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EVGA STATE OF ART STUDY
Electric vehicles testing, cold conditions operability
and requirements/needs



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1. Vehicle acoustics

One of the most important things in driving that can affect driving comfort is the interior acoustics of a vehicle. What makes this complicated is the fact that the structure of vehicle has been built from thousands of motive parts. A vehicle that has this many motive parts is probably going to have a lot of vibration; and, because vehicles have these many possible vibration and noise sources, it is very difficult to take effective measures to control the vibration and the harmful noises of the vehicle.

These days, solving the problem of interior vehicle noises is becoming much more important because customers demand more and more comfortable cars. There have been some researches in the last few years that studied interior noises of vehicles, but the pure electric automobiles are still rather inscrutable.

A pure electric vehicle is supposed to be much more quiet and comfortable than a vehicle with the traditional combustion engine. Surprisingly, if no vibration treatment is done for the vehicle, the pure electric vehicle has rather high sound pressure levels inside and outside of the vehicle. There have been only a few researches about an electric vehicle's vibrations.

With the use of the four-wheel tumbler test bench with a semi-freedom noise elimination chamber, it is possible to test noise and vibration characteristics of a new pure electric vehicle. This specific method eliminates all background noises and other interference. It is important to get rid of them because they can reduce the accuracy of a noise test.

This test system can be used to acquire information concerning noise and vibration signals from the internal noise and vibration of a vehicle. The signal analysis can track down the exact source of the interior noise in a vehicle. These measurements for the research into noise and vibration are done by placing four microphones into the vehicle's motor and gearbox. There are also thirteen acceleration sensors that are placed on the possible noise sources. The sound pressure and the acceleration signals are collected with multichannel data collectors.

Because the power source of a pure electric vehicle is different from the traditional vehicle, so are the impact factors of noises. Based on researches, it can be said that at low speed the main sources of noise are differentials. At high speed, the motor is causing most of the noise.

There are many different factors that can cause noise and vibration in a vehicle, and they need to be taken care of. Drive motors can cause howling at high speed, and acceleration and noise are also produced by gear units and planetary gear differentials. The wheels of a vehicle can also have an impact on noise, and they can also cause vibrations.

With the spectrum analysis of sound signals of an interior reference point it is possible to pinpoint the cause of interior noise. According to measurements, the main factors that cause noise in a pure electric vehicle are: motor, differential, reducer, and the friction between the tire and the road.

The vibration analysis can be used in order to track down the causes of vibration in a vehicle. Research shows that the main cause for the vibrations at low speeds is the motor and at higher speeds the vibration source is the wheels. The noise and vibration in vehicle can be greatly reduced by using a chamber for the motor and optimizing the parameters of suspension and mounts [1].

The interior acoustics of the vehicle has become one of the most important factors, which affect comfortable driving for the driver. In these days vehicle manufacturers are paying more and more attention to solving the problem of interior noise. Researchers have been able to achieve some great results in interior noise researches for the vehicles that use the traditional combustion motor. However, there have been only a few researches so far that deal, for example, with the fuel cell vehicle. The fuel cell vehicle is supposed to be the future generation vehicle, but its vibro-acoustic characteristics are still rather unknown.

The basic way to identify the interior acoustic characteristics of a vehicle, such as a fuel cell vehicle, is to use an experimental research method. In this research a vibro-acoustic test was used on a prototype of a fuel cell car. With the vibro-acoustic test, it is possible to identify the interior sound field characteristics and the main sources of the noise by analyzing the gathered information.

Fuel cell cars, which are powered by hydrogen fuel cells, have different sources of noises when compared to regular combustion engine vehicles. The noise sources are so different because of the replacement of the power system. The fuel cell vehicle's power system consists of a fuel cell stack, a cooling system, a Li-battery, and the hydrogen and oxygen supply system. The parts that mostly generate noise in a fuel cell car are the cooling pump for the fuel cell stack, the hydrogen supply pump, and also the fan. In addition to these noise sources, the assembly unit of the traction motor and the air compressor are also causing interior noise.

The research that studied the noise sources of the fuel cell car was done with the four wheel-drive chassis dynamometer in the semi-anechoic chamber of Tongji University. By using the four wheel-drive chassis dynamometer one can be sure that the results of the measurements are accurate. The measurements are done by making the conditions of the vehicle static and even traveling.

The speed starts at 20km/h and 10km/h is added at each time point until the vehicle reaches 120km/h. There are also two microphones that are placed near the driver's right ear and the passenger's right ear. There are also twelve acceleration sensors placed in the possible locations for interior noise. The sound pressure is collected with a multi-channel data collector. The devices are collecting the sound signal of the interior noise and the vibration signal of the body panels.

Locating the source of noise is one of the biggest tasks of noise control. The noise control is dependent on two requirements, and the first one is to identify the characteristics of the noise source including the type of the noise, the rule of frequency change, the primary frequency, and the transfer path. The other requirements for noise control are to find the position of the source, the main component radiating noise, and their contribution to the noise.

There are numerous ways to identify the location of a noise source: Subjective evaluation, near field measurement, sound intensity measurement, vibration level measurement, and the modern signal processing method. Usually two or three methods are needed to be used in a single case due to complications of the issues. It is also important to diagnose the noise transfer path. There are two possible ways for vibration sources to transfer noises: airborne and structure borne.

The research that has been done showed that, during the speed range of 0 to 70 km/h, the dominating frequencies of the noise at the passenger right ear position are 118Hz, 79Hz, 315Hz, and 780Hz. For the driver right ear position the dominating frequency was 118Hz. When the speed rose, the noise caused by the traction motor became more serious. At high speeds the main source of interior noise was the traction motor.

This interior noise can be reduced by increasing the airtightness of the cabin and optimizing the mount system of the traction motor, hydrogen pump, and subframe by adjusting the stiffness and damping of the mount and by changing the structure of the floor, roof, and rear panel [2].

These days it is important for the vehicle manufacturers to be able to design vehicles that have low interior noise levels and a pleasant sound quality. There have been many studies, which showed that the interior noise in a vehicle has a significant influence on the driver's perception of operation, performance, and quality. In order to be able to control the vehicle's interior noise, one needs to locate the source of the noise.

There are many different type of methods that can be used to identify the noise source, for example, sound quality, operational modal analysis, experimental modal analysis, acoustic holography, inverse boundary elements, and wavelet transforms. The powertrain of vehicles is a major noise source, but there are also other sources including the intake system, the exhaust system, wind, tires and the suspension. Also, the vibrations of the steering, gear shift and body panel are major sources of noise in a vehicle.

With the sound intensity technique it is possible to achieve the precise noise source identification. A sound intensity probe, which is composed of two microphones, is used in the sound intensity technique. The benefits of using this system are the simplicity, simple calibration, and operation of the system. This specific system is based on sound pressure and particle velocity measured by both microphones of the probe.

Sound intensity is the basic value of the energy that is flowing throughout a unit area and the unit of sound intensity is sound power per unit area. For the sound intensity measurement, it is possible to present it as a grid plane with lines and columns. One needs to measure the sound intensity at all the nodes in the plane.

This research involving sound intensity measurement has as its main objective to identify the noise source of a passenger car. In order to get the most accurate results, the tests were done in a semi-anechoic room, and the car's rear driving axle was lifted off the ground so that the transmission system of the vehicle would work normally. The measuring grids were set at the inside surfaces of the firewall, front windshield, front floor, front door, and dashboard. Every surface's sound intensity was tested at idle speed. The gathered information was saved in a laptop and processed after the tests.

With the use of these devices, the maximum source of the noise was located at the left front door. These experiments also made it possible for the researchers to calculate the maximum sound intensities inside the vehicle [3].

The comfort of the car interior is becoming more and more important in the vehicle development because of the buyers' demands and the competition in the car industries. In order to make driving more comfortable, it is important to reduce the noise, vibration, and motion inside the vehicle. Whole-body vibration certification testing covers the comfort, health, and safety of the passengers.

The assessment of driving comfort consists of the four main things: seat vibration, interior noise, steering wheel vibration, and general handling in the motion of the vehicle. Measuring and quantifying ride comfort is very important because it can help to achieve the necessary standards and regulations. This can also help to troubleshoot, understand, and improve the noise and vibration comfort in all vehicles.

There has not been developed any specific device to test commercially the comfort level in a vehicle and most of the previous research data is privatized by the car manufacturers. Because of this, there is a huge need to develop a user-friendly device, which can be available to commercially test the interior noise comfort.

In order to take into account the nonlinearity of the sensing by the human ear, it is important that the measuring equipment used in acoustics integrates devices for applying weighting-correcting curves to the input signal. Riding comfort can be analyzed in a few different respects: dynamic factors, ambient factors, and spatial factors. Also, the following factors must be taken into account for the classification of a sound event by a person: level, duration, temporal structure, spectral contribution, quantity, spatial distribution, subjective attitude, and signal information.

As mentioned earlier, when researching interior noise in vehicles, there are two different types of noise that should be considered, which are airborne noise and structural noise. The airborne noise is created by the interaction of the vehicle body with the surrounding air volume and the fuel injection system noise. The structural noise is generated by transmission resonance, suspension resonance, and gearbox rattling. The noise that is created by the cooling fans, air inlets, the exhaust system, and the engine can be considered as a combination of airborne and structural noises.

After gathering the measurement data, a subjective test was conducted in order to find a jury's evaluation for the specific sound sample. There was also a test done that studied the correlation between the subjective and the objective evaluation. The research showed that the Spectral Power feature gives the best classification of accuracy for both conditions [4].

In one research procedure, the interior noise was measured by using a mannequin that was placed on the front passenger seat. The mannequin had two microphones that were placed on its head in order to simulate human hearing. A third microphone was placed at the rear portion of the vehicle interior. There was also a measurement device that was placed on the rear seat of the vehicle and all the microphones were connected to this measurement device. The measurement device is called Orchestra. This research about

vehicle interior noise comfort level was investigated by using four FFT-based features; namely, Energy Entropy, Leq, Spectral Power, and Loudness for the overall interior noise level.

2. Ultracapacitors

One of the main problems with electric vehicles is their rather low autonomy when they are only powered by batteries. Also, when driving in urban areas, the number of accelerations and brake use are rather high. This causes peaks of power in both of these situations. These kinds of power peaks shorten the lifespan of the battery and also weaken its performance level. Because of this, the power peaks need to be limited.

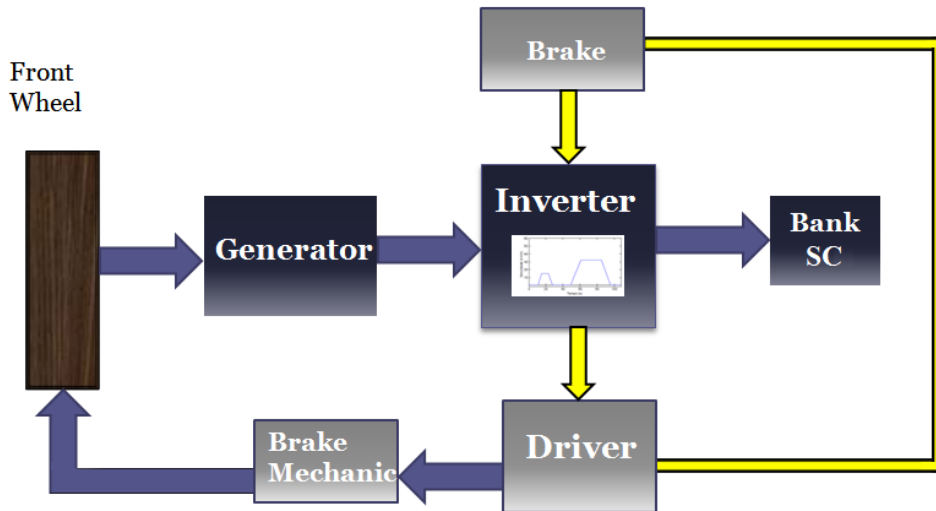
Ultracapacitors can be used as a solution to this problem in order to lose nothing from the electric vehicle's performance level. With the use of a ultracapacitor as an energy storage device, it is possible to minimize the power peaks of batteries. Ultracapacitors also play a key role in the kinetic energy recovery that is available for the electric vehicles.

Regenerative braking is a system that transforms the mechanical energy that is generated by the motor into electrical energy and feeds it back to the sources of energy. There has been research that studied the behaviour of regenerative braking power that is based on an electric vehicle with a three-phase induction motor driven by a variable frequency inverter. The research proposes using the combined action of the mechanical and the electric brake as a way to minimize the inefficiency and weak control of regenerative braking at low speeds. This conforms to the expected manner for the slowdown.

The regenerative braking is used in order to recover the kinetic energy that is lost during braking and also to reduce the mechanical brake wear. Electric vehicles have electric machines that can operate as a generator when the speed is being reduced. This process is dependent on the topology and the control given to the power electronic converter that drives the electric machine. The regenerative braking in electric vehicles includes a storage element, which in this case is the supercapacitor. It can be used to preserve the energy peaks created by braking. This research is studying the possibility of using an ultracapacitor bank as a way to supply and store energy. The research includes many tests that are done in order to find the best way to recover the kinetic energy in regenerative braking.

The proposed system is powered by an inverter and supplied ultracapacitor bank. This system integrates the electric brake with the regular mechanical brake. When a brake command is received, the inverter reduces the synthesized frequency in order to turn the slip of the motor into a generator. The generated energy is absorbed by an ultracapacitor bank. The research results show that it is necessary to use mechanical and electrical braking together. The reason for this is that in emergency situations, electromagnetic torque oscillation in low speed and the requested braking torque are higher than the power absorption capacity of the electric source. When the driving speed is very slow, it is advisable to use mechanical braking to ensure the needed braking torque.

The simultaneous use of electrical and mechanical brakes must result in a deceleration that complies with the input command that is given by the driver of the vehicle through the brake pedal. Experimental and simulation results confirm the expectations and indicate the feasibility of such a combined use of brake systems. The energy recovery depends on the driving cycle because it is related to the kinetic energy of braking [5].



In the last few years the popularity of electric vehicles has been growing rapidly due to their zero emissions into the air. The population of electric vehicles is increasing and many new technologies have been developed. One of the problems in the development of electric vehicles is the limitation of driving mileage. This has been solved by using regenerative braking. Regenerative braking is one of the ways to improve an electric vehicle’s driving range. This method can increase the driving range by 8-25%.

Regenerative braking has replaced the traditional braking system in most cars because the traditional braking system uses mechanical friction to reduce kinetic energy to heat energy in order to slow down the speed. Research results show that when driving in an urban area, about one-third to one-half of the energy required for operation of a vehicle is used during braking. This wasted energy can be converted into a more useful form and be used in the hybrid and electric vehicles. This lost energy can be used by implementing a regenerative braking system in a vehicle. Regenerative braking can capture the wasted energy.

The normal braking system of a vehicle is based on hydraulic technology and it causes energy to go to waste because it produces heat when braking. Regenerative braking can be used to capture this lost energy, and it provides much higher efficiency for a car. When in regenerative mode, the motor works as a generator and transforms the kinetic energy into electrical energy.

This generated electrical energy is then stored in batteries or capacitors. The regenerative braking has also other advantages, for example: more control over braking, preven-

tion of wear on the mechanical brake system, better fuel economy and more efficiency, saving energy, and effectiveness in stop-and-go driving conditions. The regenerative braking technology is evolving with the use of the flywheel and the ultracapacitor.

This research into regenerative braking is studying the working principle and braking controller for the regenerative braking in order to promote the efficiency and realization of energy savings in the electric vehicle. Regenerative braking is a very important system for an electric vehicle because of the possibility of saving wasted energy. By saving this lost energy, the electric vehicle is able to travel longer distances without the need to charge its battery. This system has been made even better by using advanced electronic components, for example, the ultracapacitor, the flywheel and the DC-DC converter (Buck-Boost).

The ultracapacitor can be used to improve the transient state of the electric vehicle during starting. It can also be used to enable smoother charging characteristics for the battery and also to boost the overall performance of the car's systems. The Buck-Boost can be used to maintain the power management in regenerative braking. The flywheel is used to make the power recovery process more effective [6].

Electric vehicles have become more and more popular in the last few years because they are a pollution free solution for driving. One of the things that is slowing down electric vehicles from becoming more common is the high cost of replacing the battery pack during the life of the electric vehicle.

One possible solution to this problem of battery pack replacement being too expensive is to hybridize battery electric vehicles with onboard ultracapacitors. When using ultracapacitors as part of a hybrid vehicle system, they can provide the system with high bursts of power even when the battery's capabilities have decreased because of a low state of charge. With this ability, the vehicle is able to maintain its accelerative performance even at a low state of charge. Ultracapacitors can also provide protection for batteries from high peak currents that can cause serious damage to the batteries of the hybrid vehicles. In other words, the ultracapacitors can be used to extend the lifespan of the batteries.

The greater efficiency of ultracapacitors and the ability to accept high currents from regenerative braking enables hybrid vehicles with a much greater overall efficiency. The better overall efficiency provides vehicles with a longer driving range. Using ultracapacitors is rather expensive and because of this it is advisable to replace only some batteries with supercapacitors in order to achieve the wanted benefits with lower expenses.

Ultracapacitors can be used as part of a battery/ultracapacitor hybrid system in an electric vehicle for a couple of reasons, for example: to improve overall drive efficiency and increasing driving range; to reduce capital costs by direct replacement of some batteries; to reduce life cycle costs by extending the battery life; and to improve vehicle acceleration.

Research results show that hybridizing battery electric vehicles with ultracapacitors is a very effective way to reduce peak battery currents. Studies have proven that minimizing the battery current can significantly extend the battery's lifespan [7].

3. Pre-heating battery of electric vehicle

In the last few years electric vehicles have gained a huge interest in them because reducing greenhouse gases and creating eco-friendly solutions have become one of the main issues in technology these days. The batteries that are being used by electric vehicles affect directly the vehicle's mileage performance. Because of this, it is crucial to keep on developing the battery management so that the electric vehicles can have the highest mileage possible from their batteries. Because of the limited capacity of these batteries, it is important to keep developing new solutions in order to develop their efficiency. There has been very active research that studies battery management for heat generation when the battery is configured as a module pack.

There have been many different kinds of researches on thermal management of batteries and many of them have focused on lowering the temperature, that is generated during the charge and discharge processes with the use of air or coolant. The hybrid and electric vehicles also have to be able to work in very cold temperatures like ordinary internal combustion engine vehicles.

Low temperatures can cause the batteries to have a significant decrease in performance. The energy that hybrid and electric vehicles need cannot be transmitted in a cold temperature environment. When an electric vehicle has been parked for a long time in a low temperature without being used and the battery is being charged slowly, a pre-heating system becomes necessary. With the battery pre-heating system it is possible to enhance its charging efficiency.

According to researches, a battery's internal resistance is decreased in high temperatures, and this causes an increase in both its capacity and its energy output. On the contrary, in cold temperatures, a battery's internal resistance is reduced in capacity and energy output. This means that when charging hybrid and electric vehicles in low temperature their batteries internal resistance is higher causing the charging efficiency to become weaker.

The batteries of hybrid and electric vehicles can be heated by applying heat either externally or internally. There have been created many different solutions for heating batteries, for example, electrically heated thermal jackets, a sealed enclosure with an internal heating element, liquid heating, and warm air.

These kinds of solutions usually use a separate power source for a heating element that gives the needed energy. The generated heat is then transferred to the battery with the use of a conduction or a convection system. The conduction system applies heat directly to the battery's surface while the convection system blows hot air at the battery. When a battery pre-heating system is chosen, it is important to consider what sources of energy are available and how the energy and heat are transferred to the battery.

In order to test the effectiveness and importance of pre-heating batteries, a simulation system was built using a battery HILS. This test situation was made to simulate the conditions in low temperature environments. The urban dynamometer driving schedule cycles were then run using identical battery states. In some cases the battery was heated and in other cases it was not.

Following battery stabilization, the capacities that batteries had left in them were compared. The results of the tests showed that in a cold temperature environment a battery maintains a greater capacity after these test cycles if the area around the battery is pre-heated to room temperature before the electrical vehicle is used. This shows that with the use of pre-heating batteries the electric vehicles can achieve greater mileage and performance in a low temperature condition [8].

The hybrid electric vehicles are strongly dependent on the performance of their batteries and the batteries are influenced by temperature. Cold temperatures cause the batteries to perform poorly because of high internal resistance. This can cause the hybrid electric vehicle to start slowly. Low temperatures can also affect the availability of discharge power, energy, and charge acceptance. It also has an effect on a vehicles drivability and fuel economy. In addition, cold conditions can also shorten the battery's lifespan and its replacement frequency.

Because all of this, the battery needs to be pre-heated with the use of some kind of heating system, for example, electric heaters or a hot fluid. Because of these factors, it is important that batteries operate within a temperature range that enables them to have top performance and a long lifespan. The optimal operating temperature of batteries varies with different types. Because the batteries need a certain temperature in order to perform at their peak, they need to be thermally managed for different climates and reasons.

The main goal of a thermal management system in a hybrid electrical vehicle is to maintain an acceptable temperature in a battery. The thermal management system needs to be lightweight, low cost, easily packaged, and compatible with location, in order to fill the requirements. The thermal management system can use air for heating, ventilation and cooling, liquid for cooling/heating, insulation, thermal storage or a different combination of these methods.

There are two types of thermal management systems, passive and active. Passive system heats the battery with the use of ambient air, and they work well in mild climates. Active systems are used in more extreme climates, for example in very cold conditions. An active heating system uses a heat exchange with a heat sink, for example, a vapor compression system.

All of the batteries suffer in low temperature conditions because their electrochemical processes are slowing down and overall internal resistance rises. With the use of pre-heating systems in cold conditions, the hybrid electric vehicle can achieve acceptable power and energy performance.

In a research using finite elemental thermal analysis, the subject studied was the transient thermal behavior of a typical rectangular battery that was heated with the use of four different methods. The most effective method, based on the research data, was core heating with alternating current. Core heating uses the least amount of energy and is by far the quickest of them all. It is much more effective when compared to a fluid heating system [9].

In cold temperatures an electric and a hybrid vehicle's battery performance is one of the biggest concerns. Batteries need to be warmed in cold temperatures so that they can achieve the desired performance level. Cold temperature conditions also affect the life cycle of the energy storage system by making it a lot shorter. There are many different approaches available, for example, internal core heating, external electric heating of a module, internal electric heating in the module around each cell, external fluid heating around each module, and internal fluid heating around each cell.

One of the most difficult challenges in cold conditions is the availability of energy. If the temperature is very cold, both the engine and the battery in the vehicle are cold. Electrical energy of the battery or the on-board generator can be used to generate heat. Possible sources of heat are, for example, heat from the engine for battery heating with a fluid or the electrical energy from the generator or battery. The first option is rather slow and takes a while to warm up to properly provide heat. The second option is a lot faster and even low currents can warm the battery, but drawing power is difficult.

Cold weather decreases performance of all batteries to varying degrees. Very cold conditions cause the battery to stop working properly and also shortens the lifespan. Hybrid and electric vehicles are more vulnerable to this than regular vehicles, and because of this their batteries need to be pre-heated. Warming the batteries enables one to obtain acceptable power and energy performance.

In order to find the most energy efficient way, research was done that built and analyzed several transient thermal finite element models of a typical battery. The objective of the research was to evaluate which method could be more effective for heating electric vehicle batteries in extremely cold conditions by performing thermal analysis.

The performed research showed that the most uniform way of heating the battery of hybrid and electrical vehicle was achieved with internal core heating. The core heating method reached a much higher temperature sooner than any other heating technique for the same amount of used energy. Other tested systems included external jacket heating and internal fluid heating. Using AC to battery terminals is the most practical way to heat the battery core [10].

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Ultracapacitors and the preheating of batteries are used to mitigate driving range and performance constraints in cold climate driving of electric vehicles.

A driving range and in-vehicle acoustics are important factors affecting to driving comfort. Although many studies have explored various aspects of electric vehicles driving, no research summarizing the characteristics of driving in harsh arctic and in cold climate existed up to now.

This paper presents the results of Centria University of Applied Sciences Electric Vehicles Goes Arctic-project study to provide an up to date overview of these cold weather characteristics.

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