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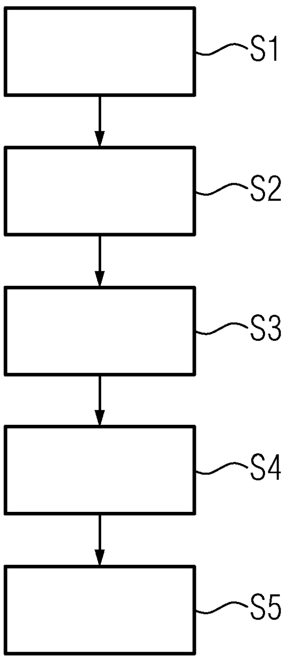
(54) **METHOD FOR DETERMINING AN INSTABILITY OF AN ENGINE-ORDER-CANCELLATION ("EOC") APPARATUS**

(57) Method for determining an instability of an engine-order-cancellation ("EOC") apparatus (2), the method comprising determining, by a determination device (15), an instability of the EOC apparatus (2) based on a comparison information.

FIG 2



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Description

[0001] The invention relates to a method for determining an instability of an engine-order-cancellation ("EOC") apparatus, the EOC apparatus being configured to generate cancellation signals for cancelling noise generated by an engine, the EOC apparatus is assignable or assigned to, for at least one specific harmonic order at a given operating state of the engine, the EOC apparatus comprising at least one acoustic signal output device configured to output a cancellation signal in a car cabin and at least one acoustic signal sensor device configured to sense a cancellation signal output in the car cabin.

[0002] Engine-order-cancellation ("EOC") apparatuses, which are sometimes also denoted as activenoise-cancellation ("ANC") apparatuses, are generally known from prior art.

[0003] The main purpose of respective EOC apparatuses is the cancellation or at least the reduction of undesired engine noise inside a car cabin which originates from the operation of the engine of the respective car equipped with the respective EOC apparatus. The frequency components of respective engine noise are typically, correlated with specific operating states of the engine, e.g. engine speed ("RPM") and its harmonics components (so called "orders"). This correlation between the engine noise and the operating states of the engine is used by respective EOC apparatuses for cancelling or at least reducing the engine noise inside the car cabin.

[0004] Thereby, respective EOC apparatuses achieve the actual noise cancellation by generating acoustic cancellation signals that are typically, opposite in phase to the engine noise present in the car cabin such that the engine noise present in the car cabin is cancelled or at least reduced.

[0005] During operation of a respective EOC apparatus, instabilities of the EOC apparatus may occur. A respective instability of a respective EOC apparatus may result from the EOC apparatus outputting a cancellation signal with a signal level (significantly, e.g. at least twice) higher than the signal level of the engine noise which is to be cancelled, for instance. Also, a respective instability of a respective EOC apparatus may result when the cancellation signal reaches a respective signal sensor device, e.g. a microphone, of the EOC apparatus almost in-phase.

[0006] A respective instability of a respective EOC apparatus may result in undesired audible noise generated by the EOC apparatus inside the car cabin. Particularly, the signal level of respective audible noises generated by an EOC apparatus may increase in an instability of the EOC apparatus.

[0007] Conventional EOC apparatus are not provided with measures to determine a respective instability of an EOC apparatus and thus, cannot solve problems caused by respective instabilities because respective instabilities cannot be properly determined.

[0008] It is therefore, the object of the present invention to provide a method allowing for a reliable determination of an instability of an EOC apparatus.

[0009] This object is achieved by a method for determining an instability of an engine-order-cancellation ("EOC") apparatus according to Claim 1. The Claims depending on Claim 1 refer to possible embodiments of the method according to Claim 1.

[0010] A first aspect of the invention refers to a method for determining an instability of an engine-order-cancellation ("EOC") apparatus.

[0011] The term "EOC apparatus" embraces any apparatus which is adapted to cancel or at least reduce engine noise present in a car cabin which engine noise results from operating an engine, i.e. typically a combustion engine, an electrical engine, or a hybrid engine, of the respective car associated with the EOC apparatus for at least one harmonic order at a given operating state of the engine. As such, the EOC apparatus may also be deemed or denoted as an active-noise-cancellation ("ANC") apparatus.

[0012] The EOC apparatus is configured to generate acoustic cancellation signals for cancelling engine noise generated by an engine, the EOC apparatus is assignable or assigned to, i.e. particularly tunable or tuned to, for at least one specific harmonic order at a given operating state of the engine. As such, a respective EOC apparatus may comprise at least one hardware- and/or software-embodied cancellation signal generating device which is adapted to generate acoustic cancellation signals that may be opposite in phase to the engine noise present in the car cabin.

[0013] The EOC apparatus further comprises at least one acoustic signal output device configured to output a cancellation signal in a car cabin. A respective acoustic signal output device can be built as or comprise at least one loudspeaker device. In an exemplary embodiment, a respective EOC apparatus may comprise a plurality of respective signal output devices being disposed at specific locations within the car cabin of the respective car associated with the EOC apparatus.

[0014] The EOC apparatus further comprises at least one acoustic signal sensor device configured to sense a cancellation signal output in the car cabin of the respective car associated with the EOC apparatus. A respective signal sensor device may be built as or comprise at least one microphone device. In an exemplary embodiment, a respective EOC apparatus may comprise a plurality of respective signal sensor devices being disposed at specific locations within the car cabin of the respective car associated with the EOC apparatus.

[0015] A pair of at least one signal output device and at least one (acoustically) assigned signal sensor device may build an acoustic channel of the EOC apparatus. The EOC apparatus may comprise a plurality of respective acoustic channels. The distance between a respective signal output device and an assigned signal sensor device represents a(n acoustical) transfer path.

[0016] The EOC apparatus is operable on basis of a number of operational parameters. Thus, operating the EOC apparatus typically, comprises controlling at least one EOC operational parameter of the EOC apparatus. Examples of respective EOC operational parameters of the EOC apparatus are the step size (μ-factor or -value) and the forgetting factor (λ-factor or -value).

[0017] Operation of a respective EOC apparatus and its sub-units, i.e. particularly the at least one acoustic noise cancellation signal generating device, the at least one acoustic signal output device, and the at least one acoustic signal sensor device, is controlled by a hardware- and/or software-embodied control unit assignable or assigned to the EOC apparatus.

[0018] In the following, the steps of the method according to the first aspect of the invention will be described: A first step of the method comprises providing a reference data set. The reference data set includes a plurality of engine noise reference signals and related signal levels of respective engine noise reference signals for pre-defined reference operating states of the engine, the EOC apparatus is assignable or assigned to. The reference data set thus, may include data couples or dependencies, whereby each data couple or dependency comprises at least one reference operating state of the engine, the EOC apparatus is assignable or assigned to, and an associated engine noise reference signal and a related signal level of the respective engine noise reference signal.

[0019] In other words, the reference data set comprises pre-defined reference operating states of the engine, the EOC apparatus is assignable or assigned to, correlated with engine noise data of the engine, the EOC apparatus is assignable or assigned to. Specifically, the reference data set comprises a dependency of the corresponding respective engine noise data, i.e. engine noise reference signals and related signal levels of respective engine noise reference signals, for the respective reference operating states of the engine, the EOC apparatus is assignable or assigned to.

[0020] The reference data set may thus, comprise the engine noise data of the engine at respective pre-defined reference operating states of the engine, the EOC apparatus is assignable or assigned to. Specifically, the reference data set comprises respective engine noise data, i.e. engine noise reference signals and related signal levels of respective engine noise reference signals at respective operating states of the engine, the EOC apparatus is assignable or assigned to.

[0021] Particularly, the reference data set may comprise pre-recorded and post-processed engine noise measured by each signal sensor device (microphone) of the EOC apparatus and/or measured by at least one external signal sensor device (e.g. an external microphone device) for various operating states of the engine, the EOC apparatus is assignable or assigned to. Respective operating states may be defined by operational parameters of the respective engine. Respective operating parameters may comprise RPM- and/or torque-values of the respective engine, driving modes or programs (e.g. economy mode or program, comfort mode or program, sport mode or program, etc.) of the respective engine, for instance. Pre-recorded measurement data for the selected operating state(s) or respective operating parameters of the respective engine may be deemed or denoted as "raw data". The reference data set may be generated by post-processing of such raw data. The reference data set may thus, comprise reference data, i.e. numeric parameters, e.g. level of the engine noise at a selected harmonic order, where the EOC apparatus operates.

[0022] Based on the dependency of the respective engine noise reference signals and related signal levels of the EOC apparatus, i.e. particularly respective cancellation signals, at the respective operating states, the reference data thus, enables deriving information of the engine noise for any given operating state of the engine irrespective of the concrete acoustic situation inside and/or outside the car cabin since the engine noise has been pre-recorded for a plurality of operating states of the engine, the EOC apparatus is assignable or assigned to.

[0023] The terms "engine noise reference signal" and "engine noise" typically, refer to the engine noise signals induced by the engine into the car cabin. In other words, the term "engine noise reference signal" refers to an acoustic signal induced by the engine into the car cabin at a specific reference operating state of the engine. The term "engine noise" refers to an acoustic signal induced by the engine into the car cabin at a specific operating state of the engine.

[0024] As indicated above, respective pre-defined reference operating states of the engine, the EOC apparatus is assignable or assigned to, contained in the reference data set are typically, defined by operational parameters of the engine. Respective operational parameters of the engine may be defined by any parameter of the engine which is related with a specific load state of the engine and/or a specific engine noise. A respective operational parameter of the engine may thus, be rotation per minute ("RPM"), torque, etc. Likewise, a respective operational parameter of the engine may be a specific operating mode of the engine, such as a specific driving mode or program (economy mode or program, comfort mode or program, sports mode or program, etc.), particularly based on at least one engine operating map of the engine. In other words, at least one reference operating state of the engine can be defined by at least one operating state parameter of the engine, particularly an engine load state, preferably defined by a specific RPM and/or a specific torque, and/or by at least one operating mode of the engine, particularly based on at least one engine operating map.

[0025] The reference data set is/was typically, generated by pre-recording engine noise signals induced in the car cabin and related signal levels for a plurality of different operating states of the respective engine, the EOC apparatus is assignable or assigned to, with inactive EOC apparatus. As such, a reference data set may be used, which comprises pre-recorded engine noise signals induced in the car cabin and related signal levels for a plurality of different operating states of the engine or a situation in which the EOC apparatus is inactive. A respective reference data set may thus, be generated in an initialization mode of the EOC apparatus or in a tuning mode of the EOC apparatus, for instance. It is also possible that a respective reference data set may be generated during a test drive of a vehicle associated with the EOC apparatus.

[0026] The reference data set may be stored in a data storage device. The reference data set may thus, be provided from a data storage device. The data storage device is typically, communicatively linked or linkable with the EOC apparatus such that the EOC apparatus can access and/or process the reference data. The data storage device can be a physical data storage device or a non-physical data storage device, e.g. a cloud storage device.

[0027] A second step of the method comprises detecting, by a detection device, a signal level of at least one cancellation signal during operation of the EOC apparatus, or a signal output level of the at least one acoustic signal output device, or a signal input level of the at least one acoustic signal sensor device, particularly for at least one specific harmonic order at a given operating state of the engine. In the second step, a signal level of at least one cancellation signal, or a signal output level of the at least one acoustic signal output device used for outputting a respective cancellation signal, or a signal input level of the at least one acoustic signal sensor device used for sensing a respective cancellation signal is detected. Hence, signal levels of cancellation signals may be detected at various positions in the car cabin, namely at a position of at least one signal output device, or at a position of at least one signal sensor device, or at any position between a respective signal output device and a respective signal sensor device. The second step of the method is performed during operation of the EOC apparatus (active EOC apparatus). The detection device used for implementing the second step of the method may be a signal sensor device of the EOC apparatus and/or a separate acoustic detection device assignable or assigned to the EOC apparatus.

[0028] A third step of the method comprises comparing, by a hardware- and/or software-embodied comparison device, the detected signal level of the at least one detected cancellation signal, or the detected signal output level of the at least one acoustic signal output device, or the detected signal input level of the at least one acoustic signal sensor device with a signal level of a corresponding engine noise reference signal from the reference data set. In the third step, a comparison between a detected signal level with a signal level of a corresponding engine noise reference signal from the reference data set is performed. The comparison may be performed based on at least one comparison rule defined by a configuration parameter of the comparison device. As an example, the signal level of a detected cancellation signal may be compared with a corresponding engine noise reference signal for at least one specific harmonic order at a given operating state of the engine. Notably, the signal level of the engine noise is not measured during operation of the EOC apparatus, but derived from the reference data set. Thereby, the current operating state of the engine is used for selecting the corresponding engine noise reference. The method thus, reflects the difficulties of isolating the current signal level of the engine noise from the acoustic situation inside the car cabin when the EOC apparatus and/or other devices outputting acoustic signals in the car cabin, such as multimedia devices, is/are operating.

[0029] A fourth step of the method comprises generating, by the comparison device, a comparison information indicating the result of the comparison of the detected signal level of the at least one detected cancellation signal, or the detected signal output level of the at least one acoustic signal output device, or the detected signal input level of the at least one acoustic signal sensor device with a signal level of a corresponding engine noise reference signal. The comparison information particularly, indicates the result of the comparison of the detected signal level of the at least one detected cancellation signal, or the detected signal output level of the at least one acoustic signal output device, or the detected signal input level of the at least one acoustic signal sensor device with a signal level of a corresponding engine noise reference signal for at least one harmonic order of the engine, the EOC apparatus is assignable or assigned to and thus, the engine for which the EOC apparatus performs the noise cancellation.

[0030] A fifth step of the method comprises determining, by a hardware- and/or software-embodied determination device, an instability of the EOC apparatus based on the comparison information. Hence, the determination of an instability of the EOC apparatus - in analogous manner, a stability of the EOC apparatus may be determined - is essentially based on the comparison of a current signal level of the at least one detected cancellation signal, or a current signal output level of the at least one acoustic signal output device, or a current signal input level of the at least one acoustic signal sensor device with a signal level of a corresponding engine noise reference signal, the latter being derived from the reference data set for the respective operating state of the engine. As indicated above, the comparison of a current signal level of the at least one detected cancellation signal, or a current signal output level of the at least one acoustic signal output device, or a current signal input level of the at least one acoustic signal sensor device with a signal level of a corresponding engine noise reference signal is particularly, done for at least one harmonic order of the engine, the EOC apparatus is assignable or assigned to and thus, the engine for which the EOC apparatus performs the noise cancellation.

[0031] The method is thus, based on the knowledge of the pre-recorded engine noise for a plurality of operating states of the engine, the EOC apparatus is assignable or assigned to, contained in the reference data set and the usage of this knowledge for the determination of an instability of the EOC apparatus. As will be more apparent from below, an instability may be determined when the signal level of the cancellation signal, or the signal output level of the at least one acoustic signal output device, or the signal input level of the at least one acoustic signal sensor device, particularly for at least one harmonic order of the engine, EOC apparatus is assignable or assigned to and thus, the engine for which the EOC apparatus performs the noise cancellation, reaches or exceeds the signal level of the engine noise for a specific operating state of the engine. In other words, an instability of the EOC apparatus may be determined when the comparison result indicates that the signal level of the cancellation signal is equal to or higher than the signal level of the current engine noise.

[0032] The method according to the first aspect of the invention may form a part of a superordinate method for operating an EOC apparatus which at least comprises the steps of determining an instability of an EOC apparatus and operating the EOC apparatus on basis of a determined instability of the EOC apparatus. The operating step may comprise performing at least one measure to avoid a further increase of a detected instability of the EOC apparatus and/or performing at least one measure to decrease the detected instability of the EOC apparatus, if an instability of the EOC apparatus was determined.

[0033] The above-mentioned devices, i.e. particularly the detection device, the comparison device, and the determination device, may be hardware- and/or software embodied devices. As will be apparent from below, single, a plurality, or all of the above-mentioned devices may form part of a superordinate hardware- and/or software embodied control unit assignable or assigned to the EOC apparatus.

[0034] Generally, an instability of the EOC apparatus may be determined when a respective comparison information meets a pre-definable or pre-defined instability criterion or condition, respectively.

[0035] As indicated above, an instability of the EOC apparatus may be determined when the signal level of the cancellation signal, or the signal output level of the at least one acoustic signal output device, or the signal input level of the at least one acoustic signal sensor device for at least one harmonic order of the engine reaches or exceeds the signal level of engine noise for the respective operating state of the engine. As such, a respective instability criterion or condition, respectively may be met when the comparison information indicates that the difference between the detected signal level of the at least one detected cancellation signal, or the detected signal output level of the at least one acoustic signal output device, or the detected signal input level of the at least one acoustic signal sensor device for at least one harmonic order of the engine and the signal level of the corresponding engine noise reference signal reaches or exceeds a pre-defined or pre-definable threshold value. Particularly, a respective instability criterion or condition, respectively may be met when the comparison information indicates that the difference between the detected signal level of the at least one detected cancellation signal, or the detected signal output level of the at least one acoustic signal output device, or the detected signal input level of the at least one acoustic signal sensor device and the signal level of the corresponding engine noise reference signal reaches or exceeds a pre-defined or pre-definable threshold value for at least one harmonic order of the engine, the EOC apparatus is assignable or assigned to and thus, the engine for which the EOC apparatus performs the noise cancellation.

[0036] The method may further comprise the step of applying a safety factor to the threshold value or using a threshold value comprising a safety factor. Applying a respective safety factor, which may be a pre-definable or pre-defined static or dynamic numerical value, to the threshold value may result in that instabilities of the EOC apparatus may be determined with high reliability. Also, dynamic adjustments in determining instabilities of the EOC apparatus are possible which allow for a customizable or customized determination of instabilities of the EOC apparatus.

[0037] The threshold value may be related with at least one static or dynamic configuration parameter of the comparison device. In other words, the configuration parameters of the comparison device, for example, the threshold value(s) may be static or dynamic. Specifically, respective configuration parameters of the comparison device may be dependent from operational parameters of the engine, the EOC apparatus is assignable or assigned to. As such, the at least one configuration parameter of the comparison device may be a dynamic value which depends on at least one operational parameter of the engine, the EOC apparatus is assignable or assigned to.

[0038] At least one reference operating state of the engine, the EOC apparatus is assignable or assigned to, may also relate to a pre-definable or pre-defined operating parameter, particularly engine age, engine running performance, engine temperature, of the respective engine. Hence, the information in the reference data set can vary for different operating parameters, particularly engine age, engine running performance, engine temperature, of the respective engine which allows for determining an instability of the EOC apparatus for different operating parameters of the respective engine. As such, a respective reference data set may also be at least partially updated for different operating states of the respective engine; the method may thus, comprise the optional step of at least partially updating the reference data set for varying operating parameters of the respective engine.

[0039] Also, at least one reference operating state of the engine, the EOC apparatus is assignable or assigned to, may relate to or is related with a pre-definable or pre-defined physical parameter, particularly cabin humidity, cabin pressure, cabin temperature, cabin occupancy, of a cabin of a vehicle comprising the engine, the EOC apparatus is assignable or assigned to. Hence, the information in the reference data set can vary for different physical parameters, particularly cabin humidity, cabin pressure, cabin temperature, cabin occupancy, of the cabin of a vehicle, the EOC apparatus is associated with, which allows for determining an instability of the EOC apparatus for different physical parameters of the respective cabin. As such, a respective reference data set may also be at least partially updated for different physical parameters of the respective cabin; the method may thus, comprise the optional step of at least partially updating the reference data set for varying physical parameters of the respective cabin.

[0040] Generally, the reference data set may include a, particularly matrix-like, multi-dimensional data space defined by at least two, particularly orthogonal, continuous or discrete data axes each referring to a specific parameter directly or indirectly influencing the engine noise induced by the engine in the cabin of a vehicle comprising the engine, the EOC apparatus is assignable or assigned to.

[0041] Thereby, a first axis may refer to a first operational state parameter, particularly RPM (or a first equivalent parameter describing the engine load), of an engine, the EOC apparatus is assignable or assigned to, and a second axis may refer to a second operational state parameter, particularly torque (or a second equivalent parameter describing the engine load), of the engine, the EOC apparatus is assignable or assigned to.

[0042] The multi-dimensional data space may comprise a plurality of cells each dependent on or related with a continuous or discrete value of a first data axis and a second data axis. The multi-dimensional data space may thus, refer to a map of engine noise levels for specific operating state parameters of the engine, the EOC apparatus is assignable or assigned to, for instance. Thereby, each cell may include the respective pre-recorded engine noise for the respective value of the first data axis and the respective second data axis. As an example, the first axis may refer to RPM of an engine, and the second axis may refer to torque of the engine, and a specific cell may include engine noise for a specific RPM value and a specific torque value.

[0043] A second aspect of the invention refers to a hardware- and/or software embodied control unit for an EOC apparatus. The control unit is, particularly in accordance with the method according to the first aspect of the invention, configured to:

- provide and/or process a reference data set including a plurality of engine noise reference signals and related signal levels of respective engine noise reference signals for pre-defined reference operating states of an engine, the EOC apparatus is assignable or assigned to;
- detect, particularly by a detection device, a signal level of at least one cancellation signal during operation of the EOC apparatus, or a signal output level of an acoustic signal output device of the respective EOC apparatus, or a signal input level of an acoustic signal sensor device of the respective EOC apparatus, particularly for at least one specific harmonic order at a given operating state of the engine;
- compare, particularly by a comparison device, the detected signal level of the at least one detected cancellation signal, or the detected signal output level of the acoustic signal output device, or the detected signal input level of the acoustic signal sensor device with a signal level of a corresponding engine noise reference signal from the reference data set;
- generate, particularly by the comparison device, a comparison information indicating the result of the comparison of the detected signal level of the at least one detected cancellation signal, or the detected signal output level of the acoustic signal output device, or the detected signal input level of the at least one acoustic signal sensor device with a signal level of a corresponding engine noise reference signal;
- determine, particularly by a determination device, an instability of the EOC apparatus based on the comparison information.

[0044] All annotations regarding the method according to the first aspect of the invention also apply to the control unit according to the second aspect of the invention.

[0045] A third aspect of the invention refers to an EOC apparatus for a vehicle, particularly a car, the EOC apparatus comprising at least one control unit according to the second aspect. All annotations regarding the method according to the first aspect of the invention and the control unit according to the second aspect of the invention also apply to the EOC apparatus according to the third aspect of the invention.

[0046] A fourth aspect of the invention refers to a vehicle, particularly a car, comprising a car cabin, an engine, and an EOC apparatus according to the third aspect of the invention. All annotations regarding the method according to the first aspect of the invention, the control unit according to the second aspect of the invention, and the EOC apparatus according to the third aspect of the invention also apply to the vehicle according to the fourth aspect of the invention.

[0047] A fifth aspect of the invention refers to a machine-readable medium, particularly a data carrier, comprising machine-readable instructions, that when executed by a processor of an EOC apparatus, cause the EOC apparatus to carry out the method according to the first aspect of the invention. All annotations regarding the method according to the first aspect of the invention, the control unit according to the second aspect of the invention, the EOC apparatus according to the third aspect of the invention, and the vehicle according to the fourth aspect of the invention also apply to the machine-readable medium according to the fifth aspect of the invention.

[0048] The method according to the first aspect of the invention may be combined and/or implemented as or in a method for operating an EOC apparatus adapted to generate noise cancellation signals for cancelling noise generated by an engine at at least one specific harmonic order at a given operating state of the engine. This method for operating an EOC apparatus represents a first further aspect of the invention.

[0049] The term "EOC apparatus" embraces any apparatus which is adapted to cancel or reduce noise (engine noise) present in a car cabin which noise results from operating an engine, i.e. typically a combustion engine, of the respective car associated with the EOC apparatus at at least one harmonic order at a given operating state of the engine - typically defined by a specific load situation of the engine, i.e. particularly a specific engine speed (rpmRPM) and/or torque of the engine. As such, the EOC apparatus may also be deemed or denoted as an active-noise-cancellation ("ANC") apparatus.

[0050] A respective EOC apparatuses may be adapted to generate acoustic noise cancellation signals. Respective acoustic noise cancellation signals are typically, opposite in phase to the engine noise present in the car cabin of the respective car associated with the EOC apparatus. As such, a respective EOC apparatus may comprise at least one hardware- and/or software-embodied acoustic noise cancellation signal generating device which is adapted to generate acoustic noise cancellation signals that are typically, opposite in phase to the engine noise present in the car cabin.

[0051] Typically, a respective EOC apparatus comprises at least one acoustic signal output device, such as a loudspeaker device, assignable or assigned to the acoustic noise cancellation signal generating device and adapted to output respective acoustic noise cancellation signals in the car cabin of the respective car associated with the EOC apparatus. A respective EOC apparatus may comprise a plurality of respective acoustic signal output devices disposed at specific locations within the car cabin of the respective car associated with the EOC apparatus.

[0052] Typically, a respective EOC apparatus also comprises at least one acoustic signal sensor device, such as a microphone device, assignable or assigned to the acoustic noise cancellation signal generating device and adapted to sense engine noise present in the car cabin of the respective car associated with the EOC apparatus. A respective EOC apparatus may comprise a plurality of respective acoustic signal sensor devices disposed at specific locations within the car cabin of the respective car associated with the EOC apparatus.

[0053] A pair of at least one acoustic signal output device and at least one acoustically assigned acoustic signal sensor device can build an acoustic channel of the EOC apparatus. The EOC apparatus may comprise a plurality of respective acoustic channels.

[0054] A respective EOC apparatus is typically, operable on basis of a number of operational parameters; thus, operating the EOC apparatus typically, comprises controlling at least one operational parameter of the EOC apparatus. Examples of respective operational parameters of the EOC apparatus are the step size (μ-factor or -value) and the forgetting factor (λ-factor or - value).

[0055] Operation of a respective EOC apparatus and its sub-units, i.e. particularly the at least one acoustic noise cancellation signal generating device, the at least one acoustic signal output device, and the at least one acoustic signal sensor device is typically, controlled by a hardwareand/or software-embodied control unit of the EOC apparatus.

[0056] The method described herein can be implemented by a respective control unit of an EOC apparatus. A respective control unit may thus, be adapted to implement the method described herein. A respective control unit may be embodied as a processor or processor unit, or may comprise at least one processor or processor unit.

[0057] The control unit may comprise appropriate machine-readable instructions, that when executed by a processor or processor unit of the control unit, cause the EOC apparatus to carry out the method described herein. Respective machine-readable instructions may be provided by a machine-readable medium, particularly a data carrier, comprising machine-readable instructions, that when executed by a processor of the control unit, cause the EOC apparatus to carry out the method described herein.

[0058] The method comprises the steps of: detecting an instability of the EOC apparatus, and performing at least one measure to avoid a further increase of the detected instability of the EOC apparatus and/or at least one measure to decrease the instability of the EOC apparatus.

[0059] Hence, according to a first step of the method, an instability of a respective EOC apparatus is detected. The method thus, allows for actively detecting an instability of a respective EOC apparatus.

[0060] As indicated above, a respective instability of a respective EOC apparatus may result from a situation in which the EOC apparatus tries to cancel noise present in the car cabin which noise does not result from the engine, but from other noise sources, e.g. external noise sources, such as other vehicles, for instance.

[0061] Specifically, a respective instability of a respective EOC apparatus may result from the fact that, due to various factors, the generated noise cancellation signals for one or more harmonic orders to be cancelled by the EOC apparatus may become suddenly out of phase, so that the EOC apparatus tries to cancel a self-generated noise cancellation signal or some harmonic orders of it.

[0062] A significant factor that may cause an instability of a respective EOC apparatus is the difference between reference frequency responses of acoustic signal output devices of the EOC apparatus, such as loudspeaker devices, and acoustic signal sensor devices of the EOC apparatus, such as microphone devices, and corresponding actual frequency responses of the acoustic signal output devices of the EOC apparatus, such as loudspeaker devices, and the acoustic signal sensor devices of the EOC apparatus. Thereby, the phase-response component plays an essential role, thus, causing the noise cancellation signal that should normally reach a respective acoustic signal sensor device of the EOC apparatus with nearly opposite phase, in fact reaches the respective acoustic signal sensor device of the EOC apparatus almost in-phase.

[0063] There are many circumstances that may cause such variations of the frequency response, such as physical conditions, e.g. humidity, temperature, etc., inside the car cabin, number of passengers in the car cabin, load of the trunk, aging or damage effects of the acoustic signal output devices and/or the acoustic signal sensor devices, windows opened, etc.

[0064] Such variations of the frequency response may be static (immanent to the particular car equipped with the EOC apparatus, e.g. due to an improper mounting of the acoustic signal output devices and/or the acoustic signal sensor devices), or semi-static (occurring permanently within one or several driving sessions due to, for example, a high number of passengers and their constitution), or sporadic (caused by sporadically occurring events, such as closing an acoustic signal output device and/or an acoustic signal sensor device, or changes of the physical conditions, e.g. humidity, temperature, etc., in the car cabin, etc.).

[0065] Other reasons of instabilities of a respective EOC apparatus may be sporadic internal or external noises, e.g. vibrations, external cars, reflections from tunnel walls, etc., having frequencies correlating with the frequencies to be cancelled by the EOC apparatus; overload of an acoustic signal output device and/or an acoustic signal sensor device due to a high energy level of the noise cancellation signal or other audio signals, e.g. music, output by the same acoustic signal output device; too sensible tuning, when the EOC apparatus strives to reach the maximum level of noise cancellation, assuming that the operating states of the engine being not changed, though in reality they are changed.

[0066] As will be more apparent from below, the detection of an instability of a respective EOC apparatus may be based on the determination that at least one predefinable or pre-defined instability condition is met or not met, respectively. Respective instability conditions of the respective EOC apparatus may be individually defined for a plurality of operating states of the engine, e.g. for a plurality of load situations of the engine, each definable or defined by a specific engine speed (RPM) or engine speed range, torque or torque range, etc. In other, words different instability conditions may apply for different operating states of the engine.

[0067] According to a second step of the method, if an instability of the respective EOC apparatus is detected, at least one measure to avoid a further increase of the detected instability of the respective EOC apparatus and/or at least one measure to decrease the instability of the respective EOC apparatus is performed. The method thus, allows for actively controlling the instability of the respective EOC apparatus by performing specific measures for controlling a detected instability of the respective EOC apparatus.

[0068] A first measure is directed to avoiding and/or stopping a further increase of the detected instability of the respective EOC apparatus. This first measure thus, allows for actively controlling the operation of the respective EOC apparatus such that a further increase of the detected instability is avoided and/or stopped. As a concrete example, an instability of the respective EOC apparatus may result in an increase of energy, particularly volume, of a noise cancellation signal generated by the EOC apparatus such that the noise cancellation signal reaches or exceeds a specific threshold energy level, i.e. particularly a specific threshold volume level, such that it is acoustically perceivable and thus, audible by a passenger in the car cabin. The first measure may thus, allow for controlling the EOC apparatus such that the energy level of a generated noise cancellation signal does not exceed the specific threshold energy level. Particularly, the first measure may allow for controlling the EOC apparatus such that the noise cancellation signal is kept at a certain energy level, particularly volume level, below the specific threshold energy level. This may be achieved by "freezing" the energy level of the generated noise cancellation signal at a specific energy level below the specific threshold energy level, for instance.

[0069] The first measure may be implemented by applying a first processing rule adapted to control the EOC apparatus, i.e. particularly respective operational parameters of the EOC apparatus, such that a further increase of the detected instability of the EOC apparatus is avoided and/or stopped. Particularly, the first processing rule may be adapted to control the EOC apparatus, i.e. particularly respective operational parameters of the EOC apparatus, such that the energy of the generated noise cancellation signal is below the specific threshold energy level and does not exceed the specific threshold energy level. This can be achieved, for example, by changing, i.e. particularly increasingdecreasing, the value of the forgetting factor λ for the harmonic order where a respective instability has occurred, thus, preventing a further increase of the respective instability.

[0070] A second measure is directed to decreasing and/or reducing the instability of the EOC apparatus.

[0071] The second measure thus, allows for actively controlling the operation of the EOC apparatus such that the detected instability is decreased and/or reduced. As mentioned above, an instability of the respective EOC apparatus may result in an increase of energy, particularly volume, of a noise cancellation signal generated by the EOC apparatus, particularly arriving at an acoustic signal sensor device of the EOC apparatus nearly in phase with the engine noise (i.e. no producing the noise instead of cancellation), such that the noise cancellation signal reaches or exceeds a specific threshold energy level, i.e. particularly a specific threshold volume level, such that it is acoustically perceivable and thus, audible by a passenger in the car cabin. The second measure may thus, allow for controlling the EOC apparatus such that the energy of a generated noise cancellation signal will be, particularly gradually, decreased to a pre-definable or pre-defined target energy level below the specific threshold energy level. This may be achieved by, particularly gradually, decreasing the energy of the generated noise cancellation signal until the energy level of the generated noise cancellation signal reaches the pre-definable or pre-defined target energy level below the specific threshold energy level, for instance. The energy of the generated noise cancellation signal may also be decreased to zero. Hence, the target energy level may also be zero.

[0072] The second measure may be implemented by applying a second processing rule adapted to control the EOC apparatus, i.e. particularly respective operational parameters of the EOC apparatus, such that an instability of the EOC apparatus is decreased and/or reduced. Particularly, the second processing rule may be adapted to control the EOC apparatus, i.e. particularly respective operational parameters of the EOC apparatus, such that the energy of the generated noise cancellation signal is, particularly gradually, decreased until the energy level of the generated noise cancellation signal reaches a pre-definable or pre-defined target energy level below the specific threshold energy level.

[0073] According to a preferred embodiment, first a respective first measure is applied and then a respective second measure is applied. As such, an increase of the instability of the EOC apparatus may be avoided and/or stopped by first applying the first measure and then, i.e. when an increase of the instability of the EOC apparatus is stopped, the instability may be decreased and/or reduced by applying the second measure. The second measure may be particularly, applied when the noise cancellation signal is kept at an energy level below the threshold energy level and the instability is thus, "frozen". Hence, a respective first measure and a respective second measure may be applied in a specific or unspecific sequence according to which the second measure is applied at a specific time, e.g. a few seconds, i.e. particularly 1, 2, 3, 4 or 5 seconds, or at an unspecific time after the first measure. In the latter case, a respective second measure may be applied when an operating state of the engine is changed. An operating state of the engine may be considered to be changed when certain operational parameters of the engine, e.g. RPM, change from a first interval or range to a second interval or range, e.g. from an exemplary first interval or range of 1000 RPM - 1100 RPM to an exemplary second interval or range of 1100 RPM - 1300 RPM.

[0074] A respective sequence may particularly result in that the application of the measures will not be acoustically perceived by a passenger, but will be acoustically perceived as constant engine noise even though the noise at least during application of the first measure is actually the noise cancellation signal generated by the EOC apparatus.

[0075] In either case, performing the at least one measure to avoid a further increase of the instability of the EOC apparatus and/or at least one measure to decrease the instability of the EOC apparatus may comprise adapting and/or adjusting at least one operational parameter of the EOC apparatus. Particularly, performing the at least one measure to avoid a further increase of the instability of the EOC apparatus and/or the at least one measure to decrease the instability of the EOC apparatus may comprise adapting and/or adjusting the step size and/or the forgetting factor of the EOC apparatus.

[0076] As mentioned above, the EOC apparatus may comprise at least one acoustic channel, the at least one acoustic channel being defined by an acoustic signal sensor device, particularly a microphone device, adapted to sense noise generated by an engine and an acoustic signal output device, particularly a loudspeaker device, adapted to output a noise cancellation signal for cancelling the noise generated by the engine. The step of detecting the instability of the EOC apparatus may comprise detecting if at least one instability condition is met for at least one specific acoustic channel. Particularly, the step of detecting the instability of the EOC apparatus may comprise detecting if at least one instability condition is met for at least one specific acoustic channel at at least one harmonic order of the engine at a specific operating state of the engine. Hence, a highly specific detection of instabilities is possible.

[0077] The at least one instability condition may be met when the signal level, i.e. typically an audio input level, of the acoustic signal sensor device and/or the signal level, i.e. typically an audio output level, of the acoustic signal output device reaches or exceeds a pre-definable or pre-defined threshold value for a specific acoustic channel. Particularly, the at least one instability condition may be met when the signal level of the acoustic signal sensor device and/or the signal level of the acoustic signal output device reaches or exceeds a defined threshold value for a specific acoustic channel and for a specific harmonic order of the engine at a specific operating state of the engine.

[0078] It is also possible that performing at least one measure to avoid a further increase of the instability of the EOC apparatus (first measure) and/or at least one measure to decrease the instability of the EOC apparatus (second measure) comprises stopping, particularly for a pre-definable or pre-defined period of time , outputting a noise cancellation signal by the or an acoustic signal output device through the specific acoustic channel at the respective harmonic order of the engine for which the or an instability condition was met. Hence, in a special scenario, the method may comprise abruptly (temporarily) interrupting of the operation of the EOC apparatus, particularly for a pre-definable or pre-defined period of time, e.g. a few seconds, i.e. particularly 1, 2, 3, 4 or 5 seconds. The abrupt (temporary) interrupt of the operation of the EOC apparatus, particularly for a pre-definable or pre-defined period of time, may also be deemed or denoted as a third measure.

[0079] All measures, e.g. particularly the at least one measure to avoid a further increase of the instability of the EOC apparatus and/or the at least one measure to decrease the instability of the EOC apparatus, may be performed during a period in which no change of an operating state of the engine, e.g. a load state of the engine, particularly an engine speed (RPM), torque, etc., occurs. As such, the at least one measure may be applied during a(n essentially) stationary operating state of the engine which increases the efficiency of the method because the stationary operating state of the engine is typically, also related with (essentially) stationary operational parameters of the EOC apparatus so that controlling of the EOC apparatus is feasible with comparatively low controlling resources. This also means that the application of a measure for avoiding a further increase of a detected instability of the EOC apparatus and/or a measure for decreasing a detected instability of the EOC apparatus may be stopped when the engine is no longer operated in a stationary operating state, i.e. when a change of an operating state of the engine occurs.

[0080] As such, a second further aspect of the invention refers to a hardware- and/or software-embodied control unit for an EOC apparatus. The control is adapted to detect an instability of the EOC apparatus, and generate control information usable or used to perform at least one measure to avoid/stop a further increase of the detected instability of the EOC apparatus and/or at least one measure to decrease/reduce the instability of the EOC apparatus. All annotations concerning the method also apply to the control unit and vice versa.

[0081] A third further aspect of the invention refers to an EOC apparatus for a vehicle, particularly a car, the EOC apparatus comprising at least one control unit as described herein. The EOC apparatus is particularly, adapted to detect an instability of the EOC apparatus, and perform at least one measure to avoid a further increase of the detected instability of the EOC apparatus and/or at least one measure to decrease the instability of the EOC apparatus. All annotations regarding the method according to the first further aspect and the control unit according to the second also apply to the EOC apparatus and vice versa.

[0082] A fourth further aspect of the invention refers to a vehicle, particularly a car, comprising at least one engine, particularly a combustion engine, and an EOC apparatus as described herein. All annotations regarding the method according to the first further aspect, the control unit according to the second further aspect, and the EOC apparatus according to the third further aspect also apply to the vehicle and vice versa.

[0083] Another aspect of the invention refers to a machine-readable medium, particularly a data carrier, comprising machine-readable instructions, that when executed by a processor of a hardwareand/or software-embodied control unit of an EOC apparatus, cause the EOC apparatus to carry out the method as described herein. All annotations regarding the method according to the first further aspect, the control unit according to the second further aspect, the EOC apparatus according to the third further aspect, the vehicle according to the fourth further aspect also apply to the machine-readable medium and vice versa.

[0084] At least one aspect of the invention can be arbitrarily combined with at least one other aspect of the invention.

[0085] Exemplary embodiments of the invention are described with reference to the Fig., whereby:

Fig. 1 shows a principle drawing of a vehicle comprising an EOC apparatus according to an exemplary embodiment;

Fig. 2 shows a diagram of a method for determining an instability of the EOC apparatus according to an exemplary embodiment; and

Fig. 3 shows a graphical representation of a reference data set according to an exemplary embodiment.

[0086] Fig. 1 shows a principle drawing of a vehicle 1, i.e. typically a car, comprising an EOC apparatus 2 according to an exemplary embodiment. As will be apparent from below, the EOC apparatus 2 is adapted to implement a method for determining an instability of the EOC apparatus 2 according to an exemplary embodiment (see Fig. 2).

[0087] The EOC apparatus 2 is adapted to generate acoustic cancellation signals 3 that are typically, opposite in phase to the engine noise 4 present in the car cabin 6 of the vehicle 1 associated with the EOC apparatus 2. The engine noise 4 originates from operation of the engine 5, i.e. typically a combustion engine, an electrical engine, or a hybrid engine, of the vehicle 1.

[0088] The EOC apparatus 1 comprises at least one hardware- and/or software-embodied cancellation signal generating device 7 which is adapted to generate respective cancellation signals 3 that are typically, opposite in phase to the engine noise 4 present in the car cabin 6, at least one signal output device 8, such as a loudspeaker device, adapted to output respective cancellation signals 3 into the car cabin 6, and at least one signal sensor device 9, such as a microphone device, adapted to sense noise in the car cabin 6. Specifically, the signal sensor device 9 is configured to sense cancellation signals 3 and/or engine noise 4 present in the car cabin 6.

[0089] The car cabin 6 may be provided with a plurality of respective acoustic signal output devices 8 and acoustic signal sensor devices 9.

[0090] A pair of at least one signal output device 8 and at least one acoustically assigned signal sensor device 9 can build an acoustic channel of the EOC apparatus 2. The EOC apparatus 2 may comprise a plurality of respective acoustic channels.

[0091] The EOC apparatus 2 is operable on basis of a number of operational parameters; thus, operating the EOC apparatus 2 comprises controlling at least one operational parameter of the EOC apparatus 2. Examples of respective operational parameters of the EOC apparatus 2 are the step size (μ-factor or -value) and the forgetting factor (λ-factor or -value).

[0092] Operation of the EOC apparatus 2 and its subunits, e.g. the cancellation signal generating device 7, the at least one signal output device 8, and the at least one signal sensor device 9 is controlled via a hardware- and/or software-embodied control unit 10 of the EOC apparatus 2.

[0093] The control unit 10 is adapted to implement the method which will be described in the following in context with Fig. 2. The control unit 10 may comprise appropriate machine-readable instructions, that when executed by a processor 11 of the control unit 10, cause the EOC apparatus 2 to carry out this method. Respective machine-readable instructions may be provided by a machine-readable medium, particularly a data carrier, comprising machine-readable instructions, that when executed by the processor 11 of the control unit 10, cause the EOC apparatus 2 to carry out this method.

[0094] Fig. 2 shows a diagram of a method for determining an instability of the EOC apparatus 2 according to an exemplary embodiment.

[0095] A first step S1 of the method comprises providing a reference data set. The reference data set includes a plurality of engine noise reference signals and related signal levels of respective engine noise reference signals for pre-defined reference operating states of the engine 5 the EOC apparatus 2 is assigned to. The reference data set thus, includes data couples or dependencies, whereby each data couple or dependency comprises at least one reference operating state of the engine 5 and an associated engine noise reference signal and a related signal level of the respective engine noise reference signal.

[0096] In other words, the reference data set comprises pre-defined reference operating states of the engine 5 correlated with engine noise data of the engine 5. Specifically, the reference data set comprises a dependency of the corresponding respective engine noise data, i.e. engine noise reference signals and related signal levels of respective engine noise reference signals, for the respective reference operating states of the engine 5.

[0097] The reference data set may thus, comprise the engine noise data of the engine at respective pre-defined reference operating states of the engine 5. Specifically, the reference data set comprises respective engine noise data, i.e. engine noise reference signals and related signal levels of respective engine noise reference signals at respective operating states of the engine 5.

[0098] Particularly, the reference data set may comprise pre-recorded and post-processed engine noise measured by each signal sensor device 9 of the EOC apparatus 2 and/or measured by some external signal sensor device (e.g. an external microphone device) for various operating states of the engine 5. Respective operating states may be defined by operational parameters of the engine 5. Respective operating parameters may comprise RPM- and/or torque-values of the engine 5, driving modes or programs (e.g. economy mode or program, comfort mode or program, sport mode or program, etc.) of the engine 5, for instance. Pre-recorded measurement data for the selected operating state(s) or respective operating parameters of the engine 5 may be deemed or denoted as "raw data". The reference data set may be generated by post-processing of such raw data. The reference data set may thus, comprise reference data, i.e. numeric parameters, e.g. level of the engine noise at a selected harmonic order, where the EOC apparatus 2 operates.

[0099] Based on the dependency of the respective engine noise reference signals and related signal levels for respective reference operating states of the engine 5 , the reference data thus, enables deriving information of the engine noise 4 for any given operating state of the engine 5 irrespective of the concrete acoustic situation inside and/or outside the car cabin 6 since the engine noise 4 has been pre-recorded for a plurality of operating states of the engine 5.

[0100] The terms "engine noise reference signal" and "engine noise" refer to the engine noise signals induced by the engine 5 into the car cabin 6. In other words, the term "engine noise reference signal" refers to an acoustic signal induced by the engine 5 into the car cabin 6 at a specific reference operating state of the engine 5. The term "engine noise" refers to an acoustic signal induced by the engine 5 into the car cabin 6 at a specific operating state of the engine 5.

[0101] Respective pre-defined reference operating states of the engine 5 contained in the reference data set are typically, defined by operational parameters of the engine 5. Respective operational parameters of the engine 5 may be defined by any parameter of the engine 5 which is related with a specific load state of the engine 5 and/or a specific engine noise 4. A respective operational parameter of the engine 5 may thus, be rotation per minute ("RPM"), torque, etc. Likewise, a respective operational parameter of the engine 5 may be a specific operating mode of the engine 5, such as a specific driving mode (economy mode, comfort mode, sports mode, etc.), particularly based on at least one engine operating map of the engine 5. In other words, at least one reference operating state of the engine 5 can be defined by at least one operating state parameter of the engine 5, particularly an engine load state, preferably defined by a specific

RPM and/or a specific torque, and/or by at least one operating mode of the engine 5, particularly based on at least one engine operating map.

[0102] The reference data set is/was typically, generated by pre-recording engine noise signals induced in the car cabin 6 and related signal levels for a plurality of different operating states of the engine 5, the EOC apparatus 2 is assignable or assigned to, with inactive EOC apparatus 2. As such, a reference data set may be used, which comprises pre-recorded engine noise signals induced in the car cabin and related signal levels for a plurality of different operating states of the engine 5 for at least one situation in which the EOC apparatus 2 is inactive. A respective reference data set may be generated in an initialization mode of the EOC apparatus 2 or in a tuning mode of the EOC apparatus 2, for instance. It is also possible that a respective reference data set may be generated during a test drive of the vehicle 1.

[0103] The reference data set may be stored in a data storage device 12. The reference data set may thus, be provided from a data storage device 12. The data storage 12 device is communicatively linked or linkable with the EOC apparatus 2 such that the EOC apparatus 2 can access and/or process the reference data (see Fig. 1) The data storage device 12 can be a physical data storage device or a non-physical data storage device, e.g. a cloud storage device.

[0104] A second step S2 of the method comprises detecting, by a detection device 13 of the EOC apparatus 2 are associated therewith, a signal level of at least one cancellation signal 3 during operation of the EOC apparatus 2, or a signal output level of the at least one acoustic signal output device 8, or a signal input level of the at least one acoustic signal sensor device 9, particularly for at least one specific harmonic order at a given operating state of the engine 5. Hence, signal levels of cancellation signals 3 may be detected at various positions in the car cabin 6, namely at a position of at least one signal output device 8, or at a position of at least one signal sensor device 9, or at any position between a respective signal output device 8 and a respective signal sensor device 9. The second step S2 of the method is performed during operation of the EOC apparatus 2 (active EOC apparatus 2). The detection device 13 used for implementing the second step S2 of the method may be a signal sensor device 9 of the EOC apparatus 2 and/or a separate acoustic detection device (not shown) assignable or assigned to the EOC apparatus 2.

[0105] A third step S3 of the method comprises comparing, by a hardware- and/or software-embodied comparison device 14, the detected signal level of the at least one detected cancellation signal 3, or the detected signal output level of the at least one acoustic signal output device 8, or the detected signal input level of the at least one acoustic signal sensor device 9 with a signal level of a corresponding engine noise reference signal from the reference data set. As an example, the signal level of a detected cancellation signal 3 may be compared with a corresponding engine noise reference signal for at least one specific harmonic order at a given operating state of the engine 5. Notably, the signal level of the engine noise 4 is not measured during operation of the EOC apparatus 2, but derived from the reference data set. Thereby, the current operating state of the engine 5 is used for selecting the corresponding engine noise reference signal which is possible due to the above-mentioned data dependencies contained in the reference data set. The method thus, reflects the difficulties of isolating the current signal level of the engine noise 4 from the acoustic situation inside the car cabin 6 when the EOC apparatus 2 and/or other devices outputting acoustic signals, e.g. music signals, in the car cabin 6, such as multimedia devices, is/are operating.

[0106] A fourth step S4 of the method comprises generating, by the comparison device 14, a comparison information indicating the result of the comparison of the detected signal level of the at least one detected cancellation signal 3, or the detected signal output level of the at least one acoustic signal output device 8, or the detected signal input level of the at least one acoustic signal sensor device 9 with a signal level of a corresponding engine noise reference signal.

[0107] A fifth step S5 of the method comprises determining, by a hardware- and/or software-embodied determination device 15, an instability of the EOC apparatus 2 based on the comparison information. Hence, the determination of an instability of the EOC apparatus 2 - in analogous manner, a stability of the EOC apparatus 2 may be determined - is essentially based on the comparison of a current signal level of the at least one detected cancellation signal 3, or a current signal output level of the at least one acoustic signal output device 8, or a current signal input level of the at least one acoustic signal sensor device 9 with a signal level of a corresponding engine noise reference signal, the latter being derived from the reference data set for the respective operating state of the engine 5.

[0108] The method is thus, based on the knowledge of the pre-recorded engine noise for a plurality of operating states of the engine 5 contained in the reference data set and the usage of this knowledge for the determination of an instability of the EOC apparatus 2. An instability of the EOC apparatus 2 may be determined when the comparison result indicates that the signal level of the cancellation signal 3 is equal to or higher than the signal level of the current engine noise, for instance.

[0109] An instability of the EOC apparatus 2 may be determined when a respective comparison information meets a pre-definable or pre-defined instability criterion or condition, respectively.

[0110] Particularly, an instability of the EOC apparatus 2 may be determined when the signal level of the cancellation signal 3, or the signal output level of the at least one acoustic signal output device 8, or the signal input level of the at least one acoustic signal sensor device 9 for at least one harmonic order of the engine 5 reaches or exceeds the signal level of engine noise 4 for the respective operating state of the engine 5. As such, a respective instability criterion or condition, respectively may be met when the comparison information indicates that the difference between the detected signal level of the at least one detected cancellation signal 3, or the detected signal output level of the at least one acoustic signal output device 8, or the detected signal input level of the at least one acoustic signal sensor device 9 for at least one harmonic order of the engine 5 and the signal level of the corresponding engine noise reference signal reaches or exceeds a pre-defined or pre-definable threshold value.

[0111] The method of Fig. 2 may form part of a superordinate method for operating an EOC apparatus 2 which at least comprises the steps of determining an instability of an EOC apparatus 2 and operating the EOC apparatus 2 on basis of a determined instability of the EOC apparatus 2. The operating step may comprise performing at least one measure to avoid a further increase of a detected instability of the EOC apparatus 2 and/or performing at least one measure to decrease the instability of the EOC apparatus 2, if an instability of the EOC apparatus 2 was determined.

[0112] The method may further comprise the optional step of applying a safety factor to the threshold value or using a threshold value comprising a safety factor. Applying a respective safety factor, which may be a predefinable or pre-defined static or dynamic numerical value, to the threshold value may result in that instabilities of the EOC apparatus 2 may be determined with high reliability. Also, dynamic adjustments in determining instabilities of the EOC apparatus 2 are possible which allow for a customizable or customized determination of instabilities of the EOC apparatus 2.

[0113] The threshold value may be related with at least one static or dynamic configuration parameter of the comparison device 14. In other words, the configuration parameters of the comparison device 14, for example, the threshold value(s) may be static or dynamic. Specifically, respective configuration parameters of the comparison device 14 may be dependent from operational parameters of the engine 5. As such, the at least one configuration parameter of the comparison device 14 may be a dynamic value which depends on at least one operational parameter of the engine 5.

[0114] At least one reference operating state of the engine 5 may also relate to a pre-definable or pre-defined operating parameter, particularly engine age, engine running performance, engine temperature, of the engine 5. Hence, the information in the reference data set can vary for different operating parameters, particularly engine age, engine running performance, engine temperature, of the engine 5 which allows for determining an instability of the EOC apparatus 2 for different operating parameters of the engine 5. As such, a respective reference data set may also be at least partially updated for different operating states of the engine 5; the method may thus, comprise the optional step of at least partially updating the reference data set for varying operating parameters of the engine 5.

[0115] Also, at least one reference operating state of the engine 5 may relate to or is related with a pre-definable or pre-defined physical parameter, particularly cabin humidity, cabin pressure, cabin temperature, cabin occupancy, of the car cabin 6. Hence, the information in the reference data set can vary for different physical parameters, particularly cabin humidity, cabin pressure, cabin temperature, cabin occupancy, of the car cabin 6 which allows for determining an instability of the EOC apparatus 2 for different physical parameters of the car cabin 6. As such, a respective reference data set may also be at least partially updated for different physical parameters of the car cabin 6; the method may thus, comprise the optional step of at least partially updating the reference data set for varying physical parameters of the car cabin 6.

[0116] Fig. 3 shows a graphical representation of a reference data set. As is apparent from Fig. 3, a respective reference data set may include a, particularly matrix-like, multi-dimensional data space defined by at least two, particularly orthogonal, continuous or discrete data axes A1, A2 each referring to a specific parameter directly or indirectly influencing the engine noise 4 induced by the engine 5 in the car cabin 6.

[0117] Thereby, a first axis A1 may refer to a first operating state parameter, particularly RPM (or a first equivalent parameter describing the engine load), of the engine 5, the EOC apparatus 2 is assigned to, and a second axis A2 may refer to a second operating state parameter, particularly torque (or a second equivalent parameter describing the engine load), of the engine 5, the EOC apparatus 2 is assigned to.

[0118] As is further apparent from Fig. 3, the multi-dimensional data space may comprise a plurality of cells each correlated with a continuous or discrete value of the first axis A1 and the second axis A2. The multi-dimensional data space may thus, refer to a map of engine noise levels for specific operating state parameters of the engine 5, the EOC apparatus 2 is assigned to, for instance. Thereby, each cell may include the respective pre-recorded engine noise for the respective value of the first data axis A1 and the respective second data axis A2.

[0119] As is apparent from Fig. 3, the first axis A1 may refer to RPM of the engine 5, and the second axis A2 may refer to torque of the engine 5, and a specific cell may include engine noise, e.g. expressed in dB, for a specific RPM value and a specific torque value as is exemplarily indicated in Fig. 3.

[0120] The cells are exemplarily filled with exemplary dB-values in Fig. 3 for illustration purposes only. Fig. 3 is not limited to these cells and/or values.

[0121] Returning to Fig. 1, Fig. 1 shows that the above-mentioned devices, i.e. particularly the detection device 13, the comparison device 14, and the determination device 15, may be hardware- and/or software embodied devices and may form part of the control unit 10 of the EOC apparatus 2.

[0122] The control unit 10 may also adapted to implement the method which will be described in the following. The control unit 10 may comprise appropriate machine-readable instructions, that when executed by a processor 11 of the control unit 10, cause the EOC apparatus 2 to carry out this method. Respective machine-readable instructions may be provided by a machine-readable medium, particularly a data carrier, comprising machine-readable instructions, that when executed by the processor 11 of the control unit 10, cause the EOC apparatus 2 to carry out this method.

[0123] The method generally refers to operating the EOC apparatus 2. Specifically, the method comprises the steps of: detecting an instability of the EOC apparatus 2, and performing at least one measure to avoid a further increase of the detected instability of the EOC apparatus 2 and/or at least one measure to decrease the instability of the EOC apparatus 2.

[0124] According to a first step of the method, an instability of the EOC apparatus 2 is detected. The method thus, allows for actively detecting an instability of the EOC apparatus 2.

[0125] Specifically, a respective instability of the EOC apparatus 2 may result from the fact that, due to various factors, the generated noise cancellation signals 3 for one or more harmonic orders to be cancelled by the EOC apparatus 2 may become suddenly out of phase, so that the EOC apparatus 2 tries to cancel a self-generated noise cancellation signal 3 or some harmonic orders of it.

[0126] A significant factor that may cause an instability of the EOC apparatus 2 is the difference between reference frequency responses of the acoustic signal output device(s) 8 of the EOC apparatus 2 and the acoustic signal sensor device(s) 9 of the EOC apparatus 2 and corresponding actual frequency responses of the acoustic signal output device(s) 8 of the EOC apparatus the acoustic signal sensor device(s) 9 of the EOC apparatus 2. Thereby, the phase-response component plays an essential role, thus, causing the noise cancellation signal 3 that should normally reach a respective acoustic signal sensor device 9 of the EOC apparatus 2 with nearly opposite phase, in fact reaches the respective acoustic signal sensor device 9 of the EOC apparatus 2 almost in-phase.

[0127] There are many circumstances that may cause such variations of the frequency response, such as physical conditions, e.g. humidity, temperature, etc., inside the car cabin 6, number of passengers in the car cabin 6, load of the trunk of the car 1, aging or damage effects of the acoustic signal output device(s) 8 and/or the acoustic signal sensor device(s) 9, windows opened, etc.

[0128] Such variations of the frequency response may be static (immanent to the particular car 1 equipped with the EOC apparatus 2, e.g. due to an improper mounting of the acoustic signal output device(s) 8 and/or the acoustic signal sensor device(s) 9), or semi-static (occurring permanently within one or several driving sessions due to, for example, a high number of passengers in the car cabin 6 and their constitution), or sporadic (caused by sporadically occurring events, such as closing an acoustic signal output device 8 and/or an acoustic signal sensor device 9, or changes of the physical conditions, e.g. humidity, temperature, etc., in the car cabin 6, etc.).

[0129] Other reasons of instabilities of the EOC apparatus 2 may be sporadic internal or external noises, e.g. vibrations, external cars, reflections from tunnel walls, etc., having frequencies correlating with the frequencies to be cancelled by the EOC apparatus 2; overload of an acoustic signal output device 8 and/or an acoustic signal sensor device 9 due to a high energy level of the noise cancellation signal 3 or other audio signals, e.g. music, output by the same acoustic signal output device 8; too sensible tuning, when the EOC apparatus 2 strives to reach the maximum level of noise cancellation, assuming that the operating states of the engine 5 being not changed, though in reality they are changed.

[0130] The detection of an instability of the EOC apparatus 2 may be based on the determination that at least one pre-definable or pre-defined instability condition is met or not met, respectively. Respective instability conditions of the EOC apparatus 2 may be individually defined for a plurality of operating states of the engine 5, e.g. for a plurality of load situations of the engine 5, each defined by a specific engine speed (RPM) or engine speed range, torque or torque range, etc. In other, words different instability conditions may apply for different operating states of the engine 5.

[0131] According to a second step of the method, if an instability of the EOC apparatus 2 is detected, at least one measure to avoid a further increase of the detected instability of the EOC apparatus 2 and/or at least one measure to decrease the instability of the EOC apparatus 2 is performed. The method thus, allows for actively controlling the instability of the EOC apparatus 2 by performing specific measures for controlling a detected instability of the EOC apparatus 2.

[0132] A first measure is directed to avoiding and/or stopping a further increase of the detected instability of the EOC apparatus 2. This first measure thus, allows for actively controlling the operation of the EOC apparatus 2 such that a further increase of the detected instability is avoided and/or stopped. As a concrete example, an instability of the EOC apparatus 2 may result in an increase of energy, particularly volume, of a noise cancellation signal 3 generated by the EOC apparatus 2 such that the noise cancellation signal 3 reaches or exceeds a specific threshold energy level, i.e. particularly a specific threshold volume level, such that it is acoustically perceivable and thus, audible by a passenger in the car cabin 6. The first measure may thus, allow for controlling the EOC apparatus 2 such that the energy level of a generated noise cancellation signal 3 does not exceed the specific threshold energy level. Particularly, the first measure may allow for controlling the EOC apparatus 2 such that the noise cancellation signal 3 is kept at a certain energy level, particularly volume level, below the specific threshold energy level. This may be achieved by "freezing" the energy level of the generated noise cancellation signal 3 at a specific energy level below the specific threshold energy level, for instance.

[0133] The control unit 10 may implement the first measure by applying a first processing rule adapted to control the EOC apparatus 2, i.e. particularly respective operational parameters of the EOC apparatus 2, such that a further increase of the detected instability of the EOC apparatus 2 is avoided and/or stopped. Particularly, the first processing rule may be adapted to control the EOC apparatus 2, i.e. particularly respective operational parameters of the EOC apparatus 2, such that the energy of the generated noise cancellation signal 3 is below the specific threshold energy level and does not exceed the specific threshold energy level. This can be achieved, for example, by changing, i.e. particularly increasingdecreasing, the value of the forgetting factor λ for the harmonic order where a respective instability has occurred, thus, preventing a further increase of the respective instability.

[0134] A second measure is directed to decreasing and/or reducing the instability of the EOC apparatus 2. The second measure thus, allows for actively controlling the operation of the EOC apparatus 2 such that the detected instability of the EOC apparatus 2 is decreased and/or reduced. As mentioned above, an instability of the EOC apparatus 2 may result in an increase of energy, particularly volume, of a noise cancellation signal 3 generated by the EOC apparatus 2 such that the noise cancellation signal 3 reaches or exceeds a specific threshold energy level, i.e. particularly a specific threshold volume level, such that it is acoustically perceivable and thus, audible by a passenger in the car cabin 6. The second measure may thus, allow for controlling the EOC apparatus 2 such that the energy of a generated noise cancellation signal 3 will be, particularly gradually, decreased to a pre-definable or pre-defined target energy level below the specific threshold energy level. This may be achieved by, particularly gradually, decreasing the energy of the generated noise cancellation signal 3 until the energy level of the generated noise cancellation signal 3 reaches the pre-definable or pre-defined target energy level below the specific threshold energy level, for instance. The energy of the generated noise cancellation signal 3 may also be decreased to zero. Hence, the target energy level may also be zero.

[0135] The control unit 10 may implement the second measure by applying a second processing rule adapted to control the EOC apparatus 2, i.e. particularly respective operational parameters of the EOC apparatus 2, such that an instability of the EOC apparatus 2 is decreased and/or reduced. Particularly, the second processing rule may be adapted to control the EOC apparatus 2, i.e. particularly respective operational parameters of the EOC apparatus 2, such that the energy of the generated noise cancellation signal 3 is, particularly gradually, decreased until the energy level of the generated noise cancellation signal 3 reaches a pre-definable or pre-defined target energy level below the specific threshold energy level.

[0136] The control unit 10 may be adapted to apply the first and second measure in a specific sequence. According to this sequence, first a respective first measure is applied and then a respective second measure is applied. As such, an increase of the instability of the EOC apparatus 2 may be avoided and/or stopped by first applying the first measure and then, i.e. when an increase of the instability of the EOC apparatus 2 is stopped, the instability of the EOC apparatus 2 may be decreased and/or reduced by applying the second measure. The second measure may be particularly, applied when the noise cancellation signal 3 is kept at an energy level below the threshold energy level and the instability is thus, "frozen". Hence, a respective first measure and a respective second measure may be applied in a specific sequence or unspecific sequence according to which the second measure is applied at a specific time, e.g. a few seconds, i.e. particularly 1, 2, 3, 4 or 5 seconds, or at an unspecific time after the first measure. In particular, a respective second measure may be applied when an operating state of the engine changes or is changed. An operating state of the engine may be considered as changing or changed when certain operational parameters of the engine, e.g. RPM, torque, etc., change from a first interval or range to a second interval or range, e.g. from an exemplary first RPM-interval or RPM-range of 1000 RPM - 1100 RPM to an exemplary second RPM-interval or RPM-range of 1100 RPM - 1300 RPM.

[0137] A respective sequence may particularly result in that the application of the measures will not be acoustically perceived by a passenger, but will be acoustically perceived as constant engine noise 4 even though the noise at least during application of the first measure is actually the noise cancellation signal 3 generated by the EOC apparatus 2.

[0138] In either case, performing the at least one measure to avoid a further increase of the instability of the EOC apparatus 2 and/or at least one measure to decrease the instability of the EOC apparatus 2 may comprise adapting and/or adjusting at least one operational parameter of the EOC apparatus 2. Particularly, performing the at least one measure to avoid a further increase of the instability of the EOC apparatus 2 and/or the at least one measure to decrease the instability of the EOC apparatus 2 may comprise adapting and/or adjusting the step size and/or the forgetting factor of the EOC apparatus 2.

[0139] The step of detecting the instability of the EOC apparatus 2 may comprise detecting if at least one instability condition is met for at least one specific acoustic channel of the EOC apparatus 2. Particularly, the step of detecting the instability of the EOC apparatus 2 may comprise detecting if at least one instability condition is met for at least one specific acoustic channel at at least one harmonic order of the engine 5 at a specific operating state of the engine 5.

[0140] The at least one instability condition may be met when the signal level, i.e. typically an audio input level, of the acoustic signal sensor device 9 and/or the signal level, i.e. typically an audio output level, of the acoustic signal output device 8 reaches or exceeds a pre-definable or pre-defined threshold value for a specific acoustic channel. Particularly, the at least one instability condition may be met when the signal level of the acoustic signal sensor device 9 and/or the signal level of the acoustic signal output device 8 reaches or exceeds a defined threshold value for a specific acoustic channel and for a specific harmonic order of the engine 5 at a specific operating state of the engine 5.

[0141] It is also possible that performing at least one measure to avoid a further increase of the instability of the EOC apparatus 2 (first measure) and/or at least one measure to decrease the instability of the EOC apparatus 2 (second measure) comprises stopping, particularly for a pre-definable or pre-defined period of time, outputting a noise cancellation signal 3 output by the acoustic signal output device 8 through the specific acoustic channel at the respective harmonic order of the engine 5 for which the or an instability condition was met. Hence, in a special scenario, the method may comprise abruptly (temporarily) interrupting of the operation of the EOC apparatus 2, particularly for a pre-definable or pre-defined period of time, e.g. a few seconds, i.e. particularly 1, 2, 3, 4 or 5 seconds, or until an operating state of the engine 5 (e.g. RPM and torque) is (essentially) changed. The abrupt (temporary) interrupt of the operation of the EOC apparatus 2, particularly for a pre-definable or pre-defined period of time, may also be deemed or denoted as a third measure.

[0142] All measures, e.g. particularly the at least one measure to avoid a further increase of the instability of the EOC apparatus 2 and/or the at least one measure to decrease the instability of the EOC apparatus 2, may be performed during a period in which no change of an operating state of the engine 5, e.g. a load state of the engine 5, particularly an engine speed, torque, etc., occurs. As such, the at least one measure may be applied during a(n essentially) stationary operating state of the engine 5 which increases the efficiency of the method because the stationary operating state of the engine 5 is typically, also related with (essentially) stationary operational parameters of the EOC apparatus 2 so that controlling of the EOC apparatus 2 is feasible with comparatively low controlling resources. This also means that the application of a measure for avoiding a further increase of a detected instability of the EOC apparatus 2 and/or a measure for decreasing a detected instability of the EOC apparatus 2 may be stopped when the engine 5 is no longer operated in a stationary operating state, i.e. when a change of an operating state of the engine 5 occurs.

Claims

1. Method for determining an instability of an engine-order-cancellation ("EOC") apparatus (2), the EOC apparatus (2) being configured to generate cancellation signals (3) for cancelling noise generated by an engine (5), the EOC apparatus (2) is assignable or assigned to, for at least one specific harmonic order at a given operating state of the engine (5),

   the EOC apparatus (2) comprising at least one acoustic signal output device (8) configured to output a cancellation signal (3) in a car cabin (6) and at least one acoustic signal sensor device (9) configured to sense a cancellation signal (3) output in the car cabin (6),
   the method comprising the steps of:

   - providing a reference data set including a plurality of engine noise reference signals and related signal levels of respective engine noise reference signals for pre-defined reference operating states of the engine (5), the EOC apparatus (2) is assignable or assigned to;
   - detecting, by a detection device (13), a signal level of at least one cancellation signal (3) during operation of the EOC apparatus (2), or a signal output level of the acoustic signal output device (8), or a signal input level of the acoustic signal sensor device (9), particularly for at least one specific harmonic order at a given operating state of the engine (5);
   - comparing, by a comparison device (14), the detected signal level of the at least one detected cancellation signal (3), or the detected signal output level of the acoustic signal output device (8), or the detected signal input level of the acoustic signal sensor device (9) with a signal level of a corresponding engine noise reference signal from the reference data set;
   - generating, by the comparison device (14), a comparison information indicating the result of the comparison of the detected signal level of the at least one detected cancellation signal (3), or the detected signal output level of the acoustic signal output device (8), or the detected signal input level of the at least one acoustic signal sensor (9) device with a signal level of a corresponding engine noise reference signal;
   - determining, by a determination device (15), an instability of the EOC apparatus (2) based on the comparison information.

2. Method according to Claim 1, **wherein** an instability

of the EOC apparatus (2) is determined when the comparison information meets a pre-definable or pre-defined instability criterion.

3. Method according to Claim 2, **wherein** the instability criterion is met when the comparison information indicates that the difference between the detected signal level of the at least one detected cancellation signal (3), or the detected signal output level of the acoustic signal output device (8), or the detected signal input level of the acoustic signal sensor device (9) and the signal level of the corresponding engine noise reference signal reaches or exceeds a predefined or pre-definable threshold value.

4. Method according to Claim 3, **further comprising** applying a safety factor to the threshold value or using a threshold value comprising a safety factor.

5. Method according to Claim 3 or 4, **wherein** the threshold value is related with at least one static or dynamic configuration parameter of the comparison device (14).

6. Method according to Claim 5, **wherein** the at least one configuration parameter of the comparison device (14) is a dynamic value which depends on at least one operational parameter of the engine (5), the EOC apparatus (2) is assignable or assigned to.

7. Method according to any of the preceding Claims, **wherein** a reference data set is used which is generated by recording engine noise signals induced in a car cabin (6) for a plurality of different operating states of the respective engine (5), the EOC apparatus (2) is assignable or assigned to, with inactive EOC apparatus (2).

8. Method according to any of the preceding Claims, **wherein** at least one reference operating state of the engine (5), the EOC apparatus (2) is assignable or assigned to, is defined by at least one operating state parameter of the engine (5), particularly an engine load state, preferably defined by a specific RPM and/or a torque, and/or by at least one operating mode of the engine (5), the EOC apparatus (2) is assignable or assigned to, particularly based on at least one engine operating map of the engine (5).

9. Method according to any of the preceding Claims, **wherein** at least one reference operating state of the engine (5), the EOC apparatus (2) is assignable or assigned to, relates to a pre-definable or pre-defined operating parameter, particularly engine age, engine running performance, engine temperature, of the engine (5), the EOC apparatus (2) is assignable or assigned to.

10. Method according to any of the preceding Claims, **wherein** at least one reference operating state of the engine (5), the EOC apparatus (2) is assignable or assigned to, relates to or is related with a pre-definable or pre-defined physical parameter, particularly cabin humidity, cabin pressure, cabin temperature, of a cabin (6) of a vehicle (1) comprising the engine (5), the EOC apparatus (2) is assignable or assigned to.

11. Method according to any of the preceding Claims, **wherein** the reference data set includes a, particularly matrix-like, multi-dimensional data space defined by at least two, particularly orthogonal, data axes (A1, A2) each referring to a specific parameter directly or indirectly influencing the engine noise (4) induced by the engine (5), the EOC apparatus (2) is assignable or assigned to, in the cabin (6) of a vehicle (1) comprising the engine (5), the EOC apparatus (2) is assignable or assigned to, wherein the multi-dimensional data space optionally comprises a plurality of cells each correlated with a value of a first data axis and a second data axis (A1, A2.

12. Method according to Claim 11, **wherein** a first axis (A1) refers to a first operating state parameter, particularly RPM, of an engine (5) of a vehicle (1), the EOC apparatus (2) is assignable or assigned to, and a second axis (A2) refers to a second operating state parameter, particularly torque, of the engine (5), the EOC apparatus (2) is assignable or assigned to; wherein the multi-dimensional data space optionally comprises a plurality of cells each correlated with a value of a first data axis and a second data axis (A1, A2).

13. Control unit (10) for an EOC apparatus (2), the control unit (10) being configured to:

- provide and/or process a reference data set including a plurality of engine noise reference signals and related signal levels of respective engine noise reference signals for pre-defined reference operating states of an engine (5), the EOC apparatus (2) is assignable or assigned to;
- detect a signal level of at least one cancellation signal during operation of the EOC apparatus (2), or a signal output level of an acoustic signal output device (8) of the respective EOC apparatus (2), or a signal input level of an acoustic signal sensor device (9) of the respective EOC apparatus (2), particularly for at least one specific harmonic order at a given operating state of the engine (5);
- compare the detected signal level of the at least one detected cancellation signal (3), or the detected signal output level of the acoustic signal output device (8), or the detected signal input

level of the acoustic signal sensor device (9) with a signal level of a corresponding engine noise reference signal from the reference data set;
- generate a comparison information indicating the result of the comparison of the detected signal level of the at least one detected cancellation signal (3), or the detected signal output level of the acoustic signal output device (8), or the detected signal input level of the at least one acoustic signal sensor device (9) with a signal level of a corresponding engine noise reference signal;
- determine an instability of the EOC apparatus (2) based on the comparison information.

14. EOC apparatus (2), comprising a control unit (10) according to Claim 13.

15. Vehicle (1), comprising a car cabin (6), an engine (5), and an EOC apparatus (2) according to Claim 14.

FIG 1

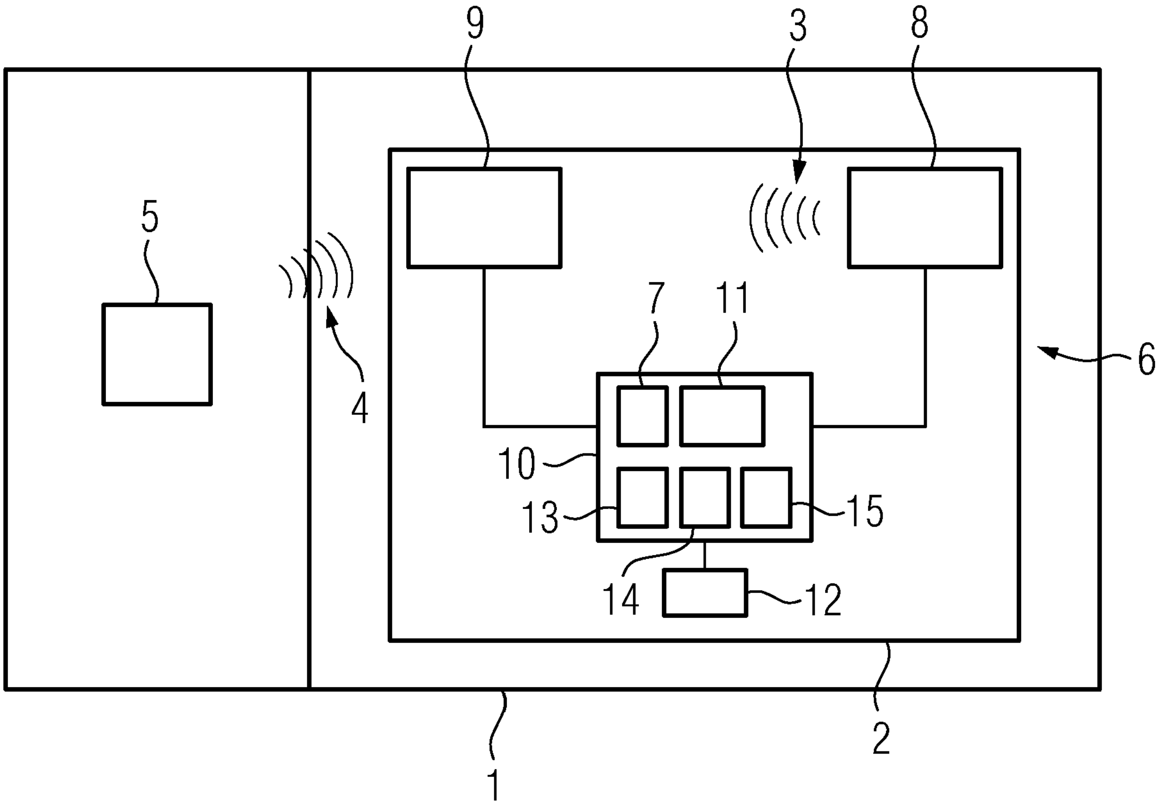


FIG 2

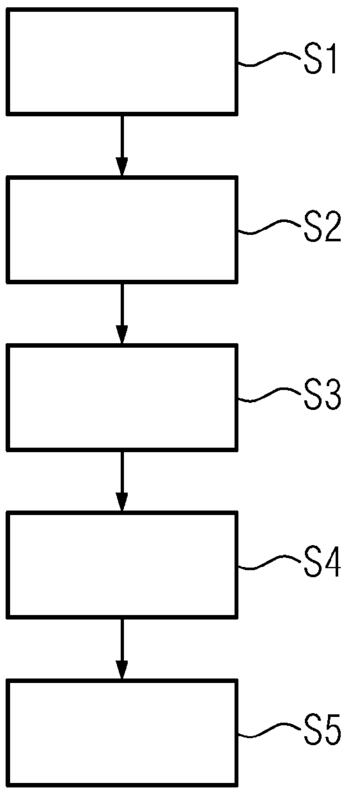
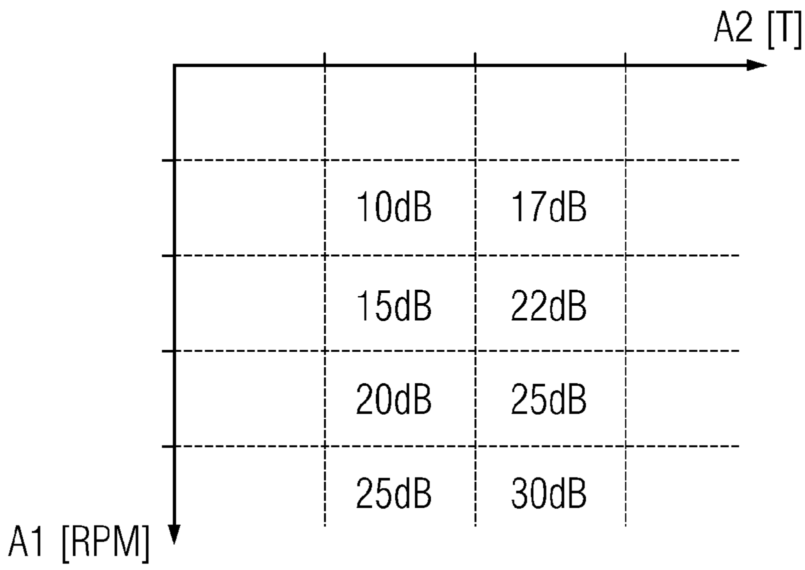

S1
S2
S3
S4
S5

FIG 3


A2 [T]
10dB
17dB
15dB
22dB
20dB
25dB
25dB
30dB
A1 [RPM]