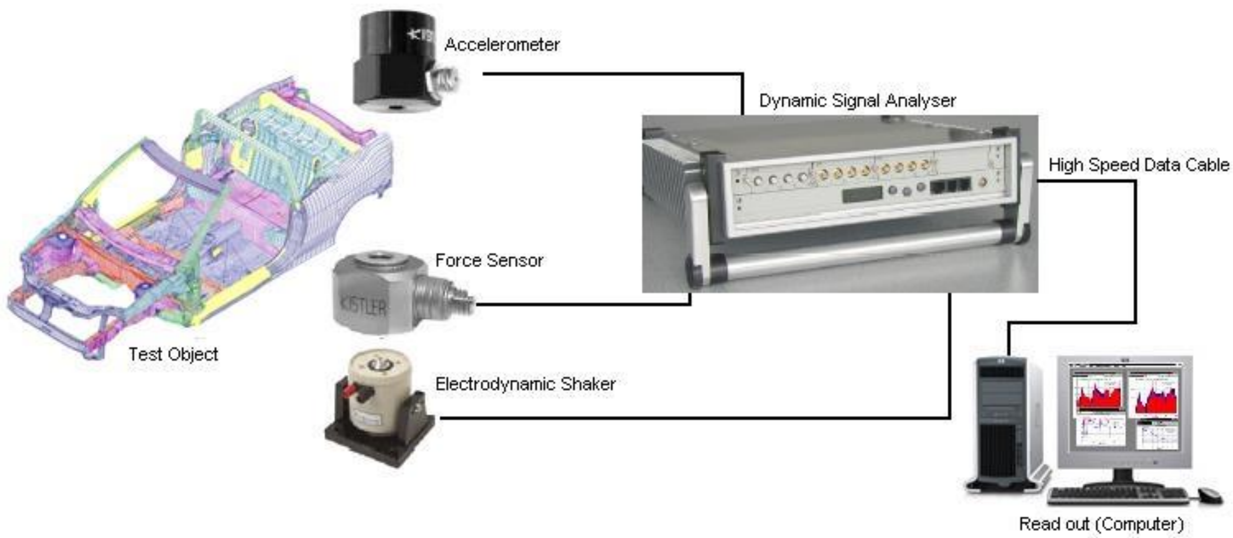

FIGURE I: Components of a vibration test system.

The most important components of the vibration test system include the LDS V875 long stroke shaker with a slip table and the climate chamber which is an environmental chamber that fits over either the slip table or the vertical vibration table during temperature and humidity testing. The LDS V875 is an air-cooled unit with a 3-inch (long) stroke, equipped with a head expander measuring 48 × 48 inches. The slip table is the same size. Two customized floor plug seals are designed for use with the chamber, to ensure a tight fit throughout the long testing periods. It is designed to test in two axes – vertical and horizontal – and to be very quick to transition between the two possibilities. The shaker can also be easily moved by means of a specially designed air glide system. As a result of special customization, the shaker can take a maximum load of 3000 pounds (1360.78 kg). Test control is with an LDS Laser Controller using white noise, sine, swept-sine, or road-load data as test data input.

Performance specifications

Shaker:

- Force rating: 29 kN (6500 lbs)
- Displacement peak-to-peak: 50.8 mm

(2 inches) minimum

- Velocity: 1.8 m/s (71 inches/sec)
- Acceleration: 735 m/sec2 (75 g)

Climatic chamber:

- From –50 °C up to 140 °C
- The temperature gradient changes at

2 °C per minute.

FIGURE 2: Shaker system

A significant case study: the steering wheel

The sources of steering wheel vibrations include the engine, the wheels and the tires, as well as the road surface. This results in various vibration patterns transmitted to the steering wheel through the steering shaft. The perceived intensity of hand-transmitted vibration is dependent on the vibration frequency and the frequency-dependence of subjective estimates may depend on the magnitude of vibration. This section focuses on the reliability tests of the steering wheel considering the results of on-car test vibrations measurements both in time domain and in frequency domain. Because of safety problems, it was not possible to measure vibrations directly on the front side of the steering wheel. Therefore, it was preferred to locate the accelerometers behind the steering wheel (Fig. 3). Two triaxial accelerometers were mounted respectively on steering wheel rigid section (it measures the source of vibrations from the vehicle) and on steering wheel electronics. Electronics section is mounted using absorbers, therefore vibrations from base are correctly damped (the overall vibrational stress on Z-axis on the steering wheel electronics is less than the base value)

FIGURE 3: Accelerometers positioning on steering wheel.

DISCUSSION/RESULTS

Figure 4 represents the acceleration values obtained from each sensor calculated averaging on three laps; it clarifies the efficacy of absorbers. The accuracy of mentioned measurements is 0.01 m/s^2 because it is the best tradeoff between sampling resolution of acquisition system (1.2µV) and accelerator accuracy (10mV/m/s^2), considering the voltage range (20V) and the physical range (200 m/s^2).

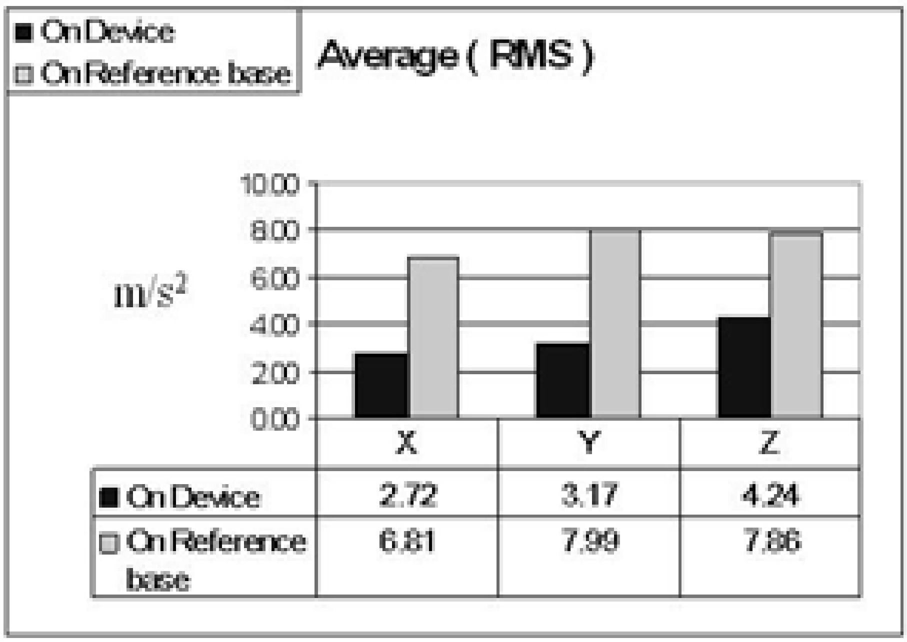

FIGURE 4: Time domain vibration on steering wheel base and electronics.

Vibration behavior is greatly modified by vehicle state conditions in terms of PSD. Below are two plots which focus on kerbs riding and straight-line running. The GT cars specification for PSD vibrational testing for all the electronic devices which are mounted on the chassis is used as reference (black dashed line). It's evident that this automotive standard is not appropriate for racing applications. As shown in the thin lines in Fig. 6, during straight line running, the PSD is concentrated on high frequency areas. When the car is on a kerb, the PSD distribution is located on lower frequencies (Fig. 7). In order to match both high frequency vibrations from engine and low frequency shocks from kerbs riding, it is opportune to perform on-bench vibration test cycling between two different PSDs. Marked lines represent the interpolation of max points of measured PSD (thin lines) and it is the input function of shaker.

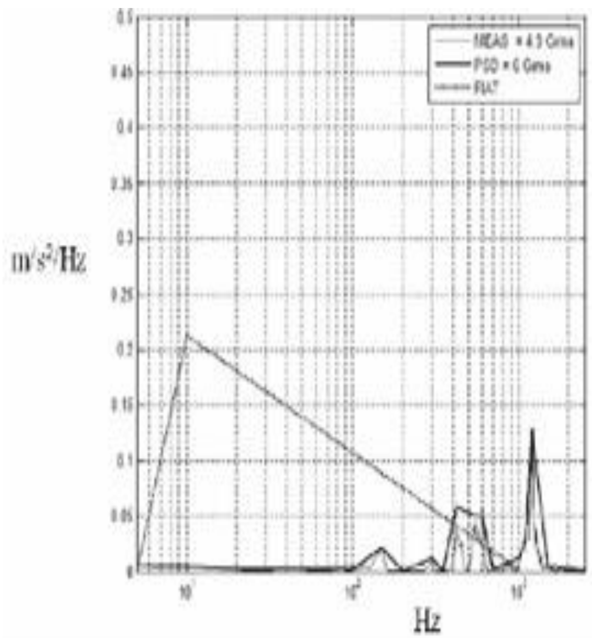

FIGURE 5:PSD vibration test on straight line running**.**

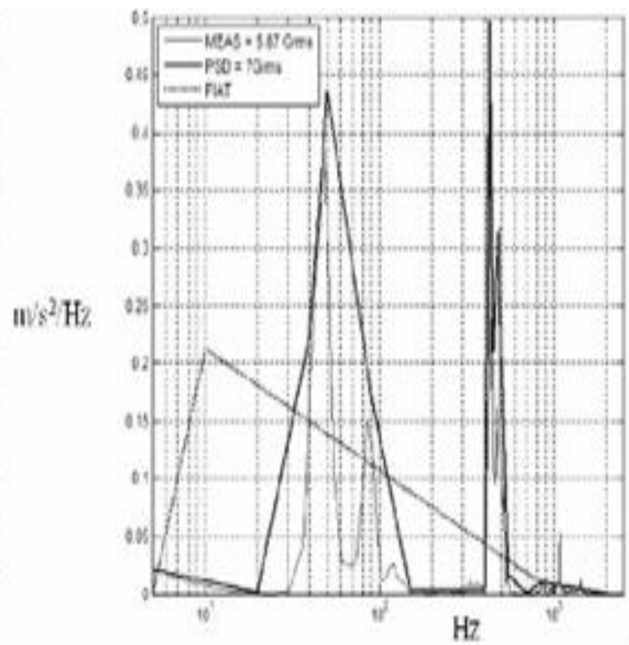

FIGURE 6:PSD vibration test on kerbs.

Adopting automotive standard, it's possible to consider only a part of real driving stress; to mount on the car a steering wheel only automotive approved could involve a risk. It's fundamental to repeat periodically these on-car measurements to use the real vibrational asset as an input of simulation bench test. In this way, it is possible to validate accurately in the laboratory the robustness of the steering wheel.

CONCLUSION

The paper describes a practical vibration monitoring procedure for electronic equipment in racing context. Three test benches are mentioned to show all data acquisition systems implemented for the vehicle. The collected vibration data are useful to several goals: mechanical stress study, shock characterization, resonance analysis, damping efficiency, noise source investigation, reliability tests and some feedback to suppliers in the continuous improvement process. The proposed approach not only guarantees the component functionality but it is useful to continuous improvement of device design/assembling. Moreover, in the considered case study, the efficacy of absorbers on the steering wheel can be assessed too by measuring how much they reduce the effects of vibrations on the wheel.

References

Broch, Jens Trampe. *Mechanical Vibration and Shock Measurements*. Naerum, Denmark: Brüel & Kjaer, 1980. Print. 18 Feb. 2016.

Dompierre, A., M. S. Traore, and L. G. Fréchette. "Measurements of Car Vibrations Under Real-Life Driving Conditions and Assessment of Energy Harvesting for Wireless Sensor Nodes." *Volume 14: Vibration, Acoustics and Wave Propagation* (2013). Web. 6 Mar. 2016.

"EcoCAR 3 I Advanced Vehicle Technology Competition." *Ecocar 3 ICal*. Web. 12 Feb. 2016.

Ehsani, Mehrdad. "Plug-in Hybrid Electric Vehicles." *Encyclopedia of Sustainability Science and Technology* (2012): 8112-123. Web. 17 Feb. 2016.

Fellah, Mohammed, Gurhari Singh, Aymeric Rousseau, Sylvain Pagerit, Edward Nam, and George Hoffman. "Impact of Real-World Drive Cycles on PHEV Battery Requirements." *SAE Technical Paper Series* (2009). Web. 15 Feb. 2016.

5.Hajian, Mahdi, Hamidreza Zareipour, and W. D. Rosehart. "Environmental Benefits of Plug-in Hybrid Electric Vehicles: The Case of Alberta." *2009 IEEE Power & Energy Society General Meeting* (2009). Web. 11 Feb. 2016.

Schwab, Harry L. "The Development of Vibration Environments for Accelerated Testing of Automotive Components." *SAE Technical Paper Series* (1994). Web. 20 Feb. 2016.

Shinkle, George A. "Automotive Component Vibration: A Practical Approach to Accelerated Vibration Durability Testing." *SAE Technical Paper Series* (1984). Web. 18 Feb. 2016.

Sioshansi, Ramteen, and Paul Denholm. "Emissions Impacts and Benefits of Plug-In Hybrid Electric Vehicles and Vehicle-to-Grid Services." *Environmental Science & Technology Environ. Sci. Technol.* 43.4 (2009): 1199-204. Web. 16 Feb. 2016.

Sovacool, Benjamin K., and Richard F. Hirsh. "Beyond Batteries: An Examination of the Benefits and Barriers to Plug-in Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-grid (V2G) Transition." *Energy Policy* 37.3 (2009): 1095-103. Web. 18 Feb. 2016.

Su, Hong. "Vibration Test Specification for Automotive Products Based on Measured

Vehicle Load Data." *SAE Technical Paper Series* (2006). Web. 11 Feb. 2016.