



## Position Measuring Device

The invention relates to a position measuring device in accordance with the preamble of claim 1.

Such position measuring devices are employed in particular in connection with processing machinery for measuring the relative position of a tool in relation to a workpiece to be processed, with coordinate-measuring machinery for determining the position and dimensions of test objects, and lately increasingly in the semiconductor industry as well, for example in connection with wafer steppers. In this case the position measuring device is an angle or linear measuring device, wherein the scale is directly installed on the drive unit (rotatory motor or linear motor), or the scale is installed on a component driven by the drive unit.

The scale of such a position measuring device known, for example, from DE 92 09 801 U1, has a periodic scale graduation for generating counting signals, as well as reference markings for generating reference marking signals. An absolute relation of the position measurement will be produced for the position of the reference marking via this reference marking signal in that a counter is placed at a predetermined counter setting.

It is often necessary at the start of a position measurement following a break in the operation because of loss of energy supply, as well as for correcting and checking the counter setting, to approach the reference marking starting from an arbitrary position. To this end, area markings have been applied to the scale, by means of which it is possible to differentiate whether the scanning device is located on one or the other side of the reference markings. This area marking is embodied on one side of the reference markings in the form of a continuous opaque

strip. On the other side of the reference markings the area marking is embodied as a transparent area. A common photo receiver is arranged in the scanning device for scanning both area markings. The decision as to whether the scanning device is located on one or the other side of the reference markings is made on the basis of a measuring signal from this photo receiver.

It has been shown that because of the signal levels of this measuring signal this differentiation is problematic, since the mutual distance between the levels is very short. This measuring signal can also easily be affected by partial soiling of the scale, so that a wrong position of the scanning device is detected.

It is therefore the object of the invention to disclose a position measuring device by means of which it is possible to more assuredly differentiate between several measuring areas next to the reference markings.

This object is attained by means of a position measuring device having the characteristics of claim 1.

Advantageous embodiments are recited in the dependent claims.

The position measuring device designed in accordance with the invention has the particular advantage that the assurance of an unequivocal differentiation as to whether the scanning device is located on one or the other side of the reference markings is relatively great. The safeguard against interference is increased.

The invention will be explained in greater detail in what follows by means of an exemplary embodiment, making reference to the drawings.

Shown are in:

Fig. 1, a schematic sectional representation of a position

measuring device,

Fig. 2, a view from above on the scale of the position measuring device in accordance with claim 1,

Fig. 3, a view from above on the photo receiver arrangement,

Fig. 4, a view from above on the scanning plate,

Fig. 5, the course of the scanning beams in the area of the reference markings,

Fig. 6, reference marking signals,

Fig. 7, the course of the scanning beams on one side of the reference markings,

Fig. 8, the course of the scanning beams on the other side of the reference markings,

Fig. 9, a circuit arrangement,

Fig. 10, the area signal, and

Fig. 11, the limit signal.

A photoelectric incremental position measuring device in the form of a linear measuring device, having a scale 1, which can be displaced in the measuring direction X in relation to a scanning device 2, is shown in Fig. 1. A periodic incremental measuring graduation 3 has been applied to the scale 1 in a first track, and in a second track a reference marking 4, as well as area markings 5 and 6. For photoelectric scanning of the scale 1, the scanning device 2 comprises a light source 7, whose light is bundled in a collimator 8 and is directed through a scanning plate 9 onto the scale 1. The light impinging on the scale 1 is reflected in a position-dependent manner at the measuring graduation 3, the reference marking 4, as well as the area markings 5 and 6 and impinges on the photo receiver arrangement 10. The scale 1 is represented in a view from above in Fig. 2, and the photo receiver arrangement 10 in Fig. 3. How the light is

affected as a function of position is represented in Figs. 5, 7 and 8.

A scanning beam bundle 11, which impinges on the reflecting phase grating 3, is modulated as a function of the position by being diffracted into different partial beam bundles, which are subsequently brought into interference with each other and impinge on the three photo receivers 111, 112, 113 which, by means of an interferential scanning principle, generate in a known manner analog periodic measuring signals M1, M2, M3 which are phase-shifted in respect to each other, from which high-resolution counting signals are generated in a known manner by interpolation.

A scanning beam bundle 12 is guided in the area of the reference marking 4 to the scanning plate 9 by the reflecting fields of the reference marking 4. In the area in which this reflected light impinges, the scanning plate 9 has a scanning field 13, which consists of an aperiodic grating with transparent fields 13.1 and transversely deflecting fields 13.2 (Fig. 4). A transverse split occurs, since the light passes through this field 13 on the way to, as well as back from the scale 1. By means of a suitable selection of the grating parameters it is possible to generate a counter-clock reference marking signal R1 from the light which reaches the receiver 131 (Fig. 6). Another part is deflected into transverse first orders, of these, one is detected by means of the photo receiver 132 and a clock reference marking signal is generated by the latter (Fig. 6). A resulting reference marking signal R is generated by superimposition ( $R = R2 - R1$ ) of the counter-clock reference marking signal R1 on the clock reference marking signal R2. The design of the scanning plate 9 for scanning the reference marking 4 is represented in Fig. 4, and the path of the scanning beams in Fig. 5. This scanning principle is extensively explained in EP 0 669 518 B1, to whose disclosure

reference is expressly made.

A first segment of the collimator 8 is used for collimating the scanning beam bundle 12 of the upper track to the photo receivers 131, 132, 133, 134, and a second segment of the collimator 8 is used for collimating the scanning beam bundle 11 of the lower track to the photo receivers 111, 112, 113. The segments are only represented schematically in Fig. 1.

The reference marking 4 in the form of an aperiodic phase grating extends over several graduation periods of the measuring graduation 3. When the scanning field 13 is located exactly opposite the reference marking 4, the photo receivers 131, 132 generate a reference marking signal which is unequivocally assigned to an incremental timing impulse. This timing impulse unequivocally defines a portion of the track which, because of the interpolation, is smaller than a graduation period of the measuring graduation.

The scale 1 is evenly reflective on the left side of the reference marking 4. If the scanning device 2 is located opposite this reflecting area marking 5, the impinging scanning beam bundle 12 is directed in accordance with the path of the scanning beams in Fig. 7 onto the photo receiver 131.

A diffraction grating 6 as an area marking is arranged at the right side of the reference marking 4 on the scale 1. This diffraction grating 6 is a phase grating which suppresses the 0th order of diffraction to a large degree and deflects the impinging scanning beam bundle 12 into the  $\pm 1$ st order of diffraction. These diffraction orders, which were reflected at the diffraction grating 6 and deflected in the measuring direction X, are concentrated on the photo receivers 133, 134 by the collimator 8.

This path of scanning beams is represented in Fig. 8.

Thus, the direction of light is deflected at the area

markings 5, 6 as a function of the position of the scale.

Gratings with their properties of grating constant and/or grating orientation are particularly suited for the direction deflection.

The information regarding the direction deflection is coded out in the focal plane of the lens 8, since a point in the focal plane of the lens 8, where suitable photo elements 131, 133, 134 can be placed, is assigned to each grating constant and each grating direction.

Advantageously the measuring graduation 3, the reference marking 4 and the area marking 6 are phase gratings, which entails the advantage that these gratings 3, 4, 6 can be produced in mutual method steps and that therefore the correct assignment of the gratings 3, 4, 6 in relation to each other is assured. In the example, the phase grating 6 has the same parameters as the measuring grating 3.

Because of the optically different design of the right and left side of the reference marking 4, the scanning beam bundle 12 is either reflected into one direction and directed onto the photo receiver 131 or, reflected into a direction different therefrom, is directed onto the photo receivers 133, 134. Thus, an unequivocal area signal B (Fig. 10) is available in both positions. In contrast to the prior art, an area signal greater than zero is available on both sides of the reference marking 4, so that a disruption of the scanning beam path, for example because of soiling, can also be detected.

Because of the step in accordance with the invention it is possible to arrange the reference marking 4 and the area markings 5, 6 on a common track, i.e. one behind the other in the measuring direction X, so that the areas 4, 5, 6 are scanned by a common light beam bundle 12. The deflection onto the photo receiver 131 or the photo receivers 133, 134 is accomplished by the

directionally selective reflection function of the areas 5 and 6 on the scale 1. This directionally selective reflection of the areas 5 and 6 can also take place in other ways, for example by differently inclined reflecting faces or conical glass faces in case of the transmitted light principle, or by differently deflecting grating areas in the form of longitudinally (in the X direction) or transversely (in the Y direction) deflecting amplitude or phase gratings.

For generating the area signal B represented in Fig. 10, the output signal R1 from the photo receiver 131 and the output signal B1 from the photo receivers 133, 134 are conducted to a differential circuit 20. An unequivocal differentiation whether the scanning device 2 is located on the right or the left side of the reference marking 4 can be made from the amplitude of the area signal B. It can be seen that the mutual distance between the levels is relatively large. Because of forming the difference, the area signal B becomes independent to a large extent of the illumination strength.

A particularly advantageous evaluation unit for forming the area signal B is represented in detail in Fig. 9. The counter-clock reference marking signal R1 and the clock reference marking signal R1 are added together, weighted differently, in an adder 21 to form the signal  $B2 = R1 + 1.45 \cdot R2$ . By means of this a smoothing of the otherwise relatively strongly oscillating area signal B is achieved in the area of the reference marking 4. The output signal B2 from the adder 21, as well as the signal B1, are supplied to the differential circuit 20 for forming the area signal  $B = B2 - 3 \cdot B1$ . The area signal B is fed to a comparator 22, in which the area signal B is compared with a reference value B0. If the reference signal B is greater than the reference value B0, this means that the scanning device 2 is located on the right

side of the reference marking 4. If the reference signal B is less than the reference value B0, this means that the scanning device 2 is located on the left side of the reference marking 4.

In the prior art (DE 92 09 801 U1) mentioned in the introduction, so-called control markings are attached to the left and right of the reference marking to the ends of the scale in addition to the area markings. These control markings define the extreme positions of the scanning device and are also called end position switches or limit markers. Position measuring devices with such end position switches, or limit markers, are also described in DE 41 11 873 C2 and EP 0 145 844 B1.

In connection with a position measuring device with area markings designed in accordance with the invention, the function of end position switches can be realized in a particularly advantageous manner in that the area markings 5, 6 are partially covered in the limit areas 50, 60. As represented in Fig. 2, screens 51, 61 have been applied to the scale 1 to this end. These screens 51, 61 can be realized in the form of displaceable clips extending around the scale 1 and made of spring sheet metal, or they can also be sputtered on or glued to the surface of the scale 1, or embodied in the form of filter glass. The screens 51, 61 particularly affect the output signals B1, R1 of the photo receivers 133, 134, 131, and therefore also the level of the area signal B in the limit areas 50, 60. Four different areas of the scale 1 can be distinguished by means of the path of the area signal B, namely the left limit area 50, the left area 5 of the reference marking 4, the right area 6 of the reference marking 4, as well as the right limit area 60. Since the different deflection of the scanning beam bundle 12 is maintained in the limit areas 50, 60, the directional information - right side, or left side of the reference marking 4 - is also contained in the

limit areas 50, 60.

A particularly advantageous circuit arrangement is represented in Fig. 9, by means of which a limit signal L can be generated, as represented in Fig. 11. The limit signal 11 generated by means of this has a relatively high level difference between the limit areas 50, 60 and the remaining area. Therefore the interference distance is relatively large.

For generating the limit signal L, the circuit arrangement has an adder 21, which adds together the counter-clock reference marking signal R1 and the clock reference marking signal R1, weighted differently, to form the signal  $B2 = R1 + 1.45 \cdot R2$ . The output signal B2 from the adder 21, as well as the signal B1, are fed to a further adder 23 for forming the signal  $L1 = B2 + 3 \cdot B1$ .

The signal L1 is supplied to a differential circuit 24 for forming the limit signal  $L = L1 - M$ , wherein M is the sum of the measuring signals M1, M2, M3 from the measuring graduation 3, which have been added together in an adder 25. The limit signal L is conducted to a comparator 26, in which the limit signal L is compared with a reference value B0. If the limit signal L is greater than the reference value B0, this means that the scanning unit 2 is located in the permissible area. If the limit signal L is less than the reference value B0, this means that the scanning unit 2 is located in one of the limit areas 50 or 60. Whether the scanning unit 2 is located in the right or in the left limit area is determined by means of the area signal B.

The directionally selective deflection onto the photo receivers 131, or 133, 134, is maintained because of the optical influence on the area markings 5, 6 in the limit areas 50, 60, so that no additional photo receivers are required for scanning the limit areas 50, 60. Furthermore, a space-saving arrangement of the area markings 5, 6, and of the limit areas is assured. It is

advantageous if for forming the area signal B, the scanning signals R1, B1 are combined in a circuit arrangement in accordance with a first linkage rule, and for forming the limit signal L in a second linkage rule differing from the first, wherein the first linkage rule contains the formation of the difference between the scanning signals ( $R1 - B1$ ), and the second linkage rule an addition ( $R1 + B1$ ). In case of soiling of the scale 1, or an interruption in the scanning beam path, the limit signal L falls below the reference value B0. In this example the same information is generated in case of an error than if a limit area had been reached.

Alternatively the limit markings can also be established in that the intensity of the orders of diffraction is varied, used for this are the grating parameter dash-gap conditions and, with phase gratings, the phase depth. With this alternative the direction of the deflected light, and therefore the area information, is also maintained.

The limit markings can also be constituted by further deflecting areas which differ from the area markings 5, 6 in such a way that they direct the impinging light in an other direction onto further photo receivers. In this case, the limit markings are then gratings with other grating parameters (graduation period and/or grating direction) than the gratings of the area markings 5, 6. If the first orders of diffraction are detected, different locations in the focal plane, and therefore different photo elements, are available to the limit areas.

In accordance with the represented example, the scale 2 is embodied to be reflecting. In a manner not represented, the scale can also be embodied to be transparent, so that the gratings 3 and 6 are designed as transparent diffraction gratings. Thus, the invention can be realized for incident, as well a transmitted

light scanning.

The different photo receivers 131, 133, 134 are discrete individual receivers, or elements of an array.

In the above represented advantageous example, the area markings for differentiating between various measuring areas along the scale are gratings with different grating parameters, wherein the grating parameters change suddenly from one measuring area to another measuring area. In an alternative way, the grating parameters can also change continuously in order to design a greater number of measuring areas differently from each other.

A further application of area markings is the marking of the surrounding area on both sides of the reference marking. It is therefore possible to generate an area signal in areas on both sides of the reference marking which points out the next reference marking, so that as a result of this it is possible to reduce the displacement speed, if required.

In conclusion, the invention therefore consists in disclosing a position measuring device having a scale and a scanning device, which is movable in relation to the latter in the measuring direction, wherein

- the scale has a measuring graduation, and periodic measuring signals can be generated by scanning the measuring graduation,

- the scale has at least one reference marking, and a reference marking signal can be generated by scanning the reference marking signal,

- the scale has optically scannable area markings, and by means of the photoelectric scanning of the area markings with a scanning beam bundle an area signal can be generated, by means of whose characteristics several measuring areas next to the reference marking can be differentiated, and

- the area markings are optically differently deflecting elements, which deflect the impinging scanning beam bundle in the various measuring areas onto different photo receivers.

## Claims

1. A position measuring device having a scale (1) and a scanning device (2), which is movable in relation to the latter in the measuring direction (X), wherein

- the scale (1) has a measuring graduation (3), and periodic measuring signals (M1, M2, M3) can be generated by scanning the measuring graduation (3),

- the scale (1) has at least one reference marking (4), and a reference marking signal (R1, R2) can be generated by scanning the reference marking signal (4),

- the scale (1) has optically scannable area markings (5, 6), and by means of the photoelectric scanning of the area markings (5, 6) with a scanning beam bundle (12) an area signal (B) can be generated, by means of whose characteristics several measuring areas (5, 6, 50, 60) next to the reference marking (4) can be differentiated, and

- the area markings are optically differently deflecting elements (5, 6), which deflect the impinging scanning beam bundle (12) in the various measuring areas (5, 6, 50, 60) onto different photo receivers (131, 133, 134).

2. The position measuring device in accordance with claim 1, characterized in that the optically deflecting elements are gratings (5, 6) with different grating parameters.

3. The position measuring device in accordance with claim 2, characterized in that the measuring graduation (3), the reference marking (4) and the area markings (5, 6) are phase grills.

4. The position measuring device in accordance with one of the preceding claims, characterized in that the area markings (5, 6) and the reference marking (4) are arranged on a common track.

5. The position measuring device in accordance with one of the preceding claims, characterized in that the various photo receivers (131, 133, 134) are arranged in such a way that a scanning beam bundle (12) impinging on the reference marking (4) is also directed onto at least one of these photo receivers (131, 133, 134).

6. The position measuring device in accordance with one of the preceding claims, characterized in that it is possible to differentiate by means of the area signal (B) whether the scanning device (2) is located on the first or the second side of the reference marking (4), in that the area marking (5) on the first side of the reference marking (4) is embodied in such a way that the impinging scanning beam bundle (12) impinges on a first photo receiver (131), and the area marking (6) on the second side of the reference marking (4) is embodied in such a way that the impinging scanning beam bundle (12) impinges on at least one second photo receiver (133, 134).

7. The position measuring device in accordance with claim 6, characterized in that the area marking (5) on the first side of the reference marking (4) is embodied to be reflecting or transparent, and the area marking (6) on the second side of the reference marking (4) is embodied as a diffraction grating.

8. The position measuring device in accordance with one of

claims 6 or 7, characterized in that the scale (1) has limit areas (50, 60), wherein the limit areas (50, 60) are formed by means of a partial change in the optical effect of the area markings (5, 6).

9. The position measuring device in accordance with claim 8, characterized in that the limit areas (50, 60) are formed by the partial covering of the area markings (5, 6).

10. The position measuring device in accordance with claim 9, characterized in that a screen (51, 61) has been applied to each of the area markings (5, 6).

11. The position measuring device in accordance with one of the preceding claims 6 to 10, characterized in that at least one reference marking signal (R1, R2) can be generated by means of the photoelectric scanning of the reference marking (4), by the photoelectric scanning of the area markings (5, 6) a second scanning signal (B1) can be generated by respectively the first photo receiver (131) and by at least the second photo receiver (133, 134), wherein for forming an area signal (B) these signals (R1, B1) are combined in an evaluation unit in accordance with a first linkage rule, and for forming a limit signal (L) are combined in accordance with a second linkage rule differing therefrom.