United States Patent Application Publication	20250264377
Kind Code	A1
Publication Date	August 21, 2025
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NOISE, VIBRATION AND HARSHNESS TEST FOR AN ELECTROMECHANICAL ACTUATOR SYSTEM

Abstract

A diagnostic apparatus (**100**) is disclosed for use in testing an electromechanical actuator system of a vehicle (**500**). The diagnostic apparatus comprising one or more controllers (**110**) and is configured to: generate a torque demand signal (**155**) corresponding to a sinusoidal torque demand profile (**310**), the sinusoidal torque demand profile configured to cause excitation of noise, vibration and harshness, NVH, characteristics of the vehicle (**402**); transmit the torque demand signal to the electromechanical actuator system of the vehicle (**404**); record a NVH characteristic of the vehicle generated in response to application of the torque demand signal (**406**); and output the recorded NVH characteristic of the vehicle (**408**).

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Family ID:	**1000008600109**
Appl. No.:	**18/702440**
Filed (or PCT Filed):	**October 18, 2021**
PCT No.:	**PCT/EP2021/078802**

Publication Classification

Int. Cl.:	**G01M17/04** (20060101)
U.S. Cl.:	
CPC	**G01M17/04** (20130101);

Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to a noise, vibration and harshness (NVH) test for an electromechanical actuator system. Aspects of the invention relate to a diagnostic apparatus, to a system, to a vehicle, to a method, and to a computer software, for testing a noise, vibration and harshness (NVH) characteristic of a vehicle due to operation of an electromechanical actuator system.

BACKGROUND

[0002] Vehicles (for example petrol, diesel, electric or hybrid vehicles) comprise active suspension systems, such as an electronic active roll control system, for maintaining vehicle stability. Such electronic active roll control systems comprise at least one actuator, the actuator being configured so as to actively impart motor control on the suspension system, the at least one actuator being coupled to a roll bar.

[0003] Such active suspension systems may include a number of individual subcomponents or mechatronic subsystems. There may be a high level vehicle control generating a system demand signal, for example a torque demand signal, to influence vehicle motion. There may be a low level controller providing control signals to an actuator (for example to provide motor control) of the active suspension system, to deliver the demanded signal provided. There may be associated mechanical or electromechanical components to deliver a physical manifestation of the demanded signal, for example a motor. There may be a dedicated power supply system. There may be significant interaction between these subsystems in order to provide operation of the active suspension system.

[0004] It is not uncommon for mechatronic systems to exhibit noise, vibration and harshness (NVH) phenomena (for example, knocking, rattling, shaking, etc.). This noise can be caused by several sources, including the overall control strategy of the vehicle, the mechanical design, system external inputs (either electrical, mechanical, or electromechanical), system integrations with the vehicle, system ageing, or a combination thereof. When NVH events occur after the vehicle has been built (i.e. is no longer in a manufacturing facility), there may be few or no means by which a user in a service environment can diagnose an issue with the active suspension system or identify the cause of the NVH event. A tool to enable investigation of causes of NVH events and similar problems arising from the active suspension system is therefore desirable.

[0005] It is an aim of the present invention to address one or more of the disadvantages associated with the prior art.

SUMMARY OF THE INVENTION

[0006] Aspects and embodiments of the invention provide a diagnostic apparatus, a system, a vehicle, a method, and a computer software as claimed in the appended claims.

[0007] According to an aspect of the present invention there is provided a diagnostic apparatus for use in testing an electromechanical actuator system of a vehicle, the diagnostic apparatus comprising one or more controllers, the diagnostic apparatus configured to: generate a torque demand signal corresponding to a sinusoidal torque demand profile, the sinusoidal torque demand profile configured to cause excitation of noise, vibration and harshness, NVH, characteristics of the vehicle; transmit the torque demand signal to the electromechanical actuator system of the vehicle; record a NVH characteristic of the vehicle generated in response to application of the torque demand signal; and output the recorded NVH characteristic of the vehicle.

[0008] The invention apparatus may be configured to compare the generated NVH characteristic of the vehicle to an expected NVH profile for the vehicle, and output a result of the comparison.

[0009] Instead of a sinusoidal torque demand profile, the torque demand signal may correspond to a continuously time varying torque demand profile with repeated zero-crossings, providing both a positive and negative torque demand.

[0010] The sinusoidal torque demand profile of the invention apparatus may comprise one or more of: an amplitude within a predetermined amplitude range, a frequency within a predetermined frequency range, and a signal duration within a predetermined signal duration range.

[0011] One or more of an amplitude and a frequency of the sinusoidal torque demand profile may be set via a vehicle software update.

[0012] The sinusoidal torque demand profile may be generated to excite NVH characteristics caused by one or more of: a gearbox of an actuator of the electromechanical actuator system; and a degraded resilient, elastomeric or plastic material in the electromechanical actuator system.

[0013] The diagnostic apparatus may be configured to, prior to applying the torque demand signal, verify that one or more safety preconditions are met.

[0014] Verifying that the one or more safety preconditions are met may comprise one or more of: ensuring that a system automotive safety integrity level, ASIL, is maintained; verifying that the vehicle is in a stationary state; and verifying that there are no fault conditions in the vehicle.

[0015] Verifying that the vehicle is in a stationary state may comprise one or more of: verifying that the vehicle is not moving, verifying that an engine of the vehicle is not active, verifying that the vehicle is not in gear, and verifying that a parking brake of the vehicle is enabled.

[0016] Verifying that there are no fault conditions in the vehicle may comprise one or more of: checking a log to see if a fault condition has been recorded, and running one or more tests to check if a fault condition is returned. The fault condition may be a fault condition relating to the electromechanical actuator system. Running one or more tests to check if a fault condition is returned may comprise checking a current value of one or more signals available to the diagnostic apparatus.

[0017] Verifying that the one or more safety preconditions are met may comprise verifying if a provided security credential meets a security authorisation level. The provided security credential may be one or more of: a chassis control module security credential, and a toolset security credential.

[0018] The diagnostic apparatus may be configured to stop application of the torque demand signal to the electromechanical actuator system if a test duration exceeds an expected time period.

[0019] The diagnostic apparatus may be configured to: identify a frequency of the recorded NVH characteristic; when the frequency of the recorded NVH characteristic is in a first frequency region, attribute the recorded NVH characteristic to a first fault type; and when the frequency of the recorded NVH characteristic is in a second frequency region, attribute the recorded NVH characteristic to a second fault type.

[0020] According to another aspect of the invention, there is provided a system comprising the diagnostic apparatus as disclosed herein, and the electromechanical actuator system of the vehicle.

[0021] According to another aspect of the invention, there is provided a vehicle comprising a diagnostic apparatus as disclosed herein, or a system as disclosed herein.

[0022] According to another aspect of the invention, there is provided a method, comprising: generating a torque demand signal corresponding to a sinusoidal torque demand profile, the sinusoidal torque demand profile configured to cause excitation of noise, vibration and harshness, NVH, characteristics of a vehicle; transmitting the torque demand signal to an electromechanical actuator system of the vehicle; recording a NVH characteristic of the vehicle generated in response to application of the torque demand signal; and outputting the recorded NVH characteristic of the vehicle.

[0023] The method may comprise verifying that one or more safety preconditions are met prior to applying the torque demand signal.

[0024] According to another aspect of the invention, there is provided computer readable instructions which, when executed by a processor, are arranged to perform a method as disclosed

herein.
[0025] Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0026] One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:
[0027] FIG. **1** shows a controller of a diagnostic apparatus according to examples disclosed herein;
[0028] FIG. **2***a* shows a control system for a vehicle connected to front and rear anti-roll bars according to examples disclosed herein;
[0029] FIG. **2***b* shows a control system for a vehicle comprising plural sub-systems, and front and rear anti-roll bars according to examples disclosed herein;
[0030] FIG. **3** shows an example torque demand profile according to examples disclosed herein;
[0031] FIG. **4** shows an example method according to examples disclosed herein; and
[0032] FIG. **5** shows a vehicle in accordance with an embodiment of the invention.
DETAILED DESCRIPTION
[0033] With reference to FIG. **1**, there is illustrated a control system **100** for a diagnostic apparatus for a vehicle. The control system **100** comprises one or more controllers **110**. The control system **100** as illustrated in FIG. **1** comprises one controller **110**, although it will be appreciated that this is merely illustrative. The controller **110** comprises processing means **120** and memory means **130**. The processing means **120** may be one or more electronic processing device **120** which operably executes computer-readable instructions. The memory means **130** may be one or more memory device **130**. The memory means **130** is electrically coupled to the processing means **120**. The memory means **130** is configured to store instructions, and the processing means **120** is configured to access the memory means **130** and execute the instructions stored thereon.
[0034] The controller **110** comprises an input means **140** and an output means **150**. The input means **140** may comprise an electrical input **140** of the controller **110**. The output means **150** may comprise an electrical output **150** of the controller **100**. The input **140** may be arranged to receive a noise, vibration and harshness (NVH) signal **165** from one or more sensors **160** of the vehicle. The inputs may be either physical (for example from a hard wired sensor) and/or may be from a vehicle communication bus. The input **140** may be arranged to additionally receive combined sensor or communication data from multiple sensors or other controller units. The NVH signal **165** is an electrical signal which is indicative of the occurrence of one or more NVH events of the vehicle. For example, the NVH signal may be indicative of a rate of change of torque across a gearbox of a electromechanical actuator system. In some examples, the NVH signal may be indicative of an impulsive force radiated through the electromechanical actuator system and into the vehicle structure. Further examples for which the NVH signal may be indicative of may include one or more of: a frequency and magnitude of vibration of the vehicle structure; a dynamic of audible noise produced in the vehicle during an NVH event; and a duration for which a particular NVH event lasts after stopping application of a torque to an actuator. The output **150** is arranged to output a torque demand signal **155** for controlling one or more actuators of an electromechanical

actuator system of the vehicle. In some examples, a measurement of vehicle roll rate may be received from a sensor connected to the controller **110** via a vehicle communication bus. In some examples, a measurement of suspension height at each corner of the vehicle may be received as a voltage reading from a hardwired sensor. In some examples, a measurement of vehicle speed may be received from an additional controller in the vehicle, via a vehicle communication bus. In some examples, a measured torque and actuator motor position may be received from one or more anti-roll bar controllers, connected to the controller **110** via a vehicle communications bus.

[0035] By outputting a torque demand signal **155** and applying said torque demand signal to one or more actuators of the electromechanical actuator system of the vehicle, a response of the vehicle due to the application of the torque demand signal can be recorded using the one or more sensors **160** of the vehicle. The torque demand signal **155** is configured to induce NVH events in the vehicle. Specifically, the torque demand signal **155** provides rapid mechanical movement of the electromechanical actuator system and any gears in the gearbox therein.

[0036] The electromechanical actuator system may be any of an active suspension system, an anti-roll control system, or other similar systems which effect one or more performance characteristics of the vehicle. The actuator may be an actuator associated with an active roll control system, wherein the active roll control system may form part of the suspension system. The actuator may be a rotary actuator. The actuator may include one or more gears or a gearbox.

[0037] The diagnostic apparatus described herein may be implemented as an external device which can be communicatively connected to the vehicle by either a physical connector or wirelessly. Alternatively, the diagnostic apparatus may be implemented by one or more dedicated controllers within the vehicle. Alternatively, the diagnostic apparatus may be implemented in software on one or more general purpose controllers within the vehicle, for example a controller of a chassis control module. In some examples, a combination of the above implementations may be used.

[0038] FIGS. **2***a* and **2***b* illustrate example control system **200** for a suspension system of a vehicle. A suspension system of a vehicle may comprise anti-roll bars **270**, **280** which are controlled using an anti-roll control system. The anti-roll control system acts to control the anti-roll bars, to control a roll of a body of the vehicle and reduce the impact of disturbances from a road surface. The anti-roll control system may be electromechanical and/or hydraulic. Anti-roll bars **270**, **280** may typically comprise stabiliser bars, typically metal, which join the vehicle suspension on either side of the vehicle axle, usually through drop links, and connect to a rotational actuator situated between the mounting points to the vehicle chassis. Each side of the anti-roll bar is able to rotate freely when a motor of the anti-roll control system is not energised. When the motor control is enabled (i.e. delivering torque), the anti-roll bar may act as a torsional spring. The anti-roll bars may be controlled to compensate for some vehicle movements such as body roll, for example from driving around a corner. Body roll can cause the wheels at the side of the vehicle outside the turn to reduce their contact with the road surface. Anti-roll bars may be controlled to counteract this effect and reduce the body roll effect, by transferring at least part of the additional load on the wheels at the side of the vehicle inside the turn to those wheels at the outside, for example by providing a torsional effect to pull the wheels towards the chassis and even out the imbalance in load on the wheels caused by cornering.

[0039] A typical suspension system may comprise passive front and rear anti-roll bars provided respectively between the front and rear pairs of wheels of a standard four-wheel vehicle. In a vehicle with an active roll control system, an anti-roll bar **270**, **280** may respectively each comprise two anti-roll bar ends (**273**, **274**; **283**, **284**) connected together by a central housing having an actuator **272**, **282**. The central housing may additionally have one or more of a gearbox, sensors, and dedicated actuator controllers. The actuator **272**, **282** acts to provide an actively controlled torque rather than a fixed torsional stiffness provided by passive anti-roll bars. One or more sensors may monitor the movement of the vehicle, and provide the sensed parameters as input to the active roll control system to control the actuator and provide a suitable torque to the anti-roll bar. The two ends of the anti-roll bar (**273**, **274**; **283**, **284**) may be identical, or may be non-identical.

[0040] FIG. **2***a* shows an example control system **200** for a suspension system a vehicle, communicatively connected to front and rear anti-roll bars **270**, **280**. The control system **200** comprises a controller **240** which is connected by a communication channel **245** to anti-roll bar controllers **250**, **260** configured to respectively control front and rear anti-roll actuators **272**, **282**. The controller **240** may be the controller **110** of FIG. **1**. The controller **240** may comprise one or more of the controllers **110** of FIG. **1**. In an example, the controller **240** may be a master controller for an electronic active roll control system in the vehicle. The controller **240** may host a vehicle level control strategy and actuation control for the electronic active roll control system in the vehicle.

[0041] The controller **240** may be configured to receive one or more sensor signal **203** from one or more sensors attached to the vehicle. The one or more sensor signals **203** may comprise, for example, a signal from a respective suspension height sensor of the vehicle suspension; a signal from a respective motor position sensor for the anti-roll bar actuators **272**, **282**; a signal from a respective hub acceleration sensor of the vehicle; and a signal from a respective torque sensor for the anti-roll bar actuators **272**, **282**. A suspension height sensor may be configured to determine a sensor signal indicative of one or more of a height of a left side and a height of a right side of the vehicle suspension. A motor position sensor may be configured to determine a sensor signal indicative of a position of a respective motor of the anti-roll bar actuators **272**, **282**. A hub acceleration sensor may be configured to determine a sensor signal indicative of an acceleration of one or more hub of a wheel of the vehicle. A torque sensor may be configured to provide a measure of an existing torque generated in the system, as a result of a target torque demand being requested by the controller.

[0042] The controller **240** may be configured to receive one or more communication signals via a communications bus **205**. The communications bus **205** may be configured to deliver data to the controller **240** from other subsystems within the vehicle. For example, the communications bus **205** may be configured to communicate a signal indicating a status of one or more modules **210**, **220**, **230** that are in communicative connection with the controller **240** to the controller **240**. In another example, the communications bus **205** may be configured to communicate a command from the controller **240** to the one or more modules **210**, **220**, **230** that are in communicative connection with the controller **240**. The one or more modules **210**, **220**, **230**, are discussed further in relation to FIG. **2***b* below. Signals transmitted over connections **203** or **245** may alternatively or additionally be transmitted over communications bus **205**.

[0043] The controller **240** may be configured to generate system demand signals to influence a vehicle's motion via the anti-roll actuators **272**, **282**. An actuator provided between a front pair of wheels of a vehicle may be called a front actuator. A front active roll control (FARC) module may be electrically connected to the front actuator, and may comprise the controller **250** to control the front actuator **272**. Similarly, an actuator provided between a rear pair of wheels of a vehicle may be called a rear actuator. A rear active roll control (RARC) module may be electrically connected to the rear actuator and may comprise a controller **260** to control the rear actuator **282**.

[0044] The front and rear anti-roll actuators **272**, **282** comprises an electric motor which is controllable by the respective anti-roll controller **250**, **260**. Each of the front and rear anti-roll actuators **272**, **282** may be controlled by its own respective anti-roll controller in some examples, or multiple anti-roll actuators may be controlled by a common anti-roll controller in some examples. Each of the anti-roll actuators **272**, **282** may be individually controlled in some cases to improve the management of the roll of the body of the vehicle. The front and rear anti-roll actuators **272**, **282** may be controlled by a control signal which is generated by the controller **240** may generate and output, through the output channel **245**, to the anti-roll bar controllers **250**, **260**. The control signal may carry instructions to be implemented by the actuator, for example by providing a torque to apply to the anti-roll bar. For example, as discussed above, when the vehicle is cornering, a control signal may be transmitted to the anti-roll bar controllers **250**, **260**, which may in turn transmit a control signal via interface **255**, **265**, so that the front and read anti-roll actuators **272**, **282** may mitigate a body roll effect. Similarly, anti-roll bar controllers **250**, **260** may transmit measured values from the anti-roll actuators to the controller **240** through output channel **245**.

[0045] FIG. **2***b* shows an example control system **200** for a vehicle comprising one or more modules **210**, **220**, **230**, a controller **240** and front and rear anti-roll bars **270**, **280**. As in FIG. **2***a*, the control system **200** comprises a controller **240** which is connected by a communication channel **245** to controllers **250**, **260** configured to respectively control front and rear anti-roll bar actuators **270**; **280**. Further, the controller **240** of the control system **200** is in a communicative connection to the one or more modules **210**, **220**, **230** via a communications bus **205**. The one or more modules **210**, **220**, **230** may be configured to perform functions relating to power supply of the suspension system. Module **210** may be a power control module configured to control a power supply system for the suspension system. Module **220** may be a conversion module configured to convert electrical energy output from a vehicle power supply system. In an example, the conversion module **220** may comprise a DC-DC converter. Module **230** may be a capacitor or supercapacitor module configured to store electrical energy for the suspension system. Together, conversion module **220** and capacitor module **230** may be configured to supply electrical energy to the controllers **250**, **260**, such that the anti-roll bar actuators **272**, **282** can be actuated. FIG. **2***b* illustrates these modules **210**, **220**, **230** as individual modules. However, there may be examples whereby components within the modules **210**, **220**, and **230** are included in a single module. Similarly, communications links **205** and **245** may be the same in some examples.

[0046] FIG. **3** shows plots **300** of an example torque demand profile **310**. The example torque demand profile **310** of FIG. **3** shows an amount of torque, in Newton meters (Nm), to be demanded from the electromechanical actuator, as a function of time. The example torque profile comprises a single frequency sinusoidal wave, with peak amplitude Q and signal period tp. The sinusoidal torque demand profile may have a duration (period) of t.sub.d.

[0047] Also in FIG. **3**, a status of the diagnostic test is shown. At the start of the process **302**, the test has not yet been requested. At the next stage in the process **304**, the test is in progress. At the next stage again in the process **306**, the test is completed. Between time t.sub.1 and t.sub.2, while the test is in progress **304**, the sinusoidal torque demand profile is applied to the electromechanical actuator system.

[0048] The use of a sinusoidal torque demand profile provides rapid mechanical movement of the electromechanical actuator system and the gearbox therein. When a rotational lash within a planetary gearbox of the electromechanical actuator system is released and quickly re-engaged, an impulsive force may radiate through the electromechanical actuator system and into the vehicle structure. This may in turn result in an NVH event being generated—that is, a noise or vibration may be sensed. The larger the rate of change of torque across the gearbox is during a lash event, the larger the resulting measured impulse may be.

[0049] The diagnostic test intention is not necessarily to ensure the system is quiet, or exhibits a low level of NVH, during the test execution, but is instead to try and ensure that the NVH characteristic of the electromechanical system does not degrade or change over time. Such testing may help users in a service or manufacturing environment to identify any mechanical or structural issues within the electromechanical actuator system.

[0050] Examples of mechanical or structural issues that may occur within the electromechanical actuator system, and which may give rise the NVH events, include degradation of resilient, elastomeric or plastic material in the electromechanical actuator system, worn gears or sets of gears in the gearbox of the electromechanical actuator system, and a misaligned gear or set of gears in the gearbox of the electromechanical actuator system.

[0051] In some examples, the peak amplitude, Q, may be configurable by a user initiating a diagnostic test on the vehicle. In some examples, the test duration, t.sub.d, may be configurable by a user initiating the diagnostic test on the vehicle. In some examples, one or more of the peak amplitude and the test duration may be configurable through a software update.

[0052] A torque demand signal corresponding to the torque demand profile **300** may be transmitted to the electromechanical actuator system of the vehicle, for example to the actuators **272**, **282** of the vehicle suspension system as shown in FIGS. **2***a*-**2***b*. Application of torque to the actuators **272**, **282** may cause motion of the vehicle. For example, application of torque to the actuators may cause the vehicle to vibrate, oscillate, or rock in a sideways motion.

[0053] The torque demand signal may be applied separately to each of the actuators **272**, **282** in some examples. Alternatively, the torque demand signal may be applied simultaneously to each of the actuators **272**, **282** in some examples.

[0054] One or more characteristics of the vehicle, in response to the application of the torque demand signal, may be monitored using one or more sensors in the vehicle. For example, a rate of change of torque across a gearbox of a electromechanical actuator system may be measured in response to the application of the sinusoidal torque profile. In some examples, one or more of the magnitude, position or direction of an impulsive force radiated through the electromechanical actuator system and into the vehicle structure may be measured. Further characteristics which may be measured include one or more of: a frequency and magnitude of vibration of the vehicle structure; a dynamic of audible noise produced in the vehicle during an NVH event; and a duration for which a particular NVH event lasts after stopping application of a torque to an actuator.

[0055] In examples, instead of a sinusoidal torque demand profile, the torque demand signal may correspond to a continuously time varying torque demand profile with repeated zero-crossings, providing both a positive and negative torque demand. A signal capable of providing rapid mechanical movement of the electromechanical actuator system, as well as repeated release and re-engaging of rotational lash within the gearbox, may be suitable as a torque demand profile. For example, a triangular wave signal, a sawtooth wave signal, or a signal comprising multiple frequency sinusoidal components may be used. In some examples, the torque demand profile may be applied in a continuous manner, and in some examples, the torque demand profile may be applied as a set of discrete events.

[0056] In some examples, a frequency of a recorded NVH characteristic may be used to identify a specific fault type. For example, a detected vibration in a first frequency region may be indicated as potential fault due to perished resilient/elastomeric/plastic material, and a detected vibration in a second frequency region may be indicated as a potential fault due to mechanical fault in a gearbox of the actuator.

[0057] FIG. **4** illustrates an example method **400** of testing system response in an electromechanical actuator system of a vehicle **500**, such as the vehicle **500** illustrated in FIG. **5**. In particular, the method is a method of testing the NVH response of the vehicle and the electromechanical actuator system to a sinusoidal torque demand profile applied to an actuator of the electromechanical actuator system. The method **400** may be performed by the system **100** illustrated in FIG. **1**. The memory **130** may comprise computer readable instructions which, when executed by the processor **120** of any diagnostic apparatus disclosed herein, perform the method **400**.

[0058] The method **400** comprises: generating a sinusoidal torque demand signal **402**; transmitting the sinusoidal torque demand signal to the electromechanical actuator system **404**; recording an NVH characteristic in response to the application of said sinusoidal torque demand signal **406**; and outputting the recorded NVH characteristic **408**.

[0059] In some examples, the method **400** may further comprise: comparing the recorded NVH characteristic to an expected NVH profile **410**; and outputting a result of the comparison **412**. The expected NVH profile against which the recorded NVH characteristic is compared may be a standard NVH profile for the particular type or model of vehicle. Alternatively the expected NVH profile may be a previously recorded NVH characteristic of the specific vehicle being tested.

[0060] In some examples, verification of satisfaction of one or more safety preconditions may be required prior to transmitting the torque demand signal. These safety preconditions may comprise one or more of: ensuring that a system automotive safety level (ASIL) is or can be maintained throughout the duration of the diagnostic test; verifying that the vehicle is in a stationary state; verifying that there are no fault conditions in the vehicle (either current or recently recorded); and verifying that a provided security credential of a user initiating the test meets a security authorisation level. In some examples, application of the torque demand signal to the electromechanical actuator system may be stopped if the duration of the diagnostic test exceeds an expected or predetermined time limit. Accordingly, system and vehicle safety is assured by one or more of: preventing access to the test by unauthorized users, as security access is required to place the controller (for example, a controller of the chassis control module) in the correct operational state to run the test; not causing active torque to be delivered by the system if any faults are present; not starting the test if vehicle level conditions are not met (for example the vehicle being stationary, the engine running); and aborting the diagnostic test if the test does not conclude within an expected time period.
[0061] In some examples, the method may further comprise comparing one or more recorded NVH characteristics to a predetermined threshold or range, and recording or outputting a fault indication if the one or more NVH characteristics are exceed the predetermined threshold, fail to meet the predetermined threshold, or are outside of the predetermined range.
[0062] In some examples, the method may further comprise measuring to ensure the NVH characteristics of the electronic actuator system are within acceptable limits. Optionally, historic data of NVH characteristics of the vehicle may be stored in order to monitor for any possible degradation of the electronic actuator system, or parts thereof.
[0063] The illustration of a particular order to the blocks of the method of FIG. **4** does not necessarily imply that there is a required or preferred order for the blocks and the order and arrangement of the blocks may be varied. Furthermore, it may be possible for some steps to be omitted or added in other examples. Therefore, this disclosure also includes computer software that, when executed, is configured to perform any method disclosed herein, such as that illustrated in FIG. **4**. Optionally, the computer software is stored on a computer readable medium, and may be tangibly stored.
[0064] A set of computer-readable instructions may be provided which, when executed, cause said controller **110** or control system **100** to implement any method disclosed herein. The set of instructions may be embedded in one or more electronic processors, or alternatively, the set of instructions could be provided as software to be executed by one or more electronic processor(s). For example, a first controller may be implemented in software run on one or more electronic processors, and one or more other controllers may also be implemented in software run on one or more electronic processors, or, optionally, on the same one or more processors as the first controller. It will be appreciated, however, that other arrangements are also useful, and therefore, the present disclosure is not intended to be limited to any particular arrangement. In any event, the set of instructions described above may be embedded in a computer-readable storage medium (for example, a non-transitory computer-readable storage medium) that may comprise any mechanism for storing information in a form readable by a machine or electronic processors/computational device, including, without limitation: a magnetic storage medium (for example, floppy diskette); optical storage medium (for example, CD-ROM); magneto optical storage medium; read only memory (ROM); random access memory (RAM); erasable programmable memory (for example, EPROM and EEPROM); flash memory; or electrical or other types of medium for storing such information/instructions.
[0065] FIG. **5** illustrates a vehicle **500** according to an embodiment of the present invention. The vehicle **500** comprises a control system **100** as illustrated in FIG. **1**. The vehicle **500** in the present embodiment is an automobile, such as a wheeled vehicle, but it will be understood that the control

system, active suspension system and diagnostic apparatus may be used in other types of vehicle.
[0066] The diagnostic apparatuses and methods described herein may enable a user in a service or manufacturing environment to identify degradation of the electromechanical actuator system or parts thereof. The diagnostic apparatuses and methods described herein may enable verification of correct system integration of the electromechanical actuator system, due to exciting NVH events in the vehicle and comparing to an expected NVH profile.
[0067] The diagnostic apparatuses and methods described herein may allow for one or more of: on demand NVH evaluation of the electromechanical actuator system; individual axle or actuator input excitation; and a repeatable electronic actuator system input excitation. Furthermore, the diagnostic apparatuses and methods described herein may help to ensure electronic actuator system functional safety is met prior to test execution. The diagnostic apparatuses and methods described herein may allow for one or more of: objective NVH vehicle assessments throughout the vehicle lifetime in order to quantify any degradation of the electronic actuator system or parts thereof; investigation and resolution of issues with vehicle integration or mechanical connectivity; investigation of mechanical degradation of an actuator of the electronic actuator system; and accurate measurement and storage of the performance of the system to identify degradation over time.
[0068] It will be appreciated that various changes and modifications can be made to the present invention without departing from the scope of the present application. As used here, ‘connected’ means ‘electrically interconnected’ either directly or indirectly. Electrical interconnection does not have to be galvanic. Where the control system is concerned, connected means operably coupled to the extent that messages are transmitted and received via the appropriate communication means.
[0069] Whilst endeavouring in the foregoing specification to draw attention to those features believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

Claims

1-15. (canceled)
16. A diagnostic apparatus for use in testing an electromechanical actuator system of a vehicle, the diagnostic apparatus comprising one or more controllers, the diagnostic apparatus configured to: generate a torque demand signal corresponding to a sinusoidal torque demand profile, the sinusoidal torque demand profile configured to cause excitation of noise, vibration and harshness, NVH, characteristics of the vehicle; transmit the torque demand signal to the electromechanical actuator system of the vehicle; record a NVH characteristic of the vehicle generated in response to application of the torque demand signal; and output the recorded NVH characteristic of the vehicle.
17. The diagnostic apparatus of claim 16, the diagnostic apparatus configured to: compare the generated NVH characteristic of the vehicle to an expected NVH profile for the vehicle; and output a result of the comparison.
18. The diagnostic apparatus of claim 16, wherein the sinusoidal torque demand profile comprises one or more of: an amplitude within a predetermined amplitude range; a frequency within a predetermined frequency range; and a signal duration within a predetermined signal duration range.
19. The diagnostic apparatus of claim 16, wherein one or more of an amplitude and a frequency of the sinusoidal torque demand profile are set via a vehicle software update.
20. The diagnostic apparatus of claim 16, wherein the sinusoidal torque demand profile is generated to excite NVH characteristics caused by one or more of: a gearbox of an actuator of the electromechanical actuator system; and a degraded resilient, elastomeric or plastic material in the electromechanical actuator system.
21. The diagnostic apparatus of claim 16, wherein the diagnostic apparatus is configured to, prior to applying the torque demand signal, verify that one or more safety preconditions are met.

22. The diagnostic apparatus of claim 21, wherein verifying that the one or more safety preconditions are met comprises one or more of: ensuring that a system automotive safety integrity level, ASIL, is maintained; verifying that the vehicle is in a stationary state; and verifying that there are no fault conditions in the vehicle.
23. The diagnostic apparatus of claim 21, wherein verifying that the one or more safety preconditions are met comprises verifying if a provided security credential meets a security authorization level.
24. The diagnostic apparatus of claim 16, configured to stop application of the torque demand signal to the electromechanical actuator system if a test duration exceeds an expected time period.
25. The diagnostic apparatus of claim 16, configured to: identify a frequency of the recorded NVH characteristic; when the frequency of the recorded NVH characteristic is in a first frequency region, attribute the recorded NVH characteristic to a first fault type; and when the frequency of the recorded NVH characteristic is in a second frequency region, attribute the recorded NVH characteristic to a second fault type.
26. A system, comprising: the diagnostic apparatus according to claim 16; and the electromechanical actuator system of the vehicle **500**).
27. A vehicle comprising a diagnostic apparatus according to claim 16.
28. A method, comprising: generating a torque demand signal corresponding to a sinusoidal torque demand profile, the sinusoidal torque demand profile configured to cause excitation of noise, vibration and harshness, NVH, characteristics of a vehicle; transmitting the torque demand signal to an electromechanical actuator system of the vehicle; recording a NVH characteristic of the vehicle generated in response to application of the torque demand signal; and outputting the recorded NVH characteristic of the vehicle.
29. The method of claim 28, comprising verifying that one or more safety preconditions are met prior to applying the torque demand signal.
30. Computer readable instructions which, when executed by a processor, are arranged to perform a method according to claim 28.