

**Method for the determination of loads/damage
in a mechanical structure**

Embodiments of the invention relate to a method for the determination of loads in a mechanical structure and/or of damage or states in the mechanical structure which result from the loads in the mechanical structure. The invention relates, in particular, to a method for the determination of building loads and/or building damage resulting from building loads and to a device suitable for this purpose.

Monitoring the structural integrity of buildings during and after building loads (for example, earthquakes, storms, weight load due to snow on a flat roof) is an important task. In addition to the need to reduce personal damage, in this context the aspect relating to minimizing downtimes in the utilization of buildings must also be taken into account. Moreover, towns which are constantly growing in size, which have highly varying terrain properties, lead to the situation where the effects of building loads, for example of earthquakes, may turn out to be very different from one part of a town to another. The type and structure of individual buildings within a very narrowly delimited region also vary very sharply. Consequently, in an extreme situation, it is possible for one building, when subjected to building loads, to be seriously damaged, whereas a directly adjacent structure remains virtually intact.

In terms of disaster protection, an extremely difficult situation consequently arises, since, as regards the optimization and coordination of rescue measures, there are no simple criteria for prioritizing the aid measures in the event of a disaster in a relatively large municipal area.

Embodiments of the invention specify a method and a device for the determination of individual building loads and/or building damage, so that a prioritization of the aid measures in the event of a disaster in a relatively large municipal area is possible.

In a first aspect of the present invention, there is provided a method for the determination of damage or states of a mechanical structure which result from a loading of the mechanical structure, wherein in each case a sensor signal of a fiber-optic rotation sensor connected mechanically rigidly at least to part of the mechanical structure is determined before and after the loading; in each case an earth's rotation signal superposed on the sensor signal is determined from the respective sensor signal; on the basis of the superposed earth's rotation signals determined in each case, a respective instantaneous orientation of the fiber-optic rotation sensor with respect to the earth's rotation axis is determined; a change in orientation of the rotation sensor is determined from the respective instantaneous orientations of the fiber-optic rotation sensor before and after loading, and the damage or states of the mechanical structure are determined on the basis of the change in orientation of the rotation sensor.

In a second aspect of the present invention, there is provided a device for the determination of damage or states of a mechanical structure which result from a loading of the mechanical structure, having a fiber-optic rotation sensor which is connected mechanically rigidly at least to part of the structure; and an evaluation means which is connected to the rotation sensor and which is designed for determining in each case a sensor signal of the fiber-optic rotation sensor before and after the loading; for

determining in each case an earth's rotation signal superposed on the sensor signal from the respective sensor; for determining a respective instantaneous orientation of the fiber-optic rotation sensor with respect to the earth's rotation axis on the basis of the superposed earth's rotation signals determined in each case, for determining a change in orientation of the rotation sensor from the respective instantaneous orientations of the fiber-optic rotation sensor before and after the loading, and for determining the damage or states of the mechanical structure on the basis of the change in orientation of the rotation sensor.

Example embodiments of the invention provide for the determination of building loads and/or of building damage resulting from building loads. Furthermore, example embodiments of the invention provide methods for the determination of loads in a mechanical structure and/or of damage or states in the mechanical structure which result from the loads in the mechanical structure.

Disclosed herein is a method for the determination of building loads and/or building damage resulting from building loads is distinguished in that the rotations of a building part which are caused by building loads or building damage are measured via a fibre-optic rotation sensor which is rigidly connected mechanically to the building part, and the building loads/building damage are deduced from the measured rotations.

In order to make the determination of the building loads/building damage more precise, a multiplicity of rotation sensors may be employed instead of a single fibre-optic rotation sensor; thus, rotations of a plurality of building parts which are caused by building loads/building damage may be measured via corresponding fibre-optic rotation sensors which are

rigidly connected mechanically to the building parts,
and the building loads/building damage may be deduced
from the measured rotations. In other words, each
rotation sensor measures the rotations of that building
5 part to which it is connected. The overall state of the
building can then be deduced from the sum of the
determined rotations of the individual building parts
or the building loads/building damage can be
ascertained individually for each part of the building.
10 Consequently, it is possible, for example, to detect
torsions within a building, for example between two
successive storeys of the building.

Each rotation sensor may, if required, be designed
15 individually as a uniaxial, biaxial or triaxial
rotation sensor, that is to say each rotation sensor
may be designed individually as a sensor which measures
rotations about one, two or three axes of rotation.
Thus, for example, particularly critical building parts
20 may be equipped with triaxial rotation sensors, in
order to allow precise measurement, whereas, in the
case of uncritical building parts, for example, biaxial
or uniaxial rotation sensors may be sufficient.

25 In one embodiment of the invention, the rotation
sensors are fastened to side walls of the building, in
such a way that the relative angles between the side
walls and the floors or ceilings of the building which
are supported by the side walls can be deduced from the
30 measured rotations. Such relative angles are a proven
measure for the assessment of building loads/building
damage, in particular of earthquake damage.

In addition to the fibre-optic rotation sensors,
35 acceleration sensors or other sensors may be provided
on the building, which are rigidly connected
mechanically to corresponding building parts and via

which translations of the building parts which are caused by building loads/building damage are measured, building loads/building damage being deduced from the measured translations. The additional provision of such sensors allows a particularly precise determination of building loads/building damage, since all six degrees of freedom of movement (to be precise, three degrees of freedom of translation and three degrees of freedom of rotation) can thereby be measured.

In one embodiment of the method according to the invention, the change in orientation of the building with respect to the axis of rotation of the earth is deduced from the measured rotations and/or translations. The change in orientation may be judged to be a reliable measure of the building loads/building damage to be determined, in particular of earthquake damage.

In generalized terms, embodiments of the invention provide a method for the determination of loads in a mechanical structure and/or of damage or states in the mechanical structure which result from the loads in the mechanical structure. The method is characterized in that the rotations of a part of the mechanical structure which are caused by loads/damage in the mechanical structure are measured via a fibre-optic rotation sensor which is rigidly connected mechanically to the structural part, and the loads/damage/states in the mechanical structure are deduced from the measured rotations.

Disclosed herein is a method for the determination of loads in a mechanical structure and/or of damage or states in the mechanical structure which result from the loads in the mechanical structure. The method is characterized in that the rotations of a plurality of parts of the mechanical structure which

are caused by loads/damage in the mechanical structure are measured via corresponding fibre-optic rotation sensors which are rigidly connected mechanically to the structural parts, and the loads/damage/states in the mechanical structure are deduced from the measured rotations.

The term "mechanical structure" is to be understood as meaning, for example, a building or part of a building (roof), a bridge, a tunnel, the fuselage or wings of an aircraft, part of the ground (for example, the rock of a mountain), a conduit or a traffic route (road, rail tracks, railway lines), etc.

Disclosed herein is a device for the determination of building loads and/or of building damage resulting from building loads. The device is distinguished by

- a fibre-optic rotation sensor which is rigidly connected mechanically to a building part, and
- an evaluation apparatus, connected to the rotation sensor, for determining the building loads/building damage on the basis of rotations of the building part which have been detected by the rotation sensor.

Disclosed herein is a device for the determination of loads in a mechanical structure and/or of damage or states in the mechanical structure which result from the loads in the mechanical structure, which device has:

- a fibre-optic rotation sensor which is rigidly connected mechanically to a part of the structure, and
- an evaluation apparatus, connected to the rotation sensor, for determining the loads/damage/ states in the structure on the basis of rotations of the structural part which have been detected by the

rotation sensor.

The statements (embodiments) afforded within the framework of the method according to the invention apply similarly to the devices according to the invention: thus, the devices according to the invention may also consist of a plurality of fibre-optic rotation sensors; the rotation sensors may be designed as uniaxial, biaxial or triaxial rotation sensors; etc.

The evaluation apparatuses of the individual rotation sensors may be network-linkable to further instrumental units, so that rotation data determined can be collected in a simple way, so that a rough damage survey can be set up even shortly after building loads/building damage. In this case, it is possible both to provide each rotation sensor with a specific evaluation apparatus and to provide a single central evaluation apparatus which is connected to all the rotation sensors and other sensors. The network-linking of the evaluation apparatuses to further instrumental units or the network-linking of the rotation sensors to a central evaluation apparatus may take place, for example, via cable lines or via radio connections.

According to embodiments of the invention, therefore, a sensor based on absolute rotation measurement is employed, which detects the deflection of the building during an earthquake dynamically in three spatial directions by means of a specialized fibre-optic gyroscope. In this case, the maximum deflection and the cumulative deflection of individual storeys or of the entire building are determined in real time and are compared with a predefined building-specific tolerance table which has previously been anchored in the sensor or in an evaluation apparatus connected to the sensor. To assist immediate measures, the result of this building

evaluation is indicated, for example, in a simple multi-step colour code and made available at the same time from an external interface. This makes it possible to connect a plurality of such sensors into an
5 overriding functional unit and to incorporate individual sensors or sensor complexes in a radio network.

The invention is explained in more detail below in
10 exemplary embodiment, with reference to the figures in which:

Fig. 1 shows a diagrammatic illustration of a building part with rotation sensors mounted on it,
15 before and after an earthquake;

Fig. 2 shows a diagrammatic illustration of two building parts contiguous to one another, before and after an earthquake; and
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Fig. 3 shows a flowchart of an embodiment of the method according to the invention.

Fig. 4 shows a torsion profile of a building during an
25 earthquake.

Components or component groups corresponding to one another are identified in the figures by the same reference numerals. In the following description, it is
30 assumed, for the sake of simplicity, that the building loads/building damage are earthquake damage.

As has already been indicated, the essential element of the concept is a (preferably) three-component inertial
35 fibre-optic rotation sensor which is firmly connected to the structural substance. In this way, the sensor participates in the movements of the building (or

building sections) and delivers the rate of rotation about three linearly independent spatial directions (for example, about the "longitudinal axis", and the "transverse axis" of the building and about the horizontal plane of the latter) as a sensor signal. These rates of rotation are integrated in the processor part of the sensor, and the cumulative maximum deflection with respect to an inertial reference system is calculated. The maximum deflection angle between a supporting wall and the concrete ceiling of a building is one of the critical variables for assessing the remaining load-bearing capacity of this building part. Too great a deflection of a ceiling panel in relation to its support leads to an overstressing of the supporting structure and, subsequently, to crack formation which is detrimental to the load-bearing capacity. In this context, it is unimportant whether this deflection takes place abruptly or in a manner distributed over a relatively long period of time. What is decisive for the durability of the structure is the maximum deflection angle.

Fig. 2 illustrates this relation graphically. Thus, Fig. 2 a) outlines a concrete ceiling 2 suspended normally on a side-wall part 1, without loads due to building inclinations, whilst b) reproduces the situation after an earthquake. If the angle of inclination (α) which has occurred due to the earthquake overshoots a particular threshold value, the building may collapse.

As compared with the use of conventional accelerometers, the method according to the invention has the advantage that it is based on the principle of absolute rotation measurement and covers a very broad dynamic range. Thus, not only high-frequency deflections are detected, but also inclination

variations taking place very slowly in frequency ranges which are no longer accessible by inertia sensors.

5 Depending on the arrangement of a plurality of sensors in a building, therefore, not only is the inclination of a structure assumed to be rigid obtained, but also the differential inclination or torsion between individual storeys and building parts equipped with such sensors.

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Accelerometers which function according to the concept of mass inertia may additionally be employed here. It thus becomes possible, for the first time, to acquire a complete sensor for all six degrees of freedom of movement (to be precise, three degrees of freedom of translation and three degrees of freedom of rotation).

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The building sensor 3 according to the invention (which may also contain translation sensors in addition to a fibre-optic rotation sensor) detects rates of rotation or the integral deflection angle of a building or building part under the action of an earthquake. For this purpose, it is to be mounted rigidly on fixed side walls 1 which represent the building behaviour, as shown in Fig. 1: Fig. 1 a) shows (diagrammatically) the situation before an earthquake and Fig. 1 b) the situation after an earthquake, for one spatial direction (the assumed inclination of the building is in the paper plane; the sensitive axis of rotation of the building sensor 3 projects out of the paper plane).

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In principle, damage to the building may also take place in the other horizontal spatial direction, as may also occur in a rotation about the vertical axis (torsional vibrations). A complete sensor triad covers all the directions of movement. Depending on the structure of the building, however, there may also be

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directions which are less at risk, for example on account of higher rigidity, so that individual sensor components may be dispensed with under certain circumstances.

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Since rotation sensors detect rotations absolutely on the basis of the Sagnac effect, the orientation of a building in relation to the axis of rotation of the earth can be evaluated automatically before, during or
10 after an earthquake in real time as a measurement criterion. This makes it possible to determine the change in orientation of a building, without having to rely on local references which could, of course, have changed due to the action of an earthquake.

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Fig. 3 shows an embodiment of a method according to the invention: the sensor 3 measures in continuous sequence the rate of rotation and the angle of rotation (this corresponds to the deflection of the building or
20 building part) and, furthermore, determines the scalar product between the earth rotation vector and the sensor normal (sensitive axis) in a step S1. Under the action of an earthquake or of a high wind load (storm gust), the observation variables yield greater amounts
25 which are compared by the control electronics with a tolerance-value table anchored in the program (step S2). This table is coordinated specifically with each building. From the comparison between the individual building tolerances and the instantaneous measurement
30 values, the processor determines the hazard potential due to the external event (step S3). In the simplest instance, this is signalled by a four-step colour code: green, yellow, orange and red.

35 By dynamic radio network-linking of any of these sensors, for example in entire town parts, an area-covering rough damage survey can then be set up, close

to real time (smart sensor application). This could be retrieved and utilized, for example, by disaster protection services, for the preparation of priority lists (step S4).

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Further aspects of the invention are to be explained in the following description:

10 Although fibre-optic gyroscopes do not yet have the sensor sensitivity of large ring lasers, nevertheless, because of their small dimensions and low power consumption, they are suitable both for field use in the region near a seismic event (aftershock zones, volcanoes, etc.) and for the instantaneous detection of
15 building states after earthquake actions, but also for the monitoring of static deformations. Combining rotation sensors and seismometers or accelerometers affords the possibility of developing and utilizing a complete sensor for all six degrees of freedom of
20 movement. An important aspect in this context is to take into account the particular conditions of rotation sensors for measurement free of local reference symbols, for example the possibility of absolute orientation of the sensor in real time, and also the
25 self-calibration of the sensor by means of the global earth rotation signal.

According to the invention, novel mobile and cost-effective sensors are provided, which, together with
30 classic seismic sensors, make it possible to observe ground movements correctly, specifically in all six degrees of freedom of movement: for a complete description of ground movements, not only translations, but also rotations, must be observed with high
35 resolution.

According to the invention, long-term extensive statements on variation and deformations can be made by means of broadened six-component recordings (novel measurement methods which can be used in a mobile, 5 cost-effective and rapid way). The additional observation variable "rotational movements" can also be used, above all, in the inversion of seat parameters (dynamic rotation), and its accuracy can be improved. In this case, in particular, the otherwise inseparable 10 coupling of inclination and translations of the measured signals on the sensor plane can be investigated and corrected by the provision of correspondingly high-resolution rotation measurements. Since the transverse acceleration and the rate of 15 rotation during an earthquake are in phase with and proportional to one another, it is not possible to prevent the seismograph from including a coupling of earthquake-induced inclination fractions into the sensor signal of the other linearly independent spatial 20 directions in a zone near the earthquake event. Only a sensor with all six independent degrees of freedom of movement, that is to say including the rotation, can afford an improvement here.

25 The concept according to the invention in the design of fibre-optic gyroscopes can cost-effectively increase the sensitivity of existing rotation sensors based on glass fibres by up to two orders of magnitude, as compared with the previous prior art, and, when 30 supplemented by a broad-band seismometer, can for the first time make all six degrees of freedom of movement available with sufficient sensitivity in a portable implementation capable of being used in the field.

35 The invention concentrates on the utilization and further development of modern rotation sensors as a novel and innovative basic technology for use in early-

warning systems. The diverse novel technological possibilities arising from this are to be applied, in particular, to the area of the monitoring of building structures and the area of seismology.

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After an earthquake, particularly in larger metropolitan areas, a rapid estimation of the damage to important buildings is of central importance, particularly in order to optimize the rescue measures.

- 10 If the co-seismic movements (time profile of the deformations, static displacements and static rotations) could be measured and could be evaluated in terms of critical variables, close to real time, in an independent sensor, then deformation-induced variations
15 could be determined virtually instantaneously, above all for critical buildings and conduits or traffic routes. According to the invention, a cost-effective intelligent 6-C sensor is provided, which can be installed in the manner of a "black box" in buildings,
20 bridges, tunnels or other structures and which records useful data material relating to the building behaviour during an earthquake or another deforming event and provides this data material for analysis. According to the invention, therefore, particular attention is also
25 placed on utilizing the properties of the rotation sensors as absolute protractors. The devices according to the invention are distinguished by a low power consumption and are suitable in manufacturing terms for cost-effective mass production. The installed
30 electronics, by the instantaneous integration and differentiation of the sensor signals within the sensor, can thus be expected to deliver a hazard or damage estimation, close to real time, for the respective building. The additional capability of the
35 combination of such sensor units of independent design into autonomous local or regional networks is in this case possible.

The aim, in terms of structural mechanics, is, via suitable sensors, to determine dynamic excitation as a result of earthquakes or other subsoil movements, such as vibrations, both as regards amplitudes and as regards relevant wavelengths. By coupling geophones or acceleration sensors with rotation sensors as absolute protractors, both characteristic variables of dynamic excitation can be detected by means of a small number of measurement points. For linear structures, the curvatures caused by the action can be described from measured rotations. According to the invention, building on this, the evaluation of the excitation can be carried out via a comparison of the measurement results with the assumptions on which the dynamic design of the structure is based. Furthermore, in addition to the detection of dynamic excitation, the remaining static deformation caused by the action is of interest. For example, by lining up a plurality of sensors with one another, the remaining deformation line can be determined via the measured rotations. The possibility of measuring the (quasi-)static and the dynamic information by means of cost-effective sensors constitutes a considerable advantage, as compared with other measurement methods. The self-calibration of the sensor and its effect independent of position as regards weight open up a broad field of use also in terms of early warning against the consequences of antropogenic actions or critical action/resistance combinations, such as, for example, high snow loads on weakened structures, actions due to extreme wind loads, etc. and could thus allow the use of the sensors even for tasks which, with other measurement methods, can be carried out only in a very complicated way and not in real time. An important area of early-warning systems which goes beyond seismic excitation and is covered by the method according to the invention is the monitoring of subsoil movements, such as occur in tunnel building,

during earth excavation, due to foundation loads or else in hill subsidence zones. Consequently, with the aid of sensors, monitoring covers dynamic actions, that is to say the causes of deformations or damage,
5 together with the remaining deformations.

Deformation observations in earthquakes and on volcanoes

10 The problems in determining the static (and dynamic) deformation from seismometer observations have been known for decades, without a satisfactory stable solution having been found hitherto. The main reason for the problems is the additional effects in
15 seismographs which occur due to rotations and changes in inclination and lead to the situation where speed or acceleration seismographs cannot be integrated. GPS instruments are only partially an improvement here, since (1) the vertical resolution is low and (2) the
20 sensing rate is not sufficiently fine for the dynamic observations. With cost-effective 6-C seismometers capable of mobile use, an area-covering observation of dynamic and static deformations would be possible. This could, in the long term, also allow improvements in the
25 real-time determination of seat parameters. Similar arguments apply to seismic observations of volcanoes in which sometimes pronounced deformations are to be expected. The unavoidable coupling of rotational and tilting movements influences the standard broad-band
30 measurements by means of seismometers and makes modelling more difficult. The combined data analysis of rotations and translations makes it possible, in this area, to have an improved mapping of seat processes and of the state of the magma chambers.

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In one embodiment of the invention, both the dynamic ground/building interaction and the structural dynamics

of the building structure are to be taken into account in determining the loads/damage.

The aim of the invention is to reduce earthquake-induced hazards and risks. The observations of the entire movement components have been urged for decades by theoretical seismologists. The most recent developments in sensor technology now seem to allow the design of a suitable measuring instrument with the required accuracy. In this context, it should be noted that measurement technology has a broad potential for use in both the purely scientific sector and the engineering sector.

15 The ever-continuing rapid growth of large metropolitan areas in earthquake-endangered regions (for example, Istanbul, Tokyo, Los Angeles and New Mexico) leads to, in the case of a strong earthquake triggered beneath them, to tremendous damage and the loss of many human lives. On account of the completely heterogeneous building structures and variable subsoil properties in these mega-metropolises, it is not possible in a short time for the respectively responsible disaster management to obtain a survey of the damage situation.

25 The rapid initiation of a coordinated rescue action is consequently seriously impeded, and the expected result is not the best possible. Autonomous monitoring systems, which co-log a damage event and evaluate, close to real time, according to predefined methods and make the result quickly available, could lead to a decisive improvement here. By dynamic weighting according to the function of the building and the automatic damage assessment carried out by the sensor, and also other criteria to be laid down (for example, optimization of the travel distance for rescue forces), an effective utilization of the critical first 6 hours after a damage event may be envisaged.

The building sensor concept according to the invention is innovative in two respects. On the one hand, it is intended to show the way to a monitoring system in which the building behaviour is logged in detail during the action of external forces (earthquake, extreme wind load, ground subsidences, etc.). In this case, a complete independence of local reference systems is achieved via the property of the rotation sensors used as absolute protractors. In this regard, the sensor corresponds to a "black box", such as is employed in aircraft. In addition to these logging functions, key parameters (for example, maximum deflection) are investigated, during measurement, for the overshooting of building-specific predefined limit values, and, if possible, may allow a classification of the damage caused (for example, the degree of risk of collapse) and transfer this to a central location (local disaster protection cell) (use of mains power-independent radio technology). This would consequently perform an important step towards quasi-real-time damage prognosis.

The sensors developed for field use in the region of strong ground movement have several shortcomings in seismology. Inclinations of the seismometer induce both a sensor signal and the translations actually to be measured. In near-earthquake zones, the complete movement vector cannot be reconstructed on account of the absent degrees of freedom of rotation. Consequently, the measurements are both incomplete and, because of the intermixing of signal sources, faulty. This constitutes a serious impediment to the inversion of earthquake parameters. It is to be expected that the complete detection of all six degrees of freedom of movement and the clear separation of translation and rotation (inclination), along with sufficient sensor sensitivity, can make a marked contribution to

improving the seismological models (independence from apparatus transfer functions).

Ring lasers are highly sensitive active optical
5 interferometers and, hitherto, the only instruments
which can quantitatively determine the rotation signals
from teleseismic events. Even for use in seismology,
where long-term stability is not a major factor, they
still require a very high temperature constancy of
10 better than 0.1 degrees per day. Thermally induced
expansion or contraction of the optical resonator
within the range of a few hundredths of a micrometer
cause a drift in the optical operating frequency which
then leads to sudden jumps in the longitudinal mode
15 index (mode jump). Furthermore, despite all the
simplifications which it has been possible to implement
successfully in the course of the GEOSensor project,
ring lasers remain a complex installation. This makes
them unsuitable for three specific applications. (1) A
20 short-term transfer of the sensor into the vicinity of
the epicentre after a strong earthquake, in order to
record aftershocks in the near field. (2) The detection
of the complete movement (all six degrees of freedom)
under the influence of strong ground movements. (3) As
25 part of a monitoring building sensor system, they are
too costly and much too sensitive. On the other hand,
fibre-optic rotation sensors, although not having the
sensitivity of ring lasers, are nevertheless robust and
compact sensors with a markedly higher temperature
30 tolerance. Furthermore, they are significantly more
cost-effective.

The method according to the invention can utilize the
self-calibratability of the system. Since rotational
35 sensors measure rotations absolutely on the basis of
the Sagnac effect, the earth rotation signal is also
always superposed on the sensor signal. This signal may

be considered, within the framework of the application proposed here, as a constant reference. It is available at any time point, that is to say before, during and after an earthquake, as a reference independent of the local surroundings and can be used in order to determine the instantaneous orientation of the sensor in relation to the axis of rotation of the earth. A comparison before and after an earthquake delivers a change in orientation of the sensor due to the seismic event or to the building deformation. Since the sensor is mounted firmly on a wall for a measurement, this change in orientation corresponds either to a building inclination or to a deformation or to a displacement between individual storeys. This signal is determined by the integration of the measured rate of rotation; and, even after a short integration time of approximately one minute, a resolution of less than 1 degree is achieved. Strictly, this method of determining the orientation of the sensor applies with high resolution in the north/south direction only. The resolution is lower in the east/west direction. The investigation of the optimal sensor implementation (reference system of the sensor) is therefore a specific operating point. After the investigation as regards the utilization of the orientation signal, the utilization of the rotation signal of the buildings is a major factor. For this purpose, (1) criteria are to be set up between measured angular deflection and stress of the building or various materials. (2) The effect of the displacement of individual storeys in relation to one another is to be quantified (interstorey rotation) and transmitted to the sensor system.

The output signal of an FOG (Fibre-Optical Gyro) is the phase difference between light waves running around a surface in opposite directions. It is proportional to

the rotational speed of the sensor and to the surface circumscribed by the light beams. The main advantage of an FOG, as compared with a ring laser, is that the optical signal can be guided in a glass fibre. In an FOG, the effective surface can be increased, without the dimensions of the sensor having to be varied appreciably. On the other hand, fibre-optic gyroscopes differ from ring lasers in that they carry out phase measurement, whereas ring lasers determine a frequency difference by interferometry and thus achieve a higher resolution by virtue of the concept adopted. This is a great disadvantage in the implementation of an FOG. The signal-to-noise coefficient (resolution) of an FOG depends not only on the scale factor, but also on the optical power density. For example, for a light source with a wavelength of $1.55 \mu\text{m}$, a luminous power of $P_0 = 100 \mu\text{W}$, a length of the glass fibre of 1000 m and a diameter D of the coil of 0.4 m , a theoretical value for the sensitivity of an FOG of $4.125 \cdot 10^{-8} \text{ rad/s}$ is obtained.

The coil consisting of polarizing optical fibre constitutes an essential component of the optical path. The fibre length and the geometric diameter of the coil are incorporated linearly into the scale factor of the gyroscope. In principle, therefore, lengthening the coil fibre used makes it possible to achieve ever higher accuracies in the measurement of the rate of rotation. At the same time, however, attenuation losses of the light intensity during passage through the fibre and phase change occurring due to disturbing effects, such as, for example, the Shupe effect or the Kerr effect, limit the implementable length of the fibre coil. Coils with a length of approximately 1000 m and with a diameter of up to 300 mm are therefore planned for the prototypes.

Fig. 4 shows a short extract from a measurement of
torsion (left-hand side), in which a building model
(right-hand side) with eccentric mass distribution has
been exposed on a vibrating table to an artificial
5 earthquake.

It may be mentioned, in this regard, that earthquake-
induced rotation observations of teleseismic events are
compatible with collated broad-band translation
10 measurements, and that additional information is
contained in the amplitude ratio.

Claims

1. A method for the determination of damage or states of a mechanical structure which result from a loading of the mechanical structure, wherein in each case a sensor signal of a fiber-optic rotation sensor connected mechanically rigidly at least to part of the mechanical structure is determined before and after the loading; in each case an earth's rotation signal superposed on the sensor signal is determined from the respective sensor signal; on the basis of the superposed earth's rotation signals determined in each case, a respective instantaneous orientation of the fiber-optic rotation sensor with respect to the earth's rotation axis is determined; a change in orientation of the rotation sensor is determined from the respective instantaneous orientations of the fiber-optic rotation sensor before and after loading, and the damage or states of the mechanical structure are determined on the basis of the change in orientation of the rotation sensor.

2. The method as claimed in claim 1, wherein in each case a further sensor signal of a further fiber-optic rotation sensor connected mechanically rigidly at least to a further part of the mechanical structure is determined before and after the loading; in each case a further earth's rotation signal superposed on the sensor signal is determined from the respective further sensor signal; on the basis of the further superposed earth's rotation signals determined in each case, a respective further instantaneous orientation of the further fiber-optic rotation sensor with respect to the earth's rotation axis is determined, a further change in orientation of the further rotation sensor is determined from the respective further instantaneous orientations of the further fiber-optic rotation sensor before and after

the loading, and the damage or states of the mechanical structure are determined on the basis of the changes in orientation of the rotation sensor and of the further rotation sensor.

3. The method as claimed in either one of claims 1 and 2, wherein the respective rotation sensors measure rotations about 1, 2 or 3 rotation axes.

4. The method as claimed in one of claims 1, 2 or 3, wherein the mechanical structure is in the form of a building.

5. The method as claimed in claim 4, wherein the rotation sensors are fastened to sidewalls of the building in such a way that the relative angles between the sidewalls and the floors and ceilings of the building which are supported by the sidewalls can be inferred from the measured rotations.

6. The method as claimed in either one of claims 4 and 5, wherein the translations of at least one building part which are caused by the building loads/building damage are measured via corresponding acceleration sensors which are connected mechanically rigidly to the at least one building part and the building loads/building damage are inferred from the measured translations.

7. The method as claimed in claim 6, wherein the change in orientation of the building with respect to the earth's rotation axis, which change in orientation is a measure of earthquake damage to be determined, is inferred from the measured rotations and translations.

8. A device for the determination of damage or states of a mechanical structure which result from a loading

of the mechanical structure, having a fiber-optic rotation sensor which is connected mechanically rigidly at least to part of the structure; and an evaluation means which is connected to the rotation sensor and which is designed for determining in each case a sensor signal of the fiber-optic rotation sensor before and after the loading; for determining in each case an earth's rotation signal superposed on the sensor signal from the respective sensor ; for determining a respective instantaneous orientation of the fiber-optic rotation sensor with respect to the earth's rotation axis on the basis of the superposed earth's rotation signals determined in each case, for determining a change in orientation of the rotation sensor from the respective instantaneous orientations of the fiber-optic rotation sensor before and after the loading, and for determining the damage or states of the mechanical structure on the basis of the change in orientation of the rotation sensor.

9. The device as claimed in claim 8, having a further fiber-optic rotation sensor which is connected mechanically rigidly to a further part of the mechanical structure and, furthermore, is connected to the evaluation means.

10. The device as claimed in claim 8, having in each case an evaluation means, connected to the rotation sensor, of an independent wireless data transmission system for the joint determination of the damage or status of the structure on the basis of rotations or torsions with respect to the earth's rotation axis which are detected by the individual rotation sensor and are jointly analyzed.

Method for the determination of loads/damage in
a mechanical structure

Abstract

5

In a method for the determination of loads in a
mechanical structure and/or of damage or states in the
mechanical structure which result from the loads in the
mechanical structure, the rotations of a part of the
10 mechanical structure which are caused by loads/damage
in the mechanical structure are measured via a fibre-
optic rotation sensor which is rigidly connected
mechanically to the structural part, and the
loads/damage/states in the mechanical structure are
15 deduced from the measured rotations.

(Fig. 1)