

July 9, 1968

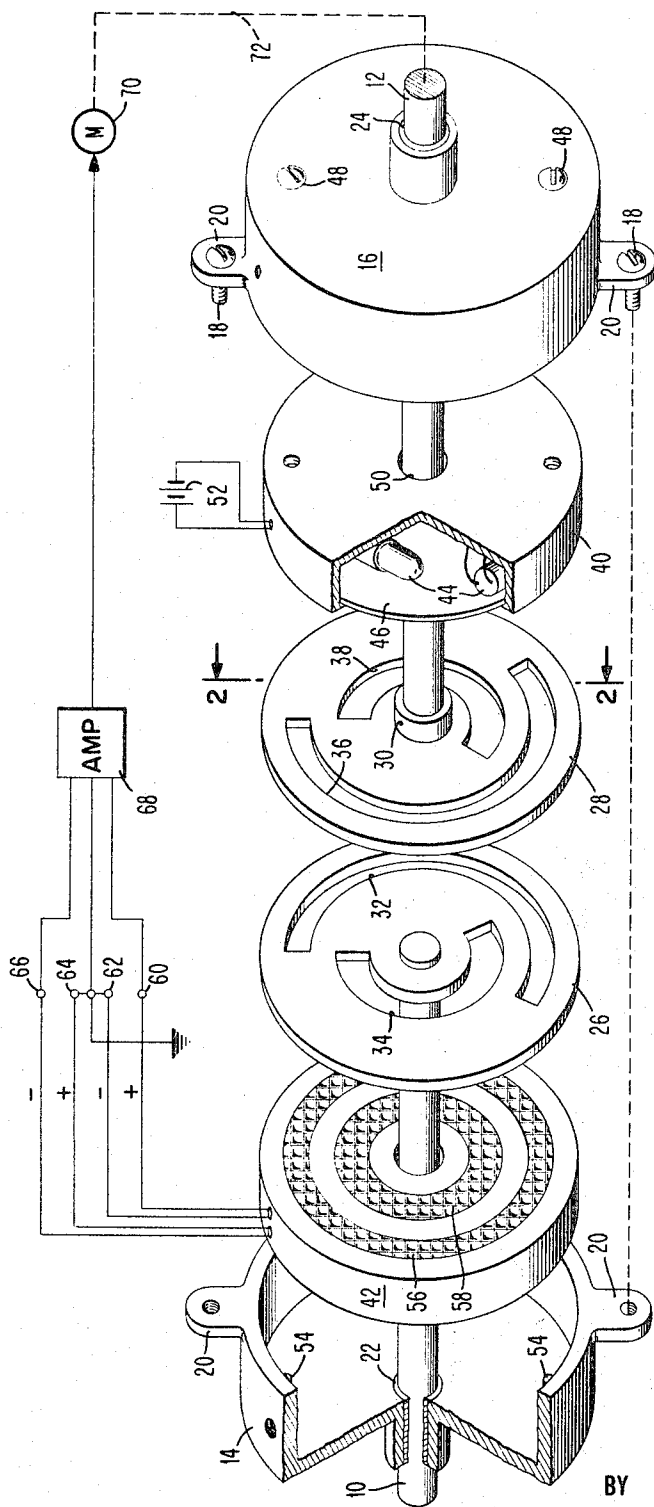
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3,392,283

TORQUELESS COUPLER HAVING ANNULAR PHOTORESPONSIVE METHOD

Filed May 25, 1964

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

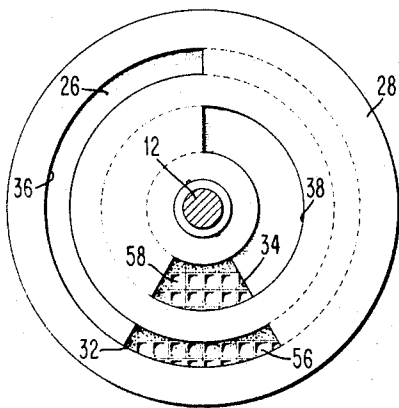


FIG. 2

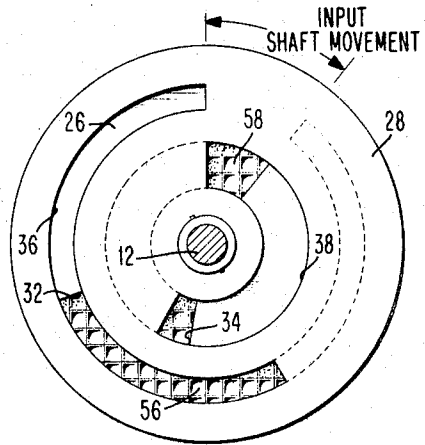


FIG. 3

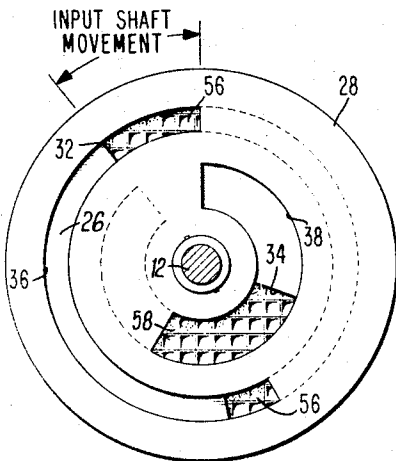


FIG. 4

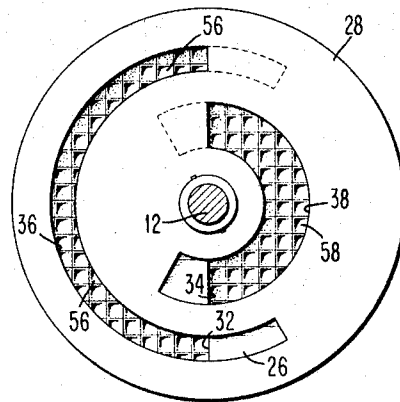


FIG. 5

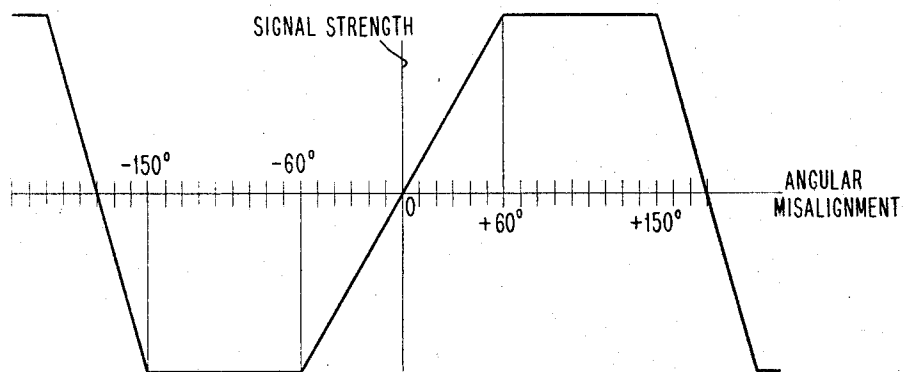


FIG. 6

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TORQUELESS COUPLER HAVING ANNULAR PHOTORESPONSIVE METHOD

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8 Claims. (Cl. 250-204)

The present invention relates generally to servomechanisms and more particularly to improvements in torqueless coupling means.

In many situations in the present day electrical and mechanical arts, it is desirable to accurately follow the movements of a member such as a shaft without in any way disturbing or affecting that movement. It is also frequently desirable to use a low power input member to drive a relatively large load. In situations such as these, devices known variously as power assist mechanisms, follow-on devices or torqueless couplers are employed. These devices have the characteristic that they can drive an output member accurately in response to movements of an input member without placing any of the output load on the input member.

Torqueless coupling devices are known in the art. One such coupler makes use of optical means for accurately positioning an output shaft with respect to movements of an input shaft. Shutters and light sensing devices detect input shaft movement and supply corresponding signals to produce the follow-on movement of the output shaft. This type of device offers the advantage of complete absence of physical connection between the input members and the follow-on apparatus. Thus, no torque is applied to the input means and, in fact, complete physical isolation between the input and output means (as by transparent barrier) is possible.

It is the object of this invention to provide an improved torqueless coupler which has the advantages just described and which is substantially simpler in construction and operation than known devices of this type.

More particularly, it is an object of this invention to provide a torqueless coupler which makes use of the control of radiation between a source and sensing means to control an output shaft in accordance with movements of an input shaft, and which includes simpler and more economical coupling apparatus.

Another object of the invention is to provide a simple and efficient torqueless coupler which has but one stable quiescent position so that angular position errors between the input and output means are avoided.

An additional object of the invention is to provide a device of the character described which is rugged, reliable, and compact and, therefore, suitable for use in such diverse environments as industrial process control systems, space vehicles, or data processing systems.

Briefly described, the present invention makes use of a pair of slotted shutter members mounted respectively on an input and an output shaft to control the amount of radiation passing from a radiation source to radiation sensing means. The sensing means comprises two concentrically arranged ring-shaped radiation responsive devices. These devices are of a type which provides an output manifestation which is proportional to the amount of radiation received. The outputs of the radiation response device are connected in opposed relation. Each of the shutter members has arcuate slots therein arranged so that when the two shafts are in proper angular alignment the slots permit illumination of equal areas of the respective radiation responsive devices. In this position the opposed outputs of the devices are balanced and a stable null condition exists. Rotation of the input shaft in either direction from the null position causes the

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slotted shutter members to uncover more of one of the radiation responsive devices than the other to produce an unbalance in the output and, consequently, a net output manifestation of one polarity or the other. This unbalance output is employed to control a reversible motor which drives the output shaft to follow the input shaft movement until the null position is reattained.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings.

In the drawings:

FIGURE 1 is an exploded perspective illustration of a torqueless coupler embodying the present invention;

FIGURE 2 is a somewhat diagrammatic illustration taken generally along the line 2-2 of FIGURE 1 and showing the relation of the shutter members when the input and output shafts are in the stable null position;

FIGURE 3 is a view similar to FIGURE 2 but showing the relative positions of the shutter members as the input shaft is rotated in a clockwise direction;

FIGURE 4 is a view similar to FIGURE 2 but showing the relative positions of the shutter member when the shaft is rotated in a counterclockwise direction;

FIGURE 5 is a view similar to FIGURE 2 but showing the relative positions of the shutter members when the shafts are in an unstable null position; and

FIGURE 6 is a chart showing the response of the coupler to angular misalignment.

Referring now in detail to the drawings, and to FIGURE 1 in particular, the improved torqueless coupler provided in accordance with this invention is shown as connecting an input shaft 10 and an output shaft 12. The coupler includes two cylindrical housing members 14 and 16 which contain the coupling apparatus and which are secured together in abutting relationship by screws 18 and cooperating ears 20.

The housings 14 and 16 include bearing members 22 and 24 which rotatably support the shafts 10 and 12, respectively. The shafts 10 and 12 are not physically connected one to the other and their adjacent ends are apart a short distance within the housings 14 and 16. Circular opaque shutter members 26 and 28 are mounted to the adjacent ends of the shafts 10 and 12. Each shutter member is nonrotatably secured to the associated shaft by suitable means such as the pin 30 shown in FIGURE 1. Each shutter member 26 or 28 is of a diameter only enough smaller than the internal diameter of the housing to avoid frictional engagement and has therein transparent areas in the form of a pair of arcuate slots. The slots in member 26 are identified by the reference characters 32 and 34 while the slots in member 28 are identified by the reference characters 36 and 38. Each slot forms a portion of an annulus. The slots 32 and 34 in the member 26 are concentrically arranged and are designed so that their areas are equal. As may be seen more clearly from FIGURE 2, these slots preferably have the same arc length and are made equal in area by varying their width. Thus, if R_1 is the radius of the inner edge of slot 32 and W_1 is the width of the slot, and if R_2 is the radius of the inner edge of slot 34 and W_2 its width, then the following relation exists:

$$2R_1W_1 + W_1^2 = 2R_2W_2 + W_2^2$$

The arc length of the slots 32 and 34 is in excess of 180° and substantially less than 360° . Effective operation is realized with slot lengths of about 210° . It will be observed that the concentric slots 32 and 34 are arranged so that they are in radial alignment at one end but extend in opposite directions and occupy opposite halves of the circular shutter member. The slots 36 and 38 in the shut-

ter member 28 are identical to the slots 32 and 34, respectively, with the exception that they are reversed. Thus, with the shutter members 26 and 28 positioned so that the radially aligned ends of the slots therein are at the top, and with shafts 10 and 12 axially aligned, the corresponding slots in the two members are diametrically opposed.

The shutter members 26 and 28 are interposed between a radiation source 40 and radiation sense means 42 mounted within the housings 14 and 16. The radiation source 40 includes a plurality of lamps 44 mounted behind a diffusing lens 46. The source 40 is secured within the housing 16 by suitable means such as the screws 48 with the lens 46 facing inwardly. A central aperture 50 is provided in the member 40 to admit the output shaft 12 without frictional engagement. While incandescent lamps are shown in the illustrative embodiment, it is apparent that the source 40 may employ other illuminating means such as, for example, electroluminescent panels.

When the lamps 44 are illuminated, for example, by connection to a power source diagrammatically indicated at 52 of FIGURE 1, the lens 46 provides a substantially uniform amount of radiation from all portions thereof directed toward the shutter members 26 and 28.

The sensing means 42 is mounted within the housing 14 and on the opposite side of the shutter members 26 and 28 from the radiation source 40. It is secured to the housing 14 by suitable means such as the screws 54. The sensing means 42 comprises a pair of concentric, ring-shaped radiation responsive device 56 and 58. In the embodiment shown in FIGURE 1, these devices take the form of voltage generating photocells. The photocells 56 and 58 are arranged to have equal exposed areas. They correspond in radial dimensions and width to the slots 32-38. The outer photocell 56 is axially aligned with and has the dimensions of the outer slots 32 and 36 of the shutter members 26 and 28 and the inner photocell 58 is axially aligned with and has the dimensions of the slots 34 and 38 of the shutters 26 and 28.

The voltage output of photocell 56 is supplied to terminals 60 and 62 with the polarities shown by the symbols "+" and "-" in FIGURE 1. The terminals 62 and 64 are connected together to ground and the terminals 60 and 66 are connected as inputs to a DC amplifier 68. With this arrangement, the amplifier 68 receives and amplifies an unbalance signal which represents the net difference between the outputs of photocells 56 and 58. If the output of photocell 56 is greater than that of photocell 58 this net difference signal will be positive with respect to ground whereas if the output photocell 58 is the larger this net difference signal will be negative with respect to ground. The output of the DC amplifier 68 is employed to drive a reversible servomotor 70. The servomotor 70 is mechanically coupled to the output shaft 12 by suitable drive connection indicated by the dotted line 72. The servomotor 70 is connected so that a positive signal supplied from amplifier 68 drives the output shaft 12 in a clockwise direction and a negative signal supplied from amplifier 68 drives the output shaft in a counterclockwise direction. The servomotor thus causes the output shaft 12 to be rotated in the direction of rotation of the input shaft 10 until the null position is reached and the unbalance signal disappears. The speed at which the servomotor 70 operates is proportional to the magnitude of the signal from amplifier 68.

FIGURE 2 of the drawings shows the relative positions of the shutter members 26 and 28 when the input and output shafts are properly aligned. This figure illustrates the respective areas of the photocells 56 and 58 which are uncovered by the slots in the members 26 and 28 in this situation. It will be observed from FIGURE 2 that in the stable null position equal areas of the photocells 56 and 58 are exposed to the light source 40. The area of each photocell exposed is proportional to twice the amount by which each slot 32-38 exceeds 180° of arc. For ex-

ample, if each slot 32-38 is arranged to have an arc length of 210°, then 60° of arc will be exposed in the stable null position. Since the photocells 56 and 58 are oppositely monitored, the net output in this situation is zero, and the motor 70 does not drive the output shaft 12.

FIGURE 3 illustrates the effect of movement of the input shaft 10 in the clockwise direction. In FIGURE 3, it is assumed that the shaft 10 and its shutter 26 have been rotated, but that no corresponding rotation of shaft 12 and shutter 28 has yet occurred. It will be observed that the exposed area of the outer photocell 56 has been increased by an amount proportional to the input shaft movement. The exposed area of photocell 58, however, remains constant. The reason for this is that the upper edges of the slots 34 and 38 were in radial alignment in the stable null position, so clockwise movement of shaft 10 produces an overlap at that end. Thus, as the exposed area of the photocell is reduced at the lower edge of slots 34 and 38 by movement of shutter 26, an exposed area of equivalent size is created at the upper edges of these slots.

The effect of counterclockwise movement of shaft 10 is shown in FIGURE 4. It will be observed that movement in this direction produces an effect which is equivalent but opposite to that shown in FIGURE 2. The exposed area of inner photocell 58 is increased, while the exposed area of outer photocell 56 is held constant.

Since the output signal from amplifier 68 is proportional to the difference in exposed areas of photocells 56 and 58, this output signal will increase from zero in a positive sense as the angular misalignment between shafts 10 and 12 increases in a clockwise direction. The output signal will increase in a negative sense in response to increasing counterclockwise angular misalignment.

The chart of FIGURE 6 illustrates the response of the coupler over 360° of angular misalignment between the input and output shafts. The horizontal axis of the chart represents clockwise (+) and counterclockwise (-) misalignment and the vertical axis represents output signal magnitude. It will be observed that with the slot pattern of FIGURE 1, angular misalignment from 0° to 60° (the arc length of overlap of the slots at the stable null position) produces an output which increases linearly with the amount of misalignment. As indicated earlier herein, this linear increase occurs because the exposure of one photocell is being increased at a fixed rate while the exposure of the other is held constant. From 60° to 150° the output is held constant, since in the range of movement the exposure of both photocells is increased equally. At 150°, one set of slots will be fully aligned. From 150° to 180° the signal will decrease rapidly to zero, as the formerly aligned slots move apart and the other set moves toward complete alignment. At 180°, the exposure of the photocells is balanced at what may be termed the "false null" position. Movement beyond 180° reverses the output signal polarity, as will be described later herein.

The coupler provided in accordance with this invention has the advantage that stable angular misalignment between the input and output shafts is not possible. Only one stable null position exists, and that is the position shown in FIGURE 2. Throughout 360° of rotation of the input shaft, there are only two positions where the outputs of the two photocells are equal: the true stable null position, and the false or unstable null position which occurs when the input shaft is rotated 180°. In this position, illustrated in FIGURE 5, the slots 32-38 are arranged so that 180° of each photocell is exposed, and a balanced condition exists. The condition is, however, unstable in that movement of the input shaft in either direction will drive the output shaft away from the unstable null and back to the true null position of FIGURE 2. For example, assume that the parts are in the false null position, and that the input shaft 10 is moved clockwise. This movement will decrease the ex-

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posed area of photocell 5, and increase the exposed area of photocell 58, producing a negative difference signal (see FIG. 6) which will cause the output shaft to move counterclockwise. Counterclockwise movement of the output shaft 12 will increase the negative signal and will continue until the parts reach the stable null position.

Counterclockwise movement of the input shaft away from the false null position of FIGURE 5 causes the exposed area of photocell 56 to increase and that of photocell 58 to decrease, producing a positive signal which will cause the servomotor 70 to drive the output shaft clockwise, thereby increasing the unbalance and producing a return to the stable null.

The true and false null positions just described may be likened, respectively, to positions of a pendulum at rest and balanced above its pivot point. The rest position is stable and the pendulum tends to return thereto when moved. The balanced position above the pivot is not stable since any movement away therefrom causes the pendulum not to return to the balanced position but to move toward the rest position.

The response of the coupler to input shaft movement may be varied by varying the slot patterns in the shutters 26 and 28. To insure a positive positional response for any amount of misalignment between the input and output shafts, and to avoid the presence of more than one stable null position it is necessary that the slots in at least one shutter, taken together, occupy at least 180° of arc, that the slots in at least one shutter be overlapped or at least in radial alignment at one end, and that the slot patterns in the two shutters be reversed, when viewed both from the same position, as in FIGURE 2. Preferably, the slots in both shutters have identical (though reversed) patterns, but this is not an absolute necessity. If the slot pairs in both shutters occupy less than 180° of arc the possibility exists that the shutters may be positioned with the slot patterns in opposite semicircular halves of the shutters, so that movements of one shutter do not produce any change in light distribution to the photocells 56 and 58. If the slots in neither shutter overlap or terminate in radial alignment at neither end, then the possibility exists that the shutters may become aligned such that no slot portions coincide and so that some relative movement is possible without bringing slots into coincidence. Reversal of the slot patterns in the two shutters is necessary to produce opposite effects on the two photocells in response to shutter rotation.

Within the limits just defined, considerable flexibility of slot arrangement is present. Response curves (such as the one shown in FIGURE 6) may be altered as desired by changing the slot design. For example, with the general slot pattern shown in FIGURES 1-5, the length of the flat portion of the response curve may be varied by varying the overlap of the slots 32 and 34 (and, likewise, the slots 36 and 38). If the overlap is reduced to 30°, then the response curve will level out at 30° and remain level until 165°. On the other hand, increasing the overlap will shorten the level portion of the curve. Complete removal of the overlap will cause the output signal to jump to the maximum value in response to any misalignment, and is generally undesirable since it will cause an excessive response which will lead to "hunting" oscillations.

If the overlap is maintained, but the arc lengths of the slots are shortened so that their upper ends move out of radial alignment, the response curve will be found to remain at the maximum for a shorter distance and to fall off with a lesser slope than in the case shown in FIGURE 6. For example, assume a slot pattern wherein the slots in each shutter overlap 60°, but are each only 180° long, thus leaving 60° of unslotted area at the top of the shutter. The response curve for such an arrangement will rise linearly from 0° to 60°, remain level from 60° to 120° and then fall linearly back to zero from 120° to 180°.

Other slot pattern variations will produce further output response changes. Specialized responses may also be achieved by varying slot width as well as length.

While the invention has been described herein as employing light responsive photocells and shutters having opaque and transparent areas, it will be obvious to those skilled in the art that other forms of radiation emitting, shielding and responsive means may be employed. Magnetic flux fields, detectors and shields may also be used. Any arrangements which employ the concentric annular responsive means and shields employing paired slots as disclosed hereinbefore are contemplated by this invention.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. Torqueless coupler means for connecting first and second axially aligned rotatable members to cause one of said members to follow rotation of the other comprising:

a source of radiation;

a pair of radiation responsive devices each having an annular radiation receiving area concentric with the axis of the rotatable members;

means to drive said one of said rotatable members in response to the difference in the amounts of radiation received by said radiation responsive devices; first and second radiation blocking shutter means secured to said first and second rotatable members respectively, both first and second shutter means being disposed between said radiation source and said radiation responsive devices to control the amount of radiation passed to the radiation responsive devices, each of said shutter means having arcuate areas therein transparent to radiation, the transparent arcuate areas in the two shutter means taken together extending at least 360° of arc, said transparent areas in the first and second shutter means being aligned to pass radiation through both shutters and being arranged so that relative rotation of one shutter means with respect to the other causes more radiation to impinge on one of said radiation responsive devices than the other to actuate said means to drive.

2. The invention defined in claim 1 wherein the arcuate transparent areas of each of the first and second shutter means include two portions each positioned to pass radiation to a different one of said radiation responsive devices, the said two portions in each shutter being partially overlapped but not in full radial alignment and the portions in each shutter means together extending through a least 180° of arc.

3. The invention defined in claim 2 wherein the arcuate transparent areas in the two shutter means are mirror images of each other when both viewed from the source of radiation.

4. Coupling means for connecting axially aligned input and output shafts to cause the output shaft to follow movements of the input shaft comprising:

a reversible servomotor drivingly connected to said output shaft;

a light source;

a pair of photocells having coplanar concentric annular light receiving surfaces of equal areas, said photocells providing output manifestations proportional to the amount of radiation received by the light receiving surfaces thereof;

means for driving said reversible servomotor in response to the net difference in outputs from said photocells;

an opaque shutter mounted on and rotatable with each of said input and output shafts, said shutters being

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disposed between said photocells and said light source, each of said shutters having arcuate light transmitting areas therein, the light transmitting areas in each shutter including first and second portions, the first portion being aligned with the annular light receiving surface of the first photocell and the second portion being aligned with the annular light receiving surface of the second photocell, the corresponding portions in the two shutters being arranged so that when the shutters are in one reference relation equal amounts of the first portions and the second portions of the light transmitting areas of the shutters are in alignment between the light source and the photocells so that equal amounts of radiation are transmitted to the first and second photocells and the servomotor is not driven, and the transparent portions in the two shutters being arranged so that relative rotation of the shutters in either direction from said one reference relation increases the extent of alignment of either the first or the second portions but not both whereby to illuminate one photocell more than the other and provide a net output manifestation for driving the servomotor.

5. The invention defined in claim 4 wherein the light transmitting area of each shutter comprises first and second arcuate slots aligned respectively with the annular light receiving areas of the first and second photocells, said first and second slots having equal areas and together occupying at least 180° of arc, said first and second slots being at least in radial alignment at one end and extending in opposite directions from said one end, and the slots in the second shutter being a mirror image of the slots in the first shutter when both shutters are viewed from the light source.

6. The invention defined in claim 5 wherein the slots in each shutter are overlapped at one end, the overlap extending for a distance less than the arc length of either slot.

7. The invention defined in claim 6 wherein the slots are in radial alignment at the other end.

8. Coupling means for connecting axially aligned input and output shafts to cause the output shaft to follow movements of the input shaft comprising:

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a reversible servomotor drivingly connected to said output shaft;

a light source;

a pair of photocells having coplanar concentric annular light receiving surfaces of equal areas, said photocells providing output manifestations proportional to the amount of radiation received by the light receiving surfaces thereof;

means for driving said reversible servomotor in response to the net difference in outputs from said photocells;

a circular opaque shutter mounted on and rotatable with each of said input and output shafts, both said shutters being disposed between said photocells and said light source, each of said shutters having arcuate light transmitting areas therein, the light transmitting areas in each shutter consisting of first and second arcuate slots spaced at two different radial distances from the axis of the associated shaft, the first slot being aligned with and of the same width as the annular light receiving surface of the first photocell and the second portion being aligned with and of the same width as the annular light receiving surface of the second photocell, the two slots in each shutter being of equal arc length and being overlapped for a distance less than the arc length of either slot, the slots in one shutter being reversed with respect to the slots in the other shutter when both shutters are viewed from the light source so that upon rotation of one shutter with respect to the other, one set of corresponding slots moves toward more complete alignment and the other set of corresponding slots moves toward less complete alignment, whereby to produce a difference in the amounts of light transmitted to the photocells and a consequent difference manifestation for driving the servomotor.

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