

Inspection method for the comb plate region of an escalator or moving walkway

The present invention relates to a method for inspecting the comb plate region of an escalator or moving walkway by means of a mobile inspection device.

Escalators or moving walkways have been used for many decades in public places with high pedestrian traffic, such as subways, shopping centers, and airports. Their operational safety depends in particular upon the design of the interfaces between moving and stationary components that are accessible to users.

In the case of escalators and moving walkways, these interfaces are side gaps that exist between the moving conveyor belt and the fixed base panels arranged on both sides along the conveyor belt. Further interfaces are comb gaps that exist between the conveyor belt and fixed combs. The combs are installed in a fixed location in comb plate regions and are arranged in two mutually opposite access regions of the escalator or moving walkway. In the case of a correct, operationally safe arrangement, the ridge/groove structures of the conveyor belt and comb teeth of the comb plates engage in one another with a specified comb gap, such that the conveyor belt can be moved in under the comb plates and moved out from under the comb plates without making contact, and foreign objects are prevented from entering the comb gap. Therefore, dimensionally maintaining the specified comb gap between the ridge/groove structures of the conveyor belt and the comb teeth of the comb plates is very important for the safe operation of the escalator or moving walkway. For example, if the comb gap is too large owing to wear, or if the comb teeth of the comb plates are bent or even broken, there is a risk that an object carried by a passenger will become trapped in the comb plate gap and that the passenger will be injured. For example, if an external foreign object such as a coin becomes trapped, this can also lead to incorrect positioning of the conveyor belt relative to the base panels arranged on both sides, causing one of the two side gaps to become too large, which poses a latent risk to the passenger.

Therefore, the side gaps and the comb gaps of the comb plate region of an escalator or moving walkway are checked periodically. This inspection is very time-consuming and requires a high level of knowledge and skill on the part of a service technician in order to carry out the inspection correctly and make an appropriate assessment.

It is therefore the object of the present invention to provide an inspection method which allows even a less qualified service technician to inspect the comb plate region quickly and correctly.

5 This object is achieved by means of a method for inspecting the comb plate region of an escalator or moving walkway by means of a mobile inspection device. This may for example be an inspection device specifically manufactured for this purpose, or a suitably equipped tablet, smartphone, or laptop. The mobile inspection device has at least a user interface, a digital storage medium, a processor, an imaging depth sensor, and a software
10 application which is stored at least temporarily in the storage medium and which has the respectively required method steps of the inspection method.

The inspection method comprises, in particular, the method steps listed below, although these do not necessarily have to be executed in this sequence.

15 In one step of the inspection method, a 3-D recording of all combs and adjacent surface regions of a comb plate region of the escalator or moving walkway is captured by means of a depth sensor of the mobile inspection device. The feature "all combs and adjacent surface regions" means that the entire comb plate region, from one base panel across all mutually
20 adjacent combs of the comb plate region to the second base panel, is imaged in the 3-D recording. The feature prefix "3-D" means that all features labeled therewith exhibit a three-dimensional, spatial structure. Since the combs and the ridge/groove structure of the conveyor belt engage in one another, a portion of a tread surface of the conveyor belt of the escalator or moving walkway is, logically, also included in the 3-D recording.

25 In a further step, a 3-D surface image of the comb plate region is extracted from the 3-D recording. Here, a 3-D surface image is generated or extracted from the three-dimensional point cloud of the 3-D recording by means of algorithms known from electronic image processing methods, which are integrated into commercially available graphics programs, photo processing programs, image evaluation and video evaluation programs, etc., or are
30 available as "open source software modules." Peripheral regions that are not of interest can be eliminated by manual intervention or by automation. The 3-D surface image is for example a further processable, three-dimensional vector graphic and contains at least the surfaces, captured in the 3-D recording, of all mutually adjacent combs of the imaged
35 comb plate region, as well as surface regions of base panels that are laterally adjacent to

the combs, and of the tread surface, situated in the comb plate region, of the conveyor belt. Extracting the 3-D surface image also includes rectification and scaling. This may be performed in a variety of ways and may also depend upon whether a single 3-D recording of the entire comb plate region has been captured, or whether the 3-D recording was captured in the form of a digital 3-D film sequence with a plurality of frames.

In other words, the 3-D surface image is substantially a digital 3-D surface model, preferably at a scale of 1:1. This substantially comprises those surfaces of the comb plate region which have been captured in the 3-D recording. During extraction, the content of the 3-D recording (the imaged comb plate region in the single 3-D image or in each frame of the 3-D film sequence) is rectified and scaled to a scale of 1:1. While a 1:1 scale is advantageous, it is not imperative. The only important thing is that the size ratios of the 3-D surface image match the virtual 3-D model described below.

In a single 3-D image, all combs are fully imaged in the 3-D recording, such that their component boundaries, such as corner points, edges, and joint gaps, can be easily identified as fixed points in the 3-D surface image by means of appropriate analysis algorithms. The image recognition and image processing algorithms required for this purpose are known from image processing programs and are widely used, and therefore no detailed description of these algorithms will be given here. For example, a suitably trained AI (artificial intelligence) program module can be used to identify prominent edges, corners, and joint gaps. 3-D surface images of the comb plate region or of a single comb, taken from a wide variety of viewpoints or camera perspectives, can be used as a basis for training the AI program module.

Fixed points may self-evidently also be defined manually by the service technician by using a zoom function to magnify the display of the 3-D recording on a user interface of the inspection device and defining prominent positions in the recording as fixed points - for example, by positioning markers provided by the software application. The markers are then linked to the location data of the marked pixel and "carried along" during the execution of further method steps.

The conversion parameters for the rectification and scaling are dependent upon the spatial position of the imaging depth sensor relative to the comb plate region and, if applicable, relative to fixed points such as a fixed prominent corner of a comb. If the actual distances

between two fixed points, e.g., the comb length, are stored in the storage medium, it is possible to determine the corresponding conversion parameters for each captured pixel of the 3-D surface image.

5 If the software application is implemented in a mobile device (smartphone, tablet, laptop), the spatial position of the imaging depth sensor for each pixel of the 3-D recording can also be determined, if necessary, using position data from the built-in, three-axis position sensor. Using these conversion parameters and known processing algorithms that are used in image processing programs and 3-D CAD programs for rectification and scaling of
10 three-dimensional digital images, the 3-D surface image can be generated from the 3-D recording.

Alternatively, the rectification and scaling may also be performed using a uniquely assignable virtual 3-D model stored in the storage medium. For example, a scaling factor can be
15 calculated on the basis of an edge length of a comb in the 3-D model and in the 3-D surface image, and the surface image can be scaled to the 3-D model, wherein the virtual 3-D model is preferably stored at a scale of 1:1. The spatial rectification of the 3-D surface image can also be achieved on the basis of the spatial position of edges and joints of the combs.

20 In a further step, a virtual 3-D model of the comb plate region is retrieved from a digital storage medium, wherein the virtual 3-D model contains at least virtual 3-D comb models of the comb plate region in a specified arrangement. The virtual 3-D model may for example have been created using a 3-D CAD system and comprise only those 3-D comb models which are mutually adjacent in the intended spatial position. It is self-evidently
25 also possible for further 3-D model modules to be present - for example, a 3-D model module of a comb plate on which the combs are arranged, lateral portions of the base panels, parts of a comb plate support, and the like. The virtual 3-D model may for example also be retrieved from a digital twin that represents the escalator to be inspected or the moving walkway to be inspected.

30 In a further step, the 3-D surface image and the virtual 3-D model are spatially combined. In other words, the 3-D model is inserted at the correct position in the rectified and scaled 3-D surface image. The individual combs have such a small base area that they can easily be imaged fully in the 3-D recording. Accordingly, their component boundaries are
35 present as edges and joints on the 3-D surface image. The spatial orientation and correctly

positioned insertion of the virtual 3-D model into the 3-D surface image can be achieved on the basis of the spatial position of these edges and joints. The image recognition and image processing algorithms required for this purpose are known from image processing programs and are widely used, and therefore no detailed description of these algorithms will be given here. For example, a suitably trained AI (artificial intelligence) program module can be used to identify prominent edges, corners, and joint gaps. 3-D surface images of the comb plate region, taken from a wide variety of viewpoints or camera perspectives, can be used as a basis for training the AI program module.

In a further step, a height of a comb gap between the tread surface imaged in the 3-D surface image and a comb subsurface structure in the virtual 3-D model is determined. Since the tread surface has a ridge/groove structure that meshes with the comb teeth of the combs, the comb gap extends in meandering fashion across the width of the conveyor belt between the two base panels. The height of the comb gap relevant for the inspection is the vertical clearance between a highest surface of a ridge of the tread surface and a tooth base, situated thereabove, of the comb, or the clearance between a groove base of the tread surface and a tooth tip surface, situated thereabove, of the comb. The previously used characteristics “overlying” and “vertical” refer to the intended operating position of these components.

In a further step, a comparison with limit specifications retrieved from the digital storage medium for the height of the comb gap is performed. If the determined height deviates from the limit specifications, a first information signal is output. The function and effects of the first information signal will be described in more detail below.

The advantage of the method described above is that the comb gap is assessed not only from the visible surfaces, but also on the basis of the hidden surfaces, in particular the underside of the combs, which are available owing to the inserted 3-D model. This eliminates the need to perform a comparison against a previously recorded reference image, as disclosed, for example, in EP 3 299 330 B1. Reference images are useful only if the inspection device is installed in a fixed location at the place of use. Since the camera perspective changes with each execution of the inspection method when using the mobile inspection device as intended according to the invention, previously recorded reference images are unusable. Furthermore, it is sought to analyze a large number of different escalators and moving walkways by means of the mobile inspection device,

which further complicates the handling and assignment of reference images taken during commissioning or after a repair.

For the inspection method according to the invention, reference images taken
5 immediately prior to the inspection are unsuitable in any case because, depending upon
the situation, they may include faults and then systematically deliver faulty results. For
example, if chewing gum is stuck to the combs, this can lead to a distortion of the heights
of the combs relative to the tread surface. By the 3-D model being inserted into the 3-D
surface image, said 3-D model is oriented as described above on the basis of the spatial
10 position of edges and joints of the combs, so that such "bumps and bulges" are
disregarded in the 3-D surface image. It is self-evidently also possible for the normally
slightly curved surface of the combs to be used for the spatial orientation of the 3-D
model, wherein the largest common area of contact between the 3-D surface image and
the 3-D model is used for the purposes of positioning.

15 In one embodiment of the inspection method, a minimum side gap width and a maximum
side gap width between the tread surface and the adjacent base panel, or the
corresponding extracted surface region, are measured on each of the two sides of the tread
surface from the scaled and rectified 3-D surface image. Two measurement points may be
20 defined for each side gap as a basis for these measurements. The spacing of said
measurement points preferably corresponds, in the case of escalators, to a step length of a
step of the conveyor belt, or in the case of moving walkways, to three pallet lengths of the
pallet belt. If necessary, the measurement points may be established automatically by
joints between the steps or pallets being identified from the 3-D surface image, and the
25 point at which they open into the step gap (corner of a step or pallet) being defined as
measurement points. According to applicable standards such as EN 115-2, each of the
side gaps must be no wider than 4 mm, and their sum must be no wider than 7 mm.
Accordingly, the two measured values of the maximum side gap width must not exceed 4
mm, and their sum must not exceed 7 mm. In other words, the maximum side gap widths
30 are compared with limit specifications retrieved from the digital storage medium for the
side gap width, and a second information signal is output if the determined side gap width
deviates from the limit specifications.

In a further embodiment of the inspection method, an inclination angle of the tread
35 surface relative to the base panel is determined from the minimum side gap width and the

maximum side gap width of one of the two side gaps. The inclination of the tread surface relative to the base panel may be caused for example by conveyor chains of different lengths on the conveyor belt, which exhibit different wear owing to asymmetrical loads (standing on the right, walking on the left). The inclination angle is subsequently
5 compared with limit specifications for the inclination angle retrieved from the digital storage medium. If the determined inclination angle deviates from the limit specifications, a third information signal is output.

In a further embodiment of the inspection method, the 3-D recording is captured in the
10 form of a digital 3-D film sequence of the comb plate region, wherein the digital 3-D film sequence shows the comb plate region from the first base panel to the opposite, second base panel in a plurality of frames. To generate the 3-D surface image, prominent fixed points such as the joints and edges of the combs mentioned further above are automatically established in the frames of the digital 3-D film sequence and used for the
15 rectification and scaling of the 3-D surface image. A prominent fixed point of the aforementioned type can also be a comb edge, a fastening screw of the comb, or a corner of the comb.

The generation of the 3-D surface image includes rectification and scaling of the surfaces
20 and contours imaged in the frames, which is advantageous owing to the changing spatial position of the imaging depth sensor of the inspection device relative to the comb plate region being recorded. The generation furthermore includes piecing together the 3-D partial surfaces of the comb plate region imaged in the frames to create the 3-D surface image. Here, too, the fixed points are used to spatially orient the imaged 3-D partial
25 surfaces relative to one another. As already mentioned further above, the image recognition and image processing algorithms required for this purpose are known from image processing programs and CAD systems and are widely used, and therefore no detailed description of these algorithms will be given here. The required distances to these fixed points are measured by the imaging depth sensor for each fixed point captured
30 in the frames of the 3-D recording and can be used by the image processing algorithms.

In a further embodiment of the inspection method, the 3-D surface image is analyzed by an analysis module and, based upon the analysis data thereof, a suitable 3-D model is retrieved from a model database that is stored in the digital storage medium. The analysis
35 module may be a program component of the software application that also contains the

above-described method steps of the inspection method. The analysis module may, however, also be a computer program which is independent of the software application and which for this purpose communicates and exchanges data, via suitable communication means (protocols, etc.), with the software application executed in the processor. The analysis module can be part of the AI program module described above.

In an alternative embodiment of the inspection method, the correct 3-D model may also be determined by scanning a barcode or QR code which is attached to the escalator to be inspected or to the moving walkway to be inspected. Following the scanning, a 3-D model associated with the barcode or QR code is retrieved from a model database that is stored in a digital storage medium.

In an alternative embodiment of the inspection method, the correct 3-D model may also be obtained by a query by the mobile inspection device. For this purpose, the mobile inspection device queries an identification number from a controller of the escalator or moving walkway. By means of the identification number, an associated 3-D model is retrieved from a model database that is stored in a digital storage medium.

In a further embodiment of the inspection method, a contour comparison of all combs is performed between the 3-D surface image and the 3-D model by the mobile inspection device. A different contour pattern indicates damage to the comb teeth. The existing differences are checked for an inadmissible deviation with regard to the tooth shapes of the comb teeth and/or with regard to missing comb teeth - for example, by orthogonal distances between the contour of the 3-D model and the contour of the 3-D surface image being determined and compared with limit specifications for these distances. The contour comparison may self-evidently also be performed via the analysis of differential areas, wherein a comparison of the visible surface of a comb is performed between the 3-D model and the 3-D surface image. An almost 100-percent overlap (differential area almost zero) indicates that the comb is in perfect condition. A deviation of, for example, 2 percent in the visible comb surface indicates an inadmissible deviation with regard to the tooth shapes of the comb teeth, or indicates missing comb teeth. If any one of the determined distances deviate from the limit specifications or if an excessively large differential area is determined, there is an inadmissible deviation with regard to the tooth shapes of the comb teeth and/or with regard to missing comb teeth, and a fourth information signal is output.

In a further embodiment of the inspection method, in the presence of a fourth information signal, those components which are affected by the deviations and which are to be replaced are marked on the 3-D surface image of the comb plate region. Since the component boundaries can be easily identified using appropriate image processing algorithms, these component boundaries or the surface lying within these component boundaries can be highlighted in color. The 3-D surface image with markings is displayed on the user interface (screen, touchscreen) of the mobile inspection device. This allows a service technician operating the inspection device to immediately identify which components need to be replaced.

In a further embodiment of the inspection method, based upon the fourth information signal, component identification numbers of those components which are affected by the deviations and which are to be replaced are displayed by the inspection device and/or are transmitted to a provisioning facility. The provisioning facility checks the stock, reports a date back to the mobile inspection device indicating when and where the requested components will be available, and provides the requested components. If necessary, a file (for example in the form of a PDF file or video clip) containing the assembly instructions specific to the requested components is additionally transmitted to the inspection device along with the date confirmation, and can then be viewed by the service technician on the user interface of the inspection device.

In a further embodiment of the inspection method, if the inspection device detects that at least one of the four information signals is present, the inspection device may place a controller of the escalator or moving walkway into a maintenance mode. This maintenance mode may be graduated depending upon the weighting of the information signal for operational safety and in accordance with the magnitude of the identified deviation from the limit specifications. The highest level (for example, if a large number of teeth of a comb have been broken off or if the comb gap is too large) means that the identified defects are so severe that the operation of the escalator or moving walkway will be blocked until repairs are carried out. A medium level (for example, if a tooth of a comb is deformed) may for example define a time window in which operation at nominal speed or operation at a reduced speed is still possible. A low level (for example, if the comb gap or one of the side gaps is close to the admissible limit specification) may for

example not initiate any action to influence operation, but merely require a service technician to schedule a maintenance appointment to carry out the repair.

5 To carry out the aforementioned method, a mobile inspection device is required which has at least a user interface, a digital storage medium, a processor, an imaging depth sensor, and a software application which is stored at least temporarily in the storage medium and which has the respectively required method steps of the inspection method. For example, a combination of a CCD camera and a LIDAR sensor, a laser scanner, a radar sensor, or a TOF camera can be used as an imaging depth sensor. The mobile
10 inspection device may be a device created specifically for this purpose. Since many mobile phones (smartphones) and tablets nowadays have suitable imaging depth sensors, in particular TOF cameras or a combination of LIDAR and CCD sensors, all of the necessary hardware components are present in these devices, and therefore only the corresponding software application having the method steps of the inspection method
15 needs to be loaded into the storage medium thereof. The method steps of the inspection method that are programmed in the software application are executed by the processor in response to an input made by the service technician via the user interface.

20 The mobile inspection device preferably has a communications module which can be connected to a communications module of at least one of the following devices for data exchange as required: a controller of an escalator or moving walkway, a central monitoring device, a provisioning facility for replacement parts, or a network node of the Internet. The functionality of the inspection device can be significantly expanded by the communications module being used, for example, to automatically order replacement
25 parts, transmit safety instructions, and/or block operating functions of the escalator or moving walkway.

Furthermore, certain functions of the software application may be outsourced - for example, to a cloud. Examples of such outsourceable functions include, for example, the
30 analysis module, the extraction of the 3-D surface image from the 3-D recordings, the storage of 3-D models and limit specifications in suitable databases, and the like. This allows the most computationally intensive and memory-intensive method steps to be outsourced, thus freeing up processor and memory resources in the inspection device.

Embodiments of the invention will be described below with reference to the accompanying drawings, wherein neither the drawings nor the description are intended to be interpreted as limiting the invention. The figures are merely schematic and not true to scale. Identical or equivalent features have the same reference signs. In the figures:

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Fig. 1 is a schematic sectional side view of an escalator and its most important components, along with peripheral devices for carrying out associated method steps of an inspection method;

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Fig. 2 is a three-dimensional partial view of the upper access region, indicated in Fig. 1, with a comb plate region, and shows a smartphone having a software application that turns it into a mobile inspection device;

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Fig. 3 is a schematic cross-section through the comb plate region illustrated in Fig. 2;

Fig. 4 is a plan view of a detail of the comb plate region illustrated in Fig. 2;

Fig. 5 is a flow diagram of the inspection method with method steps; and

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Fig. 6 is a plan view of a detail of the comb plate region illustrated in Fig. 2 with possible damage to comb teeth of the combs arranged in the comb plate region.

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Fig. 1 is a schematic sectional side view of an escalator 1 and its most important components. The escalator 1 serves to transport people, for example, between two levels E1, E2 of a building.

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The escalator 1 has a conveyor belt 26 with a plurality of escalator steps 3 which are arranged one behind the other and which can be displaced in a direction of movement 6 along a travel path with the aid of two conveyor chains 5 (only one is visible in Fig. 1) which are closed in a ring shape and arranged parallel to one another. The double arrow of the direction of movement 6 indicates that the escalator 1 can transport passengers both from level E1 to level E2 and in the opposite direction. Each of the escalator steps 3 has a tread surface 21 and is situated between and attached to the two conveyor chains 5. In order to be able to move the conveyor chains 5, the escalator 1 has a drive region 13 in which a drive shaft 17, a gear 16, a drive motor 19, and a brake 18 are arranged.

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The drive region 13 is usually arranged in the upper level E2 of the building, while a tensioning station 7, shown only schematically, with a deflection axle 15 is arranged in the lower level E1. The drive shaft 17 and deflection axle 15 and other components of the escalator 1 are held in a supporting structure 2, usually in the form of a lattice structure, which for the sake of clarity is illustrated merely as an outline in Fig. 1. The escalator 1 also has two balustrades 8 (only one visible), each of which has a handrail 4 arranged all around it.

In the case of an upward-transporting direction of movement 6, the escalator steps 3 are moved in a forward movement from a lower access region 10 of the escalator 1 adjacent to the lower level E1, via a central inclined region 11, to an upper access region 12 adjacent to the upper level E1, and are then moved back in the opposite direction in a return movement.

The drive motor 19 and the brake 18 arranged in the drive region 13 are controlled and regulated by means of a controller 14. The torque or the rotary movement of the motor shaft (concealed by the gear) of the drive motor 19 is transmitted to the drive shaft 17 via the gear 16 (a worm gear and a drive chain are shown as an example). Since there are usually two conveyor chains 5 between which the escalator steps 3 are arranged, the drive shaft 17 must also have two drive sprockets (not shown in detail) via which the conveyor belt 26 is guided in a manner so as to transmit motions. All components of the drive region 13 are also accommodated in the supporting structure 2 and are spanned by a walkable floor covering 9, which is a component of the upper access region 12 (see also Fig. 2).

Between the movable conveyor belt 26 and the fixed floor covering, there is a comb plate region 27, the combs 28 of which (see Figs. 2 to 6) are among the wearing parts of the escalator 1 and are therefore replaceable. The combs 28 have comb teeth 29 which mesh with a ridge/groove structure 30, 31 which is formed on the tread surface 21 of the steps 3. Since the comb plate region 27 is among the most critical regions of an escalator 1 or moving walkway with regard to a potential risk of injury to passengers, there are regulations in relevant standards, such as EN 115-2, which must be strictly adhered to. These regulations concern, for example, the condition of the combs 28 and the maximum admissible height h of the comb gap 33, as illustrated in Fig. 3. Accordingly, the comb plate region 27 must be inspected periodically, and serviced as necessary.

As mentioned in the introduction, an inspection method 45 according to the invention is intended to significantly simplify the inspection process. Fig. 1 therefore also shows an inspection device 40 for enabling the inspection method 45 to be carried out. Also shown
5 are further peripheral devices, such as a cloud 90, a provisioning facility 91, and a central monitoring device 92, which can be used to carry out further method steps S_n (see Fig. 2; "n" in the reference sign means an indefinite number of method steps) of the inspection method 45.

10 Since Figs. 2 to 5 are referred to for the purposes of describing the inspection method 45, said figures will be described jointly below.

Fig. 2 is a three-dimensional partial view of the upper access region 12 shown in Fig. 1. The two balustrades 8 with their balustrade bases 20 (only one is visible) are arranged on
15 both sides of the conveyor belt 26. The internal structure (not visible) of the balustrade base 20 is covered with a cladding panel 22 and a base panel 23.

A smartphone is pointed at the access region 12 and contains a software application 44 that turns the smartphone into a mobile inspection device 40. The mobile inspection device 40
20 essentially has a user interface 41 (touchscreen), a digital storage medium 42, a processor 43, an imaging depth sensor 46, and the software application 44 stored at least temporarily in the storage medium 42. The inspection method 45 implemented in the software application 44 comprises the method steps S_0 to S_8 required for the inspection, and the further method steps S_n . The mobile inspection device 40 may self-evidently also be a
25 tablet or a laptop, or a device which has been specially manufactured for this purpose and which contains at least the aforementioned components.

Fig. 3 is a cross-section through the comb plate region 27 illustrated in Fig. 2, wherein only those structures of the two balustrade bases 20, of the conveyor belt 26, and of the
30 combs 28 which are essential for the inspection are schematically shown. The contours illustrated using solid lines can be imaged by the imaging depth sensor 46, whereas the contours of the conveyor belt 26 illustrated using dashed lines cannot be captured by the depth sensor 46. The tread surface 21 of the conveyor belt 26 is structured by means of ridges 31 and grooves 30 which extend parallel to the intended direction of movement 6.
35 The comb teeth 29 of the combs 28 engage in the grooves 30 of the conveyor belt 26

without making contact, such that the step gap 33 extends in meandering fashion between the comb undersides 34 of the combs 28 and the tread surface 21 of the conveyor belt 26 from one base panel 23 to the other base panel 23. The comb underside 34, illustrated by means of a dash-dot line, of the combs 28 also cannot be captured by the depth sensor 46.

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Fig. 4 is a plan view of a detail of the comb plate region 27 illustrated in Figs. 2 and 3. The mutually adjacent combs 28 and the ridges 31 and grooves 30 of the conveyor belt 26 or of the steps 3 are clearly visible.

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Fig. 5 is a flow diagram of the inspection method 45 having the method steps S_0 to S_8 . By means of an input S_0 made via the user interface 41, the processor 43 is instructed to execute the method steps S_1 to S_8 .

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In the method step S_1 , the imaging depth sensor 46 of the mobile inspection device 40 captures a 3-D recording 51 of all combs 28 and adjacent surface regions of the base panels 23 and of the conveyor belt 26. This may be done, as indicated in Fig. 2, by recording a single 3-D image 73. Much more precise, but more complex in terms of subsequent processing, is a 3-D recording 51 in the form of a digital 3-D film sequence 70 of the comb plate region 27, by the imaging depth sensor 46 being moved transversely with respect to the transport direction 6 across the entire comb plate region 27 from one base panel 23 to the other base panel 23, as shown in Fig. 3 by the dash-double-dot arrow 52.

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In principle, owing to the distance detection for each pixel, the depth sensor 46 provides a 3-D recording 51 with a three-dimensional 1:1 image of the comb plate region 27.

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However, the 3-D images 73 are sufficiently precise only if the imaging depth sensor 46 is arranged in a fixed location relative to the comb plate region 27 during the recording process. Since the inspection device 46 is to be as mobile as possible, rectification and scaling of the 3-D recording 51 is scarcely avoidable, depending upon the imaging depth sensor 46 used. In the method step S_2 , therefore, a rectified and scaled 3-D surface image 53 of the comb plate region 27 is extracted from the 3-D recording 51. Said image contains at least the optically capturable surfaces of all combs 28 of the comb plate region 27, of the base panels 23 laterally adjacent to the combs 28, and of a tread surface 21, situated in the comb plate region 27, of the conveyor belt 26. The 3-D surface image 53 is substantially a digital 3-D surface model, preferably at a scale of 1:1, which contains only the surfaces captured in the 3-D recording 51. During extraction, the 3-D image 73 of the

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3-D recording 51, or each frame 71 of the 3-D film sequence 70 (see Fig. 3), is rectified and scaled to a scale of 1:1.

Conversion parameters for the rectification and scaling are dependent upon the spatial position of the imaging depth sensor 46 relative to the comb plate region 27 at the time of each captured pixel. It is particularly expedient for fixed points 81, 82, such as a fixed prominent corner of a comb 28 (see Figs. 2 and 4), to be identified and defined. Since the actual distances between two fixed points 81, 82, e.g., the comb length L_K , are known and are stored in the storage medium 42, it is possible to determine the corresponding conversion parameters for each captured pixel of the 3-D recording 51. This is also possible by means of distance measurements V_1 , V_2 , as well as by measurement of the associated angles α . If the software application 44 is implemented in a mobile device (smartphone, tablet), the spatial position of the imaging depth sensor 46 can optionally also be determined for each pixel of the 3-D recording 51 using position data from the built-in, three-axis position sensor 48 (see Fig. 2). By means of these conversion parameters and using known processing algorithms that are used in image processing programs for rectification and scaling of three-dimensional digital images, the 3-D surface image 53 can be generated. The extraction may also involve a conversion of the graphic format - for example, from a "pixel cloud" recorded in the 3-D image 73 or frame 71 into a more easily processable format such as a 3-D vector graphic.

In the case of a 3-D film sequence 70, the spatial position of the imaging depth sensor 46 can be determined analogously to the frame rate (i.e., for each frame 71 of the 3-D film sequence 70). As described above, this may also be done by means of distance measurements V_1 , V_2 , as well as by measurement of the associated angles α , such that rectification and scaling can be carried out continuously, i.e., for each frame 71. Furthermore, the capture of fixed points 81, 82 in each frame 71 of the 3-D film sequence 70 is helpful for piecing together the image portions, which have been extracted therefrom and rectified and scaled, of the 3-D surface image 53 in the manner of a puzzle to form the 3-D surface image 53. The capture of the fixed points 81, 82 and of the distance L_K between them is performed by means of the imaging depth sensor 46 and suitable analysis algorithms.

These analysis algorithms are based, for example, upon known image processing techniques that are optimized and applied in self-learning processes using artificial

intelligence in neural networks. In the self-learning process, for example, 3-D images of a comb 28 taken from a wide variety of viewpoints are used, and the same fixed points 81, 82 are always marked and saved via a user interface until the analysis algorithms can access a sufficient database in order to accurately identify the fixed points 81, 82. A further common image processing technique for generating information from a frame 71 or a 3-D image 73 is, for example, the calculation of the histogram, which provides information about the statistical brightness distribution in the 3-D image 73 or frame 71. Such a histogram can for example serve as a configuration for further image processing steps or as information for a human user of the software application 44, by identified outlines, edges, corners, and joints in the 3-D surface image 53 being identified and defined as fixed points 81, 82.

Other computable pieces of information relating to a 3-D image 73 are, for example, its entropy or average brightness. Based upon these pieces of information, vector analyses can be performed on 3-D images 73 and frames 71 of digital 3-D film sequences 70 in order to establish how individual fixed points 81, 82 move relative to one another. From this, conclusions can be drawn regarding the current spatial focal point of the imaging depth sensor 46 in order to obtain suitable conversion parameters for the rectification, scaling, and combination of the portions of the comb plate region 27 recorded in the individual frames 71 and in order to combine these portions to form the 3-D surface image 53. Instead of the method described above, use may self-evidently also be made of other analysis techniques and analysis methods known from the technical fields of image processing and video surveillance - for example, in order to measure the contours of the combs 28 or, as described further below, side gaps S_{1B} , S_{2B} .

In the method step S_3 , a virtual 3-D model 55 of the comb plate region 27 is retrieved from a digital storage medium 42, 54. The storage medium 42 may be part of the inspection device 40 (see Fig. 2). A storage medium 54 may, however, also be located outside the inspection device 40 - for example, as storage space in a server 56 that is part of the cloud 90 (see Fig. 1). The cloud 90 can be reached, for example, via a network node 93 of the Internet and via a communications module 49 of the inspection device 40. The virtual 3-D model 55 has at least 3-D comb models 28' of all combs 28 of the comb plate region 27 in a specified arrangement.

Since a large number of differently designed escalators and moving walkways exist, there are also a large number of differently designed comb plate regions 27 and thus also a large number of selectable 3-D models 55. In order to find the correct 3-D model 55, it is for example possible for the 3-D surface image 53 to be analyzed by an analysis module 95 (see Fig. 2). The previously described analysis algorithms can be used again here. Based upon its analysis data, a suitable 3-D model 55 can be retrieved from a model database 57 stored in the digital storage medium 42, 54.

Alternatively, the inspection device 40 may also be used to scan a barcode or QR code 58 (see Fig. 2) which is attached to the escalator 1 to be inspected or to the moving walkway to be inspected. The 3-D model 55 associated with the barcode or QR code 58 can then be retrieved from the model database 57.

Another possibility is for the mobile inspection device 40 to query an identification number ID from a controller 14 of the escalator 1 or moving walkway. Based upon this identification number ID, an associated 3-D model 55 is retrieved from the model database 57.

In the method step S₄, the 3-D surface image 53 and the 3-D model 55 are spatially combined. In other words, the 3-D model 55 is inserted at the correct position in the 3-D surface image 53. The individual combs 28 have such a small base area that they are easily imaged fully in the 3-D recording 51 and thus also in the 3-D surface image 53. Accordingly, their component boundaries in the form of comb edges 86 and joints 85 are sufficiently present in the 3-D surface image 53 to be used as fixed points 81, 82 for this method step. Fastening screws 87 and corners 88 of the combs 28 can also be defined as fixed points 81, 82 (see Fig. 4). The spatial orientation and correctly positioned insertion of the virtual 3-D model 55 into the 3-D surface image 53 can be achieved on the basis of the spatial position of these comb edges 86 and joints 85. The image recognition and image processing algorithms required for this purpose have already been mentioned above. The combination results in an evaluable 3-D model 59 of the comb plate region 27 that includes all relevant comb edges 86, joints 85, corners 88, and fastening screws 87. The cross-section illustrated in Fig. 3 corresponds approximately to a cross-section through the evaluable 3-D model 59, since the virtual 3-D model 55 is also shown in this figure for better understanding.

In method step S_5 , a height h of the comb gap 33 is determined, said gap extending in meandering fashion between the tread surface 21 and the surface 61 of the comb underside 34 in the virtual 3-D model 55. The determination of the height h is a simple query of the distance (difference between the heights) between points lying one above the other on these two surfaces 21, 61, and may be performed at a plurality of locations predefined in the software application 44 or in the virtual 3-D model 55. If a query is made at a plurality of locations, an average height h calculated from these, the smallest value for the height h , or the largest value for the height h , may be used for further evaluation. It should also be noted that the tread surface 21 with its grooves 30 and ridges 31 must be virtually extrapolated (extended) in the transport direction 6 under the comb underside 34 in order to create points lying one above the other.

In the method step S_5 , a minimum side gap width S_{1Bmin} , S_{2Bmin} and a maximum side gap width S_{1Bmax} , S_{2Bmax} between the tread surface 21 and the adjacent base panel 23 is measured on each of the two sides of the tread surface 21 from the rectified and scaled 3-D surface image 53. An inclination angle β of the tread surface 21 relative to the base panel 23 can be determined from the minimum side gap width S_{1Bmin} , S_{2Bmin} and the maximum side gap width S_{1Bmax} , S_{2Bmax} (see Fig. 4).

Furthermore, in the method step S_5 , a contour comparison 62 of the comb teeth 29 of all combs 28 is performed between the 3-D surface image 53 and the 3-D model 55. The contour comparison 62 is illustrated in particular in Fig. 6. The contour comparison 62 is carried out, for example, on the basis of a surface comparison 62A and/or on the basis of a deviation of the identified outline lines 62B. Deviations of the identified outline lines 62B indicate an inadmissible deviation with regard to the tooth shape of a comb tooth 29, and differences in the surface comparison 62A indicate missing comb teeth 29. The image recognition and image processing algorithms required for this purpose have already been mentioned above.

In the method step S_6 , the height h of the comb gap 33 is compared with limit specifications h_{min} , h_{max} retrieved from the digital storage medium 42, 54. As soon as the height h lies outside these limit specifications h_{min} , h_{max} , the inspection device outputs a first information signal H_{S1} . Furthermore, the measured side gap widths S_{1Bmax} , S_{2Bmax} , S_{1Bmin} , S_{2Bmin} are compared with limit specifications G_{1min} , G_{1max} , G_{2min} , G_{2max} retrieved from the digital storage medium 42, 54, and a second information signal H_{S2} is output if the side gap widths

S_{1Bmax} , S_{2Bmax} , S_{1Bmin} , S_{2Bmin} lie outside said limit specifications G_{1min} , G_{1max} , G_{2min} , G_{2max} . The second information signal H_{S2} is also output if the sum of the side gap widths exceeds a limit specification G_{Sum} corresponding to S_{1Bmax} , S_{2Bmax} , S_{1Bmin} , S_{2Bmin} .

5 If the calculated inclination angle β exceeds a limit specification β_{max} retrieved from the digital storage medium 42, 54, a third information signal H_{S3} is output by the inspection device 40. An excessively large inclination angle β indicates asymmetrical wear of the conveyor chains 5 of the conveyor belt 26 and/or a deformation of the base panel 23 in this region. A fourth information signal H_{S4} is output if there is an inadmissible deviation
10 with regard to one or more tooth shapes (deviation of the outline lines 62B) of the comb teeth 29 and/or if comb teeth 29 are missing (deviations in the surface comparison 62A).

In the method step S_7 , on the basis of the output information signals, the identified deviations are displayed on the user interface 41 of the inspection device 40, and
15 appropriate further method steps S_n are proposed. If a third information signal H_{S3} is output by the inspection device 40, then, as a further method step S_n , the inspection device 40 indicates to the service technician that, for example, they must check the base panels 23 for deformations and, if these are in good order, that the conveyor chains 5 of the conveyor belt 26 must be replaced.

20 To facilitate the work of the service technician, in the presence of a fourth information signal H_{S4} , those combs 29 which are affected by the deviations and which are to be replaced are marked by a marking 99 on the 3-D surface image 53 of the comb plate region 27 (see Fig. 6). The 3-D surface image 53 with markings 99 is displayed on the
25 user interface 41 of the mobile inspection device 40.

On the basis of the fourth information signal H_{S4} , the inspection device 40 may also display the component identification numbers 98 of those combs 28 which are affected by the deviations and which are to be replaced. Furthermore, the component identification
30 number 98 may also be transmitted to the provisioning facility 91 illustrated in Fig. 1. The provisioning facility 91 checks the stock, reports a date back to the mobile inspection device 40 indicating when and where the requested components will be available, and provides the requested components in accordance with the transmitted component identification numbers 98.

If the inspection device 40 has generated one of the information signals H_{S1} to H_{S4} , the inspection device 40 may place the controller 14 of the escalator 1 or moving walkway into a maintenance mode on the basis of one or more of these events. This maintenance mode may be graduated depending upon the weighting of the information signal H_{S1} to H_{S4} for operational safety and in accordance with the magnitude of the identified deviation from the limit specifications h_{min} , h_{max} , G_{1min} , G_{1max} , G_{2min} , G_{2max} , G_{sum} , β_{max} . The highest level means that the identified defects are so severe that the operation of the escalator 1 or moving walkway will be blocked until repairs are carried out. A medium level may for example define a time window in which operation at nominal speed or operation at a reduced speed is still possible. A low level may for example not initiate any action affecting operation, but merely require a service technician to schedule a maintenance appointment to carry out the repair.

In order to allow the inspection device 40 to exchange data with the peripheral devices 90, 91, 92 and/or the controller 14 illustrated in Fig. 1, said inspection device has a communications module 49. This may communicate with the peripheral devices 90, 91, 92 and the controller 14 via wired or wireless connections, using any type of suitable data transmission technology such as Bluetooth, Ethernet, etc. The inspection method 45 ends with the method step S_8 , by the service technician confirming, by an input made via the user interface 41, the execution and any resulting actions.

Although an escalator is illustrated in Fig. 1, it is clear that the inspection device 40 and the associated inspection method 45 may also be used for moving walkways.

Finally, it should be noted that terms such as "having," "comprising," etc., do not preclude other elements or steps, and terms such as "a" or "one" do not preclude a plurality. Furthermore, it should be noted that features or steps which have been described with reference to one of the above exemplary embodiments may also be used in combination with other features or steps of other exemplary embodiments described above. Reference signs in the claims should not be considered to be limiting.

Claims

1. A method (45) for inspecting the comb plate region (27) of an escalator (1) or moving walkway by means of a mobile inspection device (40), comprising the following steps:
- capturing (S_1) a 3-D recording (53) of all combs (28) and adjacent surface regions (21, 23) of a comb plate region (27) of the escalator (1) or moving walkway by means of an imaging depth sensor (46) of the mobile inspection device (40);
 - extracting (S_2) a scaled and rectified 3-D surface image (53) of the comb plate region (27) from the 3-D recording (53); at least of all combs (28) of the comb plate region (27), of surface regions, laterally adjacent to the combs (28), of the base panels (23) of the comb plate region (27), and of a tread surface (21), situated in the comb plate region (27), of a conveyor belt (26) of the escalator (1) or moving walkway;
 - retrieving (S_3) a virtual 3-D model (55) of the comb plate region (27) from a digital storage medium (42, 54), wherein the virtual 3-D model (55) has at least 3-D comb models (28') of all combs (28) of the comb plate region (27) in a specified arrangement;
 - spatially combining (S_4) the 3-D surface image (53) and the virtual 3-D model (55);
 - determining (S_5) a height (h) of a comb gap (33) between the tread surface (21) and a surface (61) of the comb underside (34) in the virtual 3-D model (55); and
 - performing a comparison (S_6) with limit specifications ($h_{\min}$, $h_{\max}$) retrieved from the digital storage medium (42, 54) for the height (h) of the comb gap (33), and outputting a first information signal (H_{S1}) if the determined height (h) deviates from the limit specifications ($h_{\min}$, $h_{\max}$).
2. The inspection method (45) according to claim 1, wherein a minimum side gap width ($S_{1B\min}$, $S_{2B\min}$) and a maximum side gap width ($S_{1B\max}$, $S_{2B\max}$) between the tread surface (21) and the adjacent base panel (23) is measured on each of the two sides of the tread surface (21) from the 3-D surface image (53), and wherein the maximum side gap widths ($S_{1B\max}$, $S_{2B\max}$) are compared with limit specifications ($G_{1\min}$, $G_{1\max}$, $G_{2\min}$, $G_{2\max}$,

G_{sum}) retrieved from the digital storage medium (42, 54), and a second information signal (H_{S2}) is output if one of the limit specifications (G_{1min} , G_{1max} , G_{2min} , G_{2max} , G_{sum}) is exceeded.

3. The inspection method (45) according to claim 2, wherein an inclination angle (β) of the tread surface (21) relative to the base panel (23) is determined from the minimum side gap width (S_{1Bmin} , S_{2Bmin}) and the maximum side gap width (S_{1Bmax} , S_{2Bmax}), and the inclination angle (β) is compared with limit specifications (β_{max}) retrieved from the digital storage medium (42, 54) for the inclination angle (β), and a third information signal (H_{S3}) is output if the determined inclination angle (β) deviates from the limit specifications (β_{max}).

4. The inspection method (45) according to any one of claims 1 to 3, wherein the 3-D recording (53) is a digital film sequence (70) of the comb plate region (27) from the first base panel (23) to the opposite, second base panel (23), wherein, to generate the 3-D surface image (53), prominent fixed points (81, 82) are defined in the frames (71) of the digital film sequence (70) and are used for extracting the 3-D surface image (53).

5. The inspection method (45) according to claim 4, wherein a prominent fixed point (81, 82) is a comb edge (86), a fastening screw (87) of the comb (28), a joint (85) between two combs (28), or a corner (88) of the comb (28).

6. The inspection method (45) according to any one of claims 1 to 5, wherein the 3-D surface image (53) is analyzed by an analysis module (95) and, based upon the analysis data thereof, a suitable virtual 3-D model (55) is retrieved from a model database (57) that is stored in a digital storage medium (42, 54).

7. The inspection method (45) according to any one of claims 1 to 5, wherein, following the scanning of a barcode or QR code (58) that is attached to the escalator (1) to be inspected or to the moving walkway to be inspected, a virtual 3-D model (55) associated with the barcode or QR code (58) is retrieved from a model database (57) that is stored in a digital storage medium (42, 54).

8. The inspection method (45) according to any one of claims 1 to 5, wherein the mobile inspection device (40) queries an identification number (ID) from a controller (14) of the escalator (1) or moving walkway and retrieves a virtual 3-D model (55) associated

with the identification number (ID) from a model database (57) that is stored in a digital storage medium (42, 54).

5 9. The inspection method (45) according to any one of claims 1 to 8, wherein a contour comparison (62) of all combs (28) is performed between the 3-D surface image (53) and the virtual 3-D model (55) by the mobile inspection device (40), by differences from the contour comparison (62B) being checked for an inadmissible deviation with regard to the tooth shapes of the combs (28) and/or the combs (28) being checked for missing comb teeth (29) by way of a surface comparison (62A), and a fourth information
10 signal (H_{S4}) is output if there is an inadmissible deviation with regard to the tooth shapes of the comb teeth (29) and/or if comb teeth (29) are missing.

15 10. The inspection method (45) according to claim 9, wherein, in the presence of a fourth information signal (H_{S4}), those components which are affected by the deviations and which are to be replaced are marked on the 3-D surface image (53) of the comb plate region (27), and the 3-D surface image (53) with marking (99) is displayed on a user interface (41) of the mobile inspection device (40).

20 11. The inspection method (45) according to claim 9 or 10, wherein, based upon the fourth information signal (H_{S4}), component identification numbers (98) of those components which are affected by the deviations and which are to be replaced are displayed by the inspection device (40) and/or are transmitted to a provisioning facility (91).

25 12. The inspection method (45) according to any one of claims 1 to 11, wherein, in the presence of at least one of the information signals (H_{S1} to H_{S4}), the inspection device (40) places a controller (14) of the escalator (1) or moving walkway into a maintenance mode.

30 13. A mobile inspection device (40) having a user interface (41), a digital storage medium (42, 54), a processor (43), an imaging depth sensor (46), and a software application (44) which is stored at least temporarily in the storage medium (42, 54) and which has the respectively required method steps ($S_1, \dots S_n$) of the inspection method (45) according to any one of claims 1 to 12, wherein the method steps ($S_1, \dots S_n$) of the inspection method (45) are processed by the processor (43) upon instigation of an input via the user interface (41).

14. The mobile inspection device (40) according to claim 13, wherein said device has a communications module (49) which can be connected to a communications module of at least one of the following devices for data exchange as required: a controller (14) of an escalator (1) or moving walkway, a central monitoring device (92), a provisioning facility (91) for replacement parts, a network node (93) of the Internet.