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POSITION-MEASURING DEVICE

The present invention is directed to a position-measuring device for generating measuring signals according to the preamble of Claim 1.

Such a position-measuring device includes a track which has an incremental graduation extending along a measuring direction having a specified graduation period which is provided at at least one reference position with a discontinuity for generating a reference signal, as well as a scanning device, movable along the measuring direction with respect to the track for the (photoelectric) scanning of the track. In this context, the discontinuity is formed by the modification of a transverse substructure of the incremental graduation that extends perpendicular to the measuring direction, which bends radiation beams originating from the scanning unit (by diffraction) having one component perpendicular to the measuring direction (transverse), the direction of bending at the discontinuity deviating from the direction of bending in the other regions of the incremental graduation; and the scanning unit having at least one reference pulse detector element, preferably at least two reference pulse detector elements, which are provided having a different direction of bending for receiving radiation beams.

The perpendicular extension of the transverse substructures with respect to the measuring direction does not mean necessarily, in this context, that the transverse substructures have to run exactly perpendicularly to the measuring direction. Rather, it is only required that the transverse substructures have at least one component in their characteristic that runs perpendicular to the measuring direction.

A position-measuring device of the type named is known from WO 03/021185 A1. The known position-measuring device is composed, for the generation of periodic incremental signals as well as at least one reference-pulse signal, of a scale having a track in which a periodic incremental graduation is developed having a certain incremental graduation period, which extends along a measuring direction, and which has a discontinuity with respect to an optical property for the generation of a reference-pulse signal, as well as of a scanning unit which is movable relative to the scale in the measuring direction over a certain measuring path, and which, besides a light source, includes several detector elements for photoelectric scanning of the incremental graduation. In this context, in a first section of the measurement path, the incremental graduation has a first transverse substructure which bends incident radiation beams into at least a first spatial direction; and in a second section of the measurement path, the incremental graduation has a second transverse substructure which bends incident radiation beams into at least a second spatial direction that differs from the first spatial direction, so that in the transition range between the first and second section there exists a discontinuity with respect to the optical bending action of the transverse substructures of the incremental graduation. In this context, in the various spatial directions, on the side of the scanning unit, reference-pulse detector elements are situated at which partial reference-pulse signal are present from whose processing the reference-pulse signal results.

Alternatively to the use of several (at least two) reference pulse detector elements, a reference pulse detector element being assigned to each radiation beam of a different bending direction, a position-measuring device of the type described above can also be operated using a reference pulse detector element which is assigned to one of the radiation beams having a different bending direction. With the aid of the illumination or non-illumination of this single reference-pulse detector element, it may then be determined whether the reference position is just being crossed.

In the known position-measuring device, the generation of a reference-pulse signal is derived from a reference mark that is integrated in the incremental track. For this, the graduation marks of the incremental graduation that is to be scanned have a transverse structuring (so-called transverse substructures) along their direction of extension (perpendicular to the measuring direction). The lateral boundary lines of the graduation marks are periodically modulated in the longitudinal direction, having a defined transverse graduation period. At the at least one reference position, the transverse graduation period changes and the reference mark is defined by this point of sudden discontinuity.

The transverse substructures bring about a bending of the radiation beams impinging upon them (by diffraction) even in the transverse direction (perpendicular to the measuring direction). The degree of bending depends, in this case, on the respective transverse graduation period, and accordingly it changes at the reference position formed by a point of sudden discontinuity of the graduation period. A certain detector element in the form of a photo element is spatially assigned respectively to the different transverse graduation periods. In the case of crossing the reference position in a relative movement of the scale with respect to the scanning

unit of the position-measuring device, the bending effect on the radiation beams changes in such a way that by this time the respectively other detector element is acted upon. From the signal pattern (pattern of the partial reference-pulse signals at the at least two detector elements, a reference-pulse signal may then be derived by signal connection, as is explained in WO 03/021185 A1.

The advantage of the integration of a reference mark into the incremental track is that greater tolerances of added construction may be allowed during assembly of the respective position-measuring devices. In this context, the set-up known from WO 03/021185 makes certain that the incremental signal is not interfered with by the reference mark.

The present invention is based on the problem of improving a position-measuring device of the type mentioned at the outset, with respect to the spatial resolution of the reference-pulse signal.

This problem is solved in accordance with the present invention by devising a position-measuring device having the features of Claim 1.

According to that, it is provided to position an imaging optics device in the beam path of the (transversely) bent radiation beams used for the generation of the reference-pulse signal.

By doing this, the spatial resolution in the generation of the reference-pulse signal is improved to such an extent that it is equivalent to the spatial resolution in the generation of the incremental signal.

The imaging optics device is used, on the one hand, for imaging, onto a specifiable imaging plane, the ranges of the track having the incremental graduation that are each

illuminated with the aid of the scanning unit, and, for this, it has at least one cylindrical lens, preferably in the form of a Fresnel cylindrical lens, on a first scanning plate. According to one further development of the present invention, two cylindrical lenses, situated one behind the other, may also be provided to be situated in the beam path of the bent radiation beams, which form a cylindrical telescope, so that a correspondingly great imaging scale may be achieved.

In the imaging plane, on a second scanning plate, at least one slit is provided onto which the radiation of the individual radiation beams (after interaction with the at least one (Fresnel) cylindrical lens) impinges and it supplies the radiation made of the radiation beams using a different bending direction (by diffraction) to different reference-pulse detector elements.

In this context, the radiation of differently bent radiation beams, when viewed in the direction of extension of the respective slit, impinges on different locations of the at least one slit, the at least one slit extending perpendicularly to the measuring direction. According to one specific embodiment of the present invention, the imaging plane is situated at a distance from the reference-pulse detector elements in the beam path of the radiation beams. According to another specific embodiment, the reference-pulse detector elements lie essentially in the imaging plane, so that the respective slit or the respective slits are to be situated immediately above the photo elements (for example physically connected to them).

The incremental graduation itself is preferably formed by markings (in the form of graduation marks) that are periodically positioned one after another and are separated from one another by intermediate areas. By periodic positioning is understood, in this connection, such a positioning of the markings that they have, for instance, a

constant center-to-center distance (defined by the graduation period) or that they have another uniquely definable distance that repeats periodically. By contrast, the concept of periodicity should not be understood in this connection as if the incremental graduation as a whole, including the shape of the individual markings, had to form a completely periodic pattern along the measuring direction. For, such a periodicity is not able to be there, within the scope of the present invention, for this reason alone, that, after all, for the formation of a reference mark at at least one reference position, corresponding discontinuity locations in the incremental graduation have to be provided.

The individual markings of the incremental graduation preferably extend (as graduation marks) in a direction perpendicular to the measuring direction, and they are situated along the measuring direction one after the other.

The transverse substructure is preferably formed by modulation of the long sides of the markings, especially in a way such that a (periodic) width-modulation of the markings comes about, and indeed particularly preferably on the basis of a sine function.

The modification of the transverse substructure, so as to obtain differently bent radiation beams, may be done in a way so that the modulation of at least one long side of a marking is varied compared to additional markings, especially by changing the period of a periodic modulation.

According to one exemplary embodiment of the present invention, exactly one marking of the incremental graduation has a transverse substructure, which deviates from the transverse structure of the other markings, and which, for the formation of a reference mark or for the generation of a reference signal pulse at the reference position, defines a discontinuity.

According to another specific embodiment of the present invention, for the formation of the discontinuity in the surroundings of the reference position, several markings are provided with a transverse substructure which deviates from the transverse substructure of the remaining markings of the incremental graduation, the distances between adjacent markings having a deviating transverse substructure differ in such a way that one and the same distance between adjacent markings having deviating transverse substructures does not appear. In this specific embodiment the number of slits in the imaging plane preferably corresponds to the number of markings having a deviating transverse substructure. The distance between the individual slits is determined, in this context, as a function of the distance between the said markings, taking into consideration other geometric variables of the imaging optics, such as the focal length.

According to a third specific embodiment of the present invention, the track to be scanned by the scanning unit and having the incremental graduation, has at least two sectors, in each of the at least two sectors a different transverse substructure being provided. In this case, the discontinuity at the at least one reference position is defined by the transition from one sector to another sector of the track.

According to a further specific embodiment of the present invention, for the formation of a code track having absolute position information, markings having a deviating transverse substructure may be distributed along the measuring directions in such a way that a code corresponding to a PRC code comes about. In this context, a certain detector element is assigned respectively to all long sides of markings that have an agreeing transverse substructure. Thus if, for example, for the formation of the codes, only two different types of transverse substructures are used, which are distributed appropriately to the (long sides of the) individual markings, two detector elements are required, of which each is assigned

to one of the two types of transverse substructures.

The assigned detector elements are formed, in this case, preferably by one periodic arrangement of active surfaces, which are developed to receive the respective radiation beams.

In all specific embodiments of the present invention, the different reference-pulse detector elements are preferably connected to one another in a push-pull manner, in order to form a reference-pulse signal, that is to be passed on, from the output signals at the individual reference-pulse detector elements (partial reference-pulse signals).

Since, because of the transverse bending effect of the transverse substructures, the bent light is split, also with regard to positive and negative orders of diffraction (and not only with regard to the type of transverse substructure provided at the respective place), two diffraction branches come about, in which, preferably, in each case an imaging optics system of the kind described above has to be provided.

In this context, the radiation beams running in the one diffraction branch, that are, depending on the direction of bending, brought on by different transverse structures, are conducted to one of several reference-pulse detector elements provided for this purpose. In the other diffraction branch, by contrast, all the radiation beams, independent of their direction of bending, are guided to a uniform detector element, which is used to generate a steady radiation level of constant intensity. The last-named detector element does not, in this context, absolutely have to be formed by a single physical detection device. What is much more decisive, is that the respective detector element is developed in such a way that it generates a signal from the incident radiation beams, which corresponds to the entire radiation of the respective radiation beams, independent of the spatial distribution, and is not, for instance, a function of the spatial distribution

of the radiation beams, as is the case in the other diffraction branch.

The steady radiation signal generated by the last-named detector element is combined with the output signals (partial reference-pulse signals) of the individual reference-pulse detector elements, for the formation of the reference-pulse signal.

A method for carrying out a position measurement, particularly using the position-measuring device according to the present invention, is characterized by the features of Claim 21.

Preferred refinements of the method are given in the claims dependent thereon.

Other features and advantages of the present invention are clarified in the following description of exemplary embodiments of the present invention, in light of the figures. The figures show:

Figure 1 a perspective illustration of a position-measuring device, having a scale developed as a graduated disk and a scanning unit for photoelectric scanning of the scale, and including the radiation beams generated during the scanning;

Figure 2a a cutout of a track provided on the graduated disk having an incremental graduation;

Figure 2b a scanning plate of the position-measuring device for use in the case of a track of the kind shown in Figure 2a;

Figure 3a a first variation of the track of Figure 2a;

Figure 3b a scanning plate of the position-measuring device
for use in the case of a track of the kind shown in
Figure 3a;

Figure 4a a second variation of the track of Figure 2a;

Figure 4b a scanning plate of the position-measuring device
for use in the case of a track of the kind shown in
Figure 4a;

Figure 5 a basic representation of a position-measuring
device according to Figure 1, in a schematic
side view;

Figures 6a

through 6c different reference-pulse signals which are
able to be generated using the devices in
Figures 1 through 5;

Figure 7 a circuit configuration for connecting detector
elements of the position-measuring device;

Figure 8 a detector element for use during the
development of a track of the
position-measuring device as a code track
having absolute position information;

Figure 9a a refinement of the track of Figure 4a;

Figure 9b a scanning plate for use with a position-measuring
device having a track of the kind shown in Figure
9a;

Figure 10 a reference-pulse composite signal which is able to
be generated with the aid of a position-measuring
device when a track as in Figures 9a and 9b is used;

Figure 11 a modification of the scanning plates of Figures 2b, 3b, 4b and 9b, which includes Fresnel cylindrical lenses.

Figure 1 schematically shows an exemplary embodiment of a position-measuring device which is used as an angle measuring device for recording rotatory motions (i.e. the angle of rotation) of two objects rotatable with respect to each other about a rotary axis 10. The position-measuring device includes a scale 1, as well as an assigned scanning unit 2¹ which are to be connected in each case to one of the two objects that are rotatable to each other. The measuring direction x, along which the two objects are movable relative to each other (that is, rotatable in the present case), runs in a circular manner in the case at hand, namely rotationally symmetrically to axis of rotation 10.

Scale 1 is formed as a graduated disk made up of a disk-shaped carrier element 11 made of glass, upon which a track 12 is disposed having an incremental graduation in the shape of a circle in the circumferential direction. The incremental graduation is made up of a plurality of markings 13, that are periodically disposed one behind the other along the measuring direction x at an incremental graduation period, which differ from intermediate area 14, lying in each case between two markings 13, in their optical properties (e.g. transmission of light). Markings 13 and intermediate areas 14 lying between them each have a longitudinal dimension along a direction y running radially to rotational axis 10, which extends perpendicularly to measuring direction x.

In the case at hand, the incremental graduation formed by markings 13 and intermediate areas 14 lying between them is formed as a transmitted light phase splitter, i.e. the

¹Translator's Note: Not shown.

successive markings 13 and intermediate areas 14 each have a different phase-shifting optical effect on radiation beams that are passing through. Alternatively to phase splitting, for the formation of an incremental graduation (for reflected light or transmitted light), so-called division of amplitude may also be used.

Scanning unit 2, situated at the other of the two objects that are movable with respect to each other (especially rotatable with respect to each other) has a radiation source in the form of a light source 21, as well as additionally an imaging optics device 20, with the aid of which radiation S emitted by light source 21, after interaction with track 12 of graduated disk 1, is guided to different detector elements 24.1, 24.2, 25.1, 25.2, 25.3, which are used for generating scanning signals.

Three incremental signal detector elements, of which in Figure 1 only two incremental signal detectors 24.1, 24.2 are recognizable, are used to record the periodic incremental signals generated using the incremental graduation of track 12, in response to the interaction of collimated radiation beam S (in the form of a laser beam generated by a laser diode as light source 21). Incremental signal detector elements 24.1, 24.2 may be designed in a known way as so-called structured detectors, or alternatively as a system of a plurality of individual photo elements.

With the aid of three incremental-signal detector elements (among them 24.1, 24.2), three incremental signals each phase-shifted by 120° with respect to one another are generated in a known manner, which in turn are interconnected to form two incremental output signals phase-shifted by 90° with respect to each other. For simplicity's sake, from here on we shall continually speak of (periodic) incremental signals.

In the case of additional detector elements 25.1, 25.2, 25.3

reference-pulse detector elements are involved, at which partial reference-pulse signals REF_1 , REF_2 and REF_3 are present, from which a reference-pulse signal will be generated in a manner that will be explained below. Reference-pulse detector elements 25.1, 25.2, 25.3 are preferably developed as photo elements.

The incremental signals and the reference-pulse signals generated by the position-measuring device are supplied to an evaluation unit (not shown in Figure 1), for example, to a control unit of a numerical machine tool, for further processing.

The function of the position-measuring device shown in Figure 1 will be explained in greater detail below.

A radiation beam S, generated by radiation source 21 in the form of a laser diode, in the form of a collimated laser beam impinges upon track 12 having incremental graduation 13, 14, on scale 1 developed as a graduated disk. For the generation of the incremental signals, incident radiation beam S is split by diffraction at the incremental graduation into two partial radiation beams S_{+1} , and S_{-1} (not recognizable in Figure 2) in measuring direction x (longitudinal), which correspond to the first and minus first diffraction order, and which spread in two different spatial directions. On the part of the scanning unit, the two partial radiation beams S_{+1} and S_{-1} encounter in each case a scanning division 22.1, 22.2 of a first scanning plate 22 in the form of a scanning grid (divided 1 : 1; (maximum) phase angle deviation 180°). From scanning divisions 22.1, 22.2 of first scanning plate 22, the two partial radiation beams S_{+1} and S_{-1} are again bent by diffraction, so that they come together in the plane of a second scanning plate in the form of a scanning grid onto a scanning division 23.1 (divided 1 : 1; (maximum) phase angle deviation 120°). There, the respective first diffraction orders are superimposed on one another as well as respectively a zero'th

one having a second diffraction order superimposed on it. The three partial radiation beams resulting from this are incident upon one detector element each 24.1, 24.2 (third detector element in Figure 1 is covered) in the form of a photo element. The phase positions of the interfering first diffraction orders as well as the interfering zero'th and second diffraction orders are, in this context, each offset by 120° . Thus are created, with respect to scanning unit 2, by a relative motion of scale 1 in the form of a graduated disk, three signals phase-shifted by 120° with respect to one another, which are electronically connected in such a way that a sine signal as well as a cosine signal is obtained from this.

For further details on such a position-measuring device we refer the reader to WO 03/021185 A1, to which full reference is made herein.

Besides the periodic incremental signals explained above, the position-measuring device shown in Figure 1 may also be used for generating a reference-pulse signal along track 12, by a reference position formed by a discontinuity. With the aid of this reference-pulse signal an absolute reference may be produced during the measurement, to which a subsequent incremental measurement may then be referred.

For this purpose, such a formation of incremental graduation 13, 14 is provided, in order to generate a reference-pulse signal by at least one discontinuity with respect to an optical property at at least one +-reference position.

In the case at hand, incremental graduation 13, 14, as may be seen in Figure 1 in connection with Figure 2a, is made up of markings 13 and intermediate area 14 situated between them that are situated one behind the other periodically having an incremental graduation period TP_{INC} in the measuring direction x, and intermediate areas 14 differ from markings 13 in

certain optical properties. Markings 13 and intermediate areas 14 lying between them are formed similar to a kind of graduation lines, longitudinally extending along a (radial) direction y running perpendicular to measuring direction x .

In the case at hand, from a track 12 having such an incremental graduation 13, 14 a reference pulse is to be obtained which, even at great tolerances with respect to added construction in the radial direction, may be reliably assigned to a certain (the correct) signal period [of the] incremental signal. For this, the reference-pulse signal has to be picked off on scale 1' developed as graduation disk, at the same place as the incremental signal, without the strength of incremental signal TP_{INC} being influenced (modulated) by the formation of the reference-pulse signal.

This may be achieved by the generation of a reference-pulse signal using periodically modulated markings and intermediate areas 13, 14, as illustrated in Figures 1 and 2a. Accordingly, individual markings 13 and also intermediate areas 14 each have a sinusoidal width modulation having a period $TP_{TRANS, 1}$. The width modulation of markings 13 and of intermediate areas 14 brings about that a part of the radiation (in the form of light) of the first and minus first diffraction order in the longitudinal direction y of markings 13 and intermediate areas 14 is ("transversely") bent, i.e. perpendicular to the longitudinal direction, along which radiation S for obtaining the incremental signal is split up into two partial radiation beams S_{+1} and S_{-1} . The angle through which the light is diffracted in the transverse direction depends, in this context, on the period length $TP_{TRANS, 1}$ of the width modulation.

In the simplest specific embodiment shown in Figure 2a, one long side of a marking 13' and accordingly one long side of a directly adjacent intermediate space 14' are modulated using a deviating period length $TP_{TRANS, 2}$. In this case, the longitudinal diffraction image in the first transverse

diffraction order corresponds essentially to the diffraction image of a gap whose width $2 * a_{\text{mod}}$ is twice as great as the amplitude a_{mod} of the width modulation of markings 13 and intermediate areas 14. In this case, a continuum is involved of diffraction orders, that is, a beam spread out correspondingly into a spectrum, which is supplied on first scanning plate 22 to a Fresnel cylindrical lense 22.3. Thereby the continuum forming the beam that is spread out into a spectrum has diffraction orders superimposed on it again in the plane of second scanning plate 23.

The two scanning plates 22 and 23 may be provided, in this context, on the front or rear side of one and the same substrate.

Depending on whether the beams, first spread out into a spectrum and then recombined using Fresnel cylindrical lens 22.3 were bent by interaction with markings 13 or intermediate areas 14 having a width modulation of the usual period $TP_{\text{TRANS}, 1}$, or by interaction with the one marking 13' or the one intermediate area 14' having a deviating period $TP_{\text{TRANS}, 2}$ of the width modulation in the transverse direction, the corresponding beams S_{T1} and S_{T2} impinge on second scanning plate 23 at a first height h_1 or a second height h_2 . By height h_1 and h_2 one understands, in this context, the distance from original radiation beam S in the form of a laser beam perpendicular to its spreading direction.

Consequently, the scanning lines of such markings 13 and intermediate areas 14, which are width-modulated at the usual period $TP_{\text{TRANS}, 1}$, are created at a first height h_1 and the image of that scanning line which is brought on by the deviating period $TP_{\text{TRANS}, 2}$ at a long side of a marking 13' or the corresponding intermediate area 14' is created at a height h_2 , deviating from the former, on second scanning plate 23.

In this context, for clarity's sake, in Figure 1, between

scale 1 developed as a graduated disk and first scanning plate 22, the splitting up of the original radiation beam S generated by light source 21 in the form of a laser diode, into two radiation beams ST1, ST2, depending on whether the just scanned signal period of the incremental graduation shows a discontinuity, is not shown. For this we refer to the schematic side view in Figure 5, which shows the course of respective radiation beams ST1, ST2 between scale 1 and the respective detector element 25.1, 25.2.

Of course, in the actual operation of the position-measuring device, in each case only one of the two bent radiation beams ST1, ST2 is present, depending on whether the currently scanned section of the incremental graduation has a discontinuity or not. In Figures 1 and 5, both radiation beams ST1, ST2 are shown together in order to make the function of the position-measuring device according to the present invention more clear, especially with respect to the different bending of the two radiation beams ST1, ST2.

On second scanning plate 23 a slit 23.2 is provided, which is situated on second scanning plate 23 in such a way, and extends there at such a length that onto it there impinge both the beams S_{T1} impinging at first height h_1 and the beams S_{T2} impinging at second height h_2 . Using this slit 23.2, the radiation is transversely diffracted in such a way that a first detector element 25.1 in the form of a photo element is only reached by beams S_{T1} , which go back to an interaction at scale 1 in the form of a graduated disk having markings 13 and intermediate areas 14 of the usual, first transverse period $TP_{TRANS, 1}$, whereas the additional detector element 25.2 in the form of a photo element is only reached by those beams S_{T2} which go back to an interaction with the one marking 13' or the assigned intermediate area 14', on whose one long side a deviating transverse period $TP_{TRANS, 2}$ of the width modulation is provided. Expressed in other words, first detector element 25.1 is always illuminated by beams S_{T1} when the scale is in a

position in which the marking 13' and the assigned intermediate area 14' having the deviating transverse period $TP_{TRANS, 2}$ are not illuminated at one long side. Second detector element 25.2, by contrast, is always illuminated when exactly this one marking 13' and the assigned intermediate area 14' having a deviating transverse period $TP_{TRANS, 2}$ are illuminated (at one long side).

By push-pull connection of the two detector elements 25.1 and 25.2, a characteristic signal pattern, shown in Figure 6a, is generated by crossing of the reference position x_{REF} , next to which the long side of marking 13' extends, which has the deviating transverse period $TP_{TRANS, 2}$.

Inasmuch as the first scanning plate 22 and the second scanning plate 23 are developed on the front side and the back side of one and the same substrate made of glass, concrete conditions for achieving the conditions described above at detector elements 25.1, 25.2 may be formulated mathematically as follows below. The focal length of the system is dimensioned in such a way that it corresponds to the image of a slit in the scanning range of scale 1 developed as a graduated disk onto slit 23.2 of second scanning plate 23, i.e.

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$$

In this context, a and b are the average distances which beams S_{T1} and S_{T2} , which are bent transversely by diffraction, traverse from scale 1 developed as a graduated disk to Fresnel cylindrical lens 22.3 on first scanning plate 22 and from Fresnel cylindrical lens 22.3 on first scanning plate 22 to slit 23.2 on second scanning plate 23. Parameters a and b may be calculated as follows, from the wavelength of original radiation beam S developed by laser radiation, from distance d_1 from scale 1 developed as a graduated disk and first scanning plate 22, as well as the distance between first scanning plate

22 and second scanning plate 23:²

$$a = \frac{1}{2} \frac{d_1}{\sqrt{1 - \left(\frac{\lambda}{TP_{TRANS,1}} \right)^2}} + \frac{1}{2} \frac{d_1}{\sqrt{1 - \left(\frac{\lambda}{TP_{TRANS,2}} \right)^2}},$$

$$b = \frac{1}{2n} \frac{d_2}{\sqrt{1 - \left(\frac{\lambda}{nTP_{TRANS,1}} \right)^2}} + \frac{1}{2n} \frac{d_2}{\sqrt{1 - \left(\frac{\lambda}{nTP_{TRANS,2}} \right)^2}}.$$

It also follows that the longitudinal imaging scale amounts to $-b/a$.

In order for the generated signals to be as free as possible of periodic interference signal having the signal period (half the beam splitting period) of the incremental signal, the width of slit 23.2 on second scanning plate 23 is preferably selected as follows:

$$B_{slit} = P_{sig} * b/a,$$

where P_{sig} gives the signal period mentioned.

According to a refinement of the exemplary embodiment of a position-measuring device described above in the light of Figures 1, 2a, 2b, 5 and 6a, several markings 13" of an incremental graduation 13, 14 may each have a deviating transverse period $TP_{TRANS, 2}$, compare Figure 3a, where this is the case with three markings 13". The image on second scanning plate 23 then corresponds at second height h_2 to the diffraction pattern of a number slit, which agrees with the number of the long sides having a deviating transverse period $TP_{TRANS, 2}$. In this context, at first height h_1 , those positions

²Translator's Note: λ in the equations below is not defined.

are illuminated in measuring direction x which remain unilluminated at second height h_2 , and vice versa.

The distances $n * SP$ between the long sides of markings 13" having a deviating transverse period $TP_{TRANS, 2}$ are selected in such a way that between adjacent long sides having a deviating transverse period $TP_{TRANS, 2}$ there are in each case different distances, meaning that one and the same distance does not occur in a multiple fashion, compare Figure 3a.

According to Figure 3b, on the second scanning plate there is a plurality of slits 23.2, which agrees with the number of long sides of deviating transverse period $TP_{TRANS, 2}$. In this context, the distances between adjacent slits 23.2 on second scanning plate 23 correspond to the $-b/a$ -fold of the corresponding distances between adjacent long sides having a deviating transverse period $TP_{TRANS, 2}$. If scale 1, developed as a graduated disk, is located, with respect to the position of scanning unit 2, within the signal period in which the reference signal is generated, all slits 23.2 of second scanning plate 23 are illuminated at height h_2 , and the light transmitted through slit 23.2 falls onto assigned detector element 25.2. The other detector element 25.1 is not illuminated. In all other signal periods, at second height h_2 at most one slit is illuminated, i.e. only such radiation falls on corresponding detector element 25.2 as that which before interacted at track 12 with at least one long side having deviating a transverse $TP_{TRANS, 2}$, while the remaining radiation impinges on the other detector element 25.1. Thereby, there is an increase in the size of the useful signal by a factor $j-1$, j indicating the number of the long sides having deviating transverse period $TP_{TRANS, 2}$ and the number of slits 23.2 on second scanning plate 23. For values of j greater than or equal to 3, the reference-pulse signal can still be reliably detected if one of the long sides of markings 13", having deviating transverse period $TP_{TRANS, 2}$, is dirty. A signal pattern that comes about for $j = 3$ is shown in

Figure 6b.

Figure 4a shows an exemplary embodiment with respect to the formation of track 12 from width-modulated markings 13a, 13b, which, besides the generation of reference-pulse signal also permits the formation of a so-called homing signal, so that, after switching on the position-measuring device, one may select a certain, predefined rotational direction for a reference run. According to that, scale 1 formed by a graduated disk includes at least two sectors 1a, 1b situated one after another in the circumferential direction, which differ in the transverse period $TP_{TRANS, 1}$ or $TP_{TRANS, 2}$ of their respective markings and intermediate areas 13a, 14a or 13b, 14b. The transversely diffracted radiation of markings 13a and 13b as well as intermediate areas 14a and 14b of different sectors 1a and 1b is detected by different detector elements 25.1 or 25.2 (compare Figures 1 and 5). At the transition between the two sectors 1a and 1b, the signal pattern constructed in the light of Figure 6c is created if one connects to each other, in push-pull mode, the two detector elements 25.1 and 25.2 that are developed as photo elements.

According to Figure 4b, in the present exemplary embodiment, second scanning plate 23 includes a slit 23.2 which conforms to corresponding slit 23.2 in the exemplary embodiment explained with the aid of Figure 2.

As in the case of the preceding exemplary embodiments, the circuit mentioned is developed in each case in such a way that the two detector elements 25.1 and 25.2 are developed as photo elements and connected to each other in push-pull mode. To the two detector elements 25.1, 25.2, a current-to-voltage converter 28.1 as well as an amplifier 29.1 are post-connected, whose output signal (generated from partial reference-pulse signals REF_1 , REF_2 of the two detector elements 25.1, 25.2) is supplied to a comparator 30 as composite reference-pulse signal REF_3 . On the other hand, a constant

light signal REF_G , that is generated by an additional detector element 25.3 in the form of a constant-light photo element (having an output signal REF_3) and is prepared by a post-connected current-to-voltage converter 28.3 and an amplifier 29.3, is supplied to comparator 30. This is used to regulate the height of the trigger point of comparator 30.

With respect to the generation of constant-light signal REF_G using constant-light detector element 25.3, it may be seen from Figures 1 through 5 that radiation beams S_{T1} , S_{T2} explained above, which impinge respectively, at a first height h_1 or a second height h_2 , on second scanning plate 23 in the region of at least one slit 23.2, and which are subsequently guided to the one or the other of the two assigned detector elements 25.1, 25.2, because of the symmetrical construction of the system, appear on both sides of partial radiation beams S_{+1} and S_{-1} , which are used for generating the incremental signal. Whereas on the one side, as described above, radiation beams S_{T1} and S_{T2} that originate from markings having different transverse periods $TP_{TRANS, 1}$ and $TP_{TRANS, 2}$, are guided to different detector elements 25.1 and 25.2, on the other side, the corresponding radiation beams are supplied, using a Fresnel cylindrical lens 22.4 of first scanning plate 22 and at least one post-connected slit 23.3 of second scanning plate to a single detector element 25.3 in the form of a constant-light detector element, in order to generate said constant-light signal REF_G . In other words, in one of the two created diffraction branches, two detector elements 25.1, 25.2 are provided, which are assigned to the different transverse periods $TP_{TRANS, 1}$ and $TP_{TRANS, 2}$; in the other diffraction branch, by contrast, a single planar detector element 25.3 is provided which is used for generating a constant-light signal REF_G in the form of a constant-light level of constant intensity, which, according to Figure 7, is combined in comparator 30 with composite reference-pulse signal REF_s generated by the first-named detector elements 25.1, 25.3.

From this association, finally, the desired reference-pulse signal REF is generated, as is shown, for example, in Figure 6c, for the case of a graduation of scale 1 that is formed by a graduated disk into at least two sectors 1a, 1b. If, in this case, the composite reference-pulse signal REF_s lies between the values which, for transverse period $TP_{TRANS, 1}$, are to be expected in the one sector 1a, and for transverse period $TP_{TRANS, 2}$, are to be expected in the other sector 1b, then comparator 30 emits a corresponding reference-pulse signal REF, which signals that the position of scale 1 relative to scanning unit 2 is in the signal period characterized by the transition from the one sector 1a to the other sector 1b.

Here, too, it is possible to increase the magnitude of the useful signal. A corresponding exemplary embodiment is shown in Figures 9a and 9b. In this context, in the transition region between the two sectors 1a, 1b of scale 1 developed as a graduated disk, two markings 13" are provided, which each have a long side having the first transverse period $TP_{TRANS, 1}$ and a long side having the second transverse period $TP_{TRANS, 2}$.

To the markings 13a, 13b having different transverse periods $TP_{TRANS, 1}$ and $TP_{TRANS, 2}$, as well as to both long sides of a marking 13", which has a different transverse period $TP_{TRANS, 1}$ and $TP_{TRANS, 2}$ on each long side, there is assigned in the one diffraction branch in each case the other of the two detector elements 25.1 and 25.2. In order that the corresponding composite reference-pulse signal REF_s , whose curve is shown in Figure 10, shall not exceed the threshold outside the transition region between the two sectors 1a, 1b which applies to transverse period $TP_{TRANS, 1}$ of the one sector 1a, or shall not undershoot the threshold which applies to transverse period $TP_{TRANS, 2}$ of the other sector 1b, the scanning plate has windows 23.4 and 23.5 situated next to the corresponding slits 23.2, which transmit still further radiation (originating from the interaction with additional markings, such as three long sides of markings 13a, 13b of track 12).

The size of windows 23.4, 23.5, as well as their position with respect to each respective slit 23.2, as a function of signal period SP of the incremental graduation, may be seen from Figures 9a and 9b.

Thus, in the transition region, forming the reference-pulse signal, between the two sectors 1a, 1b, on the one side the transversely diffracted light of at least two long sides of markings having the first transverse period $TP_{TRANS, 1}$ impinges on first detector element 25.1, while on the other side the transversely diffracted light of at least two long sides of markings having the second transverse period $TP_{TRANS, 2}$ impinges on second detector element 25.2. The curve of the signal resulting from this of composite reference-pulse signal REF_s is shown in Figure 10.

Deviating from the exemplary embodiments shown before, it is possible to image the markings having different transverse periods $TP_{TRANS, 1}$ and $TP_{TRANS, 2}$ not onto second scanning plate 23, but onto any other plane, especially also the plane in which detector elements 25.1, 25.2 are located. In this case it is advantageous to position a second Fresnel cylindrical lens 23.4 on second scanning plate 23, instead of at least one slit 23.2 for the diffraction of the transversely bent light according to Figure 11. The two Fresnel cylindrical lenses 22.3, 23.4 then form a cylindrical telescope, using which a large imaging scale may be achieved in the imaging onto the plane of detector elements 25.1, 25.2.

The function of the at least one slit 23.2, which, in the exemplary embodiments described before, was in each case provided on the second scanning plate 23, is then assumed by at least one slit directly above detector elements 25.1, 25.2. In a corresponding way, the aperture function may be assumed by a suitably structured sensor. The shape of its active surface is then similar to the shape of the respective slit

23.2 or respective slit 23.2 in the exemplary embodiments described before. Thereby position-measuring devices having a small type of construction may be implemented, even with the use of comparatively coarse detector structures.

In this case too, a beam path for obtaining a constant light signal runs symmetrically to the system described before, in this beam path, too, two Fresnel cylindrical lenses 22.4, 23.5 being situated one behind the other, and to this beam path there is assigned its own photo element 25.3, onto which both diffraction branches of the corresponding beam path impinge.

Furthermore, on the basis of the previously described development of markings 13 and intermediate areas 14 of an incremental graduation, it is possible to construct a position-measuring device having absolute position information by using different transverse periods $TP_{TRANS, 1}$ and $TP_{TRANS, 2}$. For this, in conformance to a PRC code, along the measuring direction x , certain long sides of markings are provided with at least one deviating transverse period $TP_{TRANS, 2}$, whereas the remaining long sides have the usual transverse period $TP_{TRANS, 1}$. The images of the slit which are producible by the deviating transverse period $TP_{TRANS, 2}$, are imaged, using the telescope optics, described further above, that is based on two Fresnel cylinder lenses arranged one behind the other in the beam path, on an ASIC, as shown in Figure 8. Long sides of markings having the one, usual transverse period $TP_{TRANS, 1}$ are imaged on first active surfaces 25.4 of the ASIC, whereas the long sides having the deviating transverse period $TP_{TRANS, 2}$ are imaged in a modulated way on two active surfaces 25.5 of the ASIC. The first and second active surfaces 25.4, 25.5 of the ASIC are connected to each other in push-pull mode.

First and second active surfaces 25.4, 25.5 are each made up, in this context, of subareas arranged one behind the other periodically, having a period P . In this context, the corresponding period P is given by the product of the imaging

scale of the telescope optics used and the signal period. From the output signals of the push-pull-connected active surface pairs, the respective absolute position of scale 1 with respect to scanning unit 2 is ascertained by using a table.

According to another variant, the markings forming the incremental track may also be provided with three or more different transverse periods. Thereby an absolute code may be distributed to two tracks. This makes possible the coding of comparatively long measuring paths as well as the generation of increased redundancy for improved reliability.

In the exemplary embodiments described above, the incremental graduation is in each case developed as a transmitted light graduation or a phase grating. Alternatively, amplitude gratings or structures may also be used within the scope of the present invention. In the same way, it is possible to implement a reflected light system instead of a transmitted light system.

The transverse substructure of the incremental graduation is formed in all the cases described by the width modulation of markings 13 and intermediate areas 14. In each case, these have at their long sides a periodic, sine-shaped contour boundary along their respective longitudinal direction y . The periodicity of the contour boundaries corresponds to the respective transverse periods $TP_{TRANS, 1}$ and $TP_{TRANS, 2}$. Because of these transverse substructures, besides the longitudinal bending or splitting of the radiation beams used for generating the incremental signals in the measuring direction x , there also comes about the transverse bending required for the generation of reference-pulse signal REF.

In this context, the special advantage of a sine-shaped contour boundary is that the intensity of the incremental signal is not so greatly impaired by the generation of the reference-pulse signal. The reason for this is the low field

strength of the first and minus first longitudinal diffraction order at the locations of the transverse grating structures. The extension of the sinusoidal contour boundaries in measuring direction x , i.e. the modulation amplitude of the respective sine function, determines the distribution proportion of the light intensities for the utilized sub-beams of rays of the reference-mark scanning and the incremental-signal scanning. This distribution proportion ratio may be set by the selection of the modulation period of the sine function.

Apart from sinusoidally designed contour boundaries, other periodic, transverse substructures may be used in which the long sides of the markings (contour boundaries) are shaped triangular, for example. Furthermore, the modulation amplitude of the contour boundaries and long sides of the markings could be selected to be so large that adjacent markings in the measuring direction x touch, and a cross grating having rhombic structures results.

In addition, a transverse substructure of the individual markings, particularly with respect to very short modulation periods, may be formed in that the markings, along the longitudinal direction y (transverse to the measuring direction x) are formed of a plurality of graduation markings arranged one after another along the longitudinal direction y . In the case of transmitted light division, periodic (alternating) light-transmitting and light-non-transmitting graduation markings would then follow one another, for example, in longitudinal direction y of the respective markings. Thereby, too, one could achieve the attempted modulation effect transverse to the measuring direction x .

What Is Claimed Is:

1. A position-measuring device for generating measuring signals, having
 - a track (12), which has an incremental graduation (13, 14) that has a specified graduation period (TP_{INC}) and that extends along a measuring direction (x),
 - at least one discontinuity of the incremental graduation (13, 14) at a reference position (x_{REF}) for generating a reference signal (REF) and
 - a scanning unit (2), movable relative to the track (12) along the measuring direction (x), for scanning the incremental graduation (13, 14) by radiation beams (S),

the at least one discontinuity being formed by a modification of a transverse substructure, extending in a perpendicular manner to the measuring direction (x), of the incremental graduation (13, 14), which bends radiation beams (S) originating from the scanning unit (2); the bending direction deviating at the discontinuity from the bending direction in other regions of the incremental graduation (13, 14); and the scanning unit (2) having at least one reference-pulse detector element (25.1, 25.2; 25.4, 25.5) which is provided for receiving one of the radiation beams (S_{T1} , S_{T2}) having a different bending direction,

wherein upstream of the reference-pulse detector element (25.1, 25.2; 25.4, 25.5) at least one imaging optics system (20) is situated in the beam path of the respective bent radiation beam (S_{T1} , S_{T2}).

2. The position-measuring device as recited in Claim 1,

wherein the imaging optics system (20) is used for imaging the areas of the track (12), irradiated in each case with the aid of the scanning unit (2), onto a predefined imaging plane.

3. The position-measuring device as recited in Claim 1, wherein the imaging optics system (20) for imaging the areas of the track (12) irradiated in each case with the aid of the scanning unit (2) includes at least one cylindrical lens, in particular in the form of a Fresnel cylindrical lens (22.3, 23.4).
4. The position-measuring device as recited in Claim 3, wherein the imaging optical system (20) includes at least two cylindrical lenses situated one behind the other in the beam path of the bent radiation beams (S_{T1} , S_{T2}).
5. The position-measuring device as recited in Claim 2, wherein in the imaging plane at least one slit (23.2) is provided on which the radiation of two radiation beams (S_{T1} , S_{T2}) of different bending direction impinges, and which supplies the radiation from radiation beams (S_{T1} , S_{T2}) having a different bending direction to different reference-pulse detector elements (25.1, 25.2; 25.4, 25.5).
6. The position-measuring device as recited in Claim 5, wherein the radiation of differently bent radiation beams (S_{T1} , S_{T2}) impinges on different locations of the slit (23.2).
7. The position-measuring device as recited in Claim 6, wherein the differently bent radiation beams (S_{T1} , S_{T2}) impinge upon different places (h_1 , h_2) along the extension direction (y) of the slit (23.2).
8. The position-measuring device as recited in Claim 5,

wherein the at least one slit (23.2) extends in a direction (y) perpendicular to the measuring direction (x).

9. The position-measuring device as recited in Claim 2, wherein the imaging plane lies in the beam path of the radiation beams (S_{T1} , S_{T2}) at a distance from the at least one reference-pulse detector element (25.1, 25.2; 25.4, 25.5).
10. The position-measuring device as recited in Claim 2, wherein the at least one reference-pulse detector element (25.1, 25.2; 25.4, 25.5) essentially lies in the imaging plane.
11. The position-measuring device as recited in Claim 1, wherein at least two reference-pulse detector elements (25.1, 25.2; 25.4, 25.5) are provided for radiation beams (S_{T1} , S_{T2}) having a different bending direction; and the reference-pulse detector elements (25.1, 25.2; 25.4, 25.5) are preferably situated in one plane.
12. The position-measuring device as recited in Claim 1, wherein the incremental graduation (13, 14) is formed by periodic markings (13) situated one behind the other, between which in each case intermediate areas (14) are provided.
13. The position-measuring device as recited in Claim 12, wherein exactly one marking (13') has a transverse substructure which deviates from the transverse substructure of the other markings (13), and which defines the discontinuity at the reference position (X_{REF}).
14. The position-measuring device as recited in Claim 12, wherein in the surroundings of the at least one reference

position (x_{REF}) defined by the discontinuity, a plurality (j) of markings (13") is provided with a transverse substructure which deviates from the transverse substructure of the remaining markings, and which defines the discontinuity at the reference position (x_{REF}).

15. The position-measuring device as recited in Claim 12, wherein the track (12) has at least two sectors (1a, 1b), a different transverse substructure of the incremental graduation (13a, 14a; 13b, 14b) being provided in each sector (1a, 1b).
16. The position-measuring device as recited in Claim 1, wherein two diffraction branches are formed from the radiation beam (S) emitted by the scanning unit (2) by the transverse substructure extending perpendicularly to the measuring direction (x), the radiation beams (S_{T1} , S_{T2}) that are included in the one diffraction branch and bent by the transverse substructure being supplied to one of the reference-pulse detector elements (25.1, 25.2; 25.4, 25.5); and the radiation beams included in the other diffraction branch being supplied to an additional detector element (25.3) in a uniform manner.
17. The position-measuring device as recited in Claim 16, wherein the one additional detector element (25.3) is used to generate a constant light level.
18. The position-measuring device as recited in Claim 16, wherein the output signals (REF_1 , REF_2) of the reference-pulse detector elements (25.1, 25.3) are combined with the output signal (REF_3) of the one additional detector element (25.3), for the generation of a reference-pulse signal (REF).
19. The position-measuring device as recited in Claim 18, wherein the combination is implemented with the aid of a

comparator (30).

20. The position-measuring device as recited in Claim 16, wherein an imaging optics system (20) is provided in the beam path of both diffraction branches.
21. A method for position-measuring using a track which has an incremental graduation, extending along a measuring direction, having a predefined graduation period, and which is provided at at least one reference position with a discontinuity for generating a reference signal, the discontinuity being formed by the modification of a transverse substructure of the track that extends perpendicular to the measuring direction, in which
- a) the track is moved along the direction of measurement relative to a scanning unit and is scanned by the latter,
 - b) radiation beams originating from the scanning unit are bent by the discontinuity,
 - c) the bending direction at the discontinuity location deviates from the bending direction at other regions of the track, and
 - d) the scanning unit has at least one reference-pulse detector element, using which one of the radiation beams of a different bending direction is received,
- wherein the bent radiation beams (S_{T1} , S_{T2}) are deflected with the aid of an imaging optics system (20) before impinging upon the respective reference-pulse detector element (25.1, 25.2; 25.4, 25.5).
22. The method as recited in Claim 21, wherein the bent radiation beams (S_{T1} , S_{T2}) are deflected

by diffraction.

23. The method as recited in Claim 21,
wherein the transverse substructure generating the bent
radiation beams (S_{T1} , S_{T2}) is imaged with the aid of the
imaging optics system (20) onto a plane.
24. The method as recited in Claim 21,
using at least two reference-pulse detector elements
(25.1, 25.2; 25.4, 25.5),
wherein two diffraction branches are formed from the
radiation beam (S) emitted by the scanning unit (2) by
the transverse substructure extending perpendicularly to
the measuring direction (x), the radiation beams (S_{T1} , S_{T2})
that are included in the one diffraction branch and bent
by the transverse substructure being supplied to one of
the reference-pulse detector elements (25.1, 25.2; 25.4,
25.5); and the radiation beams included in the other
diffraction branch being supplied in a uniform manner to
an additional detector element (25.3).
25. The method as recited in Claim 21,
wherein the output signals (REF_1 , REF_2) of the
reference-pulse detector elements (25.1, 25.3) are
combined with the output signal (REF_3) of the one detector
element (25.3), for the generation of a reference-pulse
signal (REF).