

Method and System for Compensating Vibrations in Elevator Cars

The invention relates to the transportation of persons in
5 elevator cars and, in particular, to a method and a system
for compensating vibrations in elevator cars according to
the definition of the patent claims.

Systems for the transportation of persons often comprise
10 an elevator car which is guided by guide shoes along
guiderrails. With this type of guidance, vibrations occur
which have their origin in the shape and fastening of the
guiderrails, and/or in pressure variations in the airstream
of the elevator car. Such vibrations transferred to the
15 elevator car, especially at high transportation speeds,
are experienced by passengers as unpleasant. It is also
possible for resonances to occur if the frequency of
vibration takes on high values when approaching the
resonant frequency of the elevator car.

20 From document US 5 811 743 a controlling means for
elevator cars is known in which vibrations are
continuously detected by sensors and then compensated by
suitable means in a feedback control system. Such
25 compensation of vibrations takes place either by movement
of the elevator car relative to the guide shoes, or else
by movement of a compensating mass relative to the
elevator car. In the latter embodiment, the coupling of
the elevator car to the guide shoes is not rigid, but
30 elastic, so that during travel of the elevator car there
is a delay in the transfer of vibrations from the guide

shoes to the elevator car, and the controlling means has sufficient time to move the compensating mass. By this means vibrations are reduced, but they are not completely eliminated.

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The objective of the present invention is therefore to obtain such highly effective compensation of vibrations in systems for transporting persons, that the vibrations are not noticed by passengers. In particular, vibrations of
10 low frequency shall be compensated, which are known as nuisance vibrations and experienced as particularly annoying by passengers. The invention shall be compatible with common technologies and methods of the freight and passenger transportation industry. Furthermore, it should
15 be possible by simple manner and means to retrofit existing passenger transportation systems with the invention.

This objective is fulfilled by the invention according to
20 the definition of the patent claims.

The invention is based on abandonment of the compensation of vibrations on elevator cars realized in the state of the art. The basic idea of the invention consists of
25 detecting vibrations, and especially nuisance vibrations, as early as possible so as to compensate them optimally. This is done by multiple detection of the vibration pattern over time. The vibrations are not only detected at the place where they are experienced as annoying, i.e. on
30 the elevator car, but are also detected where they are generated, i.e. at a source of disturbance.

Thus, the pattern over time of disturbing values of acceleration of the elevator car is detected by at least one acceleration sensor on the elevator car, and the pattern over time of disturbing values of acceleration and/or pressure values is detected by at least one further acceleration and/or pressure sensor at the source of disturbance. Disturbing values of acceleration are caused by, for example, deviations from the perpendicular, and/or ideal line, of a guide shoe along guiderails. Disturbing pressure values are, for example, pressure variations in the airstream of the elevator car. It is advantageous for the acceleration sensor to be attached to a guide shoe, and the pressure sensor to the elevator car.

The acceleration values of the elevator car are applied as feedback values, and the acceleration and/or pressure values are applied as disturbance variables to the input of a controlling means. This makes available on the input of the controlling means the pattern over time of disturbance variables and the pattern over time of feedback values, i.e. the effect of the disturbance on the elevator car. The pattern over time of the feedback values, and that of the disturbance variables, is detected as a time function, preferably at regular time intervals.

Within this detection accuracy, the time of occurrence of a disturbing force, and its development over time, are detected both at the source of disturbance and on the elevator car.

The relationship between these time functions is described by a transfer function. Disturbance variables and feedback

values are interpreted in the controlling means according to the transfer function. The transfer function is based on mechanical parameters of the passenger transportation system, such as the unladen weight of the elevator car, the hardness of the springing/damping elements, the momentary position and the weight of a compensating mass, the momentary load being transported, the momentary distribution of the load in the elevator car, etc. At least one of these mechanical parameters is known, or else its latest value is determined at preferably regular time intervals so its latest value is known. Certain mechanical parameters such as the unladen weight of the elevator car, the weight of the compensating mass, the hardness of the springing/damping elements, can be determined once before the passenger transportation system is put into operation. Other mechanical parameters, such as the position of the compensating mass, the load being transported, and the distribution of the load in the elevator car, can be determined with their latest values.

In the controlling means, disturbance variables are used for feedforward control, and feedback values for feedback control. The transfer function thus allows systematic activation of at least one compensating mass taking into account the known, or latest known, mechanical parameters of the passenger transportation system. Systematic activation of the compensating mass is understood as a driving of the linearly or rotationally moved compensating mass fastened to the elevator car, with the objective of counteracting the disturbing force which has arisen with a compensating force such that the disturbing force is

largely neutralized. The disturbing force is neutralized by a compensating force of opposite sign and preferably equal amount. The compensating force need not necessarily be equal in amount to the disturbing force, but it should be at least so large that the vibrations caused by the uncompensated parts of the disturbing force are not perceived by passengers. On the elevator car, the disturbing force as it develops over time is counteracted by a compensating force which develops over time. The compensating mass is moved by at least one drive. The drive is controlled by the controlling means by means of correcting variables.

As well as the compensation of disturbance variables as described, the acceleration of the elevator car is also controlled by feedback. A controlling function for this purpose is provided in the controlling means. For the reference value of acceleration it is given the value 0, since for optimal ride comfort the acceleration on the elevator car should be as low as possible. The feedback value for this feedback control is a measurement value for acceleration detected by at least one sensor. The correcting variable of the control function, and the compensating force compensating the disturbance, together form the correcting variable of the controlling means. Within the freely selectable detection accuracy of the disturbance variables and feedback values, activation of the compensating mass takes place very rapidly, preferably in real time; no time delay in the compensation of vibrations occurs which is perceptible by the passenger; elimination of the vibrations is total.

In support of this process, low-frequency vibrations of from 1 to 100 Hz, preferably of from 2 to 20 Hz, are systematically isolated by the controlling means. By means
5 of systematically low-frequency correcting variables, the compensating mass is driven with correspondingly low frequency, and nuisance vibrations systematically eliminated.

10 Following below, the method and system for compensating vibrations in elevator cars are explained in detail by reference to exemplary variants and embodiments illustrated by figures.

15 Fig. 1 shows a functional diagram of a first variant, with an acceleration sensor on a guide shoe;

Fig. 2 shows a functional diagram of a second variant, with a pressure sensor on the elevator car;

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Fig. 3 shows a functional diagram of a third variant, with an acceleration sensor on a guide shoe and a pressure sensor on the elevator car;

25 Fig. 4 shows a functional diagram of a fourth variant, with a memory to store a path profile;

Fig. 5 shows a block diagram of the transfer function of the controlling means;

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Fig. 6 shows a part of a first embodiment of a system with elevator car, guiderails, sensors, and controlling means;

5 Fig. 7 shows a part of a second embodiment of a system with elevator car, guiderails, sensors, and controlling means; and

10 Fig. 8 shows a part of a third embodiment of a system with elevator car, guiderails, sensors, and controlling means.

The method for compensating vibrations in elevator cars is illustrated in exemplary variants by schematic function
15 diagrams in Figures 1 to 4. The system for compensating vibrations in elevator cars is illustrated in exemplary embodiments in Figures 6 to 8. In these, an elevator car 5 is guided along guiderails 7 by means of guide shoes 6. The elevator car 5 is connected to the guide shoes 6 by
20 means of, for example, springing/damping elements 11 and a car frame 12. The guide shoes 6 roll on the guiderails 7 by means of, for example, guide rollers 6'. In the embodiments according to Figures 6 and 8, the springing/damping elements 11 are fastened to the floor of
25 the elevator car 5; in the embodiment according to Figure 7, the springing/damping elements 11 are fastened to the roof of the elevator car 5.

30 With this guidance by means of guide shoes 6, vibrations occur in the elevator car 5, especially at high guidance speeds. Such vibrations are caused by sources of

disturbance 8. Such sources of disturbance 8 are, for example, uneven joints of guiderails, or bends in guiderails 7, by which shocks, centrifugal forces, and inertia forces are generated in the elevator car 5.

- 5 Sources of disturbance 8 are transferred, for example, via the guiderail 7 onto the guide shoes 6, and from there into the elevator car 5. Other sources of disturbance 8 originate from pressure variations in the airstream of the elevator car 5, and are transmitted into the elevator car
- 10 5.

Sources of disturbance 8 are detected by means of at least one first sensor 1, 1' as disturbance variables Z. In exemplary embodiments according to Figures 6 to 8, such a

15 first sensor 1 is attached as acceleration sensor 1 to a guide shoe 6. In a further advantageous embodiment according to Figures 6 and 8, such a first sensor 1' is attached as pressure sensor 1' to the elevator car 5, for example to the side of the elevator car 5. Nuisance

20 vibrations are thus detected as disturbance variables Z as near as possible to where they occur, i.e. at the source of disturbance 8.

Acceleration values of the elevator car are detected as

25 feedback values X by at least one second sensor 2. In the advantageous embodiments according to Figures 6 to 8, such a second sensor 2 is fastened as acceleration sensor 2 on the elevator car 5, for example on the floor or on the roof of the elevator car 5. The effects of nuisance

30 vibrations are thus detected as feedback values X as near as possible to where they are experienced as annoying,

i.e. on the elevator car 5, preferably near to the springing/damping elements 11 which transmit the nuisance vibrations to the elevator car 5. The pattern over time of feedback values X, and of disturbance variables Z, is
5 detected as a time function at preferably regular time intervals. Within this detection accuracy, the time of occurrence of a disturbing force, and its development over time, are detected both at the source of disturbance and on the elevator car 5. With knowledge of the present
10 invention, the expert can undertake many diverse variations in the detection and arrangement of at least one second sensor 2. For example, in the embodiment according to Figure 7, two acceleration sensors 2 are attached. A first acceleration sensor 2 is mounted on the
15 roof of the elevator car 5 close to the springing/damping elements 11, a second acceleration sensor 2 is mounted on the floor of the elevator car 5 at a distance from the springing/damping elements 11. This permits spatially differentiated detection in the elevator car 5 of the
20 propagation and compensation of nuisance vibrations of springing/damping elements 11 by means of two acceleration sensors 2.

The detection accuracy of the sensors 1, 1', 2 matches
25 common industry standards: for example, sensors 1, 1', 2 detect, for example, 200, preferably 20, measurements per second. All known types of sensor of mechanical, optical, and/or electrical construction can be used as sensors 1, 1', 2. The embodiments shown in the figures are not
30 imperative: with knowledge of the present invention the expert can implement other placements of sensors 1, 1', 2

in passenger transportation systems. For example, a pressure sensor 1' can be mounted on the floor, or on the roof, of the elevator car 5. It is also possible to use sensors 1, 1', 2 which measure slower or faster. The feedback values X, and disturbance variables Z, are applied to the input of a controlling means 3. Such a controlling means 3 is shown in an exemplary block diagram in Figure 5. The controlling means 3 operates with a transfer function. The transfer function contains mapping rules which allow every input variable of the controlling means 3 to be assigned unambiguously to an output variable. The transfer function thus creates a relationship between the pattern over time of the feedback values X and disturbance variables Z, the input variables at the input to the controlling means 3 and the pattern over time of correcting variables Y, the output variables on the output of the controlling means 3. Advantageously the transfer function comprises a time-dependent controlling function $G_r(t)$ and a time-dependent disturbance transfer function $G_z(t)$. Present on the input of the controlling function $G_r(t)$ are the time-variable feedback values X and a specified acceleration reference value 0 for the acceleration of the elevator car with the value 0. Present on the input of the disturbance transfer function $G_z(t)$ are the time-variable disturbance variables Z. The outputs of the controlling function $G_r(t)$ and the disturbance transfer function $G_z(t)$ are subtracted, and thereby form the time-variable output correcting variable Y.

The transfer function can, in principle, be determined in two ways: firstly in that as far as possible all mechanical parameters of the passenger transportation system, which are essentially known, are detected as accurately as possible and set in relation to each other, and secondly in that at least the most important of the mechanical parameters of the passenger transportation system are estimated with sufficient accuracy by means of a modeling method. The modeling method makes use of the measured disturbance variables Z and the measured feedback values X . The mechanical parameters of the passenger transportation system are the unladen weight of the elevator car 5, the momentary position and the weight of at least one compensating mass 4, the hardness of the springing/damping elements 11, the momentary load being transported, the momentary distribution of the load in the elevator car 5, etc. Certain mechanical parameters such as the unladen weight of the elevator car, the weight of the compensating mass 4, the hardness of the springing/damping elements 11, can be determined once before the passenger transportation system is put into operation. Other mechanical parameters such as the position of the compensating mass, the load being transported, and the distribution of the load in the elevator car, are determined with their latest values.

For purely practical reasons, the second method of determination is generally used. The outlay for determining the transfer function by using an adaptable modeling method is usually less. For example, the design engineer and the installation technician naturally know

characteristic springing/damping curves which, for a given weight of the elevator car 5, result from a given hardness of the springing/damping elements 11. Often, however, the weight of the elevator car 5 is not known exactly. This is especially the case during the installation of the passenger transportation system when the elevator car is, for example, often not yet fully fitted out, for example, not cladded inside, and therefore only known with an insufficient accuracy of, for example, 10%. To perform the modeling procedure, at least one of the mechanical parameters must be known with sufficient accuracy and/or have its latest value determined at preferably regular time intervals and its latest value therefore be known with sufficient accuracy. Sufficient accuracy means that the accuracy of the parameter determination is sufficient to perform the modeling procedure successfully. The modeling procedure is successful if a relationship can be constructed between the input variables and output variables of the controlling means 3 such as to systematically compensate the effect of incoming feedback values X and disturbance variables Z by outgoing correcting variables Y. In the modeling procedure, the mechanical parameter is the basis of the transfer function. Dependent on the input variables and output variables of the controlling means 3, a model of the transfer path is created which simulates the actual behavior. As a function of the incoming feedback values X and disturbance variables Z, the model of the transfer path then delivers the outgoing correcting variables Y. The relationship between the input and output variables of the controlling means 3 is adaptively optimized, i.e. the

transfer function which creates this relationship is so adjusted in test runs that the effect of the incoming disturbance variables Z is systematically compensated by outgoing correcting variables Y . When systematically
5 compensating disturbance forces, the disturbance force which has occurred is opposed by a compensating force of equal amount. Known modeling methods which adaptively optimize such input and output variables are the least-squares method, linear regression, etc. With knowledge of
10 the present invention, the expert has many diverse possibilities for realizing such a controlling means 3.

In the controlling means 3, feedback values X are used via the controlling function $G_r(t)$ for feedback control, and
15 disturbance variables Z are used via the disturbance transfer function $G_z(t)$ for feedforward control. The transfer function allows systematic activation of at least one compensating mass 4 taking into account the known, and/or latest known, mechanical parameters of the
20 passenger transportation system. Systematic activation of the compensating mass 4 is understood as a driving of the compensating weight 4 fastened to the elevator car 5, with the objective of opposing the disturbing force which has arisen with a compensating force of equal amount, and
25 neutralizing the disturbing force.

The controlling means 3 outputs correcting variables Y to at least one drive 4' of at least one compensating mass 4 which is to be moved. The drive 4' is, for example, a
30 servodrive which positions in controlled manner a compensating mass 4 which is guided by a known means of

guidance. It is advantageous for the compensating mass 4 to be up to 5%, preferably 2%, of the permitted total weight of the elevator car 5. It is advantageous for the compensating mass 4 to be moved linearly or rotationally over a distance of ± 10 cm, preferably ± 5 cm. The drive 4' is actuated by the controlling means 3 via the correcting variables Y. The compensating mass 4 can be moved periodically or aperiodically back and forth with frequencies of, for example, from 1 to 30 Hz. By this means, the disturbing force developing over time on the elevator car 5 is opposed by a compensating force of equal amount developing over time. It is advantageous for the feedback controller, whose final control element is the drive 4' of the compensating mass 4, to be driven with an acceleration reference value of 0. In the exemplary embodiment according to Figure 6, the drive 4' and the compensating mass 4 are arranged on the roof of the elevator car 5. In the two exemplary embodiments according to Figures 7 and 8, the drive 4' and the compensating mass 4 are fastened under the floor of the elevator car 5. The manner and means of driving, the dimensioning of the compensating mass 4 which is to be moved, and the arrangement of drive 4' and compensating mass 4 relative to the elevator car 5, can be freely ordered with wide scope by the expert with knowledge of the present invention. In the exemplary embodiment according to Figure 8, the drive 4' and compensating mass 4 are arranged close to the springing/damping elements 11 so as to compensate as early as possible via the springing/damping elements 11 disturbing forces transferring to the elevator car 5, i.e.

before further propagation of annoying vibrations in the interior of the elevator car 5 to the passengers.

In the variant according to Figure 4, the at least one
5 first sensor 1 detects a path profile of the elevator car 5 along the guiderail 7. This path profile is characteristic of the system comprising elevator car, guide shoes, and guiderail. This path profile is stored in a memory 10. The memory 10 is of usual commercially
10 available construction, being, for example, an electronic, magnetic, and/or magneto-optical data store. It is advantageous for the stored path profile to be determined once in a calibrating procedure before putting the passenger transportation system into operation. Assuming
15 that the path profile is time-invariant, and with knowledge of the momentary position of the elevator car 5 on the transportation path, permanent mounting of an acceleration sensor 1 on a guide shoe 6 is then unnecessary. Positional detection is usual on elevator
20 cars, and takes place, for example, with a positional resolution of 0.1 mm. Disturbing variables Z in the form of a stored path profile are thus present on the input of the controlling means 3, and are interpreted together with the feedback values X in the controlling means 3 according
25 to the transfer function. At inspections the path profile can be checked and, if necessary, updated. The path profile is also a documentation of the condition of the system comprising elevator car, guide shoes, and guiderails.

The controlling means 3 can, through a multiple input, detect disturbance variables Z from several acceleration sensors 1 on several guide shoes, and/or from more than one pressure sensor 1' on the elevator car 5. The

5 controlling means 3 can also detect feedback values X from more than one acceleration sensor 2 on the elevator car 5. Finally, the controlling means 3 can apply correcting variables Y on multiple outputs to more than one drive 4'. Such a MIMO (multiple input multiple output) controlling
10 means is, for example, designed as a non-linear controller, a neural network, a fuzzy controller, a neuro-fuzzy controller, etc. With knowledge of the present invention, the expert has many and diverse possibilities for the design of the controlling means.

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In an advantageous embodiment, low-frequency vibrations, so-called nuisance vibrations, with frequencies of from 10 to 100 Hz, preferably from 2 to 20 Hz, are isolated in the controlling means 3, for example by means of a high-pass
20 filter with a cutoff frequency of 1 to 3 Hz. Such low-frequency vibrations are insufficiently eliminated by normal springing/damping elements 11. Nuisance vibrations are, however, experienced as particularly unpleasant by passengers. By systematic control, the compensating mass
25 is driven with the frequencies of the nuisance vibrations, and the nuisance vibrations are systematically eliminated.



Patent Claims

1. Method of compensating vibrations in an elevator car
(5) by the use of at least one sensor (1, 2), which
5 sensor (1, 2) detects vibrations of the elevator car
(5), a controlling means which interprets the detected
vibrations and controls at least one drive (4') for
moving at least one compensating mass (4) on the
elevator car (5) for compensating the detected
10 vibrations,
characterized in that
by at least one first sensor (1, 1') vibrations are
detected at a source of disturbance (8) and by at
least one second sensor (2) vibrations are detected at
15 the affected point on the elevator car (5).
2. Method according to Claim 1,
characterized in that
vibrations detected by the first sensor (1, 1') are
20 applied as disturbance variables (Z) to an input of
the controlling means (3) and that vibrations detected
by the second sensor (2) are applied as feedback
values (X) to an input of the controlling means (3).
- 25 3. Method according to Claim 1,
characterized in that
vibrations detected by the first sensor (1, 1') are
stored in a memory (10) as a path profile, and that
the path profile is applied as disturbance variables
30 (Z) to an input of the controlling means (3), and
that vibrations detected by the second sensor (2) are



applied as feedback values (X) to an input of the
controlling means (3).

4. Method according to Claim 2 or 3,
5 characterized in that
the controlling means (3) uses feedback values (X) for
feedback control, that the controlling means (3) uses
disturbance variables (Z) for feedforward control, and
that correcting variables (Y) are output on an output
10 of the controlling means (3).
5. Method according to Claim 1 or 4,
characterized in that
the drive (4') for moving the compensating mass (4) is
15 controlled by correcting variables (Y) of the
controlling means (3), and is operated with a
reference value of zero.
6. Method according to Claim 1 or 4,
20 characterized in that
vibrations with frequencies from 1 to 100 Hz,
preferably from 2 to 20 Hz, are isolated in the
controlling means (3), and that the compensating mass
(4) is driven with frequencies of the vibrations, and
25 the vibrations are systematically eliminated.
7. Method according to Claim 1 or 4,
characterized in that
a relationship between the vibrations detected by the
30 first sensor (1, 1') and vibrations detected by the
second sensor (2) is created by a transfer function of



the controlling means (3).

8. System for compensating vibrations in an elevator car

(5) consisting of at least one sensor (1, 2), which
5 sensor (1, 2) detects vibrations of the elevator car
(5), a controlling means (3) which interprets the
detected vibrations and controls at least one drive
(4') for moving at least one compensating mass (4) on
the elevator car (5) for compensating the detected
10 vibrations,

characterized in that
at least one first sensor (1, 1') detects vibrations
at a source of disturbance (8), and at least one
second sensor (2) detects vibrations at the affected
15 point on the elevator car (5).

9. System according to Claim 8,

characterized in that the controlling means (3)
isolates vibrations with frequencies from 1 to 100 Hz,
20 preferably from 2 to 20 Hz, and that the controlling
means (3) activates the compensating mass (4) with
frequencies of the vibrations and systematically
eliminates the vibrations.

25 10. System according to Claim 8 or 9,

characterized in that
the first sensor (1, 1') is an acceleration sensor (1)
on a guide shoe (6) and/or a pressure sensor (1') on
the elevator car (5), and that the second sensor (2)
30 is an acceleration sensor (2) on the elevator car (5).