Dec. 19, 1939. D. C. STOCKBARGER ET AL 2,184,160

APPARATUS FOR SCANNING

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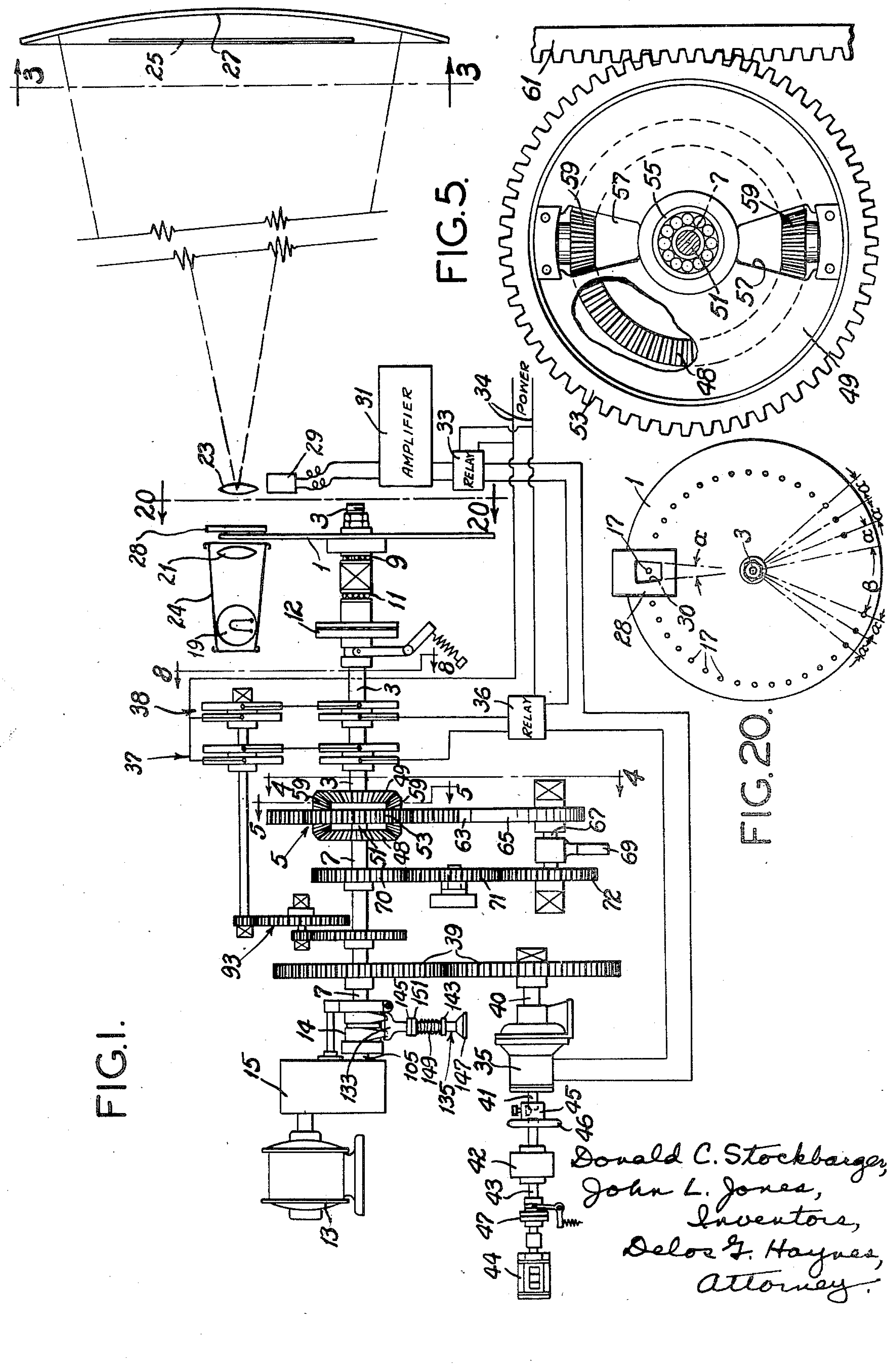

FIG. 1.

FIG. 5.

FIG. 20.

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FIG.2.

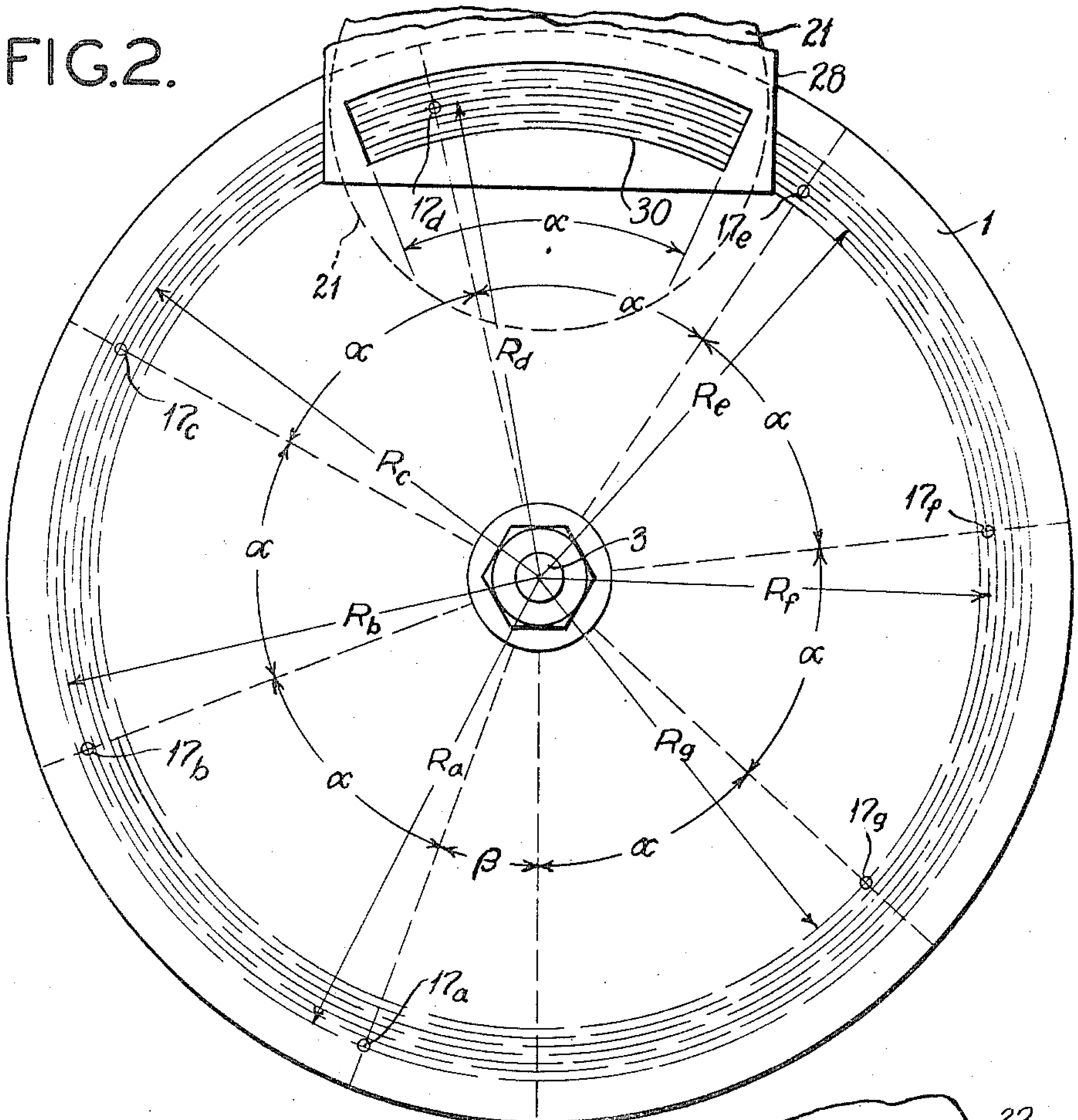
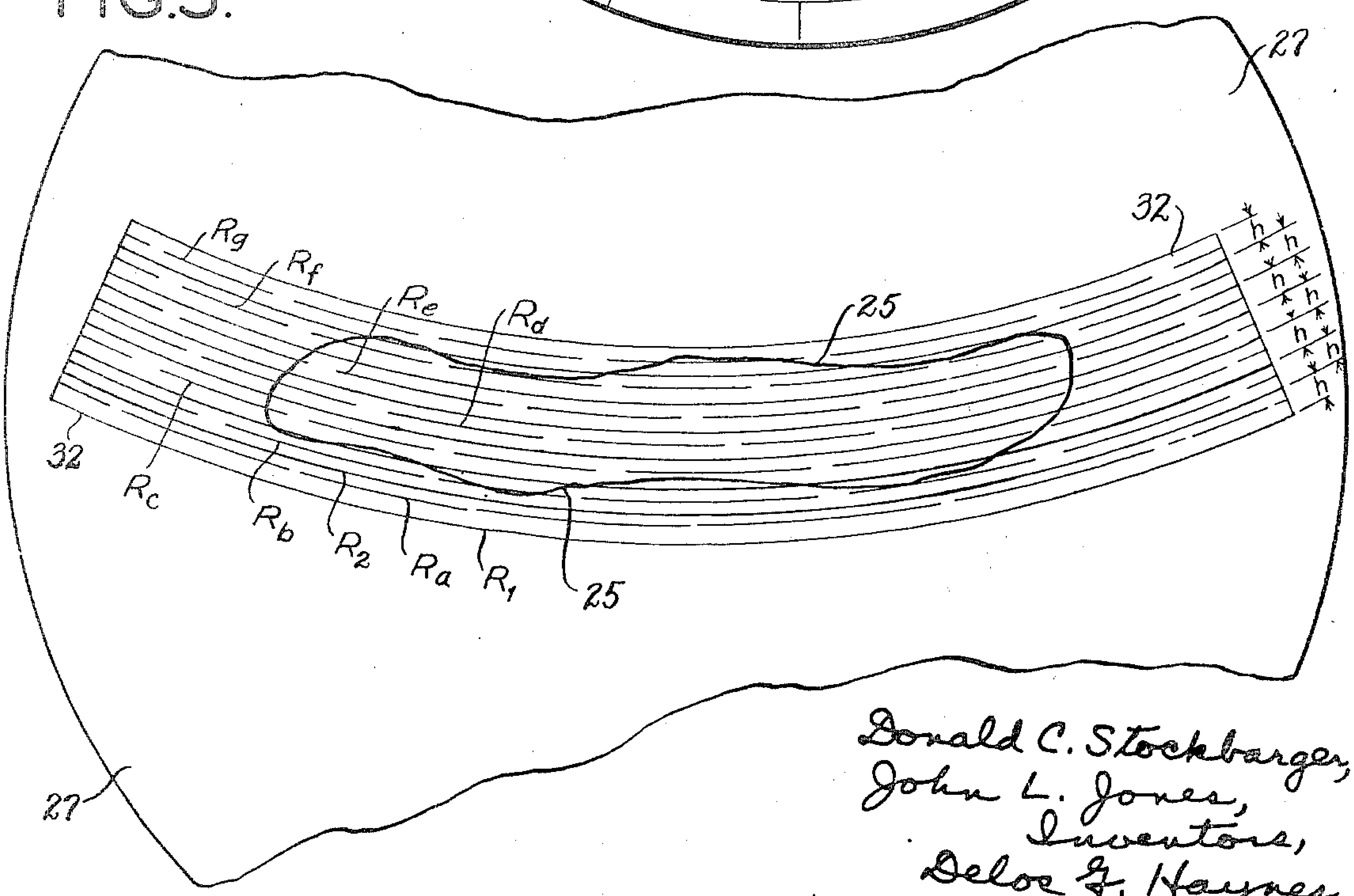


FIG.3.



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APPARATUS FOR SCANNING

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FIG. 4.

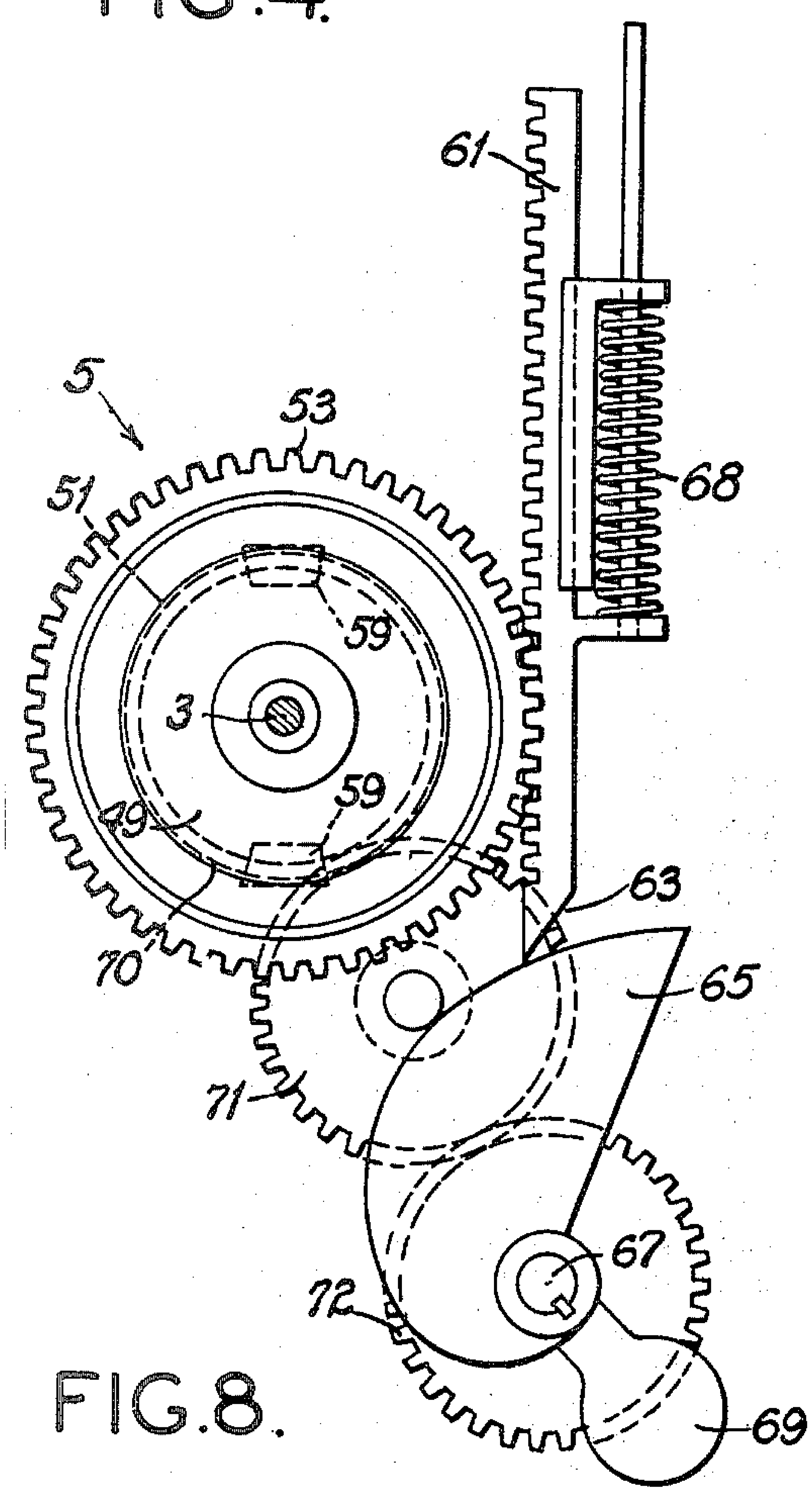

FIG. 10.

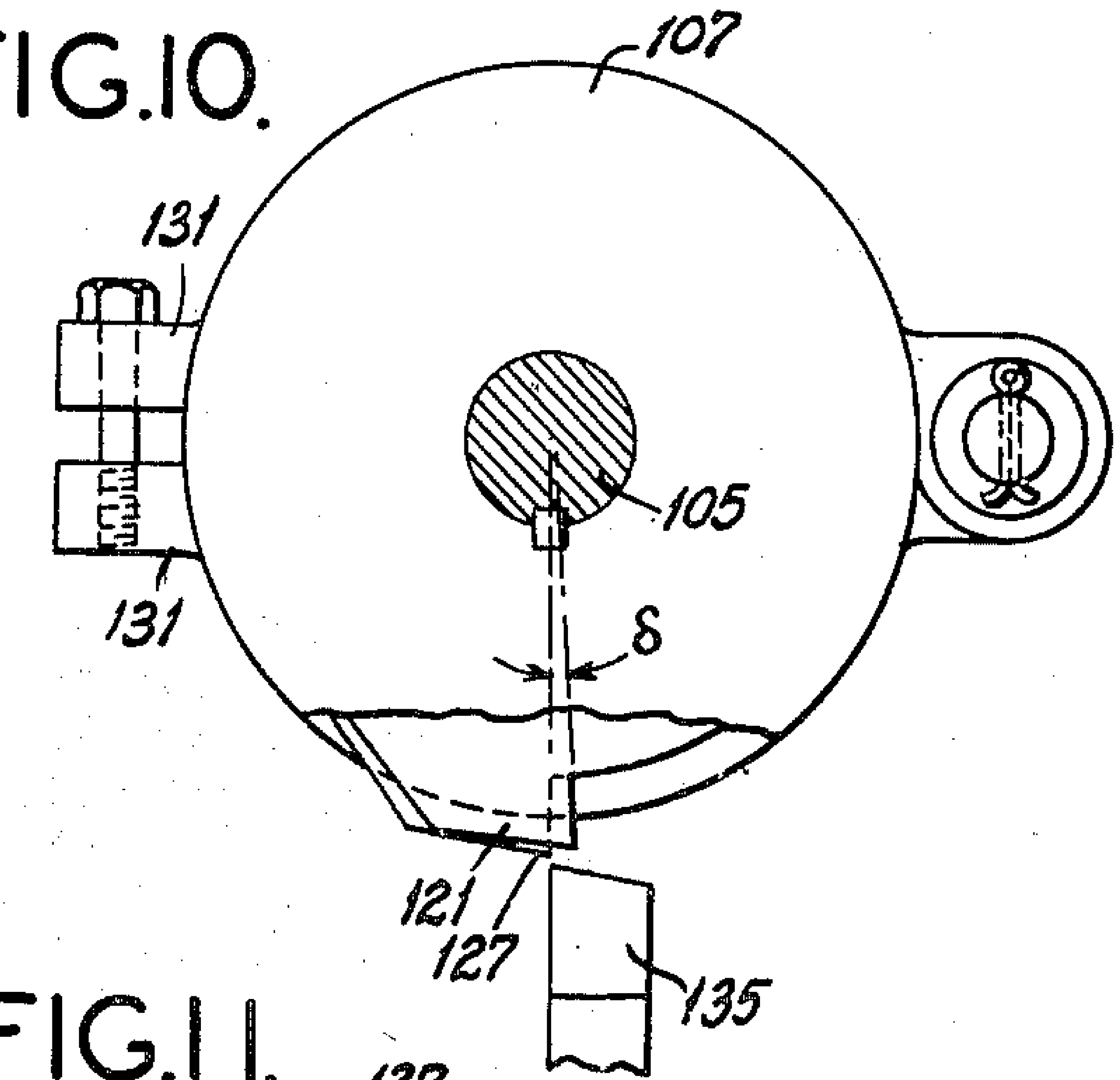

FIG. 11.

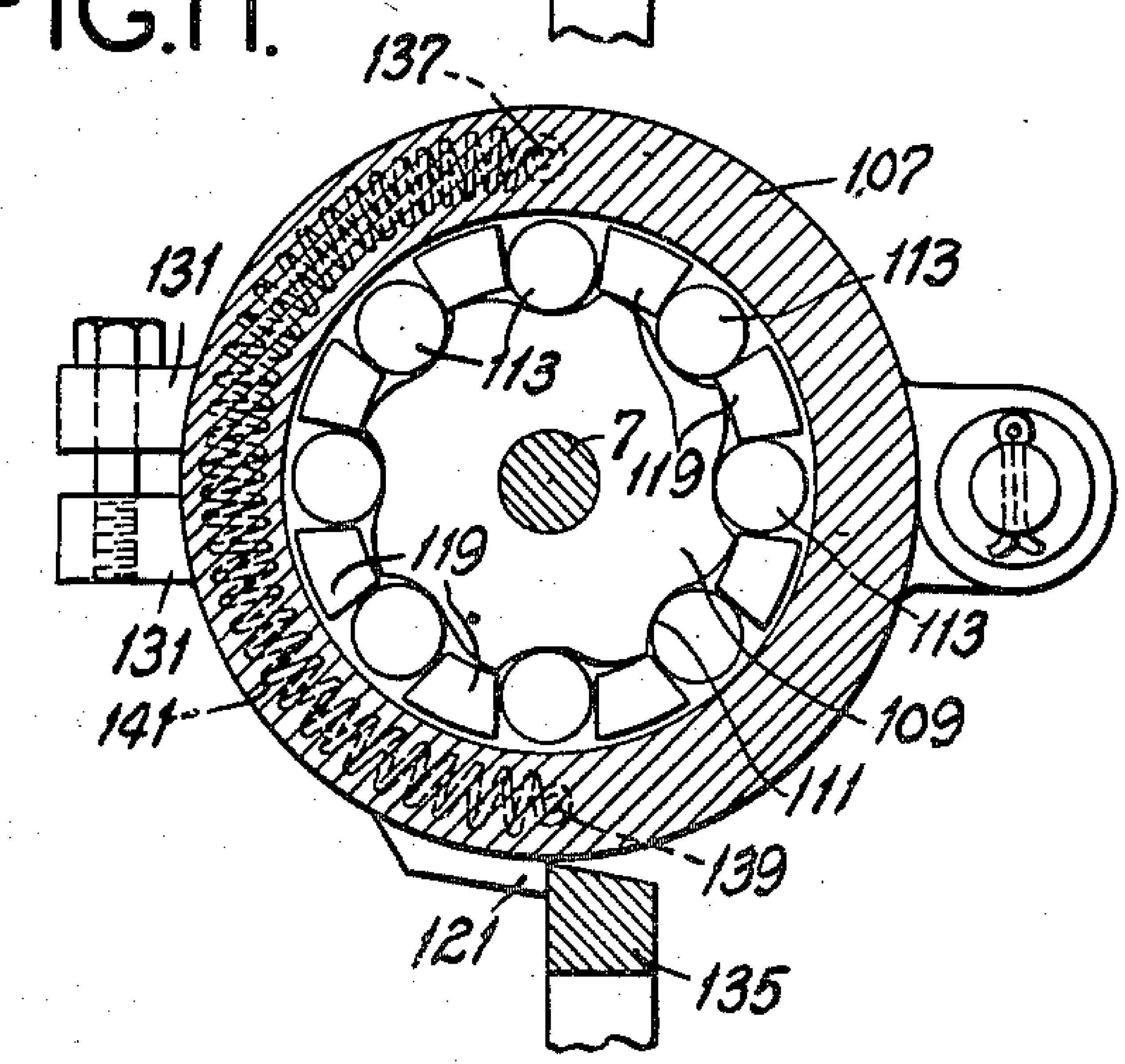

FIG. 8.

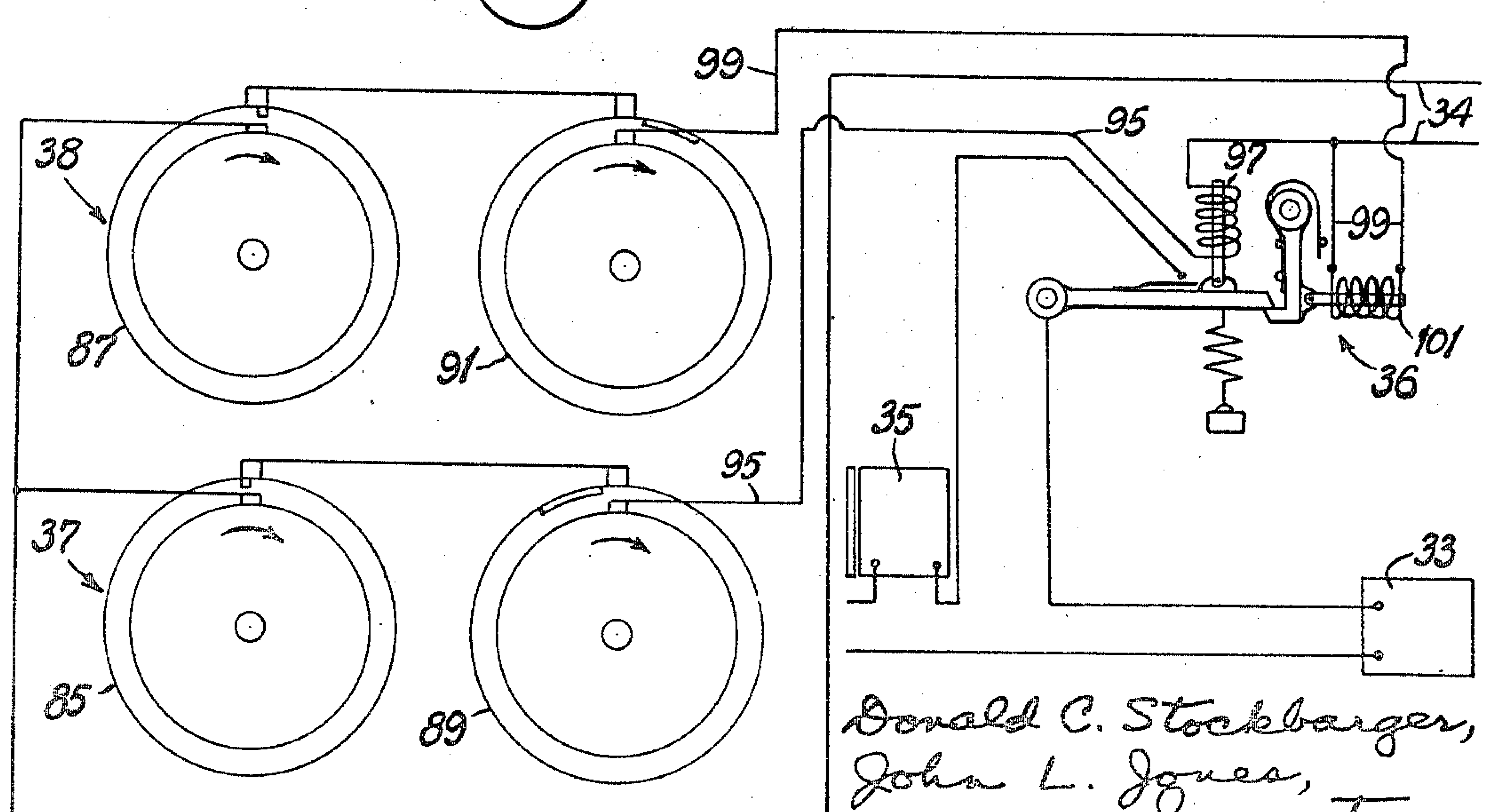

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FIG. 7.

FIG. 6.

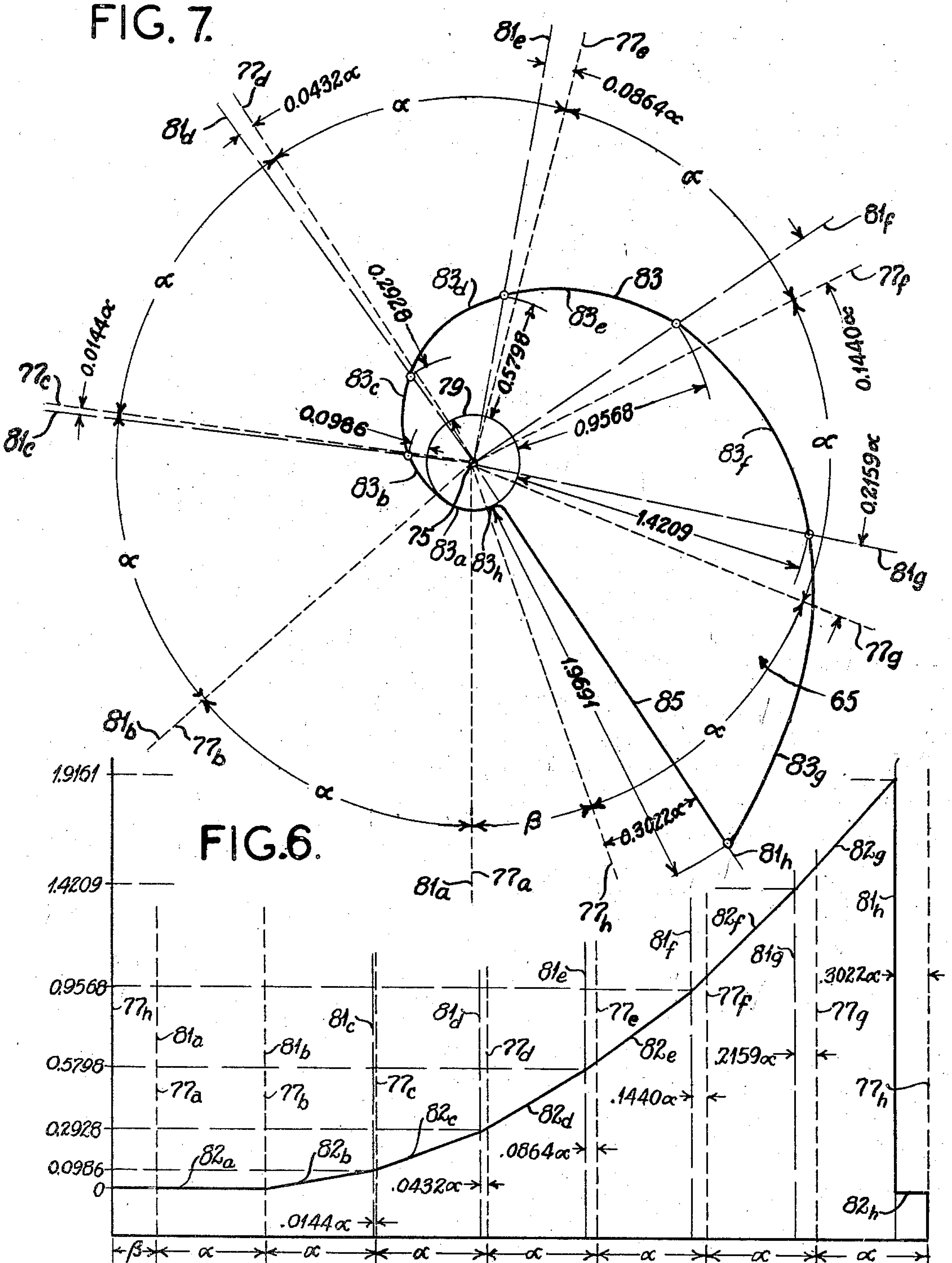

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FIG.9.

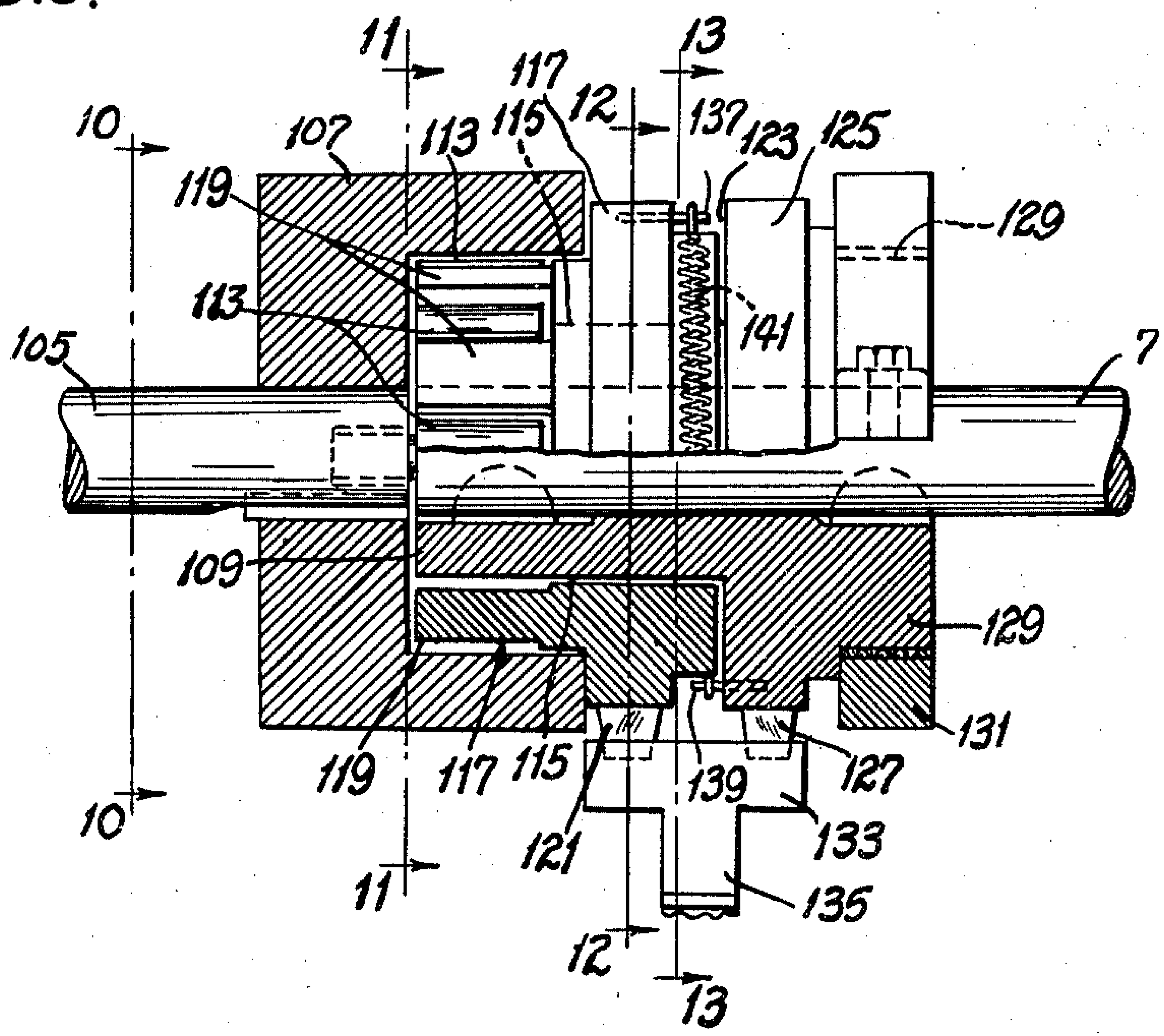


FIG.12.

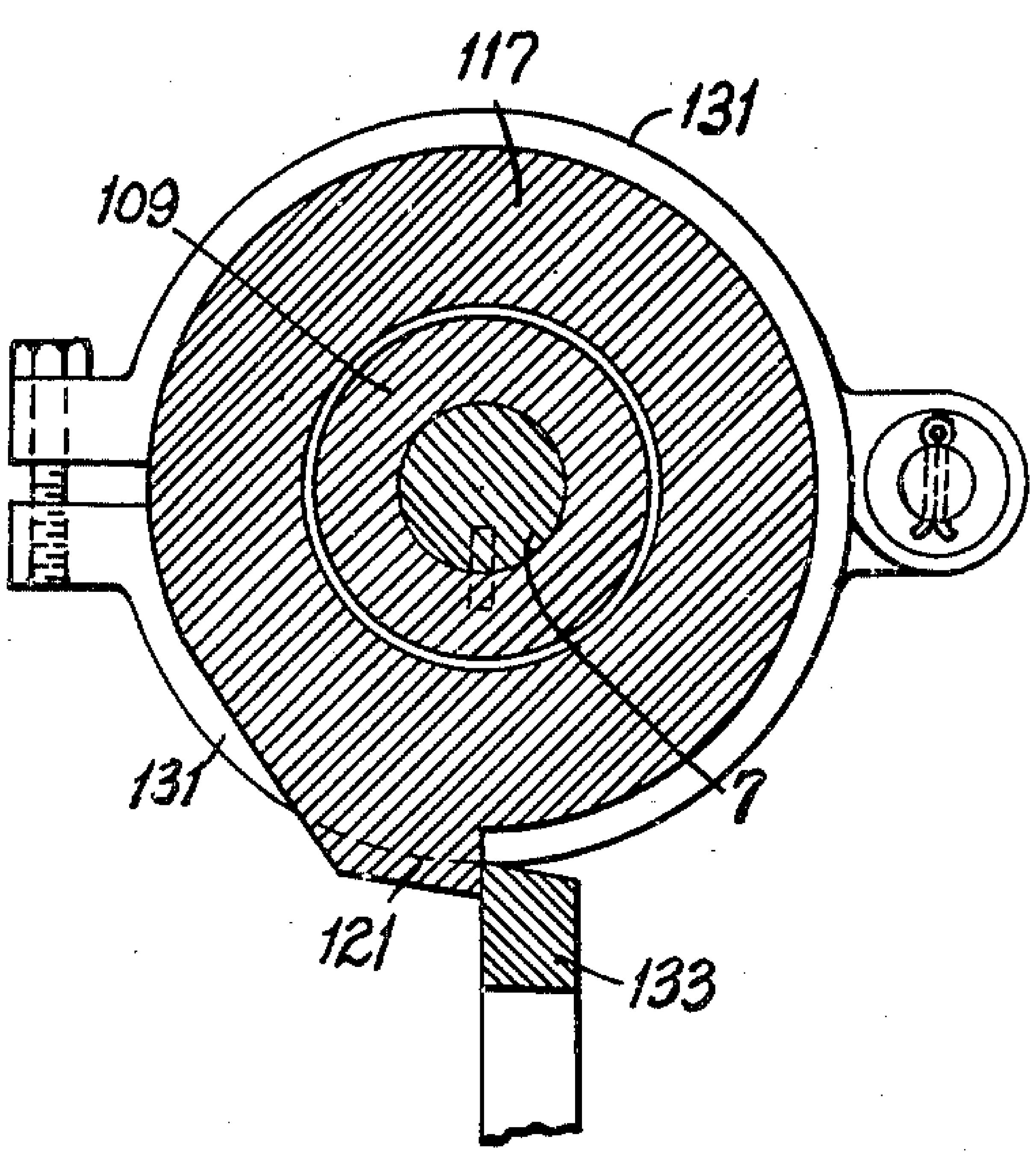
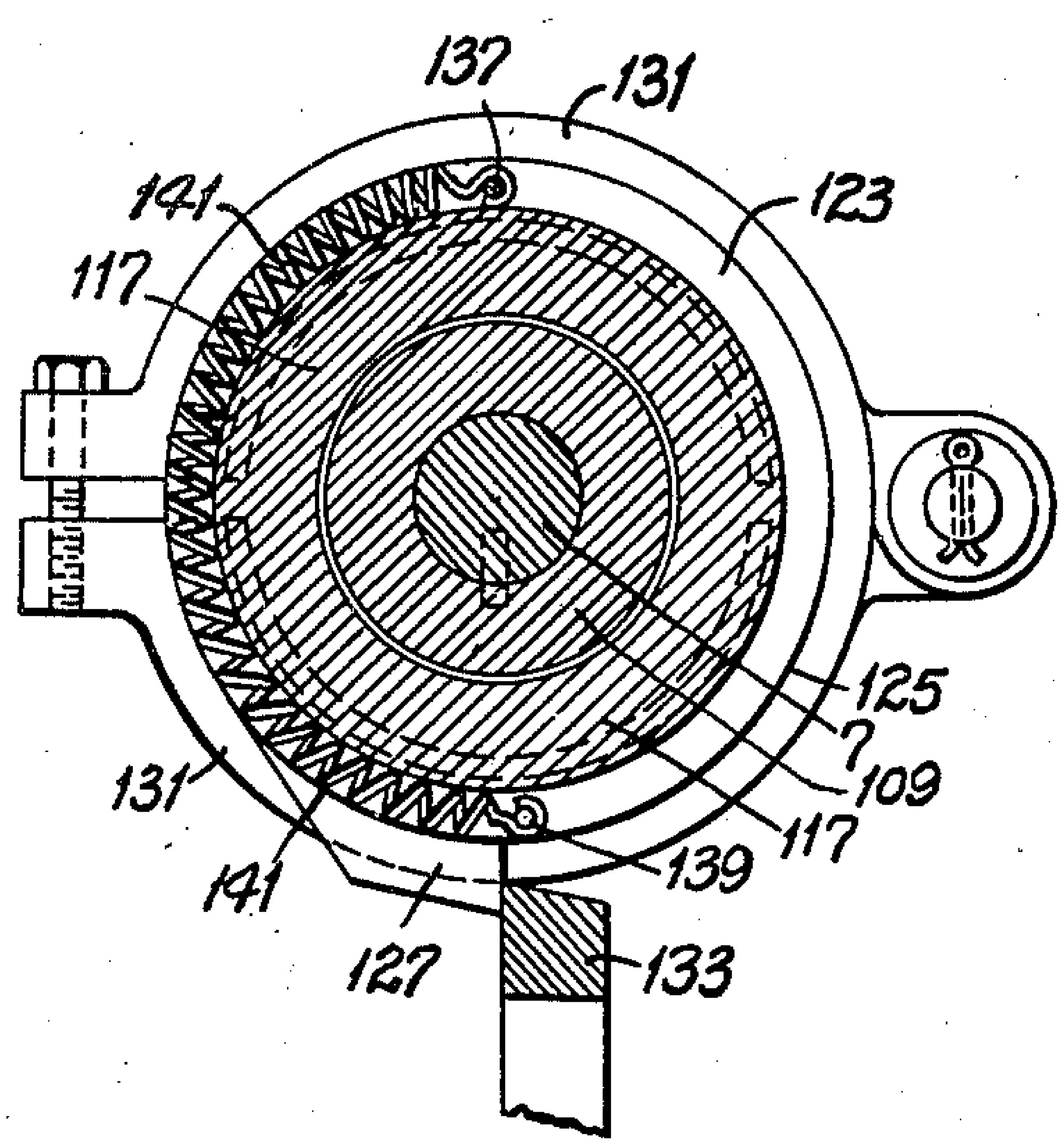


FIG.13.



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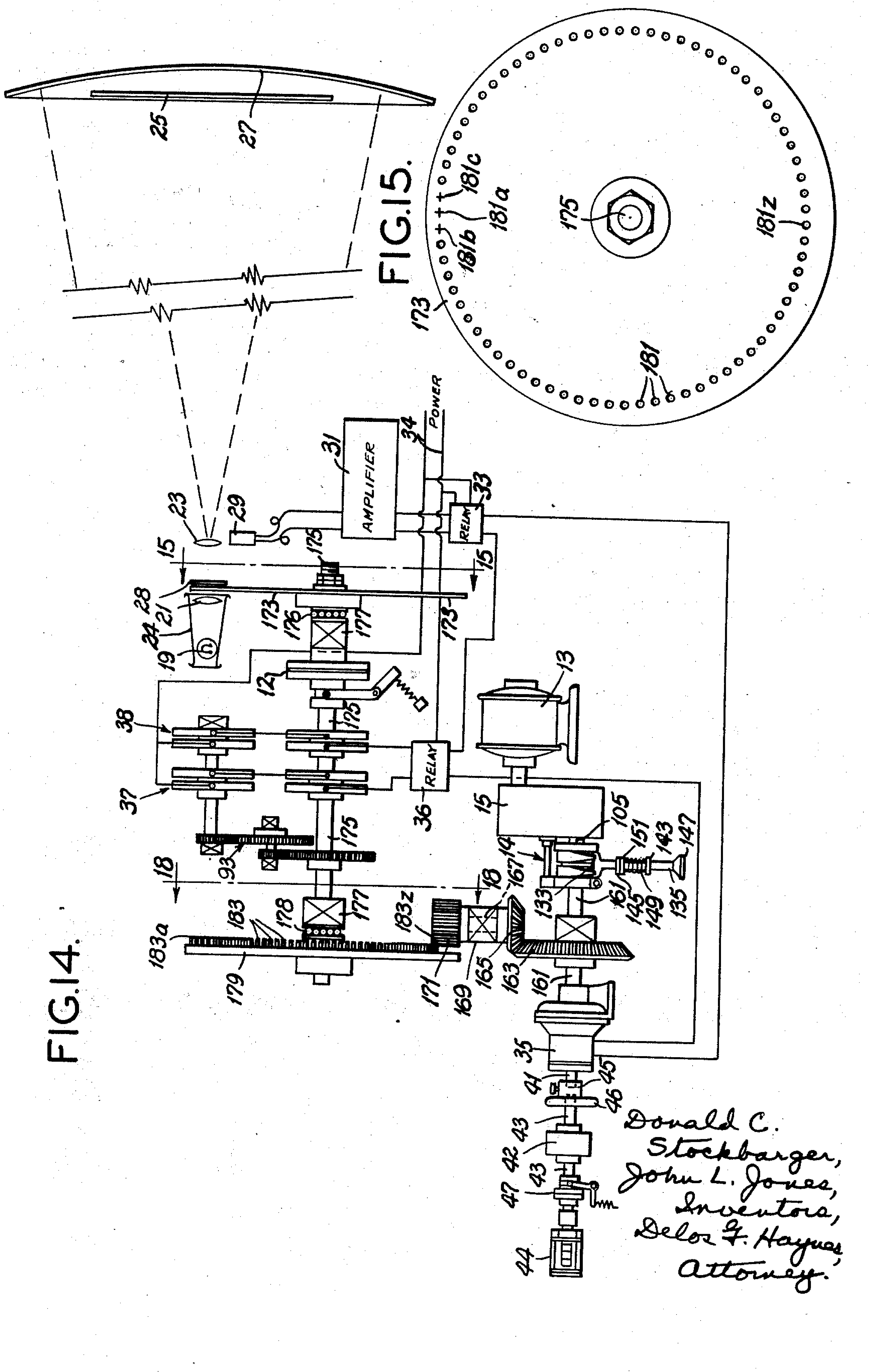

FIG. 15.

FIG. 14.

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FIG.16.

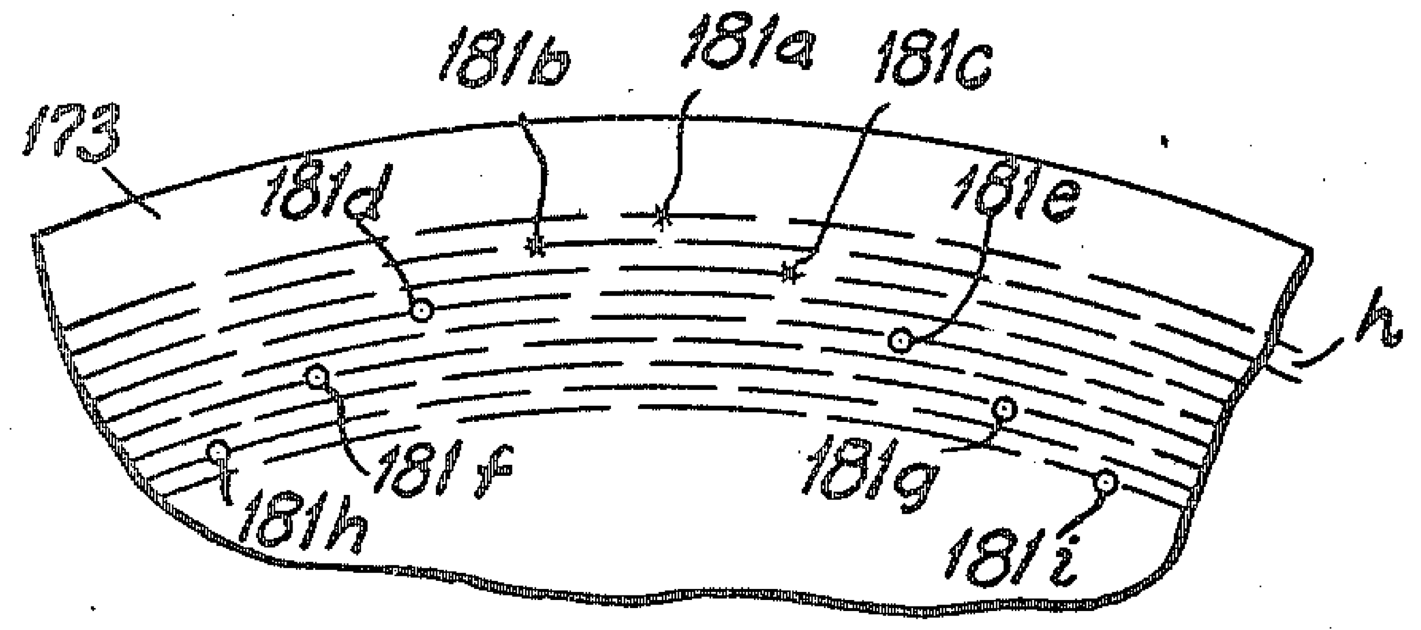


FIG.17.

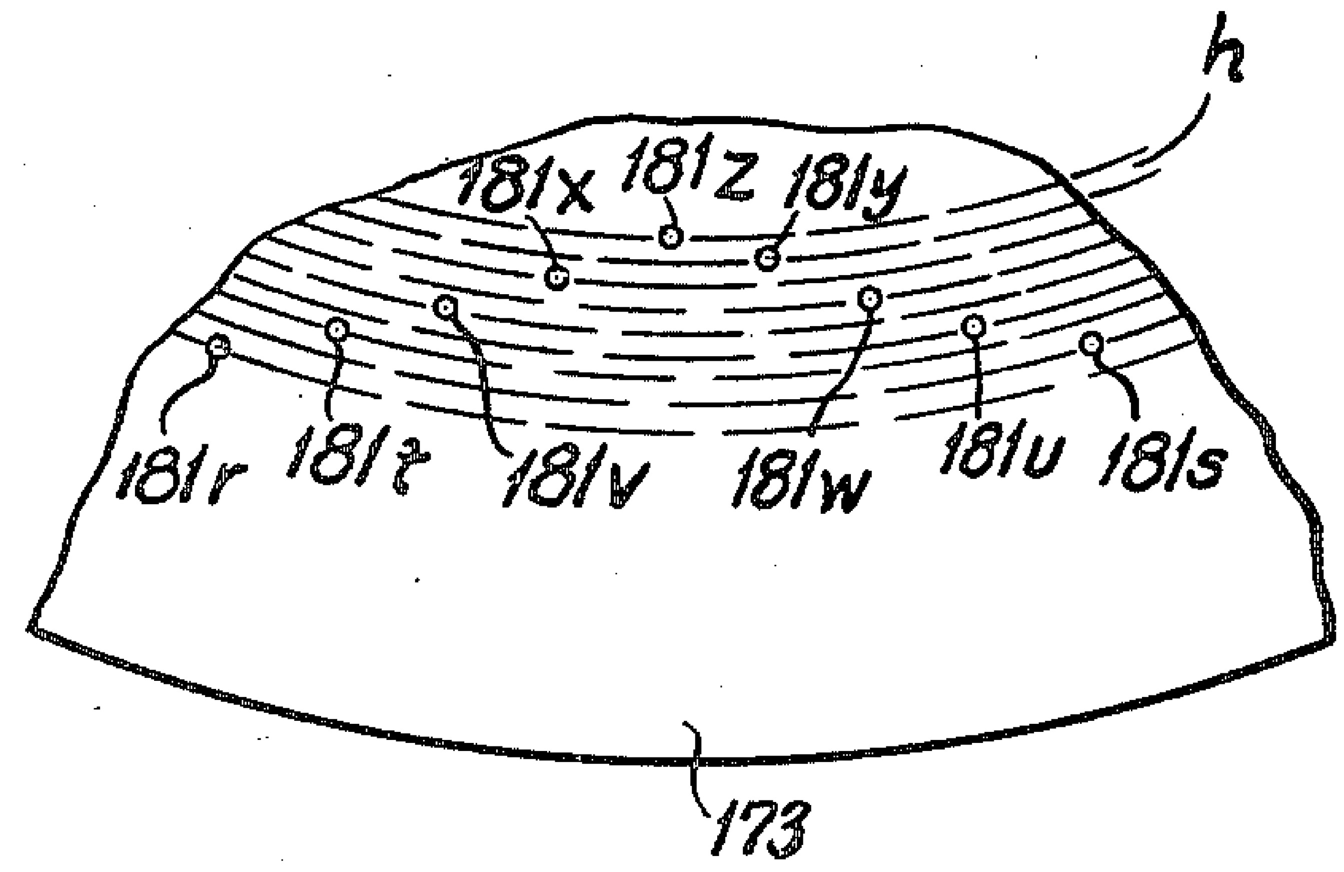


FIG.18.

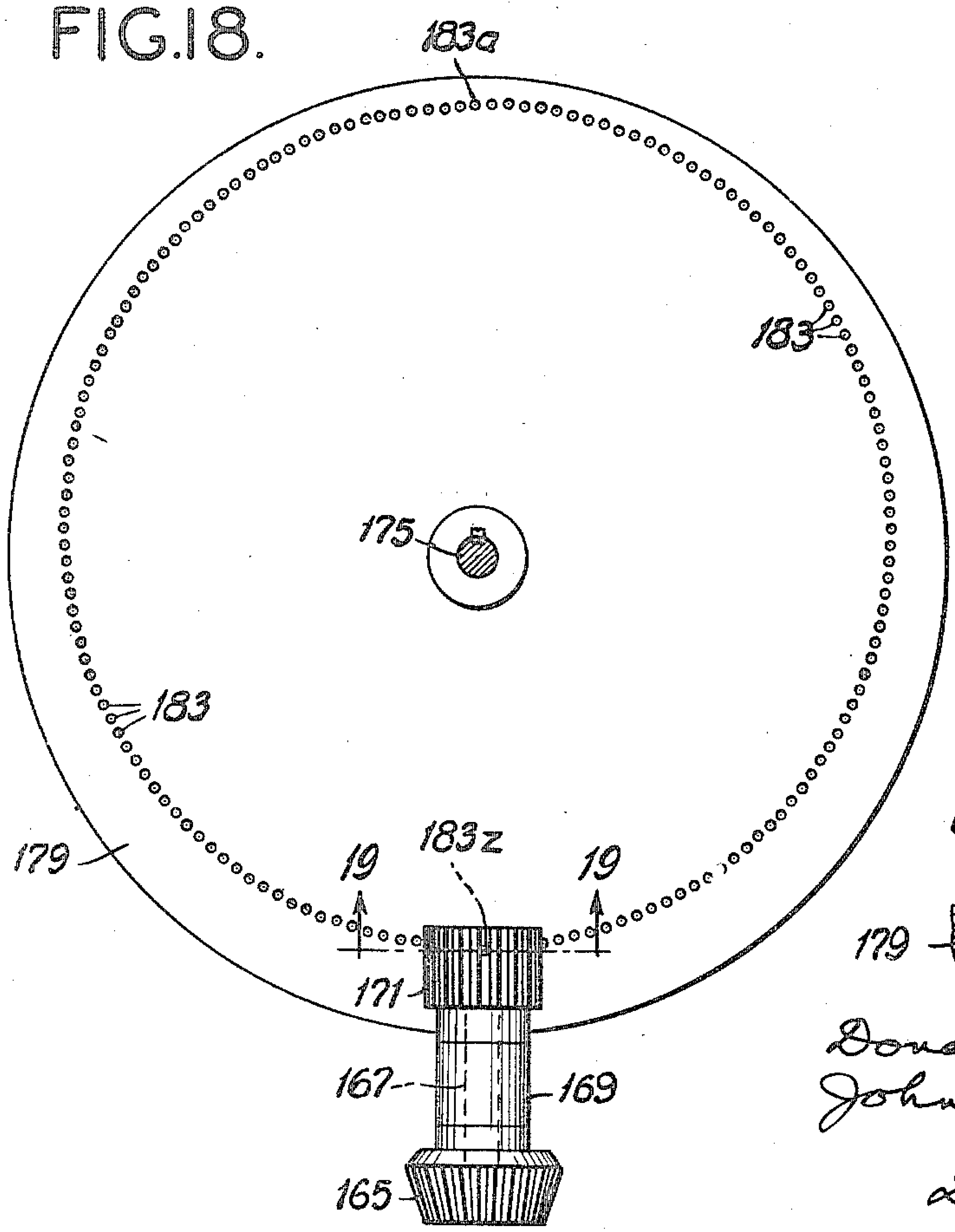
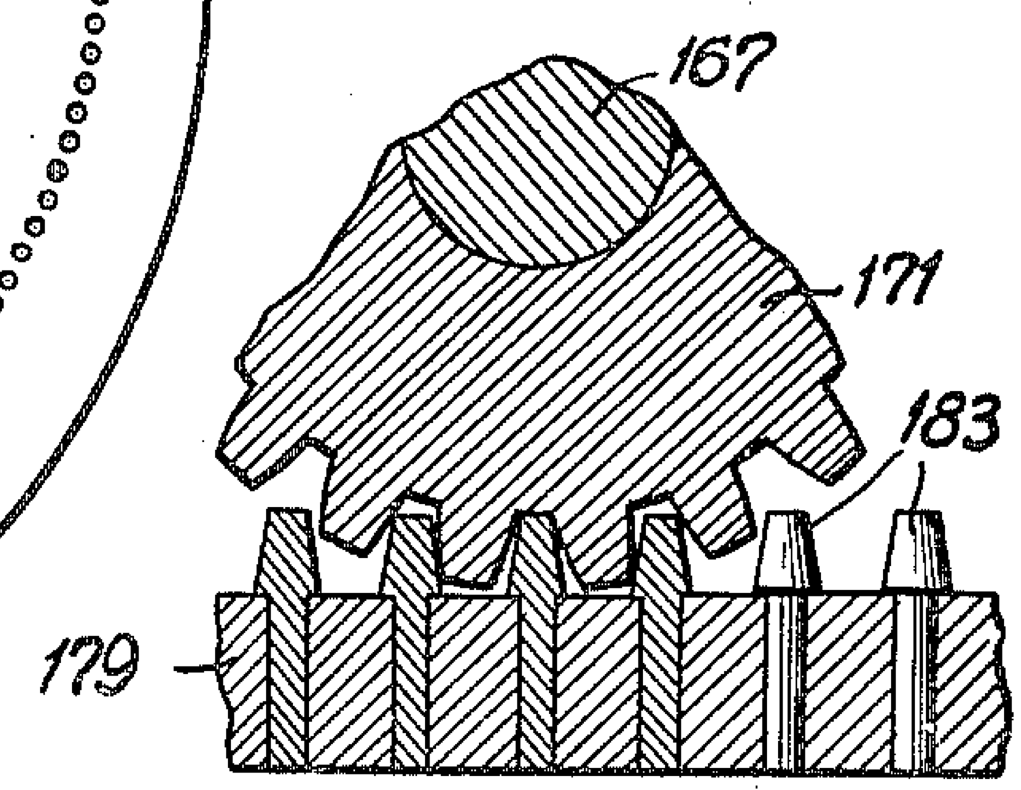


FIG.19.



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Patented Dec. 19, 1939 2,184,160

UNITED STATES PATENT OFFICE

2,184,160

APPARATUS FOR SCANNING

Donald C. Stockbarger, Belmont, and John L. Jones, North Billerica, Mass., assignors to Stockton Profile Gauge Corporation, Lowell, Mass., a corporation of Massachusetts

Application November 11, 1936, Serial No. 110,258
Renewed October 30, 1939

28 Claims. (Cl. 33—123)

This invention relates to apparatus for scanning, and with regard to certain more specific features, to apparatus for scanning and thereby measuring areas.

Among the several objects of the invention may be noted the provision of apparatus for scanning wherein scanning beams are projected against a surface the area of which it is desired to measure in such manner that they sweep the median lines of contiguous increments, such as concentric circular increments, on the surface, and so conducting the scanning that the lengths of said median lines on the surface are photoelectrically integrated into an accurate expression of the area of the surface; the provision of apparatus of the class described which produces results characterized by their high accuracy; the provision of apparatus of the class described which is designed, for example, to record scanned area increments on the surface to be measured at rates proportional to the linear speeds of the spots of interception of successive scanning beams on the surface to be measured; and the provision of apparatus of the class described which is relatively simple in construction and operation. Other objects will be in part obvious and in part pointed out hereinafter.

The invention accordingly comprises the elements and combinations of elements, and features of construction and operation, which will be exemplified in the apparatus hereinafter described, and the scope of the application of which will be indicated in the following claims.

In the accompanying drawings, in which are illustrated several of the various possible embodiments of the invention,

Fig. 1 is a diagrammatic layout of apparatus embodying the present invention;

Fig. 2 is an enlarged diagrammatic vertical section of a typical scanning disc;

Fig. 3 is a diagrammatic vertical section taken substantially along line 3—3 of Fig. 1, showing a workpiece, and the conical projection of a reflector on the plane of said workpiece;

Fig. 4 is a diagrammatic vertical section taken substantially along line 4—4 of Fig. 1;

Fig. 5 is an enlarged diagrammatic vertical section taken substantially along line 5—5 of Fig. 1;

Figures 6 and 7 are geometric figures illustrating the design of rectilinear and polar coordinate cam elements, respectively;

Fig. 8 is a diagram of certain periodic timing devices and their electrical connections;

Fig. 9 is a longitudinal section, partly in elevation, of a one-turn clutch mechanism;

Figures 10, 11, 12 and 13 are cross sections taken substantially along lines 10—10, 11—11, 12—12 and 13—13, respectively, of Fig. 9;

Fig. 14 is a diagrammatic layout of apparatus embodying an alternative form of the present invention;

Fig. 15 is a diagrammatic section taken substantially along line 15—15 of Fig. 14;

Figures 16 and 17 are enlarged fragments of the device shown in Fig. 15;

Fig. 18 is an enlarged vertical section taken substantially along line 18—18 of Fig. 14;

Fig. 19 is an enlarged cross section taken substantially along line 19—19 of Fig. 18; and,

Fig. 20 is a diagrammatic vertical section taken substantially along line 20—20 of Fig. 1.

Similar reference characters indicate the corresponding parts throughout the several views of the drawings.

Referring now more particularly to Fig. 1, there is shown, in somewhat diagrammatic form, a layout of apparatus which embodies the present invention. Numeral 1 indicates a scanning disc, which will be described more fully hereinafter. The scanning disc 1 is plane and is mounted for rotation on a shaft 3 in such a manner that the plane of the disc 1 is perpendicular to the axis of the shaft 3. The shaft 3 is driven by a differential 5, to be more fully described hereinafter, the opposite side of which differential 5 is driven by a main drive shaft 7. The shaft 3 is provided with thrust bearings 9 and 11 and with a substantially constant brake 12. The shaft 7 is driven by a motor 13 acting through a one-turn clutch 14 and a gear reduction box 15. The scanning disc 1 is provided with a spiral series of scanning holes 17 (see Fig. 20), the arrangement of which will be described in greater detail hereinafter.

Numeral 19 indicates a light source, such as an incandescent filament lamp. Numeral 21 indicates a lens, which is placed between the light source 19 and the disc 1, and which focuses an image of the light source 19 on a second lens 23, placed on the other side of the disc 1. The axis of the lens 21 coincides with the axis of the lens 23 which axis is parallel to the axis of the shaft 3 of the disc 1. A light shield 24 is desirably provided in such position as to enclose the light source 19 and lens 21, and prevent stray light from entering other parts of the apparatus. The image of the light source 19 should fill the second lens 23. The second lens 23 is arranged to focus an image of a hole 17 in the scanning disc 1 on a work piece 25, the area of which it is desired to measure. The work piece 25 is mounted at a predetermined distance from the lens 23 and with the plane of the work piece 25 parallel to the plane of the disc 1. Lenses 21 and 23 are not ordinarily single elements as shown diagrammatically in Fig. 1, but are preferably highly corrected compound lenses, such as microscope and camera lenses, for example. Behind the work piece 25, but as close to it as practically feasible, is placed a reflector 27, which, in the present embodiment, is a substantially spherical mirror. The reflector 27 is disposed to reflect light beams issuing from the lens 23 and not intercepted by the work piece 25, to a photosensitive device 29, which is desirably placed as close to the lens 23 as possible.

Between the lens 23 and the disc 1 is an opaque diaphragm or mask 28 (Fig. 20) of steel, for example, mounted in a fixed position preferably as close to the disc 1 as possible. The mask 28 has a sector-shaped aperture 30 therein which limits the lengths of the scanned paths in a predetermined manner. The size of the aperture 30 must be such that it is entirely within the so-called field of the lens 23, and is likewise such that its conical projection (using the optical center of lens 23 as an apex) on the plane of the work piece 25 (see Fig. 3, wherein this projected image of the aperture 30 is shown and indicated by numeral 32) is large enough to include any work piece it is desired to measure with the particular set-up of apparatus.

The size and position of the reflector 27 are such that its conical projection on the plane of the work piece 25 overlaps or extends beyond the said conical projection of the aperture 30 on the plane of the work piece 25.

The photosensitive device 29 is connected electrically to an amplifier 31, constructed to suit the characteristics of the particular device 29 employed, and the amplifier is in turn connected to a relay 33. The relay 33 is interposed in a circuit connecting power wires 34 to an electromagnetic clutch 35 through a second relay 36. Relay 36 is controlled by periodic timing devices 37 and 38 (hereinafter to be described) which are driven directly by the shaft 3. One end of the clutch 35 is driven by a shaft 40 through gears 39 in turn driven by shaft 7. Gears 39 are in a one to one ratio, so that shafts 7 and 40 rotate at the same speed. The other end of the electromagnetic clutch 35 drives a shaft 41, which drives a multiplier gear 42, which drives a shaft 43, which drives a rotation counter device 44. A releasable coupling 45 is provided between the electromagnetic clutch 35 and the shaft 41 for releasing the shaft 41 from the electromagnetic clutch 35 so that the counter 44 can be reset by means of a hand wheel 46 after the conclusion of a measurement of area. The multiplier gear 42 cooperates with the counter 44 to permit the measurement to take place in the desired units of area. A substantially constant brake 47 is provided on the shaft 43.

The multiplier gear 42 and the counter 44, taken as a unit, are carefully calibrated so that the rotation of the shaft 41 through a given angle from a well defined starting position produces a known change in reading of the counter 44, and the shaft 41 is provided with a coupling 45 and a hand wheel 46 for returning the shaft 41 to the starting position after the conclusion of an area measurement, said starting position being such that the counter reads "zero", for example, all backlash between shafts 41 and 43 having been removed by turning the hand wheel 46 in the forward direction. A brake 47 on shaft 43 cooperates in eliminating error due to backlash.

The electromagnetic clutch 35, as well as the counter 44, are of the customary construction finding use in this and allied arts. Suitable devices of this character are shown and described in greater detail, for example, in our copending application Serial No. 90,260, filed July 11, 1936.

The principles of operation of the apparatus thus described are presented in the following paragraph, assuming for the moment that the differential 5 drives the shaft 3 at the same rotational speed as the speed of the shaft 7, and that the shaft 7 rotates at constant speed. As will be pointed out hereinafter, the first condition is not ordinarily encountered in the operation of the apparatus, nor is it necessary for the speed of the shaft 7 to be constant. However, these assumptions are of aid in describing the general principles of operation of the apparatus.

The holes 17 in the scanning disc 1, passing between the lenses 21 and 23, project beams of light towards the reflector 27, each hole 17 producing one beam which sweeps the reflector as the disc rotates, and the successive holes 17 producing successive beams which sweep the combination of reflector 27 and work piece 25 at different angular positions. As long as these beams are not intercepted by the work piece 25, they are reflected back by the reflector to the photosensitive device 29, causing a response therein. The response of the photosensitive device is amplified by the amplifier 31, and the amplifier current holds the relay 33 (in the present embodiment) in open-circuit position, so that no power passes to the electromagnetic clutch 35. This means that no driving connection is had between the shafts 7 and 41, and hence the counter 44 does not operate. The instant, however, the beam of light (which will hereinafter be referred to as the scanning beam) is intercepted by the work piece 25, the actuating light on the photosensitive device 29 stops, thus causing the amplifier current to drop below the value required for holding the relay 33 in open-circuit position. The relay 33 thus closes, passing power to the electromagnetic clutch 35, which thereupon operates to drive the shaft 41 from the shaft 7. The counter 43 then commences to operate. The operation of the relay 36 is here disregarded, it being assumed that it does not interfere with the action of the relay 33 in passing power to the clutch 35.

The rotation of the counter 44, it will be seen, is proportional to the rotation of the scanner disc 1 during the time that the electromagnetic clutch 35 is operating, under the assumption as to the action of the differential 5 stated above. If, therefore, the rotation of the disc 1 can be made proportional to the length of the line on the work piece 25 traced by the moving scanning beam, then the value on the counter 44 will be true measure of the length of said line, and if it be assumed that the said line is the median line of an increment of constant width on the work piece, then the counter reading becomes an expression of the area of said increment.

For any one scanning beam, it will readily be seen that the above conditions are fulfilled, because the linear speed of a spot of light represented by the interception of the scanning beam on the work piece, as the beam sweeps across the piece, will be directly proportional to the angular speed of the disc 1. But a difficulty arises when successive scanning beams are considered. A beam from a scanning hole of lesser distance from the center of the scanning disc will move along the surface with the same angular speed as a beam from a scanning hole of greater distance (with the assumed constant angular speed of the disc 1), but due to its said lessed distance, the linear speed of the spot produced by the beam from the less distant hole on the work piece will be less than the linear speed of the spot produced by the beam from the greater distant hole. And, it will be seen, the linear speed of the spot is the true measuring factor of the area (or length of scanned line) on the work piece.

In the scanning disc 1 of the present embodiment, the holes 17 are arranged in a spiral manner such that the radial distance between adjacent holes is equal. In other words, referring to Fig. 2, which shows, for illustrative purposes, a greatly simplified scanning disc 1 having but seven holes 17, the difference between the distance (R_a) of an outermost hole 17_a from the center of the disc 1, and the distance (R_b) of the next inward hole 17_b on the spiral from the center of the disc 1, is the same as the difference between the distance R_b of the said hole 17_b and the distance R_c of a next inner hole on the spiral 17_c. This same difference is likewise found between the distances (R_b, R_c, R_d, R_e, R_f, and R_g) of successively inward holes 17_c, 17_d, 17_e, 17_f, and 17_g, on the spiral.

The equal radial spacing of the holes 17 on the scanning disc 1 provides for the scanning of increments of equal widths on the work piece 25, for each of the said holes 17. This statement will be better understood by reference to Fig. 3.

In Fig. 3 the light broken lines indicate the conical projections of the paths scanned by the beams produced by the several holes 17 in the scanning disc 1, said conical projections being on the plane of the work piece 25 and the center of the cone of projection being at the optical center of the lens 23. Fig. 3 indicates the paths scanned on the work piece 25 and on an imaginary plane reflector placed in the plane of the work piece 25. The line designated as R_a represents the conical projection of the scanned path of the beam produced by the hole 17_a in the disc 1, and the broken lines designated as R_b, R_c, R_d, R_e, R_f, and R_g are, respectively, the conical projections of the paths of the scanning beams produced by holes 17_b, 17_c, 17_d, 17_e, 17_f, and 17_g. The increment represented by the line R_a extends from the solid light line R_1 to the solid light line R_2, and the difference in radii of the lines R_1 and R_2 (designated as "h"), is equal to the constant differences between the radii of broken lines R_a, R_b, R_c, etc. The value h accordingly represents the width of the incremental path scanned by any one of the holes 17.

Since all of the scanned increments of a work piece 25 are thus of equal width, equal areas will be measured by equal lengths laid out on the broken lines R_a, R_b, R_c, etc. If, therefore, all of the scanning beams from all of the holes 17 can be made to move across their respective paths R_a, R_b, R_c, etc., on the work piece 25, at the same linear speed, then each scanning beam will measure area at the same rate (so many square units per unit of time) as all of the other scanning beams. Under such conditions, the operation of the counter 44 becomes a time function, the counter being arranged to operate only during such intervals of time as the scanning beams are intercepted by the work piece 25.

A problem, however, arises in securing equal linear speed for all of the scanning beams from all of the holes 17 across the work piece 25. This is because the said scanning beams are produced from the stationary light source 19 by holes 17 which travel in concentric circular paths, the paths of course being of various radii. If the scanning disc 1 is driven at a constant angular speed, it will be seen that the desired condition, namely, equal linear speed of all scanning beams on the work piece 25, cannot be secured.

The differential 5 provides the means, in the present embodiment of the invention, for correcting the speed of rotation of the scanning disc 1 so that the desired condition is achieved.

The parts of the differential 5 may be described as follows: Numeral 48 indicates a bevel gear which is non-rotatably secured on shaft 7. Numeral 49 indicates a bevel gear of identical size and pitch, which is non-rotatably secured on the shaft 3. An extended portion 51 of shaft 7 rotatably supports a differential case with a peripheral spur gear 53, which is of greater diameter than the gears 47 and 49. A bearing 55 permits the case 53 to turn freely on the extended portion 51 of shaft 7. Suitably mounted in recesses 57 in the spur gear 53 are a pair of tumbler gears 59. The tumbler gears 59 are of identical size, and are bevelled at a proper angle to mesh with the gears 47 and 49, to provide a driving connection therebetween.

It will readily be seen that, provided the spur gear 53 is held stationary, the gear 47 drives the gear 49 through the tumbler gears 59 at a one to one ratio, whereby the shafts 7 and 3 rotate at the same angular speed. However, if the spur gear 53 is rotated, then by the laws of differential action, the shaft 3 is advanced or retarded relative to the rotation of the shaft 7 by an amount determined by the extent and direction of rotation of the spur gear 53.

In the present embodiment of the invention, rotation of the spur gear 53 is achieved in the desired manner by means of a vertically slidable rack 61, the face of which rack 61 meshes with the teeth of spur gear 53, and the lower end of which rack 61 carries a wedge-shaped cam follower 63. The follower 63 engages the edge of a cam 65, which is mounted on a shaft 67, and the follower 63 is at all times held positively in contact with the cam 65 by a spring 68. The cam 65 is statically balanced about the axis of the shaft 67 by means of a counterbalance 69. The shaft 67 is driven to rotate in a one to one ratio with the rotation of main drive shaft 7, by means of gears 70, 71, and 72.

The design of the cam 65 to achieve the desired result through the differential 5 will next be described. Fig. 7 shows the progressive stages of design.

It is assumed, for purposes of illustration, that the desired scanning disc is to contain seven holes in the spiral, as shown in Fig. 2. It is also assumed that each of the holes is separated from its adjacent hole by an angular distance α. This angle α is also the angle subtended by the sides of the sector-shaped opening **30** in mask **28**. In order to provide a "dead region" for permitting the return of the cam follower to its innermost position and for other reasons hereinafter set forth, a "dead angle" β is provided. Because of the relatively small number (seven) of holes which was assumed for sake of clarity in illustrating the method of cam design, the angle α is relatively large in Fig. 2, necessitating a relatively large mask aperture **30**, which in turn would necessitate a relatively large lens system **21** and **23**. However, in commercial practice the number of holes in the scanning disc will ordinarily be largely in excess of seven (say, for example, fifty or so) as shown in Fig. 20, and the angle α will consequently be relatively small, making it possible to use lenses of more reasonable diameters, as indicated in Figures 1 and 20.

The cam **65** is designed to impart a linear motion to its follower **63**, of x units of displacement per α radians of angular motion of the cam **65**. Since the angular speed of the cam **65** is constant, relative to the angular speed of the main drive shaft **7**, and since displacement of the cam follower **63** acts through the differential to produce angular motion of the scanning disc **1** relative to the cam, the disc **1** is given the required change in speed to compensate for the change in radii of the several holes **17**. The cam follower **63** returns to its innermost position on the cam **65** during an interval following the sweep of the scanning beam from hole **17**$_g$. During this same interval, the scanning disc **1** loses its advanced angular displacement.

To simplify the calculations of the shape of the cam **65**, it is assumed that the scanning disc **1** will have seven holes **17**, with the outermost hole **17**$_a$ at a radius of 6.95 inches, and with each hole on the spiral 0.10 inch closer to the center of the disc **1**. This means that the innermost hole **17**$_g$ on the spiral will be 0.60 inch closer to the center of the disc **1** than the outermost hole **17**$_a$.

Linear motion of the rack **61** produces angular displacement of the scanning disc **1**, relative to the main drive shaft **7**, in direct proportion. Therefore a linear rack speed of x units per second produces an angular speed of kx radians per second. The factor k is determined by the size of the linear displacement unit, the dimensions of the cam **65**, and the diameter of the differential spur gear **53**. The factor k can also be given any desired value by introducing a gear train between the rack **61** and spur gear **53**. Therefore it is sufficient to design the cam **65** to impart x units of linear motion during a standard time of sweep (defined hereinafter), x being in each case proportional to the deficiency in area measuring speed relative to the area measuring speed of the outermost hole **17**$_a$ on the spiral. The standard time of sweep is defined herein as the time which would be required for the disc **1** to rotate through a given angle α, indicated in Fig. 2, for example, if no cam **65** were used. Actually, as will be seen hereinafter, the cam **65** acts to reduce the time of sweep of successive holes **17**. Therefore the displacement of the cam follower **63** must be correspondingly less than x to make the added speed proportional to x.

In the following Table I, certain factors are set down relative to the assumed scanning system. The first column of the table merely identifies the particular hole **17** in consideration. The second column sets forth the distance (R_m) of that hole from the center of the disc. The third column sets forth progressively the radii (R_s) of the increments scanned by the beams produced from the particular holes, corresponding to the values R_1, R_2, etc., in Fig. 3. For purposes of the present calculation, it is assumed that the radii of the increments on the work piece **25** are the same as the radii of images of these increments projected on the disc **1** by the lens **23**, since, in any event, these values in any properly designed system would be proportional to each other. The fourth column sets forth the difference (ΔR_m) in distances of the succeeding holes **17** from the center of the disc **1**. By the initial assumption, this expression ΔR_m is constant for all holes, with the values of 0.10. The fifth column sets forth the progressive summation ($\Sigma\Delta R_m$) of the values ΔR_m from hole to hole. The sixth column sets forth the relative area (A) included in a circle of a radius R_s, which is proportional, and hence taken as equal to, the square of such radius. The seventh column sets forth the difference (ΔA) in area for the successively shorter radii, and may be conceived of as an expression of the actual area of the increment scanned by the particular hole. This value, ΔA, can also be conceived of as the area scanned per unit of time, assuming constant and unchanging disc speed, for each of the holes **17**. The eighth column sets forth the differences between successive values of ΔA, expressed as $\Delta(\Delta A)$. This eighth column shows values, it will be seen, that are all one-fifth of the corresponding values of ΔR_m, as set forth in the fourth column. The ninth column sets forth the progressive summation ($\Sigma\Delta(\Delta A)$) of the values of $\Delta(\Delta A)$.

Table I

Hole	Radius R_m	R_s	ΔR_m	$\Sigma\Delta R_m$	Relative included area A	ΔA	$\Delta(\Delta A)$	$\Sigma\Delta(\Delta A)$
		7.00	-------	0.00	49.00		-------	0.00
17_a	6.95					1.39		
		6.90	0.10	0.10	47.61		0.02	0.02
17_b	6.85					1.37		
		6.80	0.10	0.20	46.24		0.02	0.04
17_c	6.75					1.35		
		6.70	0.10	0.30	44.89		0.02	0.06
17_d	6.65					1.33		
		6.60	0.10	0.40	43.56		0.02	0.08
17_e	6.55					1.31		
		6.50	0.10	0.50	42.25		0.02	0.10
17_f	6.45					1.29		
		6.40	0.10	0.60	40.96		0.02	0.12
17_g	6.35					1.27		
		6.30	-------	-------	39.69		-------	-------

From the foregoing table, it will be seen that either the value $\Sigma\Delta(\Delta A)$ or the value $\Sigma\Delta R_m$ can be taken as x, x having been heretofore defined as proportional to the deficiency in area measuring speed.

As hereinbefore stated it is the purpose of the cam-controlled differential **5** to correct the speed of rotation of the scanning disc **1** by advancing it relative to the rotation of the shaft **7**. Since the holes **17** are equi-radially spaced and therefore the widths h of the scanned strips on the work piece **25** are equal, the area scanned by a given beam per unit of time measured in terms of the angular displacement of the shaft **7** is

$$\frac{Ch\Lambda R_m}{t_s}$$

where Λ is the angular displacement of the disc **1**, R_m is the mean radius of the circular path of the hole **17** about the axis of the shaft **3**, t_s is the angular displacement of the shaft **7** and C is a constant. The concept of expressing time as the angular displacement of the shaft 7 can be better understood by imagining that it is determined by a clock driven synchronously by the shaft 7. If the angular speed of the shaft 7 is constant t_s, multiplied by a suitable factor, is time in the usual sense in which the unit is the second. In order for

$$\frac{Ch\Lambda R_m}{t_s}$$

to be constant, either Λ or t_s (or both) must have predetermined different values for each value of R_m. In the present embodiment, Λ is chosen constant and therefore t_s has a series of values such that

$$\frac{R_m}{t_s}$$

is constant. Regardless of the choice, however, the cam 65 lags the disc 1 in its rotation. Therefore an angular correction must be applied to the lay-out of the cam 65 or of the disc 1 (or both) depending on the choice of the speed correction method. In the present embodiment the angular correction is applied to the lay-out of the cam 65 in two ways as will be described hereinafter.

Table II (set forth hereinafter) shows the application of this correction. In Table II, the first column again gives, for identification, the designation of the particular holes on the disc 1. The second column sets forth the speed correction determined from Table I, and expressed as the values given in Table I for the quantity $\Sigma\Delta R_m$. In Table II, these values are designated as (a). Column three sets forth the angular correction (b) suggested in the preceding paragraph. This angular correction (b) is the ratio of the area scanned by a given hole 17 to the area scanned by the outermost hole 17_a during unit angular displacement of the disc 1 in each case. (b) is therefore the desired angular displacement t_s of the shaft 7 during displacement of the disc 1 through the angle α, t_s being expressed in arbitrary units such that it is unity for the outermost hole 17_a in the disc 1. That t_s should be correspondingly less than unity for any other hole 17 than the outermost hole 17_a is evident since a given angular displacement of the disc 1 results in the scanning of a smaller area than would be scanned by the outermost hole 17_a and therefore the shaft 7 must rotate through a correspondingly smaller angle in order that the counter 44 cannot register a number which is too large. Since Λ is chosen constant it is evident that the desired linear displacement of the cam follower 63 is the product of the speed correction (a) and the angular correction (b), because (a) is the linear displacement of the cam follower 63 per unit rotation of shaft 7 and (b) is the magnitude of the rotation t_s.

The fourth column of Table II sets forth the corrected speed correction (ab), which is the product of the speed correction (a) and the angular correction (b). The fifth column sets forth the progressive summation $(\Sigma(ab))$ of the values set forth in the fourth column. The sixth column sets forth the values for the expression $(1-b)$. The seventh column indicates the progressive summation $(\Sigma(1-b))$ of the values set forth in the sixth column. The last value in the seventh column, 0.3022, represents, when multiplied by the angle α, the number of radians that the disc will be advanced in excess at the end of the scanning.

Table II

Hole	Speed correction (a)	Angular correction (b)	(ab)	$\Sigma(ab)$	$(1-b)$	$\Sigma(1-b)$
17_a	0.00	1.0000	0.00000	0.0000	0.0000	0.0000
17_b	0.10	0.9856	0.09856	0.0986	0.0144	0.0144
17_c	0.20	0.9712	0.19424	0.2928	0.0288	0.0432
17_d	0.30	0.9568	0.28704	0.5798	0.0432	0.0864
17_e	0.40	0.9424	0.37696	0.9568	0.0576	0.1440
17_f	0.50	0.9281	0.46405	1.4209	0.0719	0.2159
17_g	0.60	0.9137	0.54822	1.9691	0.0863	0.3022

From the values given in Table II, a cam having the desired characteristics may be laid out directly, in the manner shown in Fig. 7. A center 75 is first established, and from this center 75 a reference line 77_a (shown as a short dashed line) is drawn. Successive angular intervals of α radians are next laid out, and defined by short dashed lines 77_b, 77_c, 77_d, 77_e, 77_f, 77_g, and 77_h. The angular distance between the lines 77_h and 77_a represents the dead space angle β on the cam.

A circle 79 is now described around the center 75, at a radius equivalent to the desired innermost edge of the cam.

The next procedure is to lay out lines 81 representative of the angular corrections necessary. These lines 81 are all shown as long dashed lines in Fig. 7. The positioning of the lines 81 is determined by the values for $\Sigma(1-b)$, as expressed in the seventh column of Table II. The first such line 81_c is laid out at an angular distance equal to 0.0144α radians behind the line 77_c. The second line 81_d is laid out at an angle equal to 0.0432α radians behind the line 77_d. Successive lines 81_e, 81_f, 81_g, and 81_h, are similarly laid out with respect to the lines 77_e, 77_f, 77_g, and 77_h. The lines 81_b and 81_a are located, respectively, on top of the lines 77_b and 77_a, for the reason that the line 81_a is a reference line, and positioned identically to the reference line 77_a, while the correction factor $(\Sigma(1-b))$ for the line 81_b, as shown in the seventh column of Table II, for the first hole, is zero.

A scale is now chosen for the values of the expression $\Sigma(ab)$, as given in the fifth column of Table II. This scale is established by the diameter of the spur gear 53, and certain other factors, as heretofore expressed in connection with the definition of the constant k. The scale used in Fig. 7 is entirely arbitrary. The values from the fifth column of Table II are now laid out progressively on the lines 81_c, 81_d, 81_e, etc. The zero point is considered as the circumference of the circle 79. Hence, the edge of the cam itself, on the lines 81_a and 81_b will be the edge of the circle 79, since the values of the expression $\Sigma(ab)$ for the reference line 81_a and the second line 81_b are both zero. The point on line 81_c is at a distance of 0.0986 unit from the circumference of circle 79. Similarly, the point on line 81_d is at a distance of 0.2928 unit from the circumference of circle 79, and the points on the succeeding lines 81_e, 81_f, 81_g and 81_h are similarly established.

The correct method of connecting the points thus established is illustrated in Fig. 6 in which the linear displacement of the cam follower 63 is plotted against the angular displacement of the cam 65, using rectangular coordinates. In Fig. 6 the points are all connected by straight lines 82_a, 82_b, 82_c, 82_d, 82_e, 82_f, 82_g, and 82_h, the object being to produce constant linear speed of the cam follower 63 relative to the speed of rotation of the cam **65** during the time of each sweep. The desired constant linear speed of the beam across the surface of the work piece **25** is obtained by adding a constant speed to the speed of the shaft **7**, both of said constant speeds being of course relative to the speed of the shaft **7**. Fig. 6 could be used to construct a linear cam which could be used to supply the desired speed corrections to the disc **1** if said cam were given a constant linear speed relative to the speed of rotation of the shaft **7**. The line, obtained by connecting the points in Fig. 6 by straight lines, when transferred to polar coordinates is shown in Fig. 7 by line **83**. While line **83** appears in Fig. 7 to be a smooth curve from line 81_b to 81_h, it will be seen from the manner in which it has been constructed from Fig. 6, it is in reality a series of sectors of Archimedean spirals of varying pitches. Section 83_a of line **83** (line 81_a to line 81_b), being taken from line 82_a, has zero pitch. Section 83_b (line 81_b to line 81_c) has a pitch determined by the slope of line 82_b. Likewise, sections 83_c, 83_d, 83_e, 83_f, 83_g, and 83_h have pitches determined by lines 82_c, 82_d, 82_e, 82_f, 82_g, and 82_h. The intersections of the several sections of line **83** are so gradual on the scale chosen for Fig. 7, that they do not show the cusps that are really present, but appear as a continuous, smooth curve. The return portion of the cam, represented by the straight line **85**, may be located exactly upon the line 81_h.

By following the principles set forth above in connection with the design of a cam for a disc of the assumed characteristics, a similar cam may be designed for discs with any other assumed characteristics, such as a greater number of holes.

In the design of the cam **65** hereinbefore described, it has been assumed for sake of simplicity that the follower **63** has a sharp wedge-shaped bearing surface, the angle of the wedge apex being sufficiently small to insure contact between said apex alone of the follower **63** and the cam **65** at all times when accuracy of follower displacement is desired, that is throughout the actual scanning process, said assumption serving to eliminate follower corrections from the calculations of the dimensions and shape of the cam **65**. If desired, the design of cam **65** can be modified to permit the use of another type of follower **63** such as a roller, for example, retaining the desired relation between the displacement of the follower **63** and the rotation of the cam **65**. For a roller follower, it is necessary to introduce both radial and angular corrections into the design of the cam **65**, because the point of tangency of such a roller follower to the cam is not always on the line connecting the cam center to the roller center.

The cam **65** should be set at such an angle on its shaft **67** that follower **63** enters section 83_a of cam **65** (e. g., crosses line 81_a) at the same instant that hole 17_a of the disc **1** passes into the field of the aperture **30** of mask **28**. If this is so, then each subsequent hole **17** will pass into the field of aperture **30** just as the follower **63** reaches the proper section **83** of the cam **65**.

The effect of the cam **65** as thus designed, when employed together with the differential **5** and the disc **1** suited to the cam, is to cause the disc **1** to rotate at a series of constant angular speeds, such that the scanning beams produced by all the holes **17**, at their point of intersection on the work piece **25**, move with substantially the same linear speed. In other words, all of the scanning beams move at such speeds that they measure a predetermined substantially constant number of area units per unit of time. Substantially the same number of units of area are measured by a scanning beam from the innermost hole 17_g, in unit time, as are measured by the outermost hole 17_a, and all other holes **17**. Since the drive of the counter **44**, being the shaft **7**, is assumed to rotate at a uniform angular speed, the counter **44** increases its reading by a uniform amount in successive unit intervals of time. Therefore, by choosing the counter gear train **42** to have the proper constants, the counter **44** is able, in the manner heretofore described, to record the actual measured area of the work piece **25**. This, it will be recalled, was one of the principal objects of the present invention.

It is now evident, however, that the assumption of constant driving speed of shaft **7**, which was introduced hereinbefore for purpose of simplicity, is unnecessary, because all moving parts of the scanning apparatus move with predetermined relative speeds and therefore the counter **44** increases its reading by a uniform amount for successive units of area scanned.

In the system described the relay **33** is so designed that when no light beam reaches the photo-sensitive device **29** the electromagnetic clutch **35** is energized and therefore shaft **7** is mechanically connected to shaft **41** so that if shaft **7** turns while no light beam reaches the photosensitive device **29** the counter **44** increases its reading. Not only during the times that light beams are intercepted by the work piece **25** does the photosensitive device **29** receive less light than is required to operate the relay **33** through the amplifier **31**, but also during at least a part of the time that the cam is rotating through the angle β plus 0.3022α, for example, no light beam reaches the photosensitive device **29**. During the return of the cam follower **63** to its innermost position on the cam **65** the disc **1** loses its advanced angular displacement relative to the cam **65** and therefore the last hole **17** in the disc **1** moves back across the aperture **30** in the mask **28** through a fraction of the angle α and subsequently re-scans through the same angle and does said re-scanning at reduced speed. It is readily understood therefore that unless the external electrical circuit of the relay **33** and the electromagnetic clutch **35** is closed and opened precisely at the beginning and end, respectively, of the scanning process an error in area measurement may result. To close and open the external circuit of the relay **33** and the electromagnetic clutch **35** at the required instants, the two accurate periodic timing devices **37** and **38** hereinbefore referred to are provided, and are driven by shaft **3** to control relay **36**, which relay **36** controls said external circuit.

Periodic timing devices are sufficiently well known to those skilled in the art that no detailed description is necessary herein. Said devices (see Figures 1 and 8) comprise relatively slowly-rotating pairs of slip rings **85** and **87**, respectively, connected in series with relatively fast-rotating pairs of slip rings **89** and **91**, respectively. The rings **89** and **91** are driven by shaft **3** through a gear train **93**. Periodic timing devices of this character are often used in clocks, for example, to close (or open) electrical circuits precisely at predetermined times once each hour, for example. In the first embodiment of the invention herein described the periodic timing device **37** is used to close the electrical circuit **95** of the "on" solenoid **97** of relay **36** once each time the shaft

7 has rotated through 360 degrees with an angular deviation from 360 degrees of 1 part in 2401, for example, and said device 37 is adjusted to close said circuit at the beginning of the scanning process, which is the time when the first light beam is permitted by the mask 28 to begin to sweep across the combination of reflector 27 and work piece 25. Periodic timing device 38 is identical with periodic timing device 37 but is used to close the electrical circuit 99 of the "off" solenoid 101 of the relay 36 at the end of the scanning process, which is the time when the last light beam has just completed its sweep across the combination of reflector 27 and work piece 25.

Relay 36, as shown diagrammatically in Fig. 8, is a self-holding relay of the type commonly used with a push-button control to stop and start motors. Said relay 36 is so connected electrically to the periodic timing devices 37 and 38 that periodic timing device 37 closes the external electrical circuit of relay 33 and electromagnetic clutch 35 whereas periodic timing device 38 opens said external electrical circuit. A suitable source of power 34 is provided for both relays 33 and 36.

The function of the one-turn clutch mechanism 14 to be described in greater detail hereinafter, is to aid in preventing the measurement of a given work piece 25 more than once. In the system as shown in Fig. 1 the drive shaft 105 of the one-turn clutch 14 is continuously rotating, but driven shaft 7 rotates only one complete revolution and only after a manual operation has been performed. The one-turn clutch 14 is adjusted to start and stop the rotation of the shaft 7 when the cam follower 63 is in contact with the cam 65 at a point within the dead angle β, said point being near the intersection of line 81_a with the circle 79.

The construction of the one-turn clutch mechanism 14 is as follows:

The one-turn clutch mechanism 14 is shown in greater detail in Figures 9, 10, 11, 12, and 13, to which reference is now directed. The main drive shaft 105 is keyed to a rotating outer sleeve member 107. An inner cam member 109 is mounted for rotation within the sleeve member 107, and has peripheral recesses 111 for receiving rollers 113. The cam member 109 has a cylindrical portion 115, on which rotates a second sleeve 117. The sleeve 117 has a cylindrical retainer ring portion 119 which extends into the sleeve member 107 and retains the rollers 113. The sleeve 117 has a peripheral projection or stop 121.

The cam member 109 is outwardly flanged beyond the end of the sleeve 117, providing a groove 123 therebetween, and a cylindrical part 125 beyond the groove 123. The cylindrical part 125 has a peripheral projection or stop 127. Beyond the cylindrical part 125 is another cylindrical part 129 of lesser diameter, said cylindrical part 129 forming the drum of a brake 131. This brake 131 can be used with relatively light pressure to aid in stopping the rotation of the cam member 109, but is adjusted in any case so that it does not prevent the stop 127 from making contact with an end 133 of the latch 135, hereinafter to be described. A pair of pins 137 and 139 are mounted, oppositely facing, on the cam member 117 and the sleeve 109 respectively, and a tension spring 141, lying in the groove 123, connects the two pins.

The drive shaft 7 is received in, and keyed to rotate with the cam member 109.

Numeral 135 indicates the hereinbefore-mentioned sliding latch that is supported for sliding movement in bearings 143 and 145. The latch 135 is provided with a handle 147 at its free end, and a tension spring 149 reacts between a collar 151 made fast to the latch 135, and the bearing 143 to cause the latch 135 to be normally in a retracted position such that the opposite end 133 of the latch 135 is positioned under the projection 121 on the sleeve 117, in such manner as to prevent the rotation of said sleeve 117 and is positioned under the projection 127 on the cam member 109 in such a manner as to prevent the rotation of the cam member 109.

Normally the sleeve 107 rotates continuously with the shaft 105, but the sleeve 117 and the cam member 109 cannot rotate with the sleeve 107 because the stops 121 and 127, respectively, are held back by the end 133 of latch 135. This holds the roller retainer 119 in such position that the rollers 113 are idling, being incapable of establishing a driving connection between the sleeve 107 and the cam member 109 and the angle subtended by the stops 121 and 127 at the axis of the shaft 7 is zero. However, the instant the latch 135 is manually moved out of locking position, by pulling the knob 147, the spring 141, reacting against the inertia of the moving parts of the scanning apparatus and against the friction of the various bearings in the scanning apparatus such as the bearing of shaft 7, for example, rotates the sleeve 117 enough forward so that the retainer 119 brings the rollers 113 into a driving connection between the sleeve 107 and the cam member 109 the angle of rotation of the sleeve 117 being δ which angle is small relative to the dead angle β on the cam 65. The cam member 109 thereupon commences to rotate, carrying the sleeve 117 and shaft 7 with it and the angle subtended by the stops 121 and 127 is the displacement angle δ. Meanwhile, the knob 147 has been released, permitting the latch 135 to return to a locking position, so that, immediately upon the completion of a single revolution, the sleeve 117 is stopped by the re-engagement of the stop 121 with the end 133 of latch 135. The stopping of the sleeve 117 moves the retainer 119 so that the rollers 113 are again brought to idling position. The rotation of the cam member 109 ceases when the stop 127 on cam member 109 engages the end 133 of latch 135. The excess rotation of the cam member 109 relative to the rotation of the sleeve 117 stores tension in the spring 141 for the next revolution. Since the mechanical conditions are substantially identical for successive operations, the revolution of the cam member 109, and hence of the shaft 7, is substantially one turn for each manual operation of the knob 147.

It is evident, however, that should the one-turn clutch 14 become worn after long use and consequently occasionally turn through an angle greater or less than 360 degrees, no error in the area measurement can result, because the maximum angle δ through which sleeve 117 can rotate, relative to the shaft 7, is a small angle relative to the dead angle β of the cam 65, and the one-turn clutch 14 is adjusted to start and stop the shaft 7, when the cam follower 63 is in contact with the cam 65 at a point within the dead angle β, said point being near the intersection of the line 81_a with the circle 79. The one-turn clutch 14 cannot rotate through an angle less than 360 degrees minus δ because said clutch 14 must continue to rotate with the shaft 105, after release of the stops 121 and 127 through temporary manual withdrawal of the end 133 of the latch 135, until the stop 121 has again arrived at the end 133 of the latch 135, at which instant the angle between the stops 121 and 127 is δ, and the angle of rotation of the one-turn clutch 14 is therefore at least 360 degrees minus δ, and thereafter the shaft 7 must rotate enough further relative to the sleeve 117 to release the rollers 113 from their contact with the cam member 107.

The same features of design, which prevent the rotation of the one-turn clutch 14 through an angle less than 360 degrees minus δ, also prevent the rotation of the one-turn clutch through an angle greater than 360 degrees plus δ. Rotation of the one-turn clutch 14 through an angle greater than 360 degrees can result only from initial displacement of the sleeve 117 relative to the cam member 109 through an angle less than δ, before the release of the stops 121 and 127 through the temporary manual withdrawal of the end 133 of the latch 135, and from final displacement of the sleeve 117 relative to the cam member 109 through an angle less than said initial angle.

Rotation of the one-turn clutch 14 through an angle greater than 360 degrees can result in no error in area measurement because said rotation is positively stopped when the cam 65 reaches such an angular position that the cam follower 63 is in contact with the cam 65 at a point within the dead angle β of the cam 65.

Angular deviations of the rotation of the one-turn clutch 14 from one complete turn cannot accumulate to exceed an angle greater than δ, in either direction, during any number of scanning cycles because the angular position of the latch 135 about the axis of the shaft 7 is fixed, and contact of the stop 121 with the end 133 of the latch 135 is a necessary condition for both starting and stopping the rotation of the one-turn clutch 14.

Thus it is clearly shown that the operation of the one-turn clutch 14 cannot produce an error in the measurement of area because the starting and stopping of the rotation of the shaft 7 always occur at instants when the cam 65 is in such an angular position that the follower 63 is in contact with the cam 65 at a point within the dead angle β of the cam 65 and no hole 17 is in position, relative to the mask 28, to scan, and the external electrical circuit of the relay 33 and the electromagnetic clutch 35 is open when the cam follower 63 is in contact with the cam 65 at any point whatever within the dead angle β of the cam 65.

The operation of the system as thus described, and as shown in Fig. 1, in order to measure the area of a work piece 25, is as follows:

The motor 13 is started, thus commencing the rotation of the shaft 105. The lamp 19 is turned on, so that the production of scanning beams can be commenced. The latch 135 is in its locking position, so that the shaft 7, and all moving parts driven by shaft 7 are stationary. The electromagnetic clutch 35 is electrically disconnected from the relay 33 by relay 36. The work piece, 25, the area of which it is desired to measure, is now placed in position in front of the reflector 27. Thereupon, the knob 147 is pulled, and the one-turn clutch 14 permits the shaft 7 to begin making one revolution. At the beginning of the scanning the relay 36 electrically connects the electromagnetic clutch 35 to the relay 33. During the one revolution of the shaft 7, a complete series of scanning beams, produced during the one revolution of the scanning disc 1, is produced, and each scanning beam actuates the photosensitive device 29 in accordance with its interception or non-interception by the work piece 25. During this interval, the electromagnetic clutch 35 is under direct control of the relay 33, which is in turn under direct control of the photosensitive device 29. In the system as described, this control means that whenever the scanning beam is intercepted by the work piece 25, the electromagnetic clutch 35 is energized so that the shaft 40, as driven by shaft 7 through gears 39, drives the shaft 41, and hence drives the counter 44, thus accumulating a measurement of the area of the work piece. However, if the scanning beam is reflected to the photosensitive device 29, then no current flows to the electromagnetic clutch 35, and the shaft 40 does not drive the counter 44, and no totalizing occurs. At the completion of the scanning the relay 36 electrically disconnects the electromagnetic clutch 35 from the relay 33. At the completion of the one revolution of the one-turn clutch 14 the shaft 7 stops rotating.

It is thus seen that, through the operation of the one-turn clutch 14, the number of scanning beams for any one work piece 25 that are effectual to operate the counter 44 is limited to one complete set of scanning beams, and no repeat of measurement of one or more increments of the work piece 25 can take place. It is also thus seen that, through the operation of the periodic timing devices 37 and 38 the counter 44 is automatically prevented from increasing its reading when no scanning is taking place even if the shaft 7 is rotating.

In the embodiment of the invention shown in Fig. 1, the description of which has just been completed, a factor of importance is that the differential 5 has been introduced into the drive of the scanning disc 1 and operated in such manner that the rotation of the counter 44 is proportional to the linear speed of the scanning beams as they sweep across the work piece 25. In the Fig. 1 embodiment, this result has been achieved by driving the shaft 43 of the counter 44 at a speed proportional to the speed of the motor 13 and then so driving the scanning disc 1 that all of the scanning beams move across the work piece 25 with the same linear speed relative to the rotational speed of the counter 43. It will readily be seen that the same result can be achieved if the differential 5 is introduced into the drive of the counter 44, say, for example, between the gear 39 and the electromagnetic clutch 35. Under such conditions, the scanning disc 1 can be driven directly from the main shaft 7. With such an embodiment, it will be seen that the angular speed of the drive for the counter 44 is varied in accordance with the now varying relative linear speeds of the scanning beams as they sweep across the work piece 25. The end result is the same, namely, the counter 44 is driven at rates proportional to the linear speeds of the scanning beams as they sweep across the work piece surface.

The differential 5 is but one form of mechanism that is suited for the required change of angular speed, be it either in the counter drive or in the scanning disc drive, to compensate for the varying relative linear speeds of the several scanning beams as they sweep the work piece 25. In Fig. 14, for example, is shown another form of mechanism that achieves substantially the same end result. Referring now more particularly to Fig. 14, it will be seen that the main drive motor 13 drives a shaft 105 through a gear reduction box 15, as in the Fig. 1 embodiment. On shaft 105 is mounted a one-turn clutch 14, as in Fig. 1, which drives a shaft 161. On the shaft 161 is secured a bevel gear 163, which meshes with a bevelled pinion 165 mounted on a countershaft 167 suitably supported in bearings 169 at right angles to the main shaft 161. The countershaft 167 non-rotatably carries a wide pinion 171. In the present embodiment, a scanning disc 173 is provided, which is non-rotatably mounted on a shaft 175 supported in suitable bearings 177. The center lines of shafts 167 and 175 intersect. Shaft 175 is provided with thrust bearings 176 and 178 and with a substantially constant brake 12.

The arrangement of the scanning holes in the disc 173 is somewhat different from that in the Fig. 1 embodiment, and will be described in greater detail hereinafter. The illuminating and optical system of the present embodiment, however, is analogous to that of the Fig. 1 embodiment, and its elements are accordingly designated with the same reference characters. The same is true of the electromagnetic clutch 35, multiplier gears 42, counter 44, coupling 45, hand wheel 46, brakes 12 and 47, periodic timing devices 37 and 38, photoelectric cell 29, amplifier 31, relays 33 and 36, work piece 25, and reflector 27. In the present embodiment, the brakes 12 and 47 are mounted on the shafts 175 and 43, respectively, and the periodic timing devices 37 and 38 are mounted on the shaft 175. The multiplier gear 42 and counter 44 are calibrated as a unit and are reset to the correct starting position after the conclusion of an area measurement by means of the hand wheel as in the first embodiment. The one-turn clutch 14 is adjusted to start and stop the rotation of the shaft 161 when the disc 173 is in such a position that the dead region defined by the dead angle θ, to be described in greater detail hereinafter, is between the lenses 21 and 23 and preferably in such a position that the first hole which is to begin the next scanning process is near the edge of the aperture 30 of the mask 28. The periodic timing devices 37 and 38 are adjusted to perform their respective functions at the beginning and end of the scanning process as described hereinbefore in connection with the first embodiment and therefore the external circuit of the relay 33 and the electromagnetic clutch 35 is broken throughout the dead portion of the cycle defined by the dead angle θ. The maximum angle δ through which the sleeve 117 of the one-turn clutch 14 can rotate, relative to the shaft 161, is a small angle relative to the dead angle θ and the operation of the one-turn clutch 14 cannot produce an error in the measurement of area for reasons analogous to the reasons set forth hereinbefore in the description of the first embodiment.

Although the shafts 161 and 175 do not in general rotate at the same speed, the pitch diameters of the gears 163, 165, 171 and disc 179 are chosen so that said shafts require the same length of time to rotate through 360 degrees.

The other end of the scanning disc shaft 175 non-rotatably carries a disc 179, which is substantially identical in diameter to the disc 173. The disc 179 serves to mount an eccentric approximately circular row of upstanding pins 183, the projecting portions of which are given the contours of rack teeth, so that they suitably mesh with the teeth of the pinion 171. The drive for the scanning disc 173 is thus as follows, from the drive shaft 105: Shaft 105 drives the one-turn clutch 14 which drives the shaft 161 which drives bevel gear 163, which drives bevel pinion 165, which drives pinion 171, which drives disc 179 by engagement with teeth 183, which drives shaft 175, which drives the scanning disc 173. The assembly consisting of the discs 179 and 173, shaft 175, periodic timing devices 37 and 38 and the drum of the brake 12 is statically balanced about the axis of the shaft 175.

The disposition of the scanning holes, now indicated generally by numeral 181, on the scanning disc 173, is indicated in Figures 15, 16, and 17. The entire series of scanning holes 181, it will be seen, seems to be arranged in a circle with its center slightly displaced from the center of the disc 173; as a matter of fact, this arrangement is not exactly circular, as will be pointed out hereinafter. All of the holes 181 are spaced at substantially uniform linear distances apart, around the approximate circle on the disc 173.

Hole 181_a, shown at the top of the disc in Fig. 15, is at the greatest distance from the center of the disc 173 of all of the holes 181. Hole 181_b, which is closer to the center of the disc 173 by a predetermined distance "h" than the hole 181_a, is placed in the next position, on the series of holes, to the left of hole 181_a. This arrangement is shown in Fig. 16, but it is to be understood that in Fig. 16, for clarity, the distance "h" has been exaggerated with respect to the angles shown, in order to make the arrangement more understandable. Hole 181_c, which is positioned "h" units closer to the center of the disc 173 than is the hole 181_b, is located in the first angular position to the right of the hole 181_a. Hole 181_d, which is "h" units closer to the center of the disc 173 than hole 181_c, however, is located on the next angular position to the left of hole 181_b. This left and right arrangement continues to the portion of the disc 173 diametrically opposite the portion occupied by hole 181_a, which is shown, with exaggerations similar to Fig. 16, in Fig. 17. Hole 181_z, which, of all the holes in the series, is closest to the center of the disc 173, is diametrically opposite hole 181_a. Hole 181_y, which is "h" units farther from the center of the disc 173 than is hole 181_z, is located on the next angular position to the right of hole 181_z. Hole 181_x, which is "h" units farther from the center of disc 173 than is hole 181_y, is located on the angular position to the left of hole 181_z.

The other holes 181 on the disc 173 are arranged in similar manner, the entire series of holes thus resembling a circle, but, as will be seen from the foregoing description, this is not a true geometrical circle. It will be understood that the use of the letters of the alphabet as subscripts designating particular holes 181 is not intended to limit the number of holes 181 on the disc 173 to the number of letters in the alphabet. On the contrary, the number of holes 181 may be made any desired number, depending upon numerous factors, such as the number of scanning beams it is desired to produce for the particular kind of measurement in hand. In Fig. 15, for example, there is shown a total of eighty-four holes 181, three of which 181_a, 181_b and 181_c are preferably covered to provide a dead angle θ analogous to the dead angle β of the Fig. 1 embodiment.

The dead angle θ is provided to eliminate measurement error due to possible slight under-running or over-running of the one-turn clutch 14 as discussed hereinbefore in the description of the Fig. 1 embodiment. The dead angle θ is defined as the minimum angle through which the shaft 175 must be turned after the completion of the scanning by the last hole 181_e, for example, in order to bring the hole 181_d, for example, into position to begin scanning. In the description of the disc 173 hereinbefore presented the inclusion of the holes 181_a, 181_b and 181_c was for the sake of simplicity, but evidently it is unnecessary to produce said holes. It will be understood that the appearance of the holes 181_a, 181_b and 181_c in Fig. 15 as well as the mention of said holes in the description hereinbefore is intended to represent the positions which said holes would occupy, which positions must be known in order to design the disc 179.

The driving pins 183 on the disc 179 are disposed in a series the line of centers of which is preferably identical, both in size and shape, to the line of centers of the series of holes 181 on the scanning disc 173. It is not necessary that there be one pin 183 for each hole 181, but this is a desirable minimum number of pins.

In Fig. 18, for example, a total of one hundred and sixty-eight pins 183 are provided, or, in other words, two pins 183 for each hole 181. It will be understood that pins 183 are provided in positions corresponding to those of the covered or non-provided holes 181_a, 181_b, and 181_c. The line of centers of the pins 183 is the same, both as to form and as to size, as the line of centers of the holes 181. The outermost pin 183_a is positioned on the drive disc 179 at such a position that when it is on the center of the pinion 171, the hole position 181_a is in the center of the optical system represented by the lenses 21 and 23. The same relation exists between the innermost pin 183_z and the innermost hole 181_z, and all other corresponding intermediate holes or hole positions and pins.

The width of the pinion 171 is such that, without longitudinal motion it is capable of engaging all of the pins 183 on the disc 179, from the outermost pin 183_a to the innermost pin 183_z.

The disposition of pins 183 and holes 181 as thus described results in the achievement of a drive for the scanning disc 173 that may be explained as follows, assuming the shaft 167 to be rotating at constant speed: Whatever hole 181 happens to be in position between the lenses 21 and 23, is moving at an angular rate determined by the distance of its corresponding pin 183 from the center of the drive disc 179. This is true because the pinion 171 rotates at a constant speed, but it drives the disc 179 at varying radii, thus changing the angular speed of rotation of the disc 179 and hence the angular speed of rotation of the scanning disc 173. Each hole 181 is driven across the optical system at the same linear speed as all of the other holes, although its angular speed is different from that of any of the other holes.

It is evident that the mechanism of the present embodiment is such that the linear speeds of all holes 181 are constant relative to the speed of shaft 161 regardless of the speed of said shaft, and therefore that all of the holes 181 produce scanning beams which move across the work piece 25 with the same linear speed relative to the angular speed of the shaft 161; hence accuracy is achieved in the registering or recording of area by the counter 44 in the same general manner as was the case with the Fig. 1 embodiment.

It will now be seen why all of the holes 181, and pins 183, are arranged in an approximately circular, eccentric line of centers, rather than in a spiral series. By the approximately circular arrangement specified, the change of angular spacing of the adjacent pins 183 is so small as to be without any substantial binding effect on the engagement of the pinion 171 with the pins 183, around the entire line of pins 183. If a spiral arrangement of pins 183 were used, there would be a considerable radial gap between the first or outermost pin of the spiral and the last or innermost pin of the spiral, and this gap would represent a relatively great and abrupt change in the angular spacing of the pins 183, which abrupt change in spacing would interfere considerably with the meshing of the pins 183 with the pinion 171.

In operation, the embodiment of Fig. 14 acts in a manner analogous to that hereinbefore described for the embodiment of Fig. 1. The motor 13 runs constantly, thus driving the shaft 105 constantly. When a work piece 25 is in the correct position in front of the reflector 27, the knob 147 is pulled and the one-turn clutch 14 permits the shaft 161 to make one revolution, which causes the disc 173 to make one revolution. When the first hole 181 begins to scan the combination of reflector 27 and work piece 25, periodic timing device 37 closes the external circuit of the relay 33 and the electromagnetic clutch 35 through the action of the relay 36 and the photoelectric cell 29 is placed in control of the electromagnetic clutch 35 in such a way that when the light of a scanning beam is not reflected to the cell 29 by the reflector 27, due to interception of the beam by the work piece 25, the electromagnetic clutch 35 is energized and an integrating operation is performed by the counter 44 in the same manner as in the Fig. 1 embodiment. When the last hole 181 completes its scanning of the combination of reflector 27 and work piece 25, periodic timing device 38 acts through relay 36 to open the external circuit of the relay 33 and the electromagnetic clutch 35 so that the counter cannot increase its reading until the beginning of the next scanning process. Following the completion of the scanning process, and at the completion of the one revolution of the shaft 161 permitted by the one-turn clutch 14, the shaft 161 stops rotating. After the reading of the counter 44 has been noted and recorded, the coupling 45, connecting the electromagnetic clutch 35 to the shaft 41, is opened and the hand wheel 46 is rotated in the forward direction until the counter 44 reads exactly "zero" or any other predetermined number. The coupling 45 is then closed to connect the electromagnetic clutch 35 to the shaft 41 and the apparatus is ready for another measurement of area.

Because of the disposition of the scanning holes 181 on the disc 173, the order in which the increments of the work piece 25, are scanned, is somewhat different from the order in the case of the Fig. 1 embodiment. It will readily be seen, however, that the order of scanning is without effect on the accuracy of the area measurement, since all of the increments are scanned once and only once, although adjacent increments are not in general scanned by successive beams.

Because of the unequal angular spacing of the holes 181, the aperture 30 of mask 28 in the Fig. 14 embodiment will not have the same shape as in the Fig. 1 embodiment.

The diameter of any scanning hole 17 in the

Fig. 1 embodiment, or 181 in the Fig. 14 embodiment, should be such that the spot it produces on the work piece 25 is not greater in diameter than the width of the increment to be scanned thereby. In the drawings, the diameters of holes 17 and 181 are necessarily enlarged, relative to the diameters of the respective scanning discs, for clarity.

The angular spacing of the scanning holes of either embodiment may readily be calculated from the width of the work piece 25 to be measured and the constants of the optical system employed.

Many of the devices shown in the drawings may readily be replaced by other devices performing the same functions in the system. For example, the reflector 27 instead of being spherical may be made up of a plurality of relatively small, properly positioned plane mirrors. The electromagnetic clutch 35 and counter 44, constituting the integrating mechanism of the apparatus illustrated, may be replaced as below indicated, or may have any other form, such as an electrically operated ratchet motor. The one-turn clutch 14 may be replaced by any other device which will perform the same function.

The photosensitive device 29 may be of any type of sufficient sensitivity for the purposes required.

As stated hereinbefore the size and position of the reflector 27 are such that the conical projection of the scanned area on the plane of the work piece 25 does not extend beyond the conical projection of the reflector 27 on the plane of the work piece 25, said scanned area being limited by the aperture 30 of mask 28. If the action of the relay 33 is reversed so that the electromagnetic clutch 35 is mechanically connected to the counter 44 when any scanning beam is reflected to the photosensitive device 29, the conical projection of the scanned area on the plane of the work piece 25 can be evaluated by operating the area measuring apparatus in the usual manner when no work piece 25 is in position to intercept scanning beam light. With the action of the relay 33 still reversed in said manner the area of a work piece 25 can be found, after operating the area measuring apparatus in the usual manner with the work piece 25 in position for measurement, by subtracting the observed area from the known value of the conical projection of the scanned area on the plane of the work piece 25. This involves no change in the principles of the invention as it merely means designating the uncovered conical projection of the scanned area on the plane of the work piece 25 as the area to be measured, and for convenience said method of determining the area of a work piece 25 may be called "the subtraction method."

If the subtraction method of area measurement is used certain modifications in the design of the reflector 27 may be made advantageously. For example, if the reflector 27 is made of a discontinuous type, wherein reflecting areas alternate with areas not reflecting sufficient light to the photosensitive device 29 to actuate it, the light received by the photosensitive device will be pulsating, and the output of the amplifier 31 is an alternating current which may be rectified and used to operate an integrating mechanism controlled by direct current, or which may be used without rectification, if at a suitable frequency, to actuate a self-starting synchronous clock-type motor as an integrating mechanism. The same effect may be achieved with a continuously reflecting mirror 27 by making the light source 19 operate intermittently, or by placing a continuously operating shutter or light chopper in such a position as to interrupt the scanning beams.

It may here be pointed out that photosensitive devices are essentially detectors of radiation. Thus, the radiations usable in the present invention are not confined to visible light rays but may include supersonic waves, infra-red rays, and ultra-violet rays, providing these radiations are not harmful to the material being measured, and provided suitable radiation detectors are used. All such radiations are comprehended to be within the scope of the term "light" as herein used.

One of the principal objects of the present invention is to attain high accuracy in the measurement of area. It is readily understood that the accuracy of measurement of any quantity, such as area, is limited by the precision with which the various parts of the measuring apparatus function and is limited by the manner in which the measuring apparatus is used. It is also readily understood that perfect measurements of any quantity, such as area, are impossible to make, and that commonly the operator of the measuring apparatus realizes that there is always present a minimum error in a measurement of the quantity, said error being caused by imperfections in the design or/and construction of the apparatus and by imperfect methods of use of the apparatus. As an example, in the measurement of length with the aid of a common steel rule or scale the accuracy of the measurement is limited by a number of factors such as imperfections in the lay-out of the lines on the scale, the resolving power of the eye which may be determined, for example, by the quality of the eyesight or by the quality of the illumination, the fineness and proximity of the rulings, and the care with which the scale is used.

Since many errors may enter into the measurement of any quantity it is necessary to reduce each error to such a magnitude that the maximum resultant error is not greater than the allowable error set by some predetermined accuracy which suffices.

In commercial practice it is usual to define the error in terms of the maximum magnitude of the quantity which can be measured so that, for example, if the maximum length L which a device can measure in a single complete measurement is 10 inches the maximum relative error may be expressed as 0.1 per cent. of 10 inches, so that any one observed length may differ from the true length by as much as 0.01 inch, regardless of whether the actual length is 0.1 inch or 10 inches, for example.

In the measurement of a quantity by a series of steps, such as the measurement of the individual areas of different parts of a surface and then adding together the results of the separate measurements, there are three types of errors which must be taken into consideration, viz., random errors, constant errors and periodic errors. Random errors, such as might result from backlash in a mechanical linkage or in a gear train, often have a tendency to cancel one another but in many cases they do not cancel one another completely and therefore should be reduced as much as possible by precision construction. Constant errors may be due to incorrect proportionality between speeds of moving parts, for example, or failure of the counter to record the last unit in a series of units being integrated, for example. Constant errors are generally easily eliminated or rendered negligible through correct design. Periodic errors are those which periodically repeat themselves, usually in a predictable manner, such as change in speed due to distorted gears, and such errors may or may not tend to cancel one another depending on the part of the measuring apparatus in which they appear and on their frequency, and should in general be eliminated as nearly completely as possible directly or indirectly, by precision construction.

It is to be understood that in designing the herein described area measuring apparatus due attention has been paid to all potential sources of error and that many of the features of the invention have been introduced for the purpose of reducing the cumulative error to such an extent that the measurement of area may be made with a degree of accuracy hitherto unattainable with commercial area measuring machines. Although great care has been exercised in the design of the hereinbefore described embodiments of the invention, it is assumed and expected that equally great care will be exercised in the construction and use of the area measuring apparatus.

In the hereinbefore described embodiments of the invention, sources of measurement error lie in the optical system, including the lenses 21 and 23 and the disc 1, and in the linear speeds of the scanning beams as they sweep across the work piece 25 relative to the angular speed of the shaft 43 of the counter 44. The lenses 21 and 23 are preferably of such high quality that the images of the holes 17 in the disc 1 on the work piece 25 are sharply defined and the median lines of the paths R_a, R_b R_c, etc. of said images on the work piece 25 are true arcs of circles having radii which are proportional to the radii of the respective holes 17. The holes 17 in the disc 1 are precisely located both angularly and radially and the thickness of the disc around each hole 17 is made as small as practicable, as by grinding, for example.

The linear speeds of the scanning beams as they sweep across the work piece 25 relative to the angular speed of the shaft 43 of the counter 44 are determined by a number of factors in addition to those which have been discussed in detail hereinbefore. The relative linear speeds of the scanning beams are affected by all types of speed errors in the moving parts of the apparatus beyond the one-turn clutch 14 such as the gears 39, for example, and by vibration and accidental movement of the scanning apparatus, or of parts thereof, which may produce a movement of the light beam across the work piece 25 and so cause false measurement. The relative speed errors of moving parts are eliminated as nearly completely as possible through precision construction of the component parts and any residual errors are reduced as required by any of the methods well known to and commonly used by instrument makers skilled in their art. For example, if the rate of rotation of the spur gear 53 is not proportional at all times to the rate of linear displacement of the rack 61 because of an error in the spacing or shaping of the teeth of either of said members, correction can be applied directly to the teeth of the gear 53 or the teeth of the rack 61, or it can be applied indirectly to the contour of the cam 65 so that the error in the relative rate of rotation of the gear 53 cannot produce a serious error in the relative rate of rotation of the disc 1. Random speed errors are eliminated as nearly completely as possible through precision construction and through rigidity of mounting of all parts such as the lenses 21 and 23, the mask 28 and the bearings of the shafts 3, 7, and 67, for example. Backlash error of all moving parts such as the gears 39, for example, is reduced to a minimum through precision construction and through the introduction of the brakes 12 and 47 on the shafts 3 and 43, respectively, of the first embodiment and on the shafts 175 and 43, respectively, of the second embodiment. In the first embodiment, any backlash in the gears 47 and 59 of the differential 5, for example, may result in backlash between the shafts 3 and 7 during the time in which the disc 1 loses its advanced angular displacement relative to the cam 65, but said backlash is easily reduced to such an extent that the brake 12 removes said backlash completely during the dead period of rotation of the shaft 7 defined by the dead angle β. Rotating parts, such as the cam 65 and the gear 179, are statistically balanced to prevent unwanted rotation due to the force of gravity.

It is important that the distance of work pieces 25 from the lens 23, measured along the axis of the lens 23, be constant and correct and that the plane of work pieces 25 be parallel to the plane of the disc 1 because otherwise serious measurement errors may result. For the same reason it is important that the distance of the disc 1 from the lens 23, measured along the axis of the lens 23, be constant and correct, and to insure this condition all lengthwise displacement of the shafts 3 and 175 is prevented by suitable thrust bearings 9 and 11, and 176 and 178, respectively.

None of the requirements hereinbefore mentioned for attaining high accuracy of area measurement is to be considered as a limitation of said accuracy, because the layout and construction of the apparatus is simple and straightforward and the required precision of design and construction of the apparatus falls within the limits of precision normally encountered in the design and construction of high grade chronometer mechanisms and high grade motion picture projectors, for example.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As many changes could be made in carrying out the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

We claim:

1. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric circular paths on said surface, and means rotating said scanning means in such manner that the linear speeds of all of said beams along said paths are substantially equal.

2. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric circular paths on said surface, and means rotating said scanning means in such manner that the angular speed of said scanning means is progressively increased as the radius of said circular paths on said surface decreases.

3. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric circular paths on said surface, and means rotating said scanning means in such manner that the linear speeds of all of said beams along said paths are substantially equal, said last-named means including a shaft rotating at a predetermined angular speed, and a cam-controlled differential interposed between said shaft and said scanning means.

4. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric circular paths on said surface, and means rotating said scanning means in such manner that the linear speeds of all of said beams along said paths are substantially equal, said last-named means including a shaft rotating at a predetermined angular speed, and a cam-controlled differential interposed between said shaft and said scanning means, the said cam being designed so that the differential advances the scanning means relative to the said shaft in a predetermined manner during part of a single rotation, and then permits the scanning means to slow up until joined by said shaft during the remainder of said single rotation.

5. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric circular paths on said surface, and means rotating said scanning means in such manner that the linear speeds of all of said beams along said paths are substantially equal, said last-named means including a shaft rotating at a predetermined angular speed, and a cam-controlled differential interposed between said shaft and said scanning means, the said cam having a spiral shape.

6. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric circular paths on said surface, and means rotating said scanning means in such manner that the linear speeds of all of said beams along said paths are substantially equal, said last-named means comprising a crown gear of approximately circular shape, but rotating about an eccentric center, said crown gear being connected for rotation with said scanning means, and a pinion engaging said crown gear and moving with substantially uniform angular speed.

7. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially uniform linear speed relative to the angular speed of the disc.

8. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed relative to the angular speed of the disc, the said holes being substantially all disposed at uniform linear distances apart near the periphery of said disc.

9. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of the disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed relative to the angular speed of the disc, the said holes being disposed at predetermined angular distances apart, the line of centers of said holes being a spiral on said disc.

10. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed relative to the angular speed of the disc, the said holes being substantially all disposed at substantially uniform linear distances apart near the periphery of said disc, the line of centers of said holes on said disc being approximately a circle, the center of which is eccentric with respect to the center of the disc.

11. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed relative to the angular speed of the disc, the said holes being disposed at substantially uniform angular distances apart, except for two holes, which are spaced apart a greater angular distance than any two of the remaining holes.

12. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed relative to the angular speed of the disc, the said last-named means comprising a rotating shaft, a differential interposed between said shaft and said scanning disc, and a cam controlling the operation of said differential.

13. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed relative to the angular speed of the disc, the said last-named means comprising a second disc rotatable with said scanning disc, said second disc having pins mounted thereon along a line of centers equivalent in size and shape to the line of centers of the holes in said scanning disc, and a rotating pinion engaging said pins to drive the said second disc.

14. A scanning disc containing a spiral arrangement of beam-controlling holes, the distances of successive holes along the spiral, from the center of the disc, increasing by a uniform distance, said holes being spaced apart by equal angular distances, except for two of the holes, which are spaced apart an angular distance in excess of the angular distances between any two of the remaining holes.

15. A scanning disc containing a plurality of beam-controlling scanning holes, each of said holes being located at a distance from the center of the disc which differs by a predetermined uniform amount from the distance of one other hole from the center of the disc, the line of centers

of said holes being approximately in the form of a circle having its center displaced from the center of rotation of the disc, said holes being disposed at substantially uniform linear distances apart.

16. In area measuring means, a rotatable scanning disc having holes therein adapted to establish scanning beams sweeping increments of the surface to be measured, photoelectric means for detecting the lengths of the paths on said surface, area integrating means under the control of said photoelectric means, and means rendering said integrating means inoperative for longer than one complete rotation of the scanning disc, for any one measurement.

17. In area measuring means, a rotatable scanning disc having holes therein adapted to establish scanning beams sweeping increments of the surface to be measured, photoelectric means for detecting the lengths of the paths on said surface, area integrating means under the control of said photoelectric means, and means rendering said integrating means inoperative for longer than one complete rotation of the scanning disc, for any one measurement, said last-named means comprising a one-turn clutch mechanism, and manually operable means for controlling said clutch.

18. In area measuring means, a rotatable scanning disc having holes therein adapted to establish scanning beams sweeping increments of the surface to be measured, photoelectric means for detecting the lengths of the paths on said surface, area integrating means under the control of said photoelectric means, and means rendering said integrating means inoperative for longer than one complete rotation of the scanning disc, for any one measurement, said last-named means comprising a one-turn clutch interposed in the drive of said scanning disc.

19. In area measuring means, the provision of a rotatable scanning disc having holes therein adapted to establish scanning beams sweeping increments of the surface to be measured, photoelectric means for detecting the length of the paths on said surface, electrically controlled area integrating means under the control of said photoelectric means, and means rendering said integrating means inoperative for longer than one complete rotation of the scanning disc, for any one measurement, said last-named means comprising a one-turn clutch, and electrical switching means associated therewith, said electrical switching means being in series with the electric control of said integrating means.

20. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric circular paths on said surface, and means rotating said scanning means in such manner that the linear speeds of all of said beams along said paths are substantially equal relative to the angular speed of the said rotating means.

21. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by said holes move at predetermined different angular speeds relative to the angular speed of said rotating means.

22. In area measuring means, a scanning disc having a series of scanning-beam forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed, said rotating means moving at predetermined different angular speeds.

23. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed relative to the angular speed of the disc, said holes being disposed at predetermined angular distances around the periphery of said disc.

24. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speed, the said holes being disposed predetermined different angular distances apart.

25. In area measuring means, a scanning disc having a series of scanning beam-forming holes therein, said holes being disposed at uniformly differing distances from the center of said disc, and means rotating the said disc in such manner that the scanning beams produced by all of said holes move at substantially the same linear speeds relative to the angular speed of the disc, said holes being disposed predetermined different angular distances apart, the line of centers of said holes being a spiral on said disc.

26. In area measuring means, a rotatable scanning disc having holes therein adapted to establish scanning beams sweeping increments of the surface to be measured, photoelectric means for detecting the length of the paths on said surface, area integrating means under the control of said photoelectric means, and means rendering the integrating means inoperative for more than the length of time required by one complete series of scanning beams to sweep the surface to be measured.

27. In area measuring means, a rotatable scanning disc having holes therein adapted to establish scanning beams sweeping increments of the surface to be measured, photoelectric means for detecting the length of the paths on said surface, area integrating means under the control of said photoelectric means, means rendering the integrating means inoperative for more than the length of time required by one complete series of scanning beams to sweep the surface to be measured, and means further rendering said integrating means inoperative for longer than one complete rotation of the scanning disc, for any one measurement.

28. In area measuring means, scanning means adapted to sweep scanning beams across a surface to be measured tracing concentric curved paths on said surface, means rotating said scanning means, photosensitive means positioned to detect when a beam is intercepted by said surface, and integrating means electrically controlled by said photosensitive means, and means mechanically driving said integrating means in accordance with the linear speeds of said beams along said paths.

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