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POSITION-MEASURING DEVICE

Background of the Invention

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

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Such a position-measuring device for determining the relative position of two objects movable relative to each other along a measuring direction (angular position measuring device) includes a periodic measuring graduation configured on a
10 ring-like material measure (i.e. on a ring-like support), e.g. in the form of a measuring strip; a scanning unit for optically scanning the measuring graduation using electromagnetic radiation (particularly using light) which is generated in an illumination device (light source) of the
15 scanning unit, the material measure and the scanning unit being movable relative to each other along the measuring direction; a scanning plate of the scanning unit having a periodic graduation (scanning graduation), which is situated in the beam path of the electromagnetic radiation used for
20 scanning the measuring graduation, so that this electromagnetic radiation interacts both with the scanning graduation and with the measuring graduation; and a detector of the scanning unit whose detector surface is used for detecting the electromagnetic radiation modified by the
25 scanning graduation and the measuring graduation, and is designed with a period P_0 for detecting an intensity pattern formed by this modified electromagnetic radiation.

Period P_0 is selected so that, given a linear arrangement of
30 the measuring strip along a straight line, period P_0 agrees with the period of the stripe pattern (Vernier pattern) which is generated by the interaction of the radiation, used for scanning the material measure, with the scanning graduation on



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one hand and with the measuring graduation on the other hand. This stripe pattern corresponds to a beat, caused by the combination of two periodic operations, namely, the interaction of the electromagnetic radiation with the scanning graduation on one hand, and the interaction of the electromagnetic radiation with the measuring graduation on the other hand.

The measuring principle on which the aforesaid position-measuring device is based is described, for example, in EP 1 081 457 A2, EP 1 028 309 A1 and EP 0 754 933 B1.

Thus, EP 1 028 309 A1 describes an optical position-measuring device for determining the relative position of two objects movable relative to each other along a measuring direction. It includes at least one periodic measuring graduation connected to one of the two objects, as well as a scanning unit connected to the other object and therefore movable relative to the measuring graduation along the measuring direction. The scanning unit has a light source, at least one scanning graduation, as well as a detector system in a detector plane that is made up of a plurality of radiation-sensitive detector elements arranged one after the other in the measuring direction.

If, given a position-measuring device of the type indicated at the outset, a measuring strip used as the carrier of the measuring graduation is arranged in ring-like fashion, particularly by applying the measuring strip on a cylindrical body in the form of a drum, the position-measuring device may then be used in particular for angular measurement. Compared with a linear arrangement of the measuring strip (so that it extends in the manner of a scale along a straight line), when working with the ring-like arrangement of the measuring strip, particularly along a circular arc, effects occur which impair the intensity of the radiation received at the detector of the scanning unit. An effect is when, given a ring-like

arrangement of the measuring strip, because of the curvature of the measuring strip associated with that, the inner surface of the measuring strip is somewhat compressed and the outer surface of the measuring strip is somewhat elongated. The extent of this compression and elongation depends upon the thickness of the measuring strip, and is, of course, all the greater, the greater its thickness. For a measuring graduation provided on the outer surface of a measuring strip arranged in ring-like fashion, this effect leads to an enlargement of the measuring-graduation period, since the outer surface of the measuring strip is elongated (compared to its linear arrangement).

Conversely, when scanning a measuring strip arranged in a ring shape, using a scanning unit that is situated at a defined distance in front of the outer surface of the measuring strip provided with the measuring graduation, a projection effect occurs which - viewed from the surface of the scanning plate - causes the distance between the individual markings (particularly graduation marks) of the measuring graduation to seemingly become increasingly smaller toward the outer edges of the scanning plate. This is attributable to the projection of the curved outer ring surface of the measuring strip, provided with the measuring graduation, onto the planar, two-dimensional surface of the scanning plate provided with the scanning graduation.

The two aforesaid effects are contrary; however, the projection effect depends exclusively on the curvature of the measuring strip, while the elongation effect at the outer surface of the measuring strip depends both on its curvature and on its thickness. For comparatively thick measuring strips having a thickness of, for example, 300 μm , it has turned out that the two contrary effects offset each other over a large range of various curvatures to the extent that the identity [sic; intensity] pattern generated at the radiation-sensitive surface of the detector exhibits a sufficient contrast for a

subsequent evaluation. For very thin measuring strips having a thickness of markedly less than $300\text{ }\mu\text{m}$, particularly less than $100\text{ }\mu\text{m}$, however, the elongation effect at the outer surface of the measuring strip is only so small that it is no longer able to sufficiently compensate for the projection effect in the case of strong curvatures. Because of the poor contrast of the intensity pattern, the signal amplitude detected by the detector can become so small that a reliable evaluation for determining position is not possible.

In the following, when using the term "measuring strip," provided it is not geared to a measuring strip of finite thickness, the intention is in each case to also include the limit case that the thickness of the measuring strip approaches zero: This limit case corresponds to a situation in which the measuring graduation is applied directly on the (cylindrical) body (in the form of a drum), which is otherwise used for accommodating the measuring strip. The elongation effect described above then plays no role; thus no compensation of the projection effect takes place.

The object of the present invention is to create a position-measuring device of the type indicated at the outset which, given a simple design, permits the combination of an annular material measure with a scanning plate having a planar, two-dimensional surface, and having an associated detector with a two-dimensional radiation-sensitive surface.

Accordingly, the period of scanning graduation P_A on one hand and the period of measuring graduation P_M on the other hand are coordinated in such a way with one another that $1/(1/P_A - 1/P_M) < P_D$. This means that by the interaction of the light with the periodic scanning graduation on one hand and the periodic measuring graduation on the other hand, given a linear arrangement of the material measure in the form of a measuring strip, a stripe pattern would be generated whose period (given by the expression $1/(1/P_A - 1/P_M)$) would be smaller than period

P_D of a stripe pattern for whose scanning the radiation-sensitive surface of the detector is designed and provided. Particularly for very thin measuring strips, the intention is thereby to compensate for the seeming reduction of the measuring-strip period occurring due to the above-indicated projection effect when working with a ring-like arrangement (which leads locally to an enlargement of the period of the stripe pattern).

This can be advantageously achieved according to the present invention in that, on one hand, the period of the material measure, particularly in the form of a measuring strip, is increased, so that $P_M > 1/(1/P_A - 1/P_D)$, or in that the period of the scanning plate is correspondingly reduced, so that $P_A < 1/(1/P_D + 1/P_M)$. In this context, it is assumed that $P_M > P_A$ (including the limit case $P_A = P_M$ explained below). The reverse case is likewise possible, but of lesser practical relevance.

The following explanations concerning the embodiment of the position-measuring device according to the present invention - also in quantitative regard - are in each instance also valid in the limit case $P_A = P_M$. Therefore, the invention can also be put into effect for this limit case in which period P_D of the stripe pattern to be detected approaches infinity.

Using the design approach according to the present invention, it is possible to use the same detector (having a planar, radiation-sensitive surface) as a component of the scanning unit movable relative to the measuring strip when working with a ring-like arrangement of a measuring strip, particularly along a circular arc, as when working with a linear arrangement of the measuring strip. It is thereby possible to produce the detector inexpensively in correspondingly greater quantity.

In this context, the limit case in which the period of the scanning graduation tends toward the period of the measuring

graduation is also expressly to be included, so that the period of the Vernier stripe pattern generated (in the linear case) tends toward infinity (compare EP 0 754 933 B1).

5 The detector is preferably a so-called structured detector (as described, for example, in EP 1 028 309 A1), whose radiation-sensitive surface is formed by detector regions, particularly in the form of individual detector elements (photoelements), arranged periodically one after the other; in
10 the present case, period P_D of the arrangement of the detector regions or detector elements is larger than the stripe-pattern period $1/(1/P_A - 1/P_M)$ which, in response to the modification according to the present invention of the period of the measuring graduation and/or of the scanning plate, would be
15 generated by the electromagnetic radiation, used for the scanning, after interaction both with the scanning grating and with the measuring graduation (in the case of a planar arrangement of the measuring strip). In other words, period P_D of the detector regions or detector elements of the detector
20 is selected so that, for a measuring strip having a specific period of the measuring graduation and for a scanning plate having a specific period of the scanning graduation - this measuring strip being provided for the linear arrangement along a straight line - period P_D agrees exactly with the
25 period of the stripe pattern that is generated by interaction of the radiation, used for the scanning, with the scanning graduation and the measuring graduation. According to the present invention, however, for scanning a measuring strip, arranged in ring-like fashion along a circular arc, for
30 angular measurement, the period of the measuring graduation and/or the period of the scanning graduation is/are modified so that, given linear arrangement of the indicated measuring strip (provided for a ring-like arrangement), the period of the detector elements would be larger than that of the stripe
35 pattern that would occur in the case of a linear arrangement of the measuring strip and the modification according to the present invention of the period of the measuring graduation

and/or of the scanning plate. In this way, it is possible to largely compensate for the projection effect in the case of a curved arrangement of the measuring strip.

5 Thus, according to the present invention, when working with a position-measuring system having a measuring strip arranged in ring-like fashion and an allocated detector having a planar, two-dimensional, radiation-sensitive surface, the period of the scanning graduation and/or the period of the measuring
10 graduation - compared to a position-measuring device having a measuring strip arranged in a straight line and an identical detector - is/are modified so that the signal amplitude of the scanning signals is perceptibly greater than if the measuring strip of a linear position-measuring device were used directly
15 for forming an angular position measuring system without modification of the period of the scanning graduation or the measuring graduation. In this context, the linear position-measuring system utilized for the comparison should in each case be configured in such a way that, given linear
20 arrangement of the measuring strip along a straight line, the stripe pattern appearing on the radiation-sensitive surface of the detector has precisely the period for whose scanning the corresponding detector is designed and provided for attaining maximum intensity of the electromagnetic radiation on the
25 radiation-sensitive surface. In the case of a periodically structured detector, this means in particular that the radiation-sensitive surface of the detector has a period that agrees with the period of the stripe pattern up to an integral multiple.

30 For typical thicknesses and radii of a measuring strip used for angular measurement, the modification of the period of the scanning graduation and/or the measuring graduation necessary for this purpose is at least 0.05% and not more than 2%; in
35 particular, it is between 0.1% and 1%.

In this context, to be understood by the period of the detector is not necessarily the period of the geometrical arrangement of the individual detector regions or detector elements. Rather, the electrical interconnection of the individual detector regions or detector elements must also be taken into account. Thus, in the case of a structured detector, it is usually provided that four detector elements are arranged on a length which corresponds to the period of the stripe pattern received on the radiation-sensitive surface of the detector, each detector element being allocated to one phase, particularly to one of the phases 0°, 90°, 180°, 270° [sic; 0°, 90°, 180°, 270°]. In this context, a plurality of groups of four detectors each are then arranged one after the other; from the individual detector groups, in each case those detector regions or detector elements are interconnected which are assigned to the same phase. The period of such a structured detector is then in each case defined by the width of one detector group that includes a plurality of detector regions, particularly four detector regions.

When using a detector having a two-dimensional, planar, radiation-sensitive surface for scanning the measuring graduation on a material measure going around in ring-like fashion, the detector extends at a defined (radial) distance from the material-measure surface provided with the measuring graduation, in a tangential direction (i.e. parallel to a tangent at the outer periphery of a measuring strip arranged in ring-like fashion). Accordingly, in the case of a structured detector, the individual detector regions or detector elements are situated one after the other along a direction parallel to a tangent of the material measure running around in a ring shape. The two disturbance effects indicated at the outset, namely, the elongation of the outer surface of a measuring strip provided with the measuring graduation on one hand, and the projection effect on the other hand do not completely offset each other even given the correction according to the present invention of the scanning

graduation and/or the period of the measuring graduation. Rather, the elongation effect predominates in the (observed in the tangential direction) middle region of the radiation-sensitive surface of the detector, since the projection does not play so great a role here. That is to say, in the middle region of the radiation-sensitive surface of the detector, the period of the measuring strip arranged in a ring shape (thus the distance between the individual markings or graduation marks of the measuring graduation) seems to be larger than provided (because of the elongation effect), while at the edge regions of the detector - observed in the tangential direction - because of the predominance of the projection effect, the period of the measuring graduation seems to become smaller. The period of the scanning graduation on one hand and the period of the measuring graduation on the other hand are coordinated in such a way according to the present invention that the stripe pattern generated on the radiation-sensitive surface deviates as little as possible from period P_0 of that stripe pattern for whose detection the radiation-sensitive surface of the detector is designed (particularly with respect to the periodic arrangement of detector regions or detector elements in the case of a structured detector).

It is noteworthy that the present invention may also be used in the case when the measuring graduation is provided on the inner surface (inner ring surface) of a measuring strip. In this case, in addition to the projection effect, a compression effect acting in the same direction comes to bear on the inner ring surface, which means the period of the measuring graduation would have to be enlarged or the period of the scanning graduation would have to be reduced for the compensation.

Both the scanning graduation and the measuring graduation may be formed by so-called amplitude gratings that interact with electromagnetic radiation (particularly light) in such a way

that - according to the period of the respective grating - a periodic sequence of brighter and darker light regions is generated. If the position-measuring device is operated in the so-called reflection method, then in each case markings (graduation marks) of greater and lesser reflectivity with regard to the electromagnetic radiation (light) used for the scanning are provided in the corresponding grating. In contrast, when using the so-called transmitted-light method, the markings (graduation marks) arranged periodically one after the other differ in transmissivity for the electromagnetic radiation (light) used for the scanning.

In addition, the scanning graduation may also take the form in particular of a so-called MAP grating (mixed amplitude phase grating) as known, for example, from Figures 2a and 2b of EP 1 081 457 A2.

Alternatively, the scanning graduation may also be formed by a phase grating.

Within the scope of the present invention, collimated (parallelized) electromagnetic radiation in the form of light is preferably used for scanning the material measure.

Other features and advantages of the present invention are clarified in the following description of an exemplary embodiment with reference to the figures, in which:

Figure 1a shows a schematic representation of a section of a measuring strip, arranged in the shape of a ring, having a periodic measuring graduation, as well as an allocated scanning plate having a periodic scanning graduation and a detector;

Fig. 1b shows the radiation-sensitive surface of a structured detector of a scanning unit according to Figure 1a;

Figure 2 shows a graphic representation of the influence of the elongation effect and the projection effect on the period of a stripe pattern, generated on the radiation-sensitive surface of the detector, when using a position-measuring device according to Figures 1a and 1b because of a ring-shaped arrangement of the measuring strip;

Figures 3a and 3b show consequences of the elongation effect and the projection effect on the normalized signal amplitudes of a position-measuring device according to Figures 1a and 1b as a function of the radius of the measuring strip, arranged in a ring shape, for two different thicknesses of the measuring strip.

Figure 1a shows schematically a position-measuring device for angular measurement having a measuring strip 1 of finite thickness d arranged in the shape of a ring along a circular arc, and having a scanning unit which includes a scanning plate 2 and a detector 3 in the form of a photodetector.

Measuring strip 1 and scanning unit 2, 3 are movable relative to each other, e.g., in that measuring strip 1 is affixed to the outer periphery of a drum rotatable about an axis D , and scanning unit 2, 3 is situated in a stationary manner in front of outer surface 11 (outer ring surface) of measuring strip 1, (and set apart from it in radial direction R).

Measuring strip 1 of thickness d , arranged in the shape of a ring along a circular arc 10 having radius R , has an outer ring surface 11 provided with a periodic measuring graduation 15 in the form of a line graduation, as well as an inner surface 12 (inner ring surface). Due to the annular arrangement of flexible measuring strip 1, its outer ring

surface 11 is elongated - compared to a linear arrangement of measuring strip 1 along a straight line - while inner ring surface 12 is compressed.

5 Because of the elongation of outer ring surface 11 of measuring strip 1 arranged in the shape of a ring, period P_m of periodic measuring graduation 15 of measuring strip 1, thus the distance between adjacent graduation marks of measuring graduation 15 formed as a line graduation, is somewhat larger
10 than for a linear, flat arrangement of the measuring strip along a straight line ("elongation effect").

A scanning plate 2 of scanning unit 2, 3 allocated to measuring strip 1 is situated in front of and set apart from
15 outer ring surface 11 of measuring strip 1, and is provided with a periodic scanning graduation 25 on its surface 21 facing outer ring surface 11. Surface 21 of scanning plate 2 facing outer ring surface 11 of measuring strip 1, as well as scanning graduation 25 formed there, each extend parallel to a
20 tangent t at outer ring surface 11 of measuring strip 1.

Viewed from measuring strip 1, a detector 3, a so-called structured photodetector, having a radiation-sensitive surface 31 is situated behind scanning plate 2. According to Fig. 1b,
25 its radiation-sensitive surface 31 is formed by a plurality of detector elements in the form of photoelements situated one after the other and having a width b . In each case four detector elements form one detector group, the four detector elements of one detector group each being allocated to one of
30 the four phases 0° , 90° , 180° and 270° . Period P_p of this arrangement of detector elements corresponds to fourfold the width b of a single detector element of the phase 0° , 90° , 180° or 270° .

35 Also shown schematically in Figure 1b are electrical connections 300 of the individual photoelements which form radiation-sensitive surface 31 of photodetector 3,

photoelements of different detector groups and allocated to the same phase 0° or 90° or 180° or 270° being interconnected so that their output signals may be jointly supplied for evaluation to an evaluation unit.

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Figure 1b shows three detector groups from radiation-sensitive surface 31 of photodetector 3, each made up of four detector elements (photoelements) of the phase 0° or 90° or 180° or 270° . This is only a section of radiation-sensitive surface 31 of photodetector 3, which typically has ten to fourteen such
10 detector groups situated periodically one after the other and each made up of four photoelements.

The above-described scanning unit 2, 3 of the
15 position-measuring device (angular position measuring device) shown in Figures 1a and 1b is used for the optical scanning of measuring graduation 15 on outer ring surface 11 of measuring strip 1 arranged in a ring shape along a circular-arc segment 10. To that end, outer ring surface 11 of measuring strip 1, provided with measuring graduation 15, is irradiated in known
20 manner with collimated electromagnetic radiation L in the form of light that was generated by a suitable illumination unit (light source) and collimated by a suitable condenser lens as known, for example, from EP 1 081 457 A2. Light L used for
25 scanning measuring graduation 15 on outer ring surface 11 of measuring strip 1 interacts both with scanning graduation 25 of light-transmitting scanning plate 2, which is situated in known manner in the beam path of light L, as well as with measuring graduation 15 on outer ring surface 11 of measuring
30 strip 1, at which light L is reflected.

Light beams L, modified both by scanning graduation 25 and by measuring graduation 15, form on radiation-sensitive surface 31 of photodetector 3 a so-called Vernier stripe pattern
35 having a period that is defined by period P_A of scanning graduation 25 and period P_M of measuring graduation 15.

The photoelements arranged on radiation-sensitive surface 31 of photodetector 3 generate an electrical signal, corresponding to this stripe pattern, which is supplied to an evaluation unit that, by evaluating the electrical output signals of photodetector 3, ascertains the extent of a relative movement between measuring strip 1 and scanning unit 2, 3.

In light of Fig. 1a, it becomes clear that, viewed from scanning plate 2, period P_M of measuring graduation 15 in the region opposite the middle region of scanning plate 2 is seemingly larger than in the regions opposite the outer ends of scanning plate 2. This is attributable to the fact that, because of the curvature $1/R$ of measuring strip 1 arranged in the shape of a ring, and because of the tangential arrangement of scanning plate 2 and photodetector 3 with respect to measuring strip 1, the location-dependent effective period P_{eff} of measuring strip 1 operative at radiation-sensitive surface 31 of detector 3 is based on a projection of measuring graduation 15 onto scanning plate 2 along a direction perpendicular to tangent t , along which scanning plate 2 extends. The projection effect described thus leads to a seeming decrease of period P_M of the measuring graduation in the regions opposite the tangential edge regions of scanning plate 2 compared to the region of measuring graduation 15 opposite the middle of scanning plate 2.

This projection effect is contrary to the earlier-described elongation effect as a result of the elongation of outer ring surface 11 of measuring strip 1 when arranged in the shape of a ring. In contrast to the projection effect, however, the elongation effect is not a function of location.

In the following, the results of the elongation effect and of the projection effect are described quantitatively in somewhat greater detail by clarifying the consequences of these two effects on the stripe pattern generated on radiation-sensitive

surface 31 of photodetector 3, the [stripe pattern] when scanning a measuring strip arranged in linear fashion along a straight line being compared to the stripe pattern of a measuring strip arranged in ring-like fashion.

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In a linear position-measuring system having a measuring strip arranged in flat fashion along a straight line, whose periodic measuring graduation has period P_M , and having a scanning plate, assigned to the measuring strip and extending parallel thereto, whose scanning graduation has period P_A (amplitude period), the following applies for the period of the stripe pattern which corresponds to the intensity pattern described above and which is generated by interaction of the light, used for scanning the measuring strip, with the scanning graduation on one hand and with the measuring graduation on the other hand:

$$P_V = 1 / (1/P_A - 1/P_M),$$

20 P_V being designated as the so-called Vernier period (compare EP 1 028 309 A1).

From the equation above, it follows that the more sharply graduation periods P_A and P_M of the scanning graduation on one hand and the measuring graduation on the other hand differ, the smaller the Vernier period P_V is.

Thus, for example, given a period of the scanning graduation $P_A = 19.512 \mu\text{m}$ and a period of the measuring graduation $P_M = 20 \mu\text{m}$, then $P_V = 800 \mu\text{m}$ results for the Vernier period P_V of the generated stripe pattern ("light-dark pattern"). This period of the stripe pattern must be taken into account when designing a structured photodetector intended to generate electrical output signals from the stripe pattern which are to be supplied to an evaluation unit. To that end, for example, for a photodetector made up of a plurality of photoelements arranged one after the other, four photoelements are situated

one after the other per period of the stripe pattern, each photoelement having an extension (along the extension direction of the radiation-sensitive surface of the photodetector) of $200\ \mu\text{m}$ and being assigned to a specific phase, e.g. 0° , 90° , 180° or 270° . In this context, the extension of the active surface of the respective photoelement is somewhat smaller than the $200\ \mu\text{m}$ indicated, since an edge for insulation must in each case be provided between the individual photoelements.

Thus, in this case, Vernier period P_v of the stripe pattern generated by interaction of the light, used for the scanning, with the scanning graduation on one hand and with the measuring graduation on the other hand, agrees exactly with period P_D , to which the radiation-sensitive surface of the detector is attuned.

If the same detector type, thus a photodetector having a two-dimensional planar surface, formed by photoelements arranged periodically one after the other, is now used as a component of a scanning unit for a measuring strip arranged in ring-like fashion, then the result of the two effects described above, namely the so-called elongation effect on one hand and projection effect on the other hand, is that the effective Vernier period P_{eff} operative at the radiation-sensitive surface of the photodetector is a function of location. Specifically, because of the elongation effect, it is smaller as far as the amount is concerned in the middle region of the radiation-sensitive surface than Vernier period P_v in the linear case, but increases toward the edges because of the projection effect. This is discernible in Figure 2, where effective Vernier period P_{eff} is represented as a function of position x on the structured photodetector. It is clearly recognizable that effective Vernier period P_{eff} in the middle of the photodetector (given $x = 0$) assumes a smaller value than Vernier period P_v of the stripe pattern in the linear case ($P_v = 800\ \mu\text{m}$) and then increases toward the edges

of the photodetector (for $x > 0$ or $x < 0$). In this context, the effective Vernier period P_{eff} is understood to mean the locally variable extension of a pair of light-dark stripes of the Vernier stripe pattern.

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If one observes the stripe-pattern phase, which in the case of a linear measuring strip increases linearly by 2π within one detector period - thus coincides with the detector phase and therefore supplies an optimal contrast in the detector signals - then the phase for a curved measuring strip initially runs somewhat ahead of the phase of the detector in the middle of the detector (since the effective Vernier period P_{eff} is smaller here than the detector period), while it lags behind toward the edge of the detector (since here the effective Vernier period P_{eff} is larger than the detector period). This phase difference causes the contrast in the detector signals to deteriorate. The phase of the stripe pattern may be determined from the local graduation periods of the scanning graduation and of the measuring graduation, as well as the geometrical conditions such as the curvature of the measuring graduation and the distance of the detector from the measuring graduation.

The increase of effective Vernier period P_{eff} toward both edges of the radiation-sensitive surface of the photodetector is a result of the projection effect which leads to a reduction of the period of measuring graduation P_M toward the edges, and therefore to a decrease of the difference $1/P_A - 1/P_M$, which in turn, according to the above equation, leads to an increase of the Vernier period.

Since of the two effects indicated above, the elongation effect is independent of location, but the projection effect is location-dependent, these two contrary effects cannot completely offset each other. However, it is possible to coordinate periods P_A and P_M of scanning graduation 25 on one hand and of measuring graduation 15 on the other hand in such

a way with one another that an optimized scanning signal is obtained for a subsequent evaluation.

A simple analytical calculation of a correction value for period P_M of measuring graduation 15 or period P_A of scanning graduation 25 is not possible. The reason is that, first of all, the elongation effect on one hand and the projection effect on the other hand are dependent in a different manner on the curvature of measuring strip 1, i.e. its radius R , and secondly, the elongation effect is also strongly dependent on thickness d of measuring strip 1 (see Figure 1a).

An optimum correction value for period P_M of measuring graduation 15 may now be determined, for example, by totaling the intensity of the light arriving in the detector regions of the same phase for different periods P_M . With knowledge of the phase position of the stripe pattern relative to the detector phase, this may be carried out in a simple manner by a vector addition. A maximum of the scanning signals may thus be ascertained by iterative alteration of period P_M of measuring graduation 15.

Figures 3a and 3b each show the intensity of the scanning signals (for normalization, specific to the linear case) as a function of radius R_i of a drum, on which measuring strip 1 is wound, for a thickness d of measuring strip 1 of 300 μm (Figure 3a) and for a thickness d of measuring strip 1 of 75 μm (Figure 3b), and specifically in each case for different periods P_M of measuring graduation 15. In Figures 3a and 3b, in each case curve K1 indicates the case $P_M = 20 \mu\text{m}$ (thus agreement with the period of the measuring graduation for a linear arrangement); curve K2 the case $P_M = 20.02 \mu\text{m}$; curve K3 the case $P_M = 20.04 \mu\text{m}$; and curve K4 the case $P_M = 20.06 \mu\text{m}$. Amplitude period P_A of scanning graduation 25 is 19.512 μm in all cases, and a structured photodetector 3 is assumed which, with its photoelements, includes fourteen Vernier periods,

thus has a total of 56 photoelements arranged one after the other and combined to form fourteen groups.

It is clearly discernible in light of Figures 3a and 3b that for very small drum radii R_i and therefore for correspondingly small radii R of measuring strip 1 arranged in a ring shape, intensity I of the signal generated by the photodetector in the case of specific curve K1 (takeover of the measuring strip from the linear position-measuring system without correction of period P_M of measuring graduation 15) drops so strongly that a reliable evaluation of the signal is not possible. This is attributable to the fact that photodetector 3 is designed for a stripe pattern having a defined period P_D , which in the exemplified case is $800\text{ }\mu\text{m}$, and from which according to Figure 2 in the case of a ring-like arrangement of the measuring strip, effective Vernier period P_{eff} deviates perceptibly because of the elongation effect and the projection effect. This holds true in particular for small strip thicknesses d , for which the elongation effect has only a comparatively small consequence, and therefore the projection effect completely asserts itself in the case of small drum radii. This explains the markedly stronger decline of intensity curve K1 in Figure 3b compared to Figure 3a; for Figure 3b is based on a strip thickness of $75\text{ }\mu\text{m}$, while Figure 3a is based on a fourfold strip thickness of $300\text{ }\mu\text{m}$.

It is also discernible that in both cases, markedly higher intensities of the detector signal may be attained for small drum radii when period P_M of the measuring graduation is increased by 0.1% (curve K2), by 0.2% (curve K3) or by 0.3% (curve K4) compared to the linear case. As a function of strip thickness d , for each drum diameter R_i there is an unequivocal value by which period P_M of measuring graduation 15 must be corrected (increased) in order to obtain the greatest possible intensity of the scanning signals. For instance, if, in Figures 3a and 3b, one compares the four curves K1, K2, K3, K4 which represent different correction values of period P_M of

measuring graduation 15, then in the case of Figure 3a (corresponding to a strip thickness $d = 300 \mu\text{m}$), given a drum diameter of $5 \cdot 10^4$, a period P_M of measuring graduation 15 in the area of $20.02 \mu\text{m}$ is advantageous, while in the case of Figure 3b (strip thickness $d = 75 \mu\text{m}$) for the corresponding drum diameter, a period P_M of measuring graduation 15 of approximately $20.06 \mu\text{m}$ supplies particularly great intensities of the detector signal.

Naturally, instead of a correction of period P_M of measuring graduation 15 compared to the linear case, period P_A of scanning graduation 25 may also be corrected. While in the case of a correction of period P_M of measuring graduation 15, the correction is implemented by addition of a correction value, in the case of a correction of period P_A of the scanning grating, period P_A must be reduced somewhat, corresponding to the subtraction of a correction value; for, as follows from the above equation for Vernier period P_V , what matters for the adjustment of the Vernier period and therefore also the effective Vernier period P_{eff} is the difference between the inverse values of P_A and P_M .

In concrete terms, it holds true that given a photodetector coordinated with period P_D of the Vernier stripe pattern, to correct the effective Vernier period P_{eff} for a ring-like arrangement of the measuring strip, either period P_M of the measuring graduation must be corrected so that $P_M > 1/(1/P_A - 1/P_D)$, or period P_A of the scanning graduation must be corrected so that

$$P_A < 1/(1/P_D + 1/P_M).$$

Claims:

1. A position-measuring device, comprising

- 5 - a measuring graduation provided on a material measure going around in ring-like fashion,
- a scanning unit for optically scanning the measuring graduation using electromagnetic radiation,
- 10 - a scanning plate having a periodic scanning graduation which is arranged in the beam path of the electromagnetic radiation used for scanning the measuring graduation so that the radiation interacts both with the scanning graduation and with the measuring graduation, and
- 15 - a detector of the scanning unit whose detector surface is used for detecting the electromagnetic radiation after interaction with the scanning graduation and the measuring graduation, and which is designed with a period P_D for detecting electromagnetic radiation in the form of a stripe pattern,

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wherein

the period P_M of the measuring graduation (15) and the period P_A of the scanning graduation (25) are coordinated so that $1/(1/P_A - 1/P_M) < P_D$, so that $P_M > 1/(1/P_A -$

25 $1/P_D)$, and so that the deviation of the period P_M of the measuring graduation (15) from the term $1/(1/P_A - 1/P_D)$ is between 0.1% and 1%.

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

wherein the detector surface (31) of the detector (3) is formed by a periodic arrangement of detector regions whose period (P_D) corresponds to the period of that stripe pattern for whose detection the detector (3) is designed.

5 3. The position-measuring device as recited in Claim 2,
wherein the detector regions are formed by detector elements, particularly in the form of photoelements.

4. The position-measuring device as recited in Claim 2,
10 wherein in each case four detector regions (0° , 90° , 180° , 270°) are combined to form a detector group, and the detector groups are arranged periodically one after the other with a defined period (P_D).

5. The position-measuring device as recited in Claim 4,
15 wherein the individual detector regions (0° , 90° , 180° , 270°) of one detector group are each assigned to one phase, and in-phase detector regions of different detector groups are electrically interconnected.

6. The position-measuring device as recited in Claim 1,
20 wherein the detector (3) has a planar, essentially two-dimensional detector surface (31).

7. The position-measuring device as recited in Claim 1,
wherein the measuring graduation (15) and/or the scanning graduation (25) is/are formed by an amplitude grating.

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8. The position-measuring device as recited in Claim 1,
wherein the scanning graduation (25) is formed by a MAP grating.

9. The position-measuring device as recited in Claim 1,
30 wherein the scanning graduation (25) is formed by a phase grating.

10. The position-measuring device as recited in Claim 1,
wherein the measuring graduation (15) of the material measure (1) is scanned by
electromagnetic radiation in the form of collimated light.

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11. The position-measuring device as recited in Claim 1,
wherein the period P_M of the measuring graduation (15) and the period P_A of the
scanning graduation (25) are coordinated so that the intensity of an output signal
generated by the detector (3) is maximized.

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12. The position-measuring device as recited in Claim 1,
wherein the material measure (1) going around in ring-like fashion is formed by a
measuring strip arranged in ring-like fashion.

15 13. A position-measuring device, comprising

- a measuring graduation provided on a material measure going around in ring-like
fashion,

20 - a scanning unit for optically scanning the measuring graduation using
electromagnetic radiation,

- a scanning plate having a periodic scanning graduation which is arranged in the
beam path of the electromagnetic radiation used for scanning the measuring
25 graduation so that the radiation interacts both with the scanning graduation and
with the measuring graduation, and

- a detector of the scanning unit whose detector surface is used for detecting the
electromagnetic radiation after interaction with the scanning graduation and the

measuring graduation, and which is designed with a period P_D for detecting electromagnetic radiation in the form of a stripe pattern,

wherein

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the period P_M of the measuring graduation (15) and the period P_A of the scanning graduation (25) are coordinated so that $1/(1/P_A - 1/P_M) < P_D$; and the detector surface (31) of the detector (3) is formed by a periodic arrangement of detector regions whose period (P_D) corresponds to the period of that stripe pattern for whose detection the

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detector (3) is designed; and the scanning graduation (25) is formed by a MAP grating.