Nov. 16, 1965 H. J. LAWRENCE 3,217,590

APPARATUS FOR PRODUCING MOIRE PATTERNS FOR USE IN DETERMINING THE RELATIVE POSITION OF A PAIR OF ELEMENTS

Filed May 14, 1962 3 Sheets-Sheet 1

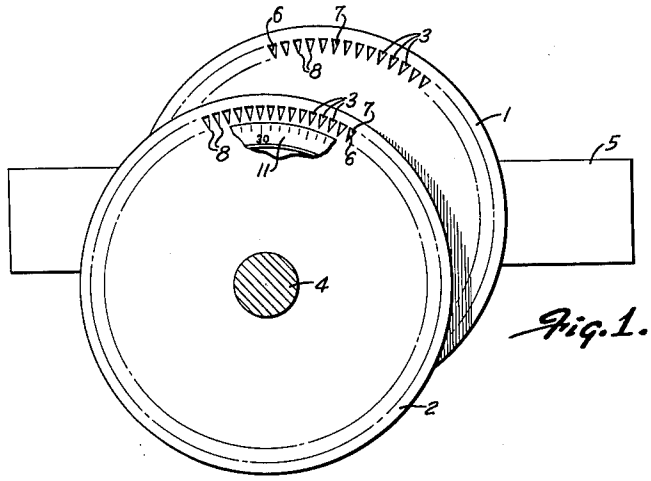

Fig. 1.

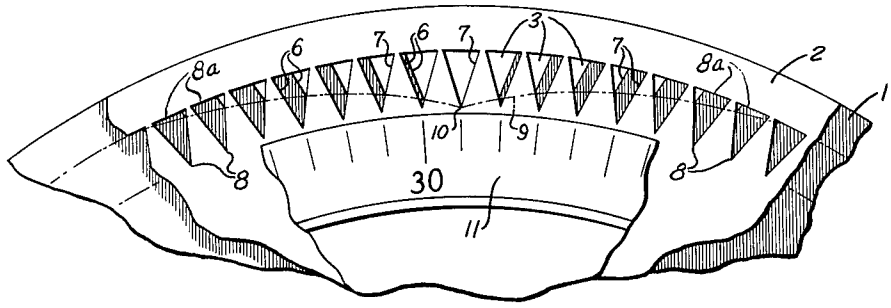

Fig. 2.

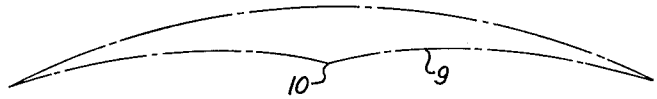

Fig. 3.

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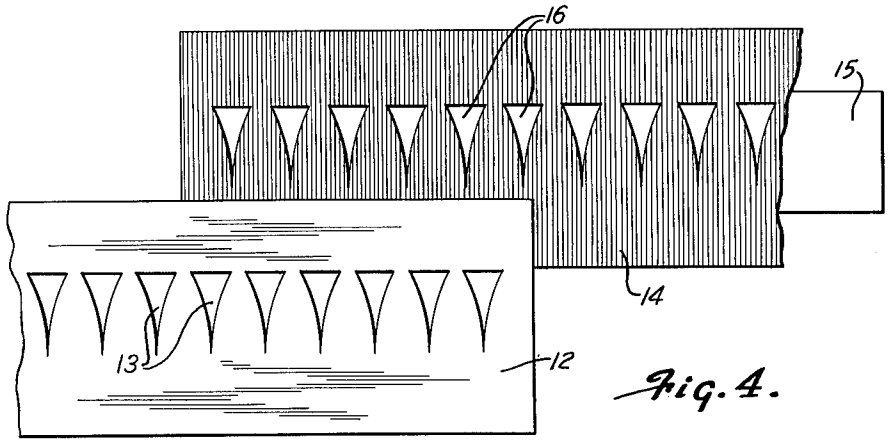

Fig. 4.

Fig. 5.

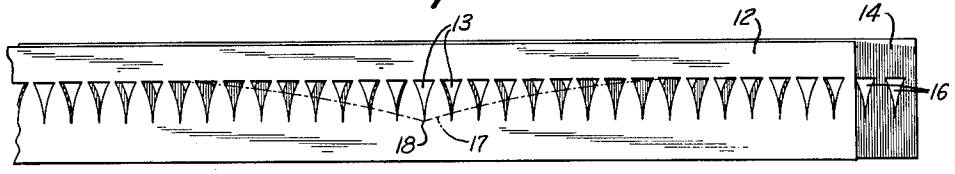

Fig. 6.

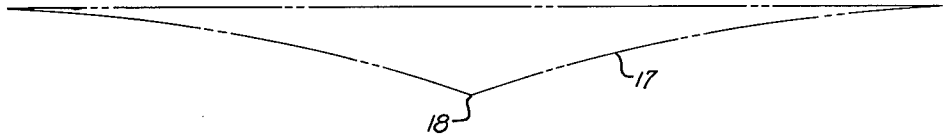

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Fig. 7.

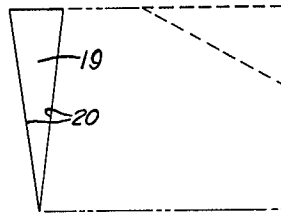


Fig. 8.

Fig. 9.

Fig. 10.

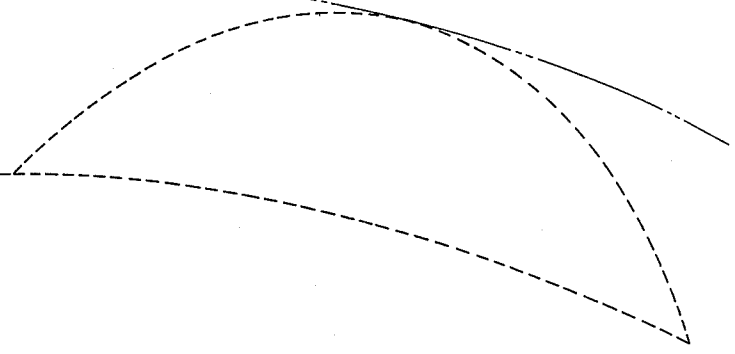
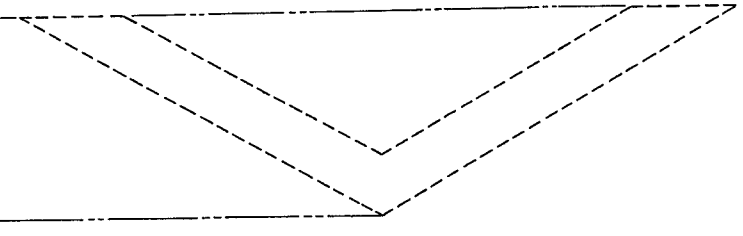


Fig. 11.

Fig. 12.



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APPARATUS FOR PRODUCING MOIRE PATTERNS FOR USE IN DETERMINING THE RELATIVE POSITION OF A PAIR OF ELEMENTS

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5 Claims. (Cl. 88—14)

This invention relates to apparatus producing moire patterns or bands as a result of light grating and is particularly directed to the construction of such apparatus in a novel manner to produce an accurate and readily discernible band pattern.

In particular, the invention concerns the establishment of a definite and well defined index pattern defined by overlapping elements having aligned cooperating areas of zones of different spatial density. The areas or zones are, in accordance with the present invention, constructed to vary the configuration of the pattern in a direction substantially normal to the direction of movement of the elements for producing a desired index pattern.

As is already well known, moire bands are produced when two or more regularly spaced patterns which differ from one another by some slight constant difference are superimposed and the pattern moves if the patterns are moved relative to one another. These bands have been used as an index of such relative motion and have produced systems of high sensitivity to such relative motion.

However, heretofore, it has been necessary to locate such bands by means of various averaging devices owing to the poorly defined maxima and minima whose locations determine the band position.

The present invention makes it possible and practicable to locate these maxima and/or minima with high precision, without the necessity for employing additional averaging devices or methods. The index pattern in accordance with the present invention is sufficiently discernible to be readable directly visually.

In accordance with the present invention, the individual zones forming graduation on the overlapping elements have converging side edges which define equally spaced points. The superposed graduations of different spatial density then define an index pattern which varies not only along the length of the superposed graduations but transversely thereof as well. The index pattern is directly related to and generally is an enlargement of the configuration of the individual zones and any desired pattern can therefore be obtained by proper configuration of the shapes of the individual zones.

The drawings furnished herewith illustrate the best mode presently contemplated for carrying out the invention.

In the drawings:

FIG. 1 is a diagrammatic illustration of a pair of overlapping and relatively angularly displaceable discs including aligned patterns defining a movable index pattern which is positioned in accordance with the relative angular position of the discs;

FIG. 2 is an enlarged fragmentary view of a portion of FIG. 1 more clearly illustrating one form of the light grating system of the present invention;

FIG. 3 is a substantially enlarged phantom view of the index pattern shown in FIG. 2;

FIG. 4 is a diagrammatic illustration of an embodiment of the invention incorporated in a pair of rectilinearly displaceable elements;

FIG. 5 is a view of the elements shown in FIG. 4 in superposed relation to define an index pattern related to the relative position of the elements;

FIG. 6 is an enlarged phantom line view of the index pattern shown in FIG. 5;

FIG. 7 is an illustration of a wedge shaped zone ;

FIG. 8 is the resulting index pattern when the wedge shaped zone is applied to rectilinearly movable elements such as shown in FIG. 5;

FIGS. 9 and 10 are views similar to FIGS. 7 and 8 showing an inverted wedge shaped sector or zone and the resulting index pattern when the zone configuration is applied to rotary apparatus; and

FIGS. 11 and 12 are views similar to FIGS 7 and 8 illustrating a further modification of the zone configuration and the resulting index pattern.

Referring to the drawings and particularly to FIG. 1, the apparatus illustrated may be employed to measure the angular displacement or relative position between a pair of discs 1 and 2 each of which carries adjacent its periphery a symmetrical pattern or graduation of substantially identically shaped transparent zones or apertures 3 which are separated by opaque zones or areas. The several zones shown in the drawings are substantially enlarged in both FIGS. 1 and 2 for purposes of clarity of explanation and convenience of pictorial representation.

The discs 1 and 2 are concentrically located with respect to each other to superimpose the symmetrical graduations. In the illustrated embodiment of the invention, disc 2 moves with some external element; for example, a shaft 4 which is coaxially secured to the disc 2 and whose angular position is to be determined. The opposite disc 1 is fixed to a relatively stationary reference frame 5 having a known or controlled position relative to the shaft.

The number of zones 3 in the graduation on respective discs 1 and 2 differ by any small whole number which is small in comparison to the total number of zones on either disc. For example, if the basic number of zones on disc 1 is equal to 360 and it is desired to read the relative angular position in minutes, the disc 2 will be provided with 366 zones.

In accordance with the present invention, the apertures are shaped to produce an index pattern which is readily and visually discernible. In the embodiment of the invention shown in FIGS. 1–3, each of the individual zones 3 is a wedge shaped segment having straight side walls or edges 6 and 7 converging radially and circumferentially inwardly. The corresponding edges of all zones 3 are similar to each other and the edges 6 and 7 of each zone meet at point 8 with the points equally spaced on a circle having a center coinciding with the center of the corresponding disc. If each zone is bisected by a radial line from said common center or axis, the zone has a height measured along the bisecting line between the point 8 and the base 8*a* which is a small multiple of the width of base 8*a*. Further, the radial distance from the center of the circle to point 8 is substantially greater than the zone height. The overlap of immediately adjacent superimposed zones 3 on the discs 1 and 2 is varied and the total opening varied accordingly. Light proceeds axially through the apertures in the discs 1 and 2 in accordance with the openings defined by the overlapping discs generally in accordance with the conventional formation of moire bands or patterns.

The configuration of the zones 3, with the side edges of corresponding overlaping zones parallel and converging in a similar manner to a plurality of spaced points, establishes a resulting index pattern shown by phantom outline 9 in FIGS. 2 and 3. The index pattern 9 is a unilateral expansion of an individual zone 3 with the point 10 of the index pattern defined by the individual superposed zones 3 within pattern 9 on discs 1 and 2. As most clearly shown in FIGS. 2 and 3, the side edges of index pattern 9 are curved to the point 10. This results from the circumferential distribution of the zones. By making the side edges of zones 3 convex, the side

edges of the index pattern may be made straight. Proceeding to either side of the aligned zones **3**, the index pattern **9** expands circumferentially and radially in accordance with the varying overlap of the zones **3** on discs **1** and **2**. The maximum height or radial dimension corresponds to the dimensions of the individual zones and the pattern width is an annular enlargement of one zone. The degree of enlargement of pattern width is determined by the ratio between the width of the individual zone at its widest portion and the angular displacement between adjacent zones on the disc **1** carrying the smaller number of zones. The total width of the index pattern **9** is equal to the smaller or base number of individaul zones on disc **1** divided by the difference between the number of zones on discs **1** and **2** times this ratio. For instance, the priviously described spacing of 360 zones **3** on disc **1** establishes one degree between adjacent spaces. If the angle subtended by the base or the widest part of the individual zone **3** is assumed to be one quarter of a degree, the index pattern width is 360 divided by six times ¼ divided by 1 or 15°. The index pattern **9** thus subtends an angle of 15° or 7½° at each side of the point **10**. The position of point **10** is readily discernible and a cooperating fixed scale **11** is shown adjacent the position of the pattern. Scale **11** is divided into any convenient fractions of the initial interval between spaces or zones in the present instance 1°. For example, dividing the scale directly into 60 units, the typical distribution of zones **3** already described provides apparatus which reads in minutes.

The present invention as illustrated in FIGS. 1–3 provides a light grating means for relating angular motion without the necessity for the usual averaging devices or methods to accurately read the position of the light pattern.

The same principle as employed in FIGS. 1–3 may be effectively utilized in the design of any suitable apparatus for linear measurement of linear displacements. For example, in FIGS. 4–6, inclusive, a suitable apparatus for that purpose is illustrated in a manner similar to that of the previous embodiment.

As shown in FIGS. 4 and 5, a graduated strip **12** is attached to and carried by the elements, not shown, whose translational position is to be determined with respect to some fixed object such as a machine frame, not shown. The strip **12** is marked with a plurality of equally spaced transparent zones **13** spaced by opaque areas similar to the zones shown in FIGS. 1–3. A second cooperating strip **14** is fixedly mounted with respect to the movement of the strip **12** and carried by a fixed reference frame **15**. Strip **14** is marked with a plurality of transparent zones **16** in parallel relation to the corresponding zones on the initial strip **12**. However, the density of the light and dark bands or areas upon the second strip **14** is different from that of the first strip **12** by a small predetermined amount. For example, the fixed strip may be provided with 100 alternate transparent and opaque bands or zones per lineal inch of light and the second strip provided with 201 alternate clear and opaque bands or zones in each two inches of lineal segment. The strips are superposed as indicated in FIG. 5 and establish a light pattern determined by the overlap of the zones on the respective strips **12** and **14**. The light pattern within any one period defined by the repetition of the relative number of zones on the strips varies both in the direction of relative movement of the strips and at an angle substantially normal thereto. As a result, the index pattern **17** is formed which is a substantially unilateral enlargement of the individual zones and extends symmetrically to opposite sides of the superposed zones within one period on the strips **12** and **14** to define a readily discernible point **18**.

The shape of the index pattern in the illustrated embodiments of the invention is controlled by the shape of the individual spaces and the desired pattern is essentially limited only by the possibility of producing properly shaped opaque or transparent zones. When applied to rotary apparatus, the circumferential spacing of the zones causes the side edges of the index pattern to change from the precise shape of the individual zones. However, practically any configuration can be provided by proper selection of the individual zones. For example, a wedge shaped zone **19** is shown in FIG. 7 having rectilinear side edges **20**. If this zone configuration is applied to a linearly movable element such as shown in FIGS. 4 and 5, an index pattern having rectilinear side edges such as shown in FIG. 8 is obtained. The precise shape or width of the pattern will be determined by the spacing of the zones and the width of the individual zones at its widest portion.

Other than pointed configurations can also be provided as symbolically shown in FIGS. 9 and 10. FIG. 9 is an inverted wedge shaped zone **21** and when applied to rotary apparatus such as discs **1** and **2** of FIGS. 1 and 2, the resulting index pattern is generally continuous curved pattern changing circumferentially and radially.

Further, the index pattern may be internally shaped by corresponding shaping of the zones; for example, as shown in FIGS. 11 and 12. FIG. 11 is a generally V-shaped zone **22**. If zones **22** are applied to rectilinearly movable elements such as shown in FIGS. 4 and 5, an enlarged V-shaped index pattern shown in FIG. 11 is obtained.

The various index patterns may be made more pronounced and narrower by making the ratio between the individual pattern width and the interval spacing of zones smaller. This may be accomplished either by making the individual zones narrower at its widest point or the number of individual elements smaller or by increasing the interval between the adjacent zones or by a combination thereof.

Skilled readers will appreciate the fact that the alternate zones into which my indexing discs and strips are divided need not be totally opaque or totally transparent. For successful operation of my invention, it is sufficient that one set of such zones or segments be relatively opaque with respect to the other set. Similarly, it is not essential that the transparent zones or segments be transparent in the strict sense; it is sufficient if they are translucent. When the terms "opaque" and "transparent" are used in the descriptive matter and claims of this specification, therefore, it is to be understood that they are intended to have the relative sense above described and are not used in their absolute sense.

The present invention thus provides a very simple and inexpensive means for employing a visible pattern effect which is readable by providing predetermined configurations of the light transmitting individual zones in accordance with a predetermined desired pattern. The present invention thus provides a very simple means of completely controlling and determining moire patterns and avoiding the necessity although not rejecting the possible use of the heretofore employed averaging and other auxiliary devices.

Various modes of carrying out the invention are contemplated as being within the scope of the following claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention.

I claim:

1. Apparatus for determining an angular position, a pair of at least partially overlapping elements rotatably movable with respect to one another around a common axis of rotation, each of said elements being provided with similarly positioned graduations in the form of closely spaced transparent zones including opposite sharply converging side edges defining an included angle substantially greater than the angle included by radial lines to said common axis of rotation and the height of each zone being a small multiple of the width, said zones being spaced from the common axis a distance substantially greater than the zone height and separated by opaque areas, all

of said zones on each element being of equal effective size and effective shape and all of said areas of each element being of equal effective size and effective shape, the spatial density of said zones on one of said elements being slightly different from that on the other of said elements.

2. The apparatus of claim 1 wherein the side edges of said zones converge inwardly and rectilinearly to define an enlarged pointed index pattern.

3. Apparatus for determining relative position, comprising a pair of at least partially overlapping elements movable relative to one another along one predetermined straight line of direction, each of said elements being provided with superimposed graduations in the form of closely spaced transparent zones each including opposite sharply converging side edges with the height of the zone being a small multiple of the width and separated by opaque areas with the graduations being maintained in the same overlapping relation in the direction normal to movement for all relative positions thereof, all of said zones on each element being of equal effective size and effective shape and all of said areas of each element being of equal effective size and effective shape, the spatial density of said zones on one of said elements being slightly different from that on the other of said elements.

4. The apparatus of claim 3 wherein said zones are wedge shaped to define a pointed index pattern.

5. The apparatus of claim 4 wherein said wedge shaped zones have concave side edges to define a pointed index pattern having concave side edges which is a unilateral enlargement of an individual zone.

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