United States Patent

Low et al.

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[54] CYCLICALLY OPERABLE OPTICAL SHUTTER

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[52] **U.S. Cl.** **95/59**, 95/12.5, 352/169

[51] **Int. Cl.**.....**G03b 9/10**

[58] **Field of Search** 95/59, 61, 11; 352/169

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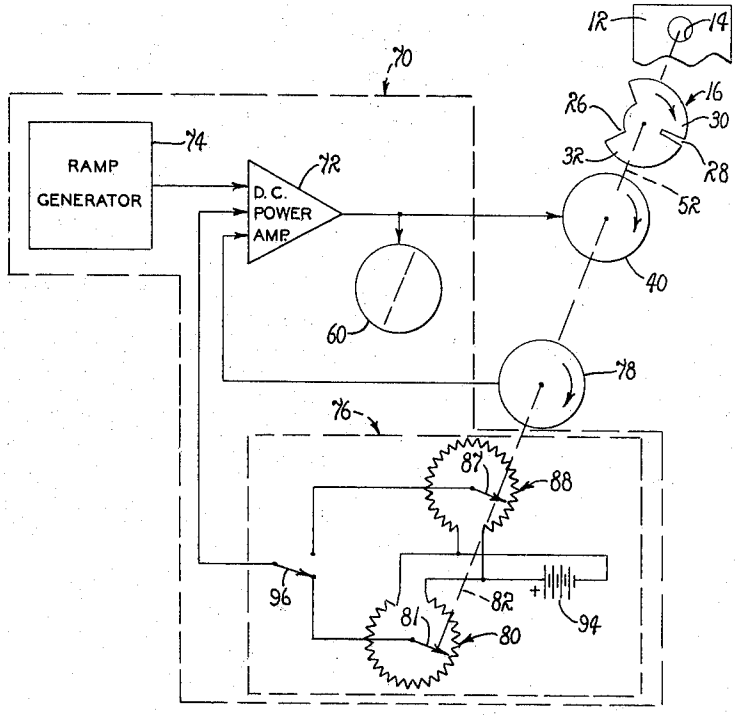
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[57] **ABSTRACT**

A cyclically operable, optical shutter particularly suited for use as a focal plane shutter, characterized by an occulting disk having a pair of radiation occulting sectors defining therebetween a pair of diametrically opposed, radiation transmitting sectors driven in rotation by a D.C. motor. A particular feature of the shutter resides in a combination of a servo-control system with the motor for accelerating the disk from a steady state of zero velocity to a preselected steady state of angular velocity, maintaining the steady state during a predetermined period of radiation transmission, and subsequently decelerating the disk to a steady state of zero velocity within a fraction of a single revolution, whereby a pulse of radiation having a preselected width is gated through an associated aperture with a high degree of uniformity and reproducibility.

8 Claims, 11 Drawing Figures



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SHEET 1 OF 4

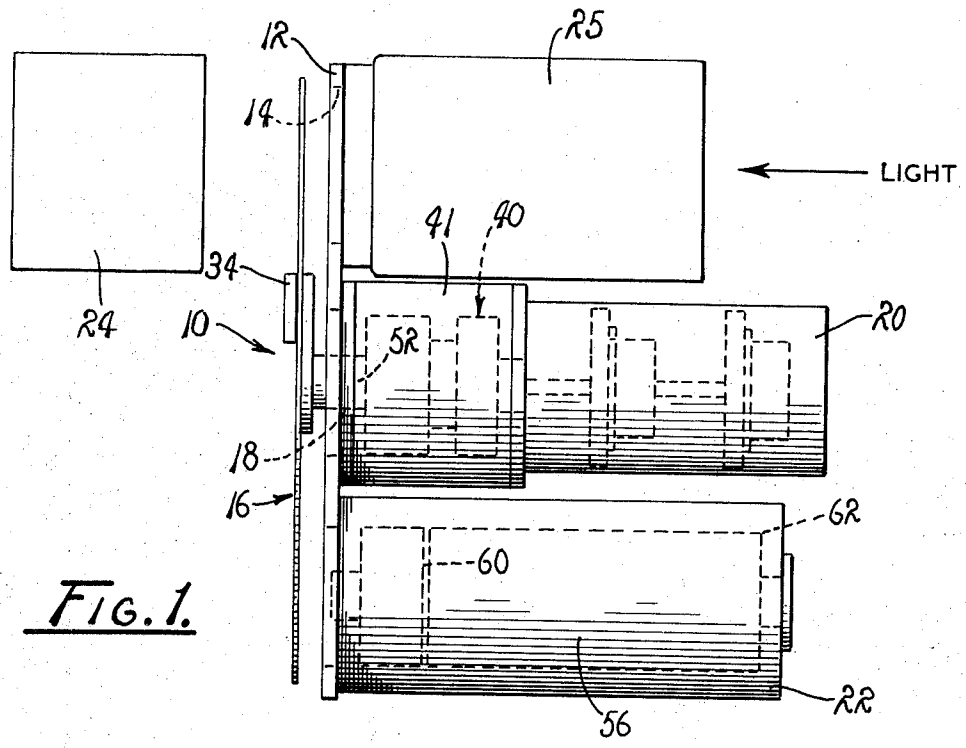


FIG. 1.

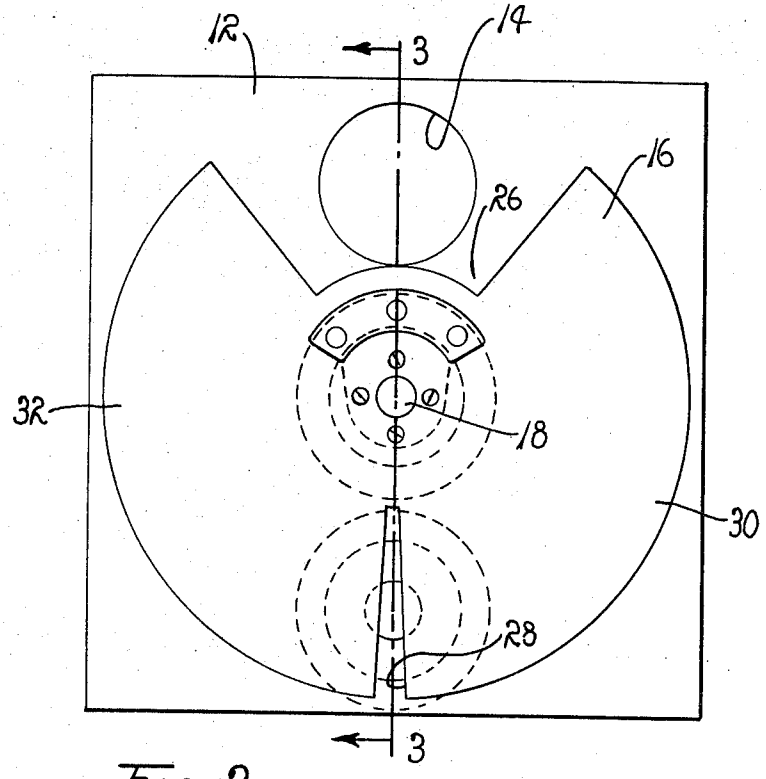


FIG. 2.

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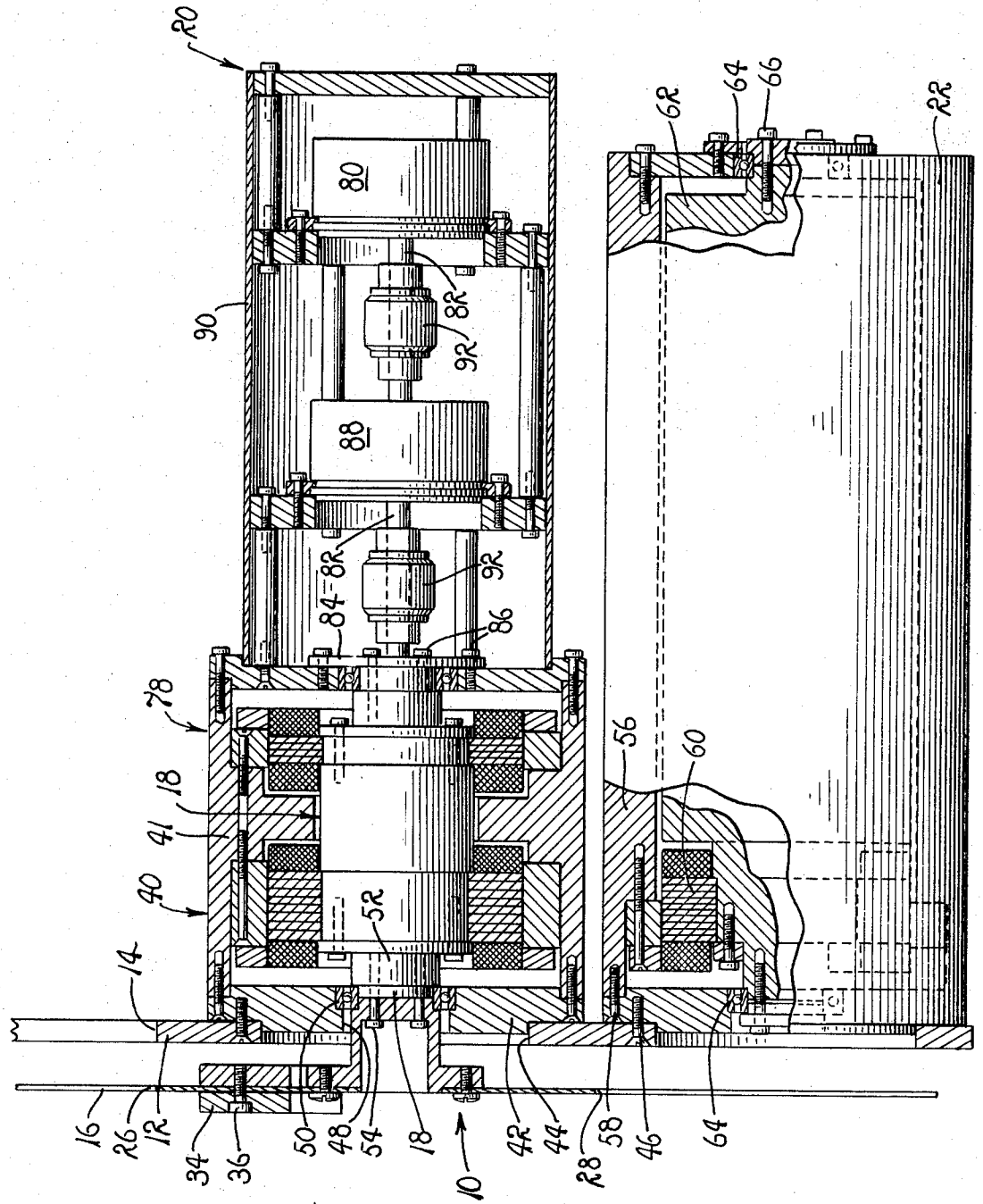


FIG. 3.

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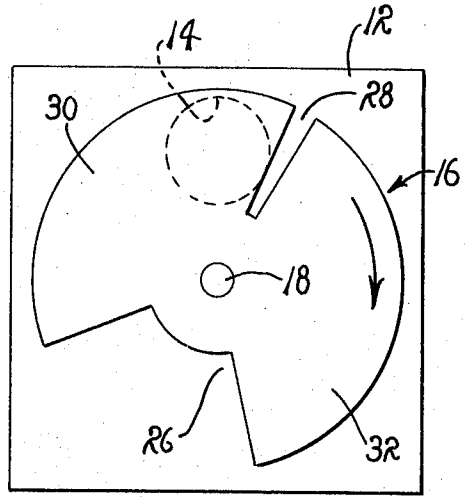


FIG. 4a.

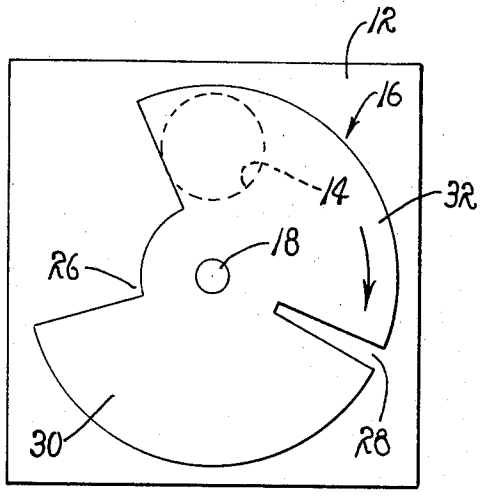


FIG. 4b.

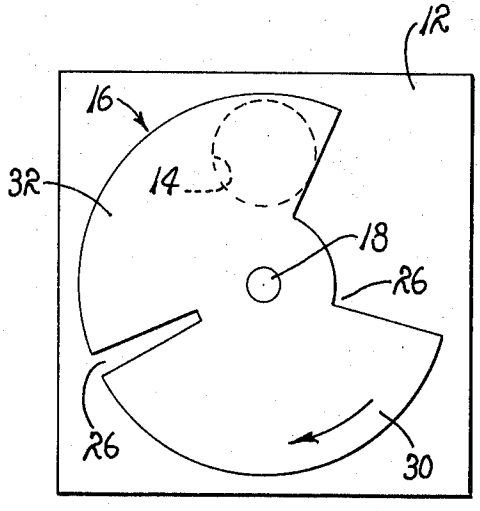


FIG. 4c.

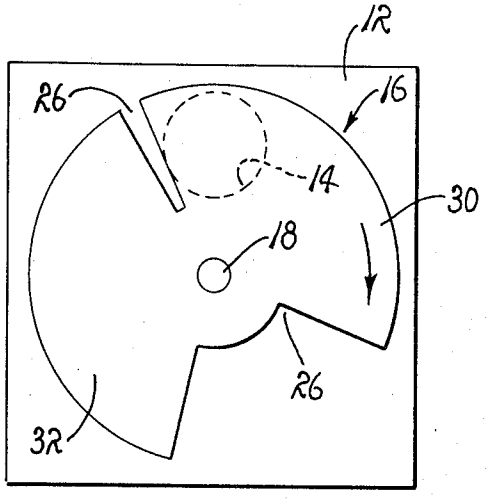


FIG. 4d.

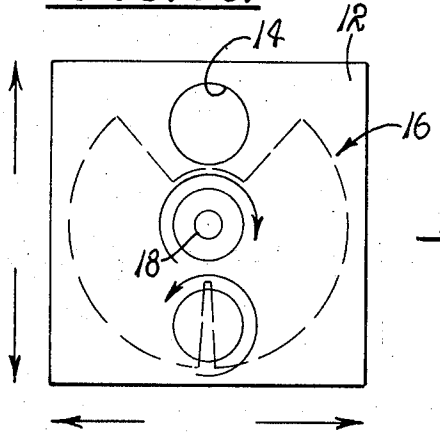


FIG. 6.

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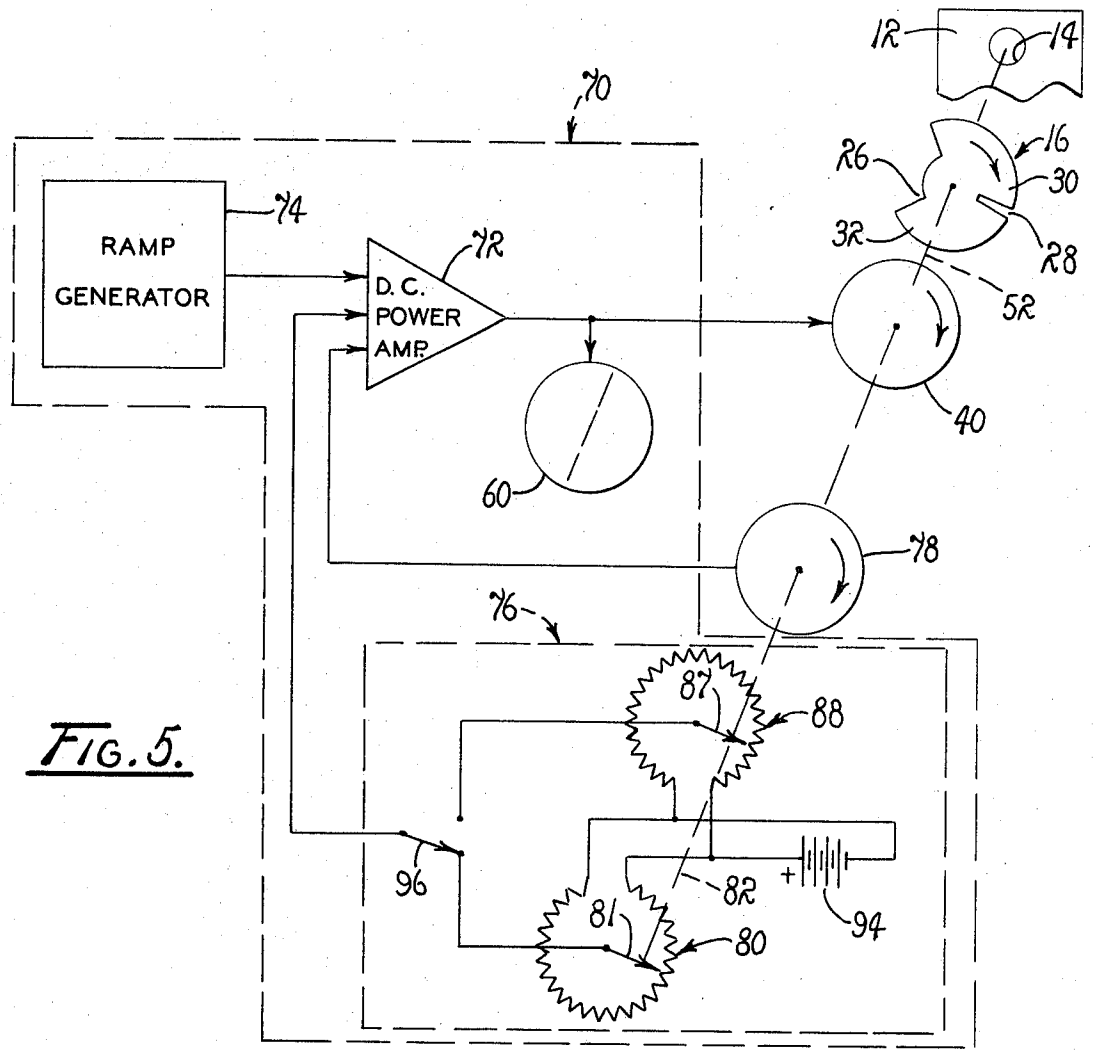


FIG. 5.

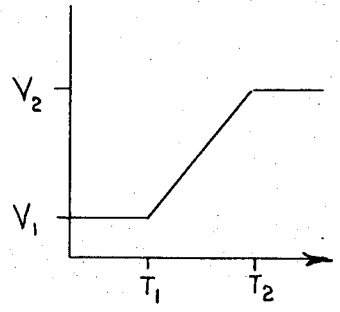


FIG. 7.

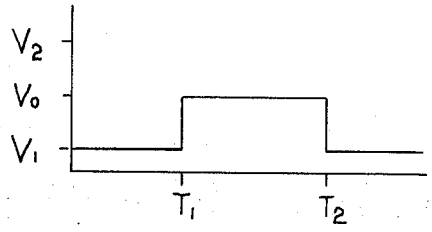


FIG. 8.

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CYCLICALLY OPERABLE OPTICAL SHUTTER

ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to operable shutters and more particularly to an optical shutter for use in photographic operations wherein accurate light gating is required in transmitting pulsed radiation through relatively large apertures with a high degree of operational predictability and light transmission uniformity.

2. Description of Prior Art

The prior art is replete with optical shutters for use with cameras employed in conventional photography. Normally focal plane shutters are restricted to a 70 millimeter format, or smaller, while larger formats employ aperture plane shuttering. Lunar and planetary photometric photography generated a need for camera shutters having uniformity of exposure of better than one percent over a field of not less than 3 inches in diameter on a 4 inch by 5 inch photographic plate with exposure periods selectable over a wide range extending from approximately 2 milliseconds to periods of 32 seconds and more. Any shutter employed must function with a high degree of reproducibility and accuracy in cycle control.

Spring and solenoid driven shutters generally are suitable for use where a light transmitting aperture is small and/or a relatively long time interval is utilized in conducting a given photographic operation. However, where a camera simultaneously utilizes a large aperture and requires a variable, relatively narrow pulse of light, difficulty in acquiring pulse reproducibility, system predictability and transmission uniformity has heretofore plagued designers of optical shutters.

OBJECTS AND SUMMARY OF THE INVENTION

Therefore, it is an object of the instant invention to provide an improved shutter for effectively gating radiation.

Another object is to provide an improved optical shutter including improved shutter components interrelated within a system having particular utility in enhancing photographic operations conducted with cameras having relatively large fields in environments requiring a wide range of selectivity in exposure intervals.

It is another object of the instant invention to provide a servo-controlled optical shutter for accurately providing uniformly gated light pulses with a high degree of pulse uniformity and reproducibility.

It is another object of the instant invention to provide a servo-controlled optical shutter which accommodates a precise utilization of large quantities of power in achieving uniformity of transmission of relatively narrow pulses of light through large apertures over a wide range of exposure intervals.

It is another object of the instant invention to provide a servo-controlled optical shutter including an occulting disk which cyclically transmits a single pulse of radiation through large apertures for cyclically establishing a single pulse of selectable duration within a fraction of a single revolution of rotation of the disk.

It is another object of the instant invention to provide an improved optical shutter which utilizes an occulting disk driven in rotation while effects of reaction torque are precluded by an application of a reversely directed reaction torque of a similar magnitude.

These and other objects and advantages of the instant invention are achieved by providing an aperture adjacent an occulting disk having a pair of diametrically opposed light transmitting sectors of differing dimensions driven by a servo-controlled system at selectively variable accelerating, steady state, and decelerating angular rates all within a fractional turn of a single revolution, whereby an accurate and uniform gating of pulsed light through large apertures is accommodated over a wide range of transmission intervals.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side elevation of a shutter which embodies the principles of the present invention.

FIG. **2** is an end elevation of the shutter of FIG. **1**.

FIG. **3** is an enlarged, partially sectioned side elevation taken generally along line **3**—**3** of FIG. **2**.

FIGS. **4***a* through **4***d* together comprise an illustration of an operative sequence for the shutter shown in FIGS. **1** through **3**.

FIG. **5** is a view schematically illustrating the shutter of FIGS. **1** through **3**.

FIG. **6** is a diagrammatic view illustrating stabilizing forces developed through an application of reaction torque acquired from a counter rotor employed in stabilizing the shutter against reaction torque induced rotation.

FIG. **7** is a diagrammatic view illustrating a given control signal obtainable from the ramp generator of FIG. **5**, as the generator is driven in a first mode of operation.

FIG. **8** is a diagrammatic view illustrating an alternate form of a signal which may be obtained from the ramp generator of FIG. **5**, as it is driven in a second mode of operation for imposing on the shutter a stepping function.

DESCRIPTION OF THE PREFERRED EMBODIMENT

General Description

Referring now to the drawings wherein like reference characters designate like or corresponding parts throughout the several views, there is shown in FIG. **1** a shutter **10** which embodies the principles of the instant invention.

The shutter **10** includes an aperture plate **12** having a circular aperture **14** extended therethrough with its optical axis, not designated, extending normal to the plane of the plate. An occulting disk **16** is supported for rotation by a bearing supported drive shaft **18** extended through the plate **12** and driven by a drive unit **20**. As illustrated particularly in FIGS. **1** and **3**, a counter rotor **22** is coupled with the plate **12** for purposes of balancing reaction torque applied to the plate **12** as the drive unit **20** imparts rotation to the occulting disk **16**. As il-

lustrated in FIG. 1, a camera unit 24 having a filter holder 25 is secured to the plate 12 for purposes of achieving a photographic exposure of light sensitive material contained therewithin.

As a practical matter, the camera unit 24 is of any suitable type, including a plate camera which utilizes a 4-by-5 inch photographic plate, not shown. In such instances, the aperture 14 provides a field of not less than 3 inches in diameter. Furthermore, while not illustrated, the shutter 10 has particular utility in conducting photographic operations utilizing a 24 inch telescope. Consequently, the specific camera camera unit employed, as well as the specific structure employed in coupling the mounting plate 12 within an operative system is a matter of convenience dictated by the particular environment in which the camera is to be employed.

It is, of course, deemed feasible to support the plate 12 in a manner such that the counter rotor 22 can be eliminated. However, since the shutter 10 normally is employed in an environment wherein accurateness, predictability of function, and uniformity of exposure is, for practical purposes, deemed to be imperative, use of the counter rotor 22 is deemed to be particularly practical. Additionally, vibration induced by the shutter operation shock would blur any short exposure without counter rotation.

Occulting Disk

As best illustrated in FIG. 2, the occulting disk 16 is a segmented disk fabricated from a suitable opaque material, such as a lightweight metal. The disk includes a first radiation transmitting sector 26 and a second transmitting sector 28 diametrically opposed to the first sector. The sector 26, in effect, is a wide angle sector, while the second sector, in effect, in a narrow angle sector. These sectors are formed by truncating the disk 16 along selected radii and in a manner such that the sectors are symmetric about a common diameter and are related in diametric opposition. Since the disk 16 is formed from an opaque material it can be appreciated that the transmitting sectors 26 and 28 are separated by a pair of mutually spaced occulting sectors, including a first occulting sector 30 and a second occulting sector 32.

For reasons which can readily be appreciated, the overall dimension of the disk 16 and the sectors 26 through 32 is determined by the operative requirements imposed on the shutter 10. As currently employed, the aperture 14 has a diameter of 3 inches, while the occulting disk has a diameter of 12 inches. Therefore, the radiation transmitting sectors 26 and 28 are formed by radially severing the material of the disk 16, from points located on its periphery, to a depth of approximately 3 inches. As a practical matter, the side edge surfaces of each of the sectors are defined by lines of severance extending along angularly related radii.

The wide angle radiation transmitting sector 26 is defined by radially extended lines of severance which, when projected to the center of the disk 16, define therebetween an included angle of 80°. Similarly, the narrow angle radiation transmitting sector 28 is provided between radially extended lines of severance which, when projected to the center of the disk, define therebetween an included angle of 5°. Therefore, the disk 16 is divided into a pair of transmitting sectors of unequal dimensions while the occulting sectors are of equal dimensions. Sector angles of 80° and 5° are chosen for convenience. Because exposure times have been arbitrarily selected to be in the ratio of a power of two, the sector angles were also chosen as a ratio of 16, i.e., 2 to the 4th power. In fact, considerable lattitude exists in choosing specific sector angles, including the use of only a single transmitting sector.

It is to be understood that the disk 16 is, in operation, selectively driven in a first mode of operation wherein the wide angle radiation transmitting sector 26 is advanced across the aperture 14, for thereby providing a radiation pulse of a relatively long duration and driven in a second mode, for thereby advancing the sector 28 across the aperture 14 for thus providing a pulse of radiation of a relatively short duration. Hence, it can readily be appreciated that by driving the occulting disk 16 in selected modes at selected rates, a controlled gating of radiation delivered through the aperture 14 is achieved for accurately providing selectively pulsed radiation for thus accommodating selectivity in photographic operations.

Due to the inequality in the quantity of the material removed from the diametrically opposed portions of the disk 16, in establishing the radiation transmitting sectors 26 and 28, the occulting disk 16 is both statically and dynamically unbalanced. Therefore, a counterweight 34 of appropriate mass is coupled to the disk 16 through any suitable means, including screws 36. Consequently, both static and dynamic balance is achieved for the disk 16 as it is driven in rotation by the drive unit 20.

Drive Unit

The drive unit 20, as illustrated in FIG. 3, includes a torque motor 40 operatively mounted within a housing 41. The housing rigidly is coupled to the plate 12 through a bearing collar 42 seated within a circular opening 44 appropriately formed therewithin. The collar 42 is coupled to the plate 12 through a multiplicity of mounting screws 46 extended through suitable openings formed in the plate and threadably received within the collar 42.

The collar 42 includes a circular opening 48 within which is seated an annular bearing race 50. This bearing race serves to rotatably support the drive shaft 18 near its output end 52, to which is coupled the disk 16. As a practical matter, the drive shaft 18 is coupled with the disk 16 through a plurality of studs threadingly received within the drive shaft, so that as the drive shaft is driven in rotation a responsive rate of rotation is imparted to the occulting disk 16.

The particular motor employed is dictated by the prevailing operative requirement, such as required rates of angular acceleration to be imparted to the occulting disk 16. Since D.C. motors are well known and are commercially available, a detailed description of the motor employed is omitted in the interest of brevity. However, it is noted that the motor currently utilized in driving the disk 16 is a D.C. motor which consumes 75 watts of power in driving the occulting disk to its highest rate of angular velocity of approximately 420 rpm (revolutions per minute) within 70° of angular rotation.

For reasons which readily are apparent, as the motor **40** is energized for driving the disk **16**, the plate **12** experiences an application of reaction torque. The effect of this torque is countered through an energization of the counter rotor **22**, which serves to apply reaction torque in opposition to the reaction torque applied by the motor **40**.

Preferably, the applied reaction torques are of equal magnitudes. To achieve this condition, the counter rotor **22** is mounted within a housing **56** and coupled to the plate **12** through a plurality of screws **58**, in a manner similar to that in which the housing **41** is coupled with the plate **12**. In practice, a housing **56** includes therein a D.C. torque motor **60** of a design and having operative characteristics closely matched to those of the motor **40**. The motor **60** operatively is coupled with a dummy fly-wheel **62** and is adapted to be reversely rotated thus to act in opposition to the occulting disk **16**. However, it particularly is to be understood that the dummy fly-wheel **62** is supported by a suitable plurality of bearings **64** arranged within the housing **56** and coupled thereto through a multiplicity of screw-threaded studs **66** in order that opposed angular momentum be imparted to both the fly-wheel **62** and the disk **16** as the motors **40** and **60** simultaneously are driven at common rates, but in opposed directions. Hence, the motors **40** and **60** develop and apply oppositely directed reaction torques to the mounting plate **12**. This application of opposed and equal torques serves to achieve a cancellation of displacement inducing forces developed in response to an energization of the motors, as illustrated by the force vector arrows in FIG. **6**.

Since the shutter **10** is employed in gating radiation for photographic purposes, it is imperative that only a single pulse of radiation be delivered through the aperture **14**, for each cycle of shutter operation, in order to prevent an occurrence of "double exposure" of photographic medium being exposed by the radiation. Therefore, the motor **40** must accelerate the occulting disk **16** to an appropriate steady state as one of the occulting sectors **30** and **32** transverse the opening of the aperture **14**, and yet achieve a deceleration of the disk **16** to a zero velocity steady state while the other occulting sector traverses an opening of the aperture, subsequent to a passage of a single one of the transmitting sectors **26** and **28**, from before the opening.

As illustrated in FIGS. **4***a* through **4***d*, where the gating of radiation is to be achieved employing the wide angle transmitting sector **26**, acceleration of the disk **16** is initiated while an occulting segment **30** is coincident with the opening of the aperture **14**. The motors **40** and **60** simultaneously are energized for imparting clockwise rotation to the disk **16**, as viewed in FIGS. **2** and **4***a* through **4***d*. As the disk **16** is rotated from the position illustrated in FIG. **4***a* to that illustrated in FIG. **4***b*, it is accelerated from a zero velocity to a steady state velocity. This, of course, occurs as the occulting sector **30** traverses the opening of the aperture **14**.

Consequently, the angular velocity of the disk **16** is stabilized before transmission of radiation through the aperture **14** is initiated, as displacement of the sector **26** across its opening is initiated. As the disk **16** is driven in its steady state rotation, from the position illustrated in FIG. **4***b* to that illustrated in FIG. **4***c*, a gating of a pulse radiation is achieved as radiation is delivered through the aperture **14**. The width of the pulse is determined by the duration of the delivery of the radiation, which is terminated as the occulting sector **32** is displaced into coincidence with the opening so that it effectively covers the aperture **14**. At this point, deceleration of the disk **16** is initiated in order to prevent an overshoot of the sector **32**. Such an overshoot would cause the transmitting sector **26** to be brought into operative alignment with the aperture **14** and would result in transmission of a second pulse during a single cycle of operation of the shutter **10**. Hence, it should readily be apparent that during a single cycle of shutter operation a fractional turn of a single revolution of a disk **16** is employed for gating a single pulse of radiation through the aperture.

In order to achieve a second cycle of operation, following the cycle illustrated in FIGS. **4***a* through **4***d*, a reverse direction of rotational is imparted to the disk **16** for causing the disk to rotate in a counter direction wherein a progression through the steps illustrated in FIGS. **4***a* through FIGS. **4***d* is reversed so that a second cycle is completed as the disk comes to rest in a position, substantially as shown in FIG. **4***a*.

Control Circuit

In order to control the operation of the motors **40** and **60**, circuitry similar to that illustrated in FIG. **5** has been provided.

Due to the fact that the disk **16** is, in effect, oscillated in fractional turns of rotation, for thus causing selected radiation transmitting sectors to traverse the opening **14**, the motors **40** and **60** reversely are energized for the purposes of reversing directions of rotational displacement imposed on the disk. Therefore, for purposes of illustration, it can be assumed that the motors **40** and **60** are controlled through a servo-control circuit **70**, which serves to dictate direction of angular displacement imparted to the disk **16** as the motors **40** and **60** are energized and to detect and control and operative angular position of the disk relative to the aperture **14**.

Acceleration, steady state angular velocity, and deceleration are achieved by employing a D.C. power amplifier **72** which simultaneously delivers an integrated output signal to the motors **40** and **60** for driving the motors in a selectable and accurately controlled manner. The power amplifier **72** is of the commercially available design which serves to sum three separate input signals simultaneously derived from a ramp generator **74**, a bank of shaft-connected potentiometers **76** and a tachometer **78**. Since the circuit components herein employed are of a known design and are commercially available, a detailed description of the components is omitted in the interest of brevity. It is, however, to be understood that the ramp generator **74** serves to provide a ramp output signal of an increasing voltage, such as that illustrated in FIG. **7**. Such a signal is a selectively variable signal which can readily be achieved through a selective operation of ramp signal generators of known design. In practice, the output signal derived from the ramp signal generator **74** is utilized as a reference signal indicating a desired angular position for the disk **16** for each point in time, between points in time designated T–1 and T–2. Therefore, the

voltage level of the signal derived from the ramp generator **74** serves to indicate the appropriate position for the disk **16**, at each instant, while the slope of the signal is indicative of the rate of position change or the required velocity of the disk **16**.

The output bank of potentiometers **76** is employed to provide an output signal which is delivered to the power amplifier **72** in order to indicate the instantaneous position of the disk **16** at any given instant in time. The signal derived from the bank of potentiometers **76** is added to the input signal derived from the ramp generator **74** and utilized in driving the amplifier circuit **72** for acquiring a power output utilized in achieving an appropriate angular position at a given instant in time.

The bank of potentiometers **76** includes a first potentiometer **80** having a wiper arm **81** coupled with the output shaft **18** of the motor **40** through a suitable drive shaft **82**, FIG. **3**. This shaft is coupled with the output shaft of the motor **40** through a suitable coupling including a bearing collar **84** mounted on the housing **41** through studs **86**. The shaft **82** further is coupled to a wiper arm **87** of a second potentiometer **88** coaxially aligned with the first potentiometer **80**, mounted at either side thereof. The potentiometers **80** and **88** suitably are supported within a housing **90** extended from the housing **41** of the motor **40**.

The particular order in which the potentiometers are mounted is a matter of convenience. However, in order to facilitate the coupling of the shaft **82** with the coaxially aligned potentiometers, suitable pin-and-sleeve couplings **92** are employed. The potentiometers, therefore, are driven in a manner such that their wiper arms **81** and **87** are displaced at a rate and in a direction dictated by the motor **40** as it is driven to impart displacement to the disk **16**. The potentiometers each have 360° of free mechanical rotation but, as a practical matter, only 350° of electrical rotation, with the wiper arms thereof being in parallelism with each other and with the axis of symmetry of transmitting sectors **26** and **28**. As illustrated in FIG. **5**, the potentiometers **80** and **88** are aligned 180° apart, with respect to their electrical polarity and the relative orientation of their 10° gaps. This arrangement permits the potentiometers to track the angular position of either of the transmitting sectors **26** and **28** of the disk **16** over 350° of rotation so as to provide an input signal to the power amplifier **72** indicative of the tracked position. As a practical matter, the potentiometers **80** and **88** directly are coupled with a suitable source **94** of the D.C. voltage, while a switch **96** is provided between the power amplifier **72** and the potentiometers **80** and **88**. Hence, signals selectively can be derived from either of the potentiometers through the switch **96**, depending upon which sector is being used.

The particular potentiometer selected for a given mode is dictated by the desired mode of operation to be imposed on the disk **16**. For example, where the gating of radiation is to be achieved employing the wide angle transmitting sector **26**, the power amplifier **72** is coupled with the potentiometer **80**, as illustrated in FIG. **5**. Since the narrow angle radiation transmitting sector **28** is, in effect, diametrically opposed to the wide angle sector, the arm **87** of the potentiometer **88** is related to the arm **81** of the potentiometer **80**. It is to be understood that depending upon the transmitting sector being driven for gating radiation through the aperture **14**, a position signal is derived from the bank **76** of potentiometers **80** and **88** and this signal is applied to the power amplifier **72** for purposes of deriving a signal for use in driving the motors **40** and **60**.

In order to reduce the inherent tendency of the output of the power amplifier **72** to rapidly vary, due to the continuous summing of the signals derived from the bank of potentiometers **76** and the ramp generator **74**, a damping voltage signal is acquired from the tachometer **78**, which is coupled with the motor **40** in tandem and driven by its output shaft **18**, FIG. **3**. The output of the tachometer **78** is proportional to the rate of the rotation imparted to the shaft **18** and is applied to the amplified **72** in a manner such as to damp out variation in the voltage levels of the signals applied to the motors **40** and **60**. These variations result from variations occurring in potentiometer position as the position of the motor shaft attempts to follow the output signal derived from the ramp generator. The use of tachometer derived damping signals for second order positional servo systems is well known and is described in detail in numerous texts on the subject.

Since such damping techniques are well within the skill of the art and form no specific part of the instant invention, a detailed description is omitted in the interest of brevity. Therefore, it is to be understood that the servo-control circuit **70** is, in effect, a position servo-system, wherein the angular acceleration imposed on the disk **16** is, at its various positions relative to the aperture **14**, dictated by a signal derived from the ramp generator **74**, summed with the signal derived from the potentiometer and the signal derived from the tachometer.

In certain instances, it may be found desirable to provide exposure intervals of excessive duration. This is achieved by gating the radiation in a manner such that the resulting pulses are of a width commensurate with a desired interval. This can be achieved simply by "-stepping" the disk **16** in a manner such as to present the opening of the aperture **14** to a selected source of radiation for a predetermined period. This stepping mode can be achieved by driving the ramp generator **74** in a manner such as to acquire an output signal of a shape such as that illustrated in FIG. **8**. Wherein a constant voltage condition is imposed on the motors **40** and **60** for a given period of time extending between T–1 and T–2.

OPERATION

It is believed that in view of the foregoing description, the operation of the shutter will be readily understood and it will be briefly reviewed at this point. The shutter **10** is, in practice, associated with a camera unit **24** and aligned in a manner consistent with the intended use of the camera. With the camera unit **24** and shutter **10** thus positioned and aligned, a selection of a wide angle or a narrow angle transmitting sector is made with occulting sectors **30** and **32** being exposed in a radiation blocking relationship to the opening of the aperture **14**.

Assuming that the radiation to be gated is to be delivered in relatively wide pulses, the switch **96** is coupled with the potentiometer **80**, as illustrated in FIG. **5**, and the occulting disk **16** is positioned in a manner con-

sistent with that illustrated in FIG. 4*a*. The ramp generator **74** now is triggered, in response to any given signal, developed electronically or manually. The signal derived from the ramp generator **74** is delivered to the power amplifier **72** with the output thereof being delivered to the motors **40** and **60** for purposes of accelerating the disk **16** as the occulting sector **30** is advanced to the position illustrated in FIG. 4*b*. As the disk thus is driven in rotation, a signal is delivered from the bank of potentiometers **76** and summed with the signal delivered from the ramp generator **74** for providing a signal indicative of the instantaneous position change required in order to achieve a steady state of rotation for the disk **16**. No later than the instant at which the occulting disk **16** is rotated to position the occulting sector **30** of the disk **16** in a position indicated in FIG. 4*b*, a steady state of angular velocity is established for the disk **16**. As the transmitting sector **26** traverses the aperture **14**, at a steady and uniform rate, radiation is delivered through the aperture **14** to provide a uniform pulse of radiation in order to achieve a photographic exposure within the camera unit **24**.

Depending upon the lapse of time required by the sector **26** in traversing the opening of the aperture **14**, an exposure interval of a predetermined length is established as gating of the radiation occurs by the passage of the sector **26**. Once the transmitting sector **26** has traversed the opening of the aperture **14** deceleration of the disk **16** is initiated, as the occulting sector **32** covers the opening of the aperture for thus terminating the pulse.

Due to the reaction torque applied to the plate **12**, as the motor **40** is energized, the plate **12** necessarily tends to rotate about an axis of rotation. However, due to the fact that the motor **60** concurrently is energized and is driven in a direction opposite to the direction of the motor **40**, for purposes of driving the dummy flywheel **62**, a reverse reaction torque is applied to the plate **12**. The two forces tend to achieve mutual cancellation and rotation of the plate is avoided.

In the event that exposure is to be achieved over a relatively short period of time, the narrow angle transmitting sector **28** is prepared to be driven across the aperture **14**. This is achieved in a manner similar to that hereinbefore described with respect to the wide angle radiation transmitting sector **26**. In this instance, however, the switch **96** is caused to close a circuit between the potentiometer **88** and the power amplifier **72**. A cycle of operation then is achieved in a manner similar to that described with respect to the gating of radiation employing the wide angle transmitting sector **26**. When a pulse of a large width is required, the ramp generator **74** is driven to provide an output signal similar to that illustrated in FIG. **8** whereby the transmitting segment is caused to traverse the opening of the aperture **14** at very low but constant rates.

With the system assembled in the manner hereinbefore described, it is to be understood that the disclosed embodiment of the instant invention provides an optical shutter **10** which accurately, reproducibly and with better than one percent uniformity, transmits pulsed radiation through a 3 inch diameter aperture for a wide range of selectable time intervals, ranging between one-five-hundred-and-twelfth second, to pulses of very large pulse widths including 32 seconds, while the occulting disk **16** is driven through less than a single turn of rotation.

The disk **16** is capable of obtaining a constant, but selectively variable, angular velocity of approximately 420 rpm, with a precision of plus or minus one percent, in about 70° of angular displacement. By selectively reducing the output of the ramp generator **74** in binary steps, the narrow angle radiation transmitting sector **28** can produce increasing exposure intervals between one-five-hundred-twelfth second and one-sixty-fourth second, while the wide angle radiation transmitting sector **28** can produce exposure pulses ranging between one-thirty-second second to one-fourth second. Of course, when employing the shutter **10** in a stepping mode, the shutter can be caused to gate the radiation pulses to provide pulses of arbitrary widths up to 4 seconds.

In view of the foregoing, it is readily apparent that the aforedescribed embodiment of the instant invention provides a simplified, improved and practical optical shutter for use in photographic operations requiring large formats and accurately controlled radiation gating.

Although the invention has been herein shown and described in what is conceived to be the most practical and preferred embodiment, it is recognized that departures may be made therefrom within the scope of the invention, which is not to be limited to the illustrative details disclosed.

What is claimed is:

1. A cyclically operable optical shutter comprising:

A. means defining a radiation transmitting aperture having an optics axis;

B. an occulting disk including means defining therein a pair of radiation occulting sectors and a radiation transmitting sector interposed between the occulting sectors;

C. means abaxially related to said aperture supporting said disk for oscillatory rotation in a plane disposed in close proximity to said aperture and normally related to said optics axis, whereby said sectors sequentially are caused to traverse the aperture as the disk is driven in oscillatory rotation;

D. cyclically energizable means coupled with said disk for angularly accelerating the disk from zero velocity to a selected steady-state angular velocity, as a first occulting sector is caused to traverse said aperture, maintaining said steady-state angular velocity for said disk as the radiation transmitting sector traverses said aperture, and thereafter decelerating said disk to a zero velocity as a second occulting sector is caused to traverse said aperture, whereby during each cycle of operation a radiation transmitting sector is caused to traverse said aperture at a constant velocity for providing a pulse of radiation having an accurately predictable width; and

E. a counter rotor operatively coupled with said support means for applying thereto reaction torque in a direction and with a magnitude sufficient for countering reaction torque responsively applied to the support as a consequence of the oscillatory rotation imparted to said disk.

2. The shutter of claim 1 wherein the disk further includes means defining another radiation transmitting sector interposed between said pair of radiation occulting sectors in diametric opposition to the first mentioned radiation transmitting sector.

3. The shutter of claim 2 wherein said occulting sectors are defined by circumscribing surfaces of equal dimensions while said transmitting sectors are defined by surfaces of unequal dimensions.

4. The shutter of claim 2 wherein said transmitting sectors comprise truncated portions of the occulting disk.

5. The shutter of claim 3 wherein one of said sectors is defined between surfaces having a projected included angle of 80° while the other transmitting sector is defined between surfaces having a projected included angle of 5° for thereby providing a wide and a narrow radiation transmitting sector.

6. An optical shutter comprising:

A. a mounting plate;

B. a means defining an aperture in the mounting plate;

C. an occulting disk including a pair of diametrically related, radiation transmitting sectors and a pair of occulting sectors interposed between the radiation transmitting sectors;

D. means mounting said disk on said mounting plate for rotation in a plane parallel to the plane of the aperture and in a manner such that the transmitting sectors and the occulting sectors alternately traverse said aperture as the disk is rotated, whereby pulsed radiation is gated through said aperture;

E. drive means including an electrically energizable motor coupled with said occulting disk for imparting selected fractional turns of rotation to said disk;

F. control means coupled with said drive means including a ramp generator for providing a reference signal indicative of selected instantaneous angular dispositions to be imposed on said disk as rotation is imparted thereto;

G. a bank of potentiometers including means for delivering an output signal indicative of instantaneous angular dispositions imposed on the disk as it is driven in rotation;

H. a D.C. power amplifier coupled with said ramp generator and said bank of potentiometers for receiving and electrically summing signals delivered thereto from the ramp generator and said bank potentiometers and for delivering an output voltage to said drive means for causing said drive means to correct position error operationally established between the instantaneous angular dispositions imposed on said disk and the selected instantaneous dispositions to be imposed on said disk; and

I. a tachometer coupled with said drive means and said power amplifier for delivering a damping voltage to said power amplifier.

7. The shutter of claim 6 wherein means including a counter-rotor operatively is coupled with said mounting plate for cancelling reaction torque developed and applied to said mounting plate by said drive means.

8. The shutter of claim 7 wherein said counter-rotor includes a motor and an operatively associated dummy fly-wheel driven simultaneously in opposition to said disk and at rates coincident therewith.

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