

Vibration isolation system with diagnostic function, and diagnostic method

Description

5 The invention relates to a preferably stationary vibration isolation system with diagnostic function and to a diagnostic method. In particular, the invention relates to an active, stationary vibration isolation system on which a machine for processing semiconductor devices and/or nanostructured substrates or elements, in particular wafers, masks, or displays, such as flat-panel displays, or for measuring semiconductor devices and/or nanostructured substrates, such as an
10 electron microscope, is arranged.

Furthermore, laboratory equipment and/or medical devices, such as imaging examination devices such as magnetic resonance tomographs (MRT) or microscopes, can also be arranged on the stationary vibration isolation system.
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Background of the invention

Active, stationary vibration isolation systems are used in particular in the semiconductor industry for supporting processing machines, such as lithography devices, and measuring devices, such as electron microscopes, in order to support sensitive devices for processing semiconductor components in a vibration-isolated manner.
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Such a vibration isolation system for a machine or machine parts usually consists of a plate which is supported in a vibration-isolated manner on at least three, often four, and in some cases more than four vibration isolators, each of which comprises a spring.
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Alternatively or additionally, one or more isolators can be used which are not placed on a plate but are arranged in the device between two parts, for example between a base frame and a stage or a granite plate. Isolators can also be arranged outside the machine; for example, the machine as a whole can be placed on one or more isolators.
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This protects the machine or machine parts from vibrations. The machine or machine parts, together with a plate if applicable, form the vibration-isolated load.

5 Active vibration isolation systems are particularly well known in practice, in which the vibration isolators comprise actuators, in particular magnetic actuators, in addition to the spring, which actively counteract vibrations. There are also vibration isolation systems in which additional sensors or actuators are attached to other parts of the machine separately from the vibration isolators.

10 Vibrations are detected by sensors, which can be arranged both at the base of the vibration isolator and/or near the base of one or more vibration isolators, as well as on the vibration-isolated load. Based on the sensor signals, the actuators are controlled in order to compensate for vibrations by generating counterforces.

15 Such active control can be used to counteract both vibrations entering the system from outside and vibrations generated by the vibration-isolated load itself (e.g., by a movable platform, such as a stage, or a moving robot).

20 The applicant's patent specification EP 2 295 829 B1 shows a vibration isolation system in which actuators are provided to generate compensation forces in several degrees of freedom.

Such vibration isolation systems comprise a control unit (often referred to as a controller) for processing the sensor signals, which detects the sensor signals and generates control signals based on the sensor signals, by means of which the actuators are controlled in order to generate compensating forces.

25 The control unit can be designed as a central processing unit to which both the sensors and the actuators of all isolators of the vibration isolation system are connected. Document EP 3 726 094 A1 of the applicant describes a method for controlling such a stationary vibration isolation system.

30 The invention is based on the task of further improving or better assessing the performance of the vibration isolation system and thus the performance of the machine or device connected to the vibration isolation system, or of optimizing the availability of the machine.

In particular, the invention is based on the task of obtaining further data on the vibration isolation system and/or on the vibration-isolated machines or devices, with which, for example, the performance of the machines or devices can be determined or predicted, or which allow changes to or in the environment of the machine, such as signs of wear, to be detected in good time and
5 provide information so that remedial action can be taken. In this context, the performance of the machines is understood to mean their precision, accuracy, availability, and productivity.

The inventors have taken on this task.

10 This task is accomplished by a vibration isolation system with a diagnostic function and a method for diagnosing a vibration isolation system and/or a load supported on it in a vibration-isolated manner according to one of the independent claims. Preferred embodiments and further developments of the invention can be found in the respective subclaims.

15 The subject matter of the invention is therefore, in a first aspect, a

vibration isolation system, in particular with a diagnostic function, preferably a stationary, active vibration isolation system, by means of which a vibration-isolated load can be supported, comprising
20 at least one vibration isolator, preferably a plurality of vibration isolators, which can counteract vibrations occurring during operation by means of actuators,
at least one sensor, preferably a plurality of sensors, which are designed to record measured values relating to the vibration isolation system and/or the supported load and/or the environment and to make them available as input data to a computer-assisted
25 method for performance analysis of the vibration isolation system and/or the supported load.

The vibration isolators can actively or passively counteract vibrations that occur. Active and passive vibration isolators can also form components of the vibration isolation system together.

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Measured values relating to the supported load may relate in particular to a machine or parts thereof supported by the vibration isolation system. For example, a vibration sensor may be attached to an optical sensor of such a machine or, in the case of an electron microscope, to the

electron beam column. The sensor does not even have to be attached to the supported load or the vibration isolation system itself. For example, vibrations of the system, the load, or parts thereof could also be detected by optical sensors located outside this system.

- 5 For the purposes of this disclosure, performance analysis is understood to mean a classification of the operating state with regard to harmful disturbances and effects. In a vibration isolation system, these disturbances are in particular effects caused by undesirable movements of the system, especially vibration movements.

- In addition to the classification of disturbance variables, the performance analysis also includes
 10 the classification of whether the system is working well, in particular optimally, including whether the system is optimally adjusted or set. For example, performance can be classified as good or bad in terms of the settling time after the movement of a component of the system, such as after the movement of an xy table, but also in terms of the frequency responses that occur during this process, or other environmental conditions, such as other processes or operating conditions
 15 occurring simultaneously in the machine, temperatures, or load cases on the stage.

- In general, a distinction can be made between operating states and processes or machine functions with regard to performance analysis. In both cases, forces from the machine's actuators or from the environment are introduced into the dynamic system, the structural dynamics of the
 20 machine. In structural dynamics, vibrations are excited which can be detected by the sensors of the vibration isolation system. In operating states, quasi-static force introduction or constant vibration states are assumed. In processes or machine functions, transient force introductions or vibration states are present. In both cases, the sensors of the vibration isolation system can detect and evaluate the amplitude and spectral composition of the vibration signals. In the case of
 25 processes or machine functions, the time behavior of the vibration amplitudes and the spectral composition are also taken into account. From these observations, evaluations and classifications of the respective operating states and processes or machine functions can then be derived as a performance analysis.

- 30 In particular, the performance analysis includes the evaluation of a large number of measured values provided by the sensor(s) of the vibration isolation system, as well as the evaluation of the operating state of the system, expressed by an output value. However, additional or other information can also be used or utilized, such as information on whether the machine is producing

the required quality. The output value can comprise one of several classes that characterize the operating state of the system. In the simplest case, a classification into only two classes is made, which characterize a good and a bad operating state. The output value can also be a sliding value within a specified range, for example in the form of a percentage. An output value of 100% could indicate an optimal operating state, while a value of 75% could indicate a barely acceptable state, for example.

Movements, such as vibrations and their suppression, are naturally of particular importance for the performance of a vibration isolation system. Therefore, according to a second aspect of this disclosure, a vibration isolation system is provided for the vibration-isolated supporting of a load, comprising at least one, preferably several vibration isolators and at least one sensor, wherein the sensor is arranged to detect a movement variable, in particular a mechanical vibration, movement, or acceleration, as well as a computing device, wherein the computing device contains an artificial neural network, wherein the artificial neural network is designed to process data on the movement magnitude provided by the at least one sensor and to classify whether the vibration isolation system with the supported load is in an operating state with sufficiently little or too much movement disturbance. This classification can then be output. In a simple case, the output can be intended to inform the operating or monitoring personnel about the operating state. The output can also be used by the vibration isolation system itself or another - device connected via information technology to influence the operating state if it has been classified as disturbed by too much movement. Movement variables that serve as input data can primarily be vibrations, in particular their amplitude and frequency. However, other alternative or additional movement variables can also be accelerations and velocities. For the sake of simplicity, the aforementioned operating states are also referred to below as "good" (operating state sufficiently unaffected by movement) or "bad" (operating state affected by too much movement). Of course, as explained above, the classification can include further or finer gradations, for example in the form of a sliding output value.

A particularly preferred form of data output by the sensor and processed by the artificial neural network are spectrograms. For the purposes of this disclosure, a spectrogram is understood to be, in particular, a data set containing the temporal progression of the amplitudes of several vibration frequencies.

The present invention makes it possible to use sensor measurements as input data to obtain performance data of the vibration isolation system and/or the supported load.

5 The supported load can comprise, for example, processing machines or parts thereof, in particular in the semiconductor industry, such as machines for processing semiconductor devices and/or nanostructured substrates or elements, in particular wafers, masks, or displays, lithography equipment, or measuring devices or equipment, in particular for measuring semiconductor components and/or nanostructured substrates, such as an electron microscope, or other sensitive devices, machines, or systems, for example laboratory equipment or medical
10 devices, such as imaging examination devices such as magnetic resonance imaging (MRI) scanners. For the sake of brevity and simplicity, the term "machine" or "device" is used generally below.

15 In many embodiments of the invention, the supported load may comprise a plate, in particular as a mount, on which the machine or device can be arranged and secured. Devices or machines arranged on such a plate are thus protected from vibrations. The plate and the devices or machines arranged on it can together form the vibration-isolated load. The supported load can be supported by means of a three-point support via three, but also via four or more vibration
20 isolators.

According to a preferred embodiment of the invention, the sensors are designed to record a variety of information or measured values relating to the vibration isolation system and/or the supported load or even the environment during operation and make them available to suitable computer-aided processes. According to the invention, this input data can be used for a
25 performance analysis of the vibration isolation system and/or the supported load. The result of the performance analysis can be used to diagnose the vibration isolation system and/or the supported load, so that the vibration isolation system can have a diagnostic function.

30 According to a preferred embodiment of the invention, the sensors can provide a wide range of information, for example measured values, which can be seen in certain contexts and whose evaluation using rule-based or statistical methods is only of limited use or even impossible. This can be of great interest, for example, when using the vibration isolation system on or with

machines or systems in the semiconductor industry or in the field of inspection or measurement technology, or even in general when used on or with machines.

5 For example, it may be helpful for certain types of machines to reduce or eliminate vibrations as much as possible. The performance, for example, the optical resolution of a measurement or inspection system, can depend heavily on the vibrations that occur.

Accordingly, there may be a complex relationship between the vibrations that occur and the performance of the load supported by the vibration isolation system.

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To reduce the vibrations, sensors can be provided which can measure vibrations occurring at defined points in the system. These can be, for example, acceleration sensors which can detect acceleration in one of the spatial directions x, y, or z of a Cartesian coordinate system. Since in many cases there is a relationship between the performance of the vibration isolation system and the supported load, whereby this refers in particular to the performance of the supported machine or device, and the vibrations that occur, but at the same time the vibrations can also be measured, it is possible to make a statement about the performance of the supported load, or the supported machine or device, based on the measured values of the sensors.

20 The inventors have discovered that further information can be obtained from the sensor readings. For example, it is possible to determine whether a supported machine is still operating within its specifications or not. The characteristics of the vibrations can also be used to determine the cause of a possible deviation from the specification, for example, whether a mounted xy table or cross table ("stage") is working correctly, or whether, for example, a vacuum pump connected to the system is transmitting too many vibrations to the system, or whether there is a seismic cause for the deviation. For the purposes of this disclosure, the characteristics of the vibrations are understood to be temporal changes in the spectral distribution and correlations between signals, whereby one signal represents the excitation and the other signal or signals represent a response behavior. In general, the characteristics of the vibrations can also be represented by the time-
25 dependent intensity of the various frequencies of the occurring frequency spectrum, for example after an impulse excitation.
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Furthermore, information about the operating state of the machine can also be obtained from the characteristics of vibrations, for example, whether an xy table is in a certain position, such as a transfer position for a substrate, or whether it is still in motion. The vibration spectrum can change depending on the position of the table. Certain vibration patterns can also indicate specific operating conditions or faults, such as a defective vacuum pump.

Furthermore, information about the wear and tear or maintenance status of the machine can be obtained from the characteristics of the vibrations. This information can also be made available to the machine control software or the operating personnel.

The current operating conditions of the supported load can also be taken into account, for example, idle state, acceleration, or movement of an xy table.

Other measurable factors that influence the performance of the machine include vibrations in the environment, such as the floor, especially at the installation site, or existing electromagnetic fields, or the temperature.

A subject matter of the present invention is therefore to use the information obtained by the sensors of a vibration isolation system not only directly for vibration isolation, i.e., to control the actuators for vibration reduction, but also for further analysis of the performance of the vibration isolation system and/or the load supported on it, and in this way to perform a performance analysis that enables diagnosis.

According to one embodiment of the invention, it is also intended to use this information, for example, for the control and regulation of the vibration isolation system and/or the load, or the machine or device, supported on it, or other system components such as a vacuum pump.

The evaluation of the measured values can be very complex. In the case of data relating to vibrations, for example, different frequencies with different amplitudes can occur, which can be represented in the time domain, in the frequency domain, or in a spectrum, among other things. Additional environmental conditions or machine states that need to be taken into account further increase the complexity.

Rule-based, computer-aided procedures and methods can be used for evaluation or performance analysis. Here, certain rules can be defined which can generate initial information based on the measured values or data. An example of a simple rule is that a machine no longer operates within the specification if the amplitude of a vibration exceeds a specified limit value.

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Therefore, analytical, statistical, or other mathematical methods can be used to generate the desired information according to analytical or statistical rules that are to be defined. These rules are generally generated manually.

10 This allows information to be obtained for a simple performance analysis, which can include information on the following aspects, for example:

- Earthquakes or floor vibration,
- "Windowing function": is the xy table in position for a transfer,
- 15 – Monitoring of vibration levels according to limit values.

Statistical or other rule-based methods, which require rules to be created and stored manually, according to which the desired information is generated from the input data, reach their limits when the input data becomes too complex or interdependent.

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For example, it may be the case that a vibration or acceleration may exceed a limit value if this occurs in a specific operating state of a machine as supported load, in which case this short-term exceedance is not or hardly relevant to performance, and/or if there are compensating influences on the machine at the same time, and/or if the exceedance does not occur frequently. Manually
25 defining rules for such complex relationships is not only very time-consuming, but also very error-prone and, in the case of complex relationships, impossible or at least unreliable.

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According to the invention, a computer-assisted performance analysis based on artificial neural networks is therefore provided, which can be trained instead of fixed rules. In this way, it is possible to obtain significantly more information about the performance of the vibration isolation system and/or the supported load and make it available for control and regulation.

In one aspect of the invention, a vibration isolation system is provided which uses artificial intelligence methods or processes, preferably artificial neural networks, for performance analysis of the vibration isolation system and/or the supported load.

5 The input data obtained from the measured values may relate to the vibration isolation system as such, the supported load, or other information. This input data can be used individually or in combinations. For diagnostic purposes, the information can be classified, both individually and in combinations.

10 Suitable sensors can be selected and provided to record the desired measured values. If specific sensors are mentioned below, this is only a selection and should not be considered exhaustive.

The input data may, for example, relate to the vibration behavior of the vibration isolation system, including the signal distribution in the frequency spectrum (changes in the frequency range) and
15 the impulse and decay behavior (changes in the time range). Suitable sensors may include, for example, acceleration sensors, preferably for measurement in three spatial directions.

To record the underlying measured values, the sensors can be provided in or on the vibration isolation system and measure, for example, the vibration behavior in one direction or in several
20 directions. Preferably, sensors with one degree of freedom are used. By using several such sensors, several degrees of freedom, for example up to six, or vibration directions can then be recorded accordingly. According to another embodiment, however, one or more sensors can also be used which can measure in more than one direction or in more than one degree of freedom.

25 For this purpose, the sensors can be arranged not only in or on the vibration isolation system, but also on the supported load, for example, on or in a supported machine or on or in a supported device. If the supported load comprises a plate, it may also be advantageous, according to a preferred embodiment of the invention, to assign the sensors to this plate.

30 Furthermore, the sensors can also be arranged on or in other associated components, for example on an xy table, on an optical element, on a cover, on a vacuum pump, or on another component of the vibration isolation system.

The input data may also include operating states ("On", "Off", "Idle", "In Process", "Service", "Fault") of the vibration isolation system and/or individual components of the supported load . In this way, information can be obtained regarding the standstill or operation of the vibration isolation system and/or the supported load, a possible acceleration, a movement of an xy table, or the operating states of a component, such as a vacuum pump. For this purpose, optical sensors, ultrasonic sensors, or distance sensors may be provided, for example.

Additional sensors can be assigned to the environment of the vibration isolation system, for example, the floor or the installation site, or to the surroundings, for example, other components in the vicinity of the vibration isolation system. In particular, it is advisable to select components that can transmit vibrations to the vibration isolation system and/or the supported load.

Furthermore, it may be helpful to record the strength and spectral composition of electromagnetic fields prevailing at the installation site of the vibration isolation system, which may also impair the performance of the vibration isolation system and/or the supported load. In the sense of the invention, information other than vibration information can also be used to determine the performance data of the machine. For example, instead of a magnetic field spectrum, it is also possible to determine whether the machine is still operating within specifications, i.e., within the permitted tolerances, with this magnetic field. A combination of a magnetic field and vibration data can also be used for this purpose. Although this is becoming increasingly complex, it is precisely this that is the advantage of the device described here, whose strength lies in its ability to process complex relationships. In many cases, the performance of the supported load depends on various environmental factors, such as magnetic fields. By recording various signals, the effect of combinations of different disruptive influences on the performance of the machine can also be taken into account. Magnetic field sensors or fluxgate magnetometers or saturation core magnetometers can be used to measure electromagnetic fields.

It may also be advantageous to measure the strength of acoustic fields present at the installation site. Similar advantages apply here as in the embodiments described above with the detection of magnetic fields. In many cases, the performance of the supported load depends on various environmental factors, such as sound pressure. By detecting various signals, the effect of combinations of different disruptive influences on the performance of the machine can also be

taken into account. For this purpose, pressure sensors and microphones, for example, can be provided.

5 Furthermore, for the same reasons, it may also be advantageous to obtain information about the temperature at the installation site and/or at components of the vibration isolation system and/or the supported load. Appropriate thermocouples may be provided for this purpose.

10 In many cases, the performance of the supported load depends on various environmental factors, such as temperature. By recording various signals, the effect of combinations of various disruptive influences on the performance of the machine can also be taken into account. In this way, it may be possible to detect faulty operating conditions of the vibration isolation system or the supported load, for example, overheating of a faulty component, or to detect operating conditions in which normal operation is no longer possible, for example, in the case of optical measurements.

15 Based on the measured variables described above, it is apparent that any correlations between any input variables can be determined in relation to the performance data of the machine, provided that they are available and measurable. Without being limited to specific measured variables and their sensors, a further development of the invention therefore provides that the vibration isolation system is set up to perform a classification of the performance status of a device supported by the vibration isolation system on the basis of a correlation of the input data from the multiple sensors that record different measured variables.

25 In accordance with the invention, a performance analysis can be carried out on the basis of the input data using computer-aided methods, in particular with the support of artificial neural networks, in order to classify the performance of the vibration isolation system and/or the supported load.

30 The classification may, for example, comprise the characteristics "good" or "bad". Based on this performance analysis, the diagnosis may, for example, provide the evaluation "operation possible" or "operation not possible". A classification as "good" or "bad" may, for example, also refer to the throughput of a device supported by the vibration isolation system. If the settling times after a movement of the device are too long and if the process performed by the device depends on whether the device is at rest, an unfavorable vibration spectrum leads to downtimes and thus

to a slowdown in production or measurement. If, on the other hand, the process does not directly take vibrations into account, the vibrations can in turn influence the measurement accuracy or production accuracy. In this regard, too, the condition of the vibration isolation system can be classified as, for example, "good", "acceptable", or "poor". Further diagnoses could be "operation possible with restrictions" or "operation possible with changes to the control or regulation of a component".

The diagnosis may therefore concern, for example, the setting or adjustment of the vibration isolation system itself, whereby the specification of the vibration isolation system can be used as a reference value. The classification "good" may mean that the vibration isolation system is operating within the specification ("operation possible").

In a further embodiment of the invention, the supported load can be analyzed, for example, to determine whether a supported machine or device is operating or can operate within the specification ("good") or not ("bad"). Here, too, the specification of the machine or device can be used as a classification criterion. All of the signals described above can be used as input information for classification, for example, the specification of the environment, such as floor vibration level, or electromagnetic or acoustic environmental conditions and other vibration data, whereby the various data can also be combined for classification.

According to the invention, computer-aided methods, preferably comprising or based on artificial neural networks, can be used to generate the output data from the input data. Suitable data preparation or processing methods, which will not be discussed in detail here, can be used to prepare the measured values or generate the input data.

For the performance analysis according to the invention, different configurations of neural networks for machine learning can be used.

In a preferred embodiment of the invention, the artificial neural network can train at least one model comprising at least one folding level (convolutional layer) and/or at least one neuron level (neural layer). It may also preferably comprise at least one of the following additional components: an activation layer, a pooling layer, a flatten layer, and/or a drop layer.

Advantageously, the artificial neural network comprises data for weighting at least one, preferably

several, and particularly preferably all weightable components of the model. This weighting can be determined particularly easily by a training process.

Possible layers of a suitable artificial neural network are briefly outlined here:

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- Input layer: here, the spectrogram is read into the network
- Folding level or Convolutional layer(s): A variety of configurations are possible (e.g., regarding the number of layers, the number and size of filters, the activation functions, MaxPooling functions).

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- Flatten layer: Conversion of the 3-dimensional result of the last convolutional layer into a one-dimensional format for transfer to the neural layers

- Neural layer: A variety of configurations are possible (e.g., regarding the number of layers, the number of neurons, the activation functions, dropouts). In certain cases, it is also possible to dispense with the neural layers altogether (this also applies to the classification layer). In such a

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- case, the classification can also be generated by a convolution layer.
- Neural layer for classification: The neurons represent the desired classes, e.g., two neurons for the classes "good" and "bad". During the learning process, the parameters of the network are optimized by iterative target/actual comparison of the generated classification; these parameters are then applied in the classification application. A softmax activation can be used to generate a

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- float value to represent the class membership of the spectrogram to the two classes "good" and "bad".

The learning process of such artificial neural networks is often understood as a self-adaptive algorithm or "machine learning". If a series of hierarchical levels or "layers" is used, this is also referred to as "deep learning," although the number of "layers" required for this is not precisely defined.

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The training or learning of the artificial neural network will be briefly outlined using the example of input data relating to the vibration behavior of the vibration isolation system.

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The frequency of the vibration of the vibration isolation system is used as the measured variable, which is recorded by suitable sensors and represents the input variable for the artificial neural network in the form of spectrograms. Each spectrogram can represent a process that is to be

evaluated as "good" or "bad", provided that these two classes are to be formed for analysis. This is followed by "labeling", i.e., the assignment of the spectrograms to the "good" or "bad" classes.

5 Variances can be generated by augmenting the spectrograms, i.e., by modifying or transforming the data sets. This means that deliberate deviations in the spectrograms or input variables are generated, preferably also with the aid of a computer, in order to increase the number of different training data sets.

10 In this way, i.e., by recording a large number of positioning sequences and possibly augmentations, a large number of spectrograms can be generated with which the artificial neural network used can be trained. The spectrograms are assigned to the intended categories or classes for this purpose. According to one embodiment of the invention, the assignment can also be performed automatically with computer support.

15 For good performance analysis and diagnosis, it is helpful if sufficient spectrograms are available in the corresponding classes. In certain cases, 10 to 100 input data sets, for example spectrograms, per class may already be sufficient, but it is better to provide, for example, approximately 1.000 or even 10.000 or more data sets per class in order to improve and increase the quality of the performance analysis.

20 The artificial neural network is created, for example, a convolutional network as described above. In the example discussed, the artificial neural network can have two output neurons, which represent the two defined classes "good" and "bad". In this way, learning can take place. The training of an artificial neural network is generally known to experts and will therefore not be
25 discussed further here. The result is the creation of a so-called "weights file", which contains the parameterization of the individual elements and connections of the CNN network.

30 It goes without saying that the training method described above is only one example and that the number and type of classes as well as the input variables may vary, and that other architectures of artificial neural networks and other input data may also be used.

For example, 4-dimensional input information can also be used, in which the fourth dimension can be a time axis, along which the times for different spectrograms are located.

It is also understood that, in regular operation of the vibration isolation system, a previously trained or taught artificial neural network is preferably used.

5 In an advantageous embodiment of the invention, it is provided that the artificial neural network can be trained or further trained during regular operation of the vibration isolation system. This offers the advantage that the vibration isolation system according to the invention can be easily adapted to the conditions prevailing at the installation site.

10 In a further advantageous embodiment of the invention, it is provided that the artificial neural network uses trained data from a previous learning process or from another external source.

The performance analysis can be used to generate information or output data, for example control parameters for controlling or regulating the vibration isolation system and/or the supported load. An important aspect of the invention is therefore that these control parameters can be used
15 directly or indirectly to control or regulate the vibration isolation system and/or the supported load.

The invention therefore also includes a method for controlling or regulating a vibration isolation system, whereby control parameters for controlling the vibration isolation system are obtained and used during operation as part of a performance analysis as described above. In this way, a
20 self-learning vibration isolation system can be provided which can, for example, respond to changes in the environment, such as vibrations occurring via the ground.

The vibration isolation system may comprise an active, stationary vibration isolation system as described above. In this case, a load supported vibration-isolated can be supported by a plurality
25 of vibration isolators, and vibrations can be actively counteracted by a plurality of actuators.

The invention also includes, in a further aspect, a method for diagnosing a vibration isolation system comprising a vibration isolation system as described above.

30 The invention also includes, in yet another aspect, a processing machine, in particular in the semiconductor industry, such as a machine for processing semiconductor devices and/or nanostructured substrates or elements, in particular wafers, masks, or displays, a lithography device, or a measuring device or apparatus, in particular for measuring semiconductor

components and/or nanostructured substrates, such as an electron microscope, or another sensitive device, a machine or system, for example a laboratory device or a medical device, such as an imaging examination device such as a magnetic resonance tomograph (MRT), comprising a vibration isolation system as described above.

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The method can enable analysis of the performance of the vibration isolation system, but also of the supported load.

Further details of the invention are apparent from the description of the embodiments shown and
10 the appended claims.

The drawings show:

- 15 Fig. 1 a schematic top view of the basic structure of a stationary vibration isolation system,
- Fig. 2 a schematic example of the structure and use of an artificial neural network with machine learning for the evaluation of input data,
- 20 Fig. 3 a schematic diagram of a possible structure of a suitable artificial neural network,
- Fig. 4 schematically shows a process for training an artificial neural network,
- 25 Fig. 5 the vibration behavior of an xy table in the three directions of a Cartesian coordinate system during different operating phases,
- Fig. 6 an example of a spectrogram,
- 30 Fig. 7 an example of the process of training an artificial neural network using spectrograms according to a first embodiment,

	Fig. 8	an example of the classification process using spectrograms obtained during regular operation according to the embodiment shown in Fig. 7,
	Fig. 9	an example of a spectrogram according to a second embodiment,
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	Fig. 10	an example of the process of training an artificial neural network using spectrograms according to the second embodiment.
	Fig. 11	an example of the classification process using spectrograms obtained during regular operation according to the embodiment shown in Fig. 10,
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	Fig. 12	an example of input data according to a third embodiment,
	Fig. 13	an example of the process of training an artificial neural network using input data according to the third embodiment,
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	Fig. 14	an example of the classification process according to the embodiment from Fig. 13,
20	Fig. 15	an example of input data according to a fourth embodiment,
	Fig. 16	an example of the process of training an artificial neural network using input data according to the third embodiment,
25	Fig. 17	an example of the classification process according to the embodiment from Fig. 15, and
	Fig. 18	schematically a process for adapting an artificial neural network.
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Detailed description of preferred embodiments

5 In the following detailed description of preferred embodiments, for the sake of clarity, the same reference numerals denote essentially the same parts in or on these embodiments. However, for better clarification of the invention, the preferred embodiments shown in the figures are not always drawn to scale.

10 Fig. 1 shows a schematic top view of the basic structure of a vibration isolation system 1. The vibration isolation system 1, which is also shown schematically, comprises a plurality of vibration isolators 2a - 2d, which comprise a spring and support a vibration-isolated load 4. The supported load 4 can be supported by means of a three-point support via three or four vibration isolators 2a-2d, as shown in the example in Fig. 1.

15 In the example shown, the supported load 4 comprises only the plate; a vibration-isolated supported machine or device is not shown for the sake of clarity. In other words, in regular operation, the supported load typically comprises, in addition to the plate, the machine or device to be supported in a vibration-isolated manner.

20 The supported load 4 can, for example, comprise processing machines or parts of such machines, in particular in the semiconductor industry, such as machines for processing semiconductor components and/or nanostructured substrates or elements, in particular wafers, masks, or displays, lithography devices, or measuring devices or equipment, in particular for measuring semiconductor components and/or nanostructured substrates, such as an electron
25 microscope, or other sensitive devices, machines, or systems, for example laboratory devices or medical devices, such as imaging examination devices such as magnetic resonance imaging (MRI) scanners.

30 Each of the vibration isolators 2a - 2d comprises actuators 5a - 5d and sensors 6a - 6d. The sensors 6a - 6d detect vibrations of the vibration-isolated supported load 4 and/or the base of the vibration isolator coupled to the ground. The sensors 6a-6d, like the actuators 5a-5d, are connected to a computing device 3, which in the example is centrally located. Based on the

signals from sensors 6a - 6d, the computing device 3 calculates compensation signals for controlling actuators 5a - 5d. In this case, the computing device 3 also functions as a control unit.

5 The vibration isolators 2a - 2d are preferably effective in both the vertical and horizontal directions, as in the embodiment. The vibration isolators 2a - 2d may comprise a spring, in particular a pneumatic spring. Sensors, springs, and actuators can be integrated components of such a vibration isolator or can also be designed as separate units. In the latter case, the separate, in particular spatially adjacent units of sensors, springs, and actuators together form a logical unit that has the function of an active vibration isolator, which not only acts as a passive
10 spring but also actively counteracts vibrations.

The vibration isolation system 1 according to the invention comprises a plurality of actuators by means of which vibrations are actively counteracted by generating forces acting on the vibration-isolated supported load. The actuators can be designed in particular as magnetic actuators, as in
15 the embodiment, or as pneumatic actuators. Control parameters for controlling or regulating the vibration isolation system 1 can be converted into a current, for example, in the form of control signals via a digital-to-analog converter (not shown) in order to control the magnetic actuators.

The computing device 3 is designed to execute a program which generates control signals to
20 generate the compensating forces, taking into account the measured values of the sensors. The control signals are signals that serve to control the actuators on the basis of the sensor signals and to generate counterforces. Preferably, compensation forces are generated in at least two, and particularly preferably at least three, degrees of freedom via the actuators in the isolator.

25 According to a preferred embodiment, the vibration isolation system 1 shown in Fig. 1 comprises actuators 5a-5d, via which compensation forces can be generated in three degrees of translational freedom according to the three spatial directions x, y, and z and/or in three degrees of rotational freedom.

30 The vibration isolation system 1 according to the invention can be designed as a stationary, active vibration isolation system, which means that it stands firmly on a designated installation surface during operation and can actively counteract vibrations that occur, which can be transmitted via the floor, for example. In another embodiment, the vibration isolation system is

passively constructed. In this case, the computing device is designed in particular to monitor the operating state of the system with the supported load on the basis of the input data from the sensor(s) using performance analysis.

- 5 The measured values of the sensors are made available as input data to the computer-aided method, which is stored as a program in the computing device 3, and are used not only for vibration damping but also for a performance analysis of the vibration isolation system 1 and/or the supported load 4. This allows performance data of the vibration isolation system 1 or the supported load 4 to be obtained.

10

The sensors 5a-5d are set up to record a variety of information or measured values during operation concerning the vibration isolation system 1 and/or the supported load 4 or even the environment, for example the installation surface, in order to enable a performance analysis of the vibration isolation system 1 and/or the supported load 4 as part of a diagnosis. For the sake of simplicity, only the sensors 5a-5d associated with the plate are shown in the illustrated embodiment. Additional sensors may be associated with a supported device or machine and/or the environment, for example, the floor or installation surface, the wall, the ceiling, or the like.

15

According to the invention, a computer-aided performance analysis based on artificial neural networks is provided, which can be trained instead of fixed rules. In Fig. 1, an artificial neural network 10 is shown schematically as a component of the computing device 3, in particular designed as a control unit, for illustrative purposes only. The invention therefore provides a vibration isolation system 1 that uses artificial intelligence methods, in particular artificial neural networks, for performance analysis and diagnosis of the vibration isolation system 1 and/or the supported load 4.

20

25

The input data obtained from the sensor measurements may relate to the vibration isolation system 1 as such, the supported load 4, or other information. This input data can be used individually or in combinations. For diagnosis, the information can be classified both individually and in combinations.

30

In the embodiment shown in Fig. 1, the input data includes the vibration behavior of the plate. This can include the amplitude, period duration, frequency, and/or frequency spectrum of the

plate. For this purpose, sensors 5a-5d are designed as acceleration sensors. In one example, the acceleration data in the x-direction of the acceleration sensor 6a of the isolator 2a is used here.

5 The following is an example of an embodiment of the vibration isolation system 1 according to the invention, which is designed to enable the quality of the setting or adjustment of the vibration isolation system 1 to be classified as "good" or "bad". It is understood that these two classes are only given as examples, and that other classes, such as "medium", or other classifications are also possible and conceivable. For the embodiment, a plate with an xy table ("stage") is assumed to be the load 4 supported vibration-isolated. This xy table allows movement in the x and y spatial
10 directions.

It is apparent to the skilled person that the xy table specified in the examples is only selected as an example for illustration purposes and that the underlying principles and methods also apply to other mounted machines and devices.

15

Fig. 2 schematically illustrates, using an example, the structure and use of an artificial neural network with machine learning for the evaluation of input data. From the input data, for example the amplitude of an oscillation over time or an acceleration representing the oscillation, a spectrogram can be generated by means of data processing, in the example the temporal course
20 of the frequency spectrum, which can be entered into the artificial neural network. The output data is a classification, i.e., an assignment of the spectrogram to the classes "good" or "bad".

Fig. 3 shows a schematic representation of a possible structure of a suitable artificial neural network. The numbers indicate the different levels or layers, which for the sake of simplicity will
25 only be briefly mentioned below.

- (1) Input layer
- (2) Folding level or Convolutional layer(s)
- (3) Flatten layer
- 30 (4) Neural layer
- (5) Neural layer for classification.

In a suitable embodiment of the invention, the artificial neural network forms at least one model comprising at least one Folding level (convolutional layer) and/or at least one neuron level (neural layer).

- 5 The artificial neural network is fed with data, in the example with spectrograms, for weighting at least one, preferably several, and particularly preferably all weightable components of the model. This weighting can be determined particularly easily by a training process.

Fig. 4 schematically shows a suitable, possible sequence for training an artificial neural network, whereby the output data comprises two classes. The sequence comprises the steps designated by reference numerals 101 to 109 in the flowchart. In step 101, data is recorded. Step 102 is data processing. In step 103, the processed data is labeled. This is followed by augmentation in step 104, resulting in a set of training spectrograms (step 105) and a set of test spectrograms (step 106). This is used to create a network, for example a CNN network, in step 107. In step 108, the
15 neural network is trained, whereupon a weight vector or weight file is created in step 109. The individual steps are described in more detail below with reference to the example in Fig. 5:

- 20 (1) Recording of vibration data, in the example (Fig. 5) the amplitude of the acceleration of the mounted load in the spatial direction x over time, determined at a vibration isolator
- (2) Generation of the spectrograms used here as input variables for the network. In the example, each spectrogram represents a process to be evaluated as "good" or "bad".
- (3) Labeling, i.e., assignment of the spectrograms to the defined classes "good" or "bad".
- 25 (4) Optional generation of variances by augmenting the spectrograms. This can be done manually, but preferably also with computer support.
- (5) The network used requires spectrograms for learning, testing, and validation during the learning process. The spectrograms are assigned to the previously defined classes for this purpose, but this assignment can also be done automatically by the program. Sufficient spectrograms must be available for each class (e.g., 1.000 or
30 10.000 per class).
- (6) The network is created, in this example a CCN network. The network has two output neurons for the two defined classes ("good" and "bad").
- (7) The learning process is carried out.

- (8) The weights file is generated, which contains the parameterization of the individual elements and connections of the CNN network.

Fig. 5 shows an example of the vibration behavior of an xy table ("stage") in the three spatial directions during different operating phases over one cycle. The upper graph shows the three amplitudes of the vibration behavior in the three spatial directions x, y, z over time during the various operating phases, starting with the acceleration measured by the acceleration sensor of a vibration isolator in the spatial directions x, y, z (only the acceleration in the x-direction is used in the example) in the rest phase before the acceleration of the stage, followed by the acceleration measured by the sensor during the acceleration of the stage, then followed by the acceleration measured by the sensor in the uniform motion of the stage, then during deceleration, and in the rest phase after the motion of the stage. The lower graph shows the acceleration of the stage in the spatial directions x and y over time. It can be seen that in the example shown, acceleration or deceleration only occurs in the y direction, while vibrations or accelerations are measured in all spatial directions.

In the example shown, it is easy to see that each of the individual operating phases or cycles is characterized by a specific frequency response. The characteristics of this frequency response (frequencies, amplitudes, time sequence) depend on whether or not the machine is still delivering the required performance data. Other information can also be obtained. For example, it is possible to detect faults in the system that affect the frequency response, such as a defective bearing, provided that this bearing affects the frequency response. This defective bearing can then lead to a "poor" classification. With the appropriate design of the neural network, it is even possible to identify the bearing in question directly as the source of the fault.

For training purposes, a sufficiently large number of spectrograms are generated, with each spectrogram corresponding to a complete run through the four operating phases in accordance with a complete stage cycle. These are "labeled," i.e., classified into the designated classes ("good"/"bad").

Fig. 6 shows a spectrogram for illustrative purposes only. The spectrogram can contain the vibration data of the xy table in one of the spatial directions x, y, or z. However, it is also possible to superimpose the vibrations in all three spatial directions x, y, and z in one spectrogram, as is

the case in the example shown in Fig. 6, although Fig. 6 only shows the spectrogram in one spatial direction.

5 It is also possible to display the vibrations in the spatial directions x, y, and z in separate spectrograms and process them together in the artificial neural network.

The vibration behavior with respect to the axes of rotation in the x, y, or z directions can also be recorded and processed. This allows more information to be used for classification, which can be useful and increase the reliability of the classification. However, additional information also
10 increases the complexity of the neural network, so it makes sense to determine the information that is ultimately needed for the classification "good" and "bad" in the specific application.

The vibration data can also be represented in other ways, for example, via representations in the time domain or in the frequency domain. This is also assumed for the embodiments described
15 here and the following ones.

A spectrogram, as shown in Fig. 6, represents a collection of a large number of measured values. The spectrogram contains time curves for a large number of frequencies, i.e., also the spectral composition of the vibrations that occur. In a performance analysis, this large number of
20 measured values, or their totality, is evaluated and the result is expressed in an output value. This can be a class designation that indicates, for example, whether the operating condition is good or bad. Not only in the specific example of a spectrogram, but in general, the measurement values are evaluated in their entirety in the neural network, which typically also involves complex weighting and calculation of the measurement values in order to obtain the output value.

25

In the embodiment shown in Fig. 7, an artificial neural network is to be trained to generate a classification into the classes "good" or "bad" from vibration data in the spatial direction x. For illustrative purposes, three spectrograms from vibrations in the x-direction of space are shown in each case., which are classified into the categories "good" or "bad". It goes without saying that in
30 practice, not only three spectrograms are used, but preferably a multiple thereof, for example, 100 or more, or even 1.000 or more.

For classification, the "weights file" generated during training, or weight file 13, is loaded into the network 15, and the spectrograms obtained during regular operation of the vibration isolation system 1, or more generally the measurement data 14, are fed into the network 15, Fig. 8. This data is then classified, i.e., assigned to at least two classes 16, 17, preferably to classes "good" or "bad".

In a further, second embodiment illustrated in Figs. 9 and 10, which is based on the aforementioned embodiment, the motion phases of acceleration, (uniform) motion, deceleration, and rest state of an xy table are to be distinguished. This assignment enables a more accurate classification of the operating state of the xy table, i.e., the classification can be performed with greater reliability, since the vibration data differ in these movement phases and not, as assumed in the embodiment of Fig. 5, over a complete movement cycle comprising all four movement phases in a summed view.

The input data is assumed to be vibrations from a vibration sensor of a vibration isolation system 1 in a spatial direction, e.g., in the spatial direction x, during the movement of an xy table.

As a result, information about the quality of the setting or adjustment of the vibration isolation system 1 can be provided in the categories "good" and "bad", separately for each movement phase.

This enables a more accurate performance analysis of the vibration behavior in the individual movement phases, so that deviations from the specification of the xy table or, more generally, of a supported device or machine, for example a bearing damage as discussed above, can be detected even more accurately.

A sufficient number of spectrograms 20 are used for training, whereby a spectrogram corresponds to a specific movement phase (acceleration, movement, deceleration, rest position) or a specific combination of movement phases, such as the phase from the rest position to reaching a maximum speed. The spectrograms 20 represent the data on the movement variable provided by the sensors 6a–6d, which contain the temporal progression of the amplitudes of several vibration frequencies. These spectrograms 20 are also divided into the designated classes, in the example into the classes "good" and "bad". Each spectrogram is additionally

assigned information about the movement phase or the corresponding cycle of the xy table, as shown in the example in Fig. 9. Based on the four movement phases of the xy table, the assignments in Fig. 9 are as follows:

- 5 - Data P1: Data for movement phase 1, acceleration
 - Data P2: Data for movement phase 2, movement
 - Data P3: Data for movement phase 3, deceleration
 - Data P4: Data for movement phase 4, rest phase
- 10 Several spectrograms 20 of the different movement phases are then used for training, which are separated according to the movement phases, Fig. 10.

For classification, the "weights file" generated by training, or weight file 13, is loaded into the artificial neural network, and the measurement data 14, in particular in the form of spectrograms
 15 and the assignment of the movement phase from regular operation of the machine, are fed into the network 15. This data is then classified as "good" or "bad" and output assigned to the respective movement phases, Fig. 11.

According to a further, third embodiment of the invention, additional information is to be used for
 20 the performance analysis. Otherwise, this embodiment is based on the aforementioned embodiments.

In the third embodiment, additional information is added, or different types of information are combined. The input data may include, for example, the following information, although the
 25 following list is not to be considered exhaustive:

- the vibration information of the vibration isolation system 1 and/or the supported load 4, in particular the supported machine or device
- the vibration information of a connected component, such as a vacuum pump
- 30 - the vibration information from the floor or the installation surface of the vibration isolation system 1, or the vibration information of a component within the machine, for example the vibrations at an optical sensor, or the vibrations at an electron beam tube, or the vibrations at a vacuum pump
- the strength of acoustic vibrations

- the temperature of the environment, the vibration isolation system 1, and/or the supported load 4, in particular the supported machine or device
- the strength of electromagnetic radiation at the machine or device.

- 5 The vibration information in turn relates to the vibration behavior, including the amplitude, the period duration, the frequency, and/or the frequency spectrum.

For this, fig. 12 shows an example selection of input data, whereby the following assignments apply:

- 10 - X1: Vibration information of the vibration isolation system 1,
 - X2: Vibration information of the vacuum pump
 - Xn: Measured values for temperature, electromagnetic radiation, acoustic vibration

- 15 As a result, when the input data is combined appropriately, the output data generated can provide information about the performance of the vibration isolation system 1 and/or the supported load 4, in particular the supported machine or device, for example operating parameters that indicate good or poor performance of the vibration isolation system 1 and/or the supported load 4, in particular the supported machine or device. In the manner described, information about performance data can also be obtained independently of vibration information. For example, the
- 20 electromagnetic radiation, which is characterized by a frequency of the radiation, and/or an amplitude of the radiation, and/or a direction of the radiation, can also be used to classify the performance data of the machine if the network is trained accordingly.

- 25 In turn, a sufficient amount of information is required for training, which is "labeled" after appropriate processing, i.e., assigned to the specified classes, Fig. 13.

Fig. 14 shows an example of the classification process based on measured values or input data obtained during regular operation.

- 30 According to a further, fourth embodiment of the invention, the performance analysis of the vibration isolation system 1 is used to detect causes of faults. Otherwise, this embodiment is based on the aforementioned ones.

As a result, the output data generated can, when combined with the input data, provide information as to whether the vibration isolation system 1 and/or the supported load 4, in particular the supported machine or device, is operating within the specified specifications or whether there are deviations from these.

5

Information can be generated as to whether the vibration isolation system 1 or the machine or device is operating within the specification. If it is operating outside the specification, it is possible to determine which component is the cause. The prerequisite for this is that the input data or, in regular operation, the measured values provide sufficient information to enable a corresponding classification.

10

The input data may include, for example, information indicating faulty or suboptimally adjusted components or environmental conditions. The following list is illustrative and should not be considered exhaustive:

15

- the vibration information of a vibration isolation system 1 operating within the specification, in particular the machine or device
- Vibration information from a vacuum pump operating within the specification
- Vibration information from a vibration isolation system 1 that is not operating within the specification, in particular a machine or device
- the vibration information of a vacuum pump that does not operate within the specification

20

The vibration information in turn relates to the vibration behavior, including the amplitude, period duration, frequency, and/or frequency spectrum.

25

For this, fig. 15 shows a selection of input data purely as an example, whereby the following assignments apply

- X1: Vibration information vibration isolation system 1
- X2: Vibration information for vacuum pump

30

Several input data sets are then used for teaching, which represent the various possible combinations. With regard to the above example, the following input data may be used:

- Vibration isolation system 1 is operating within specification, vacuum pump is operating within specification
- Vibration isolation system 1 is not operating within specifications, vacuum pump is operating within specifications
- 5 - Vibration isolation system 1 operates within specification, vacuum pump does not operate within specification

In addition to the information already discussed, the input data therefore also includes information that indicates a faulty component or environmental conditions. Further input data may therefore
 10 also relate to the supported load 4, in particular a supported machine or a supported device, for example an xy table.

For example, a frequency spectrum can be used for teaching that is generated when an xy table moves correctly in one direction, for example in the y direction. If bearing damage occurs in a
 15 bearing that is used when this xy table moves in the y direction, a deviation in the frequency spectrum may occur during regular operation. Deviations in the frequency spectrum can also have a variety of causes, e.g., aging of components, faulty/suboptimal repairs or software updates, changed movement sequences in the machine for which it is not optimized, loose contacts in cables, compressed air fluctuations.

20 Data from such components can also be used as input variables.

The training and creation of the "weights file" is carried out as described above, whereby care must be taken to ensure that there is a sufficiently large number of data records in the various
 25 categories, Fig. 16.

Fig. 17 shows an example of the classification process based on data obtained during regular operation.

For classification, the "weights file" generated during the training of the artificial neural network is
 30 loaded into the network, and the data from the machine operation to be classified is entered into the network. This data is then classified and, if applicable, assigned to a faulty component.

In the above-mentioned embodiments, the sensors are not only arranged in or on the vibration isolation system 1, but also on or in the supported load 4, in particular on the plate or a machine supported thereon, or on or in a supported device.

5 Furthermore, the sensors can also be arranged on or in the associated components, for example on an xy table, on an optical sensor, on light- or electron-optical elements of a microscope, on spectroscopic, scatterometric or interferometric measuring devices, or also on a scanning probe microscope, on a distance sensor, for example to measure the distance of a light-optical element from a substrate, on a cover, on a vacuum pump, or on another component of the vibration
10 isolation system.

The sensors may comprise, for example, optical sensors, ultrasonic sensors, acceleration sensors, or distance sensors, whereby acceleration sensors are provided in the present case.

Further sensors may be assigned to the environment of the vibration isolation system 1, for
15 example, the floor or the installation surface, or also to the surroundings, for example, other components in the vicinity of the vibration isolation system. In particular, it is advisable to select components that can transmit vibrations to the vibration isolation system and/or to the supported load. This can be, for example, the ceiling or a hoist located in the vicinity, such as a hall crane or overhead crane.

20 Magnetic field sensors or fluxgate magnetometers or saturation core magnetometers are provided for detecting electromagnetic fields.

Pressure sensors are provided for detecting the strength of acoustic fields.

25 Thermocouples are provided for measuring the temperature at the installation site and/or on components of the vibration isolation system and/or the supported load.

The generation of output data from the input data and the classification for performance analysis
30 are computer-assisted, whereby the programs can be stored in the computing device 3. Of course, it is also possible to store the programs or the components of the artificial neural network at other locations.

For example, in a further development of the invention, it is envisaged that the components of the artificial neural network 10 will be stored centrally in a higher-level computing device and used for several decentralized vibration isolation systems 1. This has advantages in terms of maintenance and training.

5

In a further development of the invention, the artificial neural network can also be designed in such a way that information or input data from several vibration isolation systems 1 is used to generate control parameters for the control and regulation of one or more vibration isolation systems 1 connected to the higher-level computing device after the performance analysis.

10

The generation of variances can be achieved by augmenting the spectrograms or other forms of representation of vibrations, i.e., by changing or transforming the data sets, meaning that deliberate deviations of the spectrograms or input variables are generated, preferably also with the aid of a computer, in order to increase the number of different training data sets.

15

This is advantageous because a large amount of data is required for training, among other things to capture the scatter of input information that occurs during regular operation as far as necessary. Such data can also be generated artificially or with computer support within certain limits by artificially or computer-assisted falsification of the data. For example, noise can be added to the vibration data.

20

In this way, a large number of spectrograms can be generated with which the artificial neural network used can be trained. The spectrograms are assigned to the desired categories or classes for this purpose. According to one embodiment of the invention, the assignment can also be performed automatically with computer support, which can significantly simplify manual data preparation.

25

For good performance analysis and diagnosis, it is helpful if sufficient spectrograms are available in the corresponding classes. In certain cases, 10 to 100 input data or spectrograms per class may already be sufficient, but it is better to provide, for example, approximately 1.000 or even 10.000 or more data sets per class in order to improve and increase the quality of the performance analysis.

30

During regular operation of the vibration isolation system 1, a previously trained or taught artificial neural network is used. In an advantageous embodiment of the invention, this trained artificial neural network is further trained during operation.

- 5 In this way, the vibration isolation system 1 can be easily adapted to the conditions prevailing at the installation site.

In a further advantageous embodiment of the invention, the artificial neural network uses semi-trained data from a previous learning process or from another external source.

10

The performance analysis can be used to generate information or output data, for example control parameters for controlling or regulating the vibration isolation system 1 and/or the supported load 4. An important aspect of the invention is therefore that these control parameters can be used directly or indirectly to control or regulate the vibration isolation system 1 and/or the supported load 4.

15

The invention therefore also includes a method for controlling or regulating a vibration isolation system 1, whereby control parameters for controlling the vibration isolation system 1 are obtained and used during operation as part of a performance analysis as described above. In this way, a self-learning vibration isolation system 1 can be provided which can, for example, react to changes in the environment, such as vibrations occurring via the ground.

20

The vibration isolation system 1 is designed as an active, stationary vibration isolation system and, in the embodiment, comprises four vibration isolators, whereby vibrations occurring during regular operation can be actively counteracted by means of the four actuators.

25

Another aspect of the invention comprises a method for diagnosing, in particular for analyzing the performance of, a vibration isolation system 1 comprising a vibration isolation system as described above.

30

The method can enable an analysis of the performance of the vibration isolation system, but also of the supported load.

A further development of the invention provides for the adaptation of the artificial neural network. This may become necessary if influencing factors change during the use of the network, e.g.:

- More data may arise during use of the network, which can be used to improve classification.
 - 5 - For example, a mounted machine may be able to cope better with disturbances due to improved software.
 - The product processed by the machine changes, which places different demands on the machine.
- 10 Since retraining the artificial neural network can be costly, according to this development, it is proposed to perform a continuous optimization during regular operation of the artificial neural network. This saves time for retraining and shortens the time between network updates. The process is shown in a schematic overview in Fig. 18. Here, while the AI model is being applied,
- 15 the AI model is continuously trained with the help of external performance indicators and evaluation indicators that classify the state of the system. An AI model is understood here to be a model that contains the neural network described.

In addition to the architectures described above for classifying input data, there are other approaches. In the above examples, the input data is evaluated within a time period, for example,

20 a time period of two seconds for a sequence consisting of the phases acceleration, movement, deceleration, and rest.

There are also architectures that process the sequence of time periods. One example of this is LSTM ("Long Short-Term Memory") neural networks, which can process a sequence of smaller

25 time periods in an additional dimension. Such architectures can be used in a similar way for the classification tasks described above.

Reference list

1	Vibration isolation system
2a – 2d	Vibration isolator
3	Computing device
4	Load
5a – 5d	Actuator
6a – 6d	Sensor
10, 11	Set of spectrograms
13	Weight file
14	Measurement data
15	Network
16, 17	Class
20	Spectrogram
101	Step: Data acquisition
102	Step: Data processing
103	Step: Labeling
104	Step: Augmentation
105	Training spectrograms
106	Test spectrograms
107	Step: Network creation
108	Step: Training the network
109	Step: Creating a weight vector or weight file

Patent claims:

1. Vibration isolation system, in particular with a diagnostic function, preferably a stationary, active vibration isolation system, by means of which a load supported vibration-isolated can be supported, comprising

at least one vibration isolator, preferably a plurality of vibration isolators, which can counteract vibrations occurring during operation by means of actuators,

at least one sensor, preferably a plurality of sensors, which are designed to record measured values relating to the vibration isolation system and/or the supported load and/or the environment and to make them available as input data to a computer-assisted method for performance analysis of the vibration isolation system and/or the supported load.
2. Vibration isolation system according to the preceding claim, wherein the computer-assisted method comprises or is based on at least one artificial neural network.
3. Vibration isolation system (1), in particular according to one of the preceding claims, for the vibration-isolated support of a load, comprising at least one, preferably several vibration isolators (2a – 2d) and at least one sensor (6a – 6d), wherein the sensor (6a – 6d) is designed to detect a movement variable, in particular a mechanical vibration, movement, or acceleration, as well as a computing device (3), wherein the computing device (3) contains an artificial neural network (10), wherein the artificial neural network (10) is designed to process data of the movement variable provided by the at least one sensor (6a – 6d) and to classify whether the vibration isolation system (1) with the supported load is in an operating state with sufficiently little or too much disturbance from movements, and to output this classification.
4. Vibration isolation system according to one of the preceding claims, characterized in that the motion magnitude data provided by the at least one sensor (6a–6d) comprises spectrograms (20) which contain the temporal progression of the amplitudes of several vibration frequencies.

5. Vibration isolation system according to one of the preceding claims, wherein a trained or taught artificial neural network is used in regular operation.
- 5 6. Vibration isolation system according to one of the preceding claims, wherein the supported load is supported via three or four vibration isolators.
- 10 7. Vibration isolation system according to one of the preceding claims, wherein the supported load comprises processing machines or parts thereof, in particular in the semiconductor industry, such as machines for processing semiconductor devices and/or nanostructured substrates or elements, in particular wafers, masks, or displays, lithography devices, or measuring devices or equipment, in particular for measuring semiconductor components and/or nanostructured substrates, such as an electron microscope, or other sensitive devices, machines or systems, for example laboratory devices or medical devices, such as imaging examination devices such as magnetic
15 resonance imaging (MRI) scanners.
- 20 8. Vibration isolation system according to one of the preceding claims, wherein the input data comprise the vibration behavior of the vibration isolation system, in particular the amplitude, the period duration, the frequency, or the acceleration.
- 25 9. Vibration isolation system according to one of the preceding claims, wherein the input data comprise the temperature at the installation site and/or at components of the vibration isolation system and/or the supported load.
- 30 10. Vibration isolation system according to one of the preceding claims, wherein the input data comprises the strength of electromagnetic fields at the installation site.
11. Vibration isolation system according to one of the preceding claims, wherein the input data comprise the strength of acoustic fields at the installation site.
12. Vibration isolation system according to one of the preceding claims, wherein the sensors are arranged in or on the vibration isolation system, and/or on the supported load and/or

in the environment, in particular on the ground, the installation surface, or on components or elements in the vicinity of the vibration isolation system.

- 5 13. Vibration isolation system according to one of the preceding claims, wherein the artificial neural network forms at least one model comprising at least one folding level (convolutional layer) and/or at least one neuron level (neural layer), and/or further components, for example activation layers.
- 10 14. Vibration isolation system according to one of the preceding claims, wherein the artificial neural network can be trained, in particular during operation of the vibration isolation system, and/or uses trained data from a previous learning process.
- 15 15. Vibration isolation system according to one of the preceding claims, wherein the artificial neural network uses at least one of the methods of regression, machine learning, or deep learning.
- 20 16. Vibration isolation system according to one of the preceding claims, wherein, for training the artificial neural network, data sets are modified or transformed computer-assisted to obtain a plurality of training data sets.
17. Vibration isolation system according to one of the preceding claims, wherein control parameters for controlling the vibration isolation system and/or the supported load are generated on the basis of the performance analysis.
- 25 18. Vibration isolation system according to one of the preceding claims, wherein the control parameters are used to control the vibration isolation system and/or the supported load.
- 30 19. Method for controlling or regulating a vibration isolation system, preferably according to one of the preceding claims, wherein control parameters for controlling the vibration isolation system are obtained and used during operation by means of performance analysis.

20. Method for diagnosing, in particular for performance analysis, a vibration isolation system, preferably according to one of the preceding claims 1-14.