AUTOMATIC SHUTTER CONTROL FOR MAINTAINING CONSTANT A PREDETERMINED IMAGE FIELD SIZE

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SUMMARY OF THE INVENTION

In accordance with the present invention, two servo systems are provided for independently controlling the length and width of the shutter opening. In each system, two variable voltages are provided, which are respectively proportional to a desired image field size dimension and to the distance of the image plane from the X-ray tube. These two voltages are provided in analogue circuitry, which produces a third voltage proportional to the proper shutter opening in a corresponding dimension.

The third or shutter reference voltage is supplied along with a voltage that is proportional to the actual shutter opening in the corresponding dimension, to a differential amplifier, which produces an output voltage that is proportional to the difference between its two input voltages. The output voltage of the differential amplifier is used to control a power amplifier, which supplies current to the armature of a direct current (D.C.) motor that mechanically opens and closes the shutter. The power amplifier has the capability of reversing the polarity of the current supplied to the motor, thus allowing it to be driven in either direction. If the two inputs to the differential amplifier are not equal, the power amplifier supplies current to the D.C. motor to drive it in a proper direction to correct the shutter opening. When the shutter has the correct opening, the two signals applied to the differential amplifier are equal and the output signal to the power amplifier will be such as to apply no driving current to the motor.

Each shutter can be controlled manually by adjusting a potentiometer to provide an output voltage proportional to a desired image field dimension. In addition, fixed voltages corresponding to various image field dimensions can be selected by means of a selector switch for automatic shutter size adjustment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram useful in understanding the geometric considerations involved in practicing the invention.

FIG. 2 is a simplified schematic drawing of circuitry for developing a reference voltage that is a function of an image field dimension and distance between the image plane and an X-ray tube.

FIG. 3 is a schematic diagram illustrating a complete automatic shutter control (except for power supplies) embodying the invention; and,

FIG. 4 is a schematic diagram showing connections of motors that open and close the shutters.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates the geometry necessary to an understanding of the invention. Although only a two-dimensional diagram is shown, it is understood that a third dimension is involved. In other words, only one dimension of the two dimensions (length and width) that determine the shutter opening size and image field size are shown. A similar diagram could be drawn using height as one dimension and the other shutter opening and field dimensions as its other dimensions. As shutter opening represents a desired image field dimension (a variable) in an image plane. B represents distance from a point source (X-ray tube) to a shutter plane (a constant). C represents a minimum allowable distance between the...
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The following proportionality equations can be written for the diagram of FIG. 1:

\[ E = \frac{B}{A + B + C + D} \]  

or

\[ E = \frac{AB}{B + C + D} \]

It is noted that Equation 2 has the same form as the well-known electrical equation \( I = V/R \), where \( I \) is current flowing through a resistance \( R \), and \( V \) is voltage applied across the resistance \( R \). It follows then that Equation 2 can be set up using electrical parameters rather than spatial parameters. FIG. 2 shows a simple analogue circuit that may be used for solving that equation.

As shown, a potentiometer 16 having a movable arm 16A is connected across a source of direct current, shown as a battery 18B. The negative side of the battery 18B is grounded. The position of the movable arm 16A of the potentiometer determines the voltage applied to the remainder of the circuit, and it is set to obtain a voltage that corresponds to the term A in Equation 2. The terms in the denominator of Equation 2 are represented by series-connected resistors 20, 22, 24 connected between the potentiometer arm 16A and ground. The resistor 20 is variable, and the resistors 22, 24 are of fixed value. The variable resistor 20 represents the variable distance \( D \) in Equation 2 and the resistors 22, 24, respectively represent the constant distances \( B \) and \( C \) in that equation. The current that flows through the resistors 20, 22, 24 is a function of their resistance values and the potential applied across them from the arm 16A of the potentiometer 16. That current is a measure of the desired shutter opening \( E \) in Equation 2. A potential \( V_{\text{sh}} \) representing that shutter opening is taken from across the resistor 24, and is proportional to the current flowing through the resistors.

FIG. 3 is a schematic diagram of an automatic shutter control embodying the invention. As previously mentioned, two servo circuits are provided so that the length and width of the image field can be individually controlled. As shown in FIG. 3, the two servo systems or channels are designated generally as A and B. Inasmuch as the circuitry of the channels A, B is identical, a detailed description will be given of channel A only. In the drawing, the elements of the circuitry of channel A are designated by reference numerals having a suffix A, and corresponding elements in channel B have similar reference numerals with the suffix B. The analogue computing circuitry shown in simplified form in FIG. 2 is shown in FIG. 3 in a more detailed form, and is generally designated as 30A. The differential amplifier previously referred to is designated generally by the numeral 32A, and the power amplifier for supplying power to the shutter drive motor is designated generally as 34A. The motors, which are driven by the outputs of the power amplifiers 34A, 34B are shown in FIG. 4, which is to be considered in conjunction with the following description of FIG. 3. Power is supplied for the circuitry from one or more direct current power sources (not shown), which are connected to supply +13 volts on a line 36 as shown in FIG. 4. The line 36 is connected through a resistor 40 to a line 42, which is in turn connected to ground through a Zener diode 44. The line 42 is maintained at +9 volts by the breakdown action of the Zener diode 44. The line 38 is connected to a line 46 through a resistor 48, and the line 46 is connected to ground through a resistor 50 and a Zener diode 52 connected in parallel. The Zener diode 52 maintains the line 46 at -9 volts.

The analogue circuitry 30A provides a shutter reference voltage to the differential amplifier 32A. The shutter reference voltage is proportional to a proper shutter opening in one dimension as a function of the distance of the image plane from the X-ray tube and as a function of a desired image field size in a corresponding dimension, as described with reference to FIGS. 1 and 2. A voltage proportional to a desired image field dimension may be adjusted manually or various voltages proportional to various dimensions can be selected by means of a selector switch for automatic shutter opening adjustment. Either manual or automatic operation is selected by a single-pole, two-contact switch 54A, whose movable pole is mechanically connected to a pole of a similar switch 54B in channel B. One contact of the switch 54A is connected to the movable arm of a potentiometer 56A connected between the line 42 and ground. The movable arm of the potentiometer 56A may be adjusted manually to provide a voltage on the pole of the switch 54A that is proportional to a desired image field size dimension when the switch 54A is in the "Manual" position shown. The second contact of the switch 54A is connected to a pole of a single-pole, multiple-contact switch 58A, which is ganged to a similar switch 58B in channel B. When the switch 54A is in its "Automatic" position, the pole of the switch 54A is connected to the pole of the switch 58A.

The various contacts on the switch 58A are connected to a plurality of voltage dividers to provide different voltages to the pole of that switch that are proportional to various preselected values of the chosen dimension of the image field. For example, a first contact of the switch 58A is connected directly to the line 42 and to ground to a resistor 60A. A second contact of the switch is connected to the juncture of resistors 62A, 64A connected in series between the line 42 and ground; a third contact is connected to the juncture of resistors 62A, 68A similarly connected between the line 42 and ground; and a fourth contact is connected to the juncture of resistors 70A, 72A connected in series between the line 42 and ground. Thus, various preselected voltages may be provided from the pole of the switch 52A to the pole of the switch 58A, when the switch 58A is in the "Automatic" operation position. Similar voltage dividers are provided for the switch 58B in channel B.

The pole of the switch 54A is connected to ground through a series combination of a variable resistor 74A and fixed resistors 76A, 78A. A capacitor 80A is connected across the series-connected resistors 76A, 78A. A juncture point of the resistors 74A, 76A, 78A constitutes the base of an NPN transistor 82A in the differential amplifier 32A. The variable resistors 74A, 74B in channels A and B are mechanically connected together and, through suitable gaging (not shown), to mechanism (not shown) for holding an X-ray sensitive film and defining the image plane 10 (FIG. 1). Such a film holding mechanism is commonly known in the art as a "spot filmer." The spot filmer is mounted for movement toward and away from an X-ray tube 12, through the distance D shown in FIG. 1. As the spot filmer moves through the distance D, it mechanically adjusts the variable resistors 74A, 74B and 34A, 34B to keep the resistances of the resistors 74A, 76A, 78A respectively corresponding to the resistors 20, 22, 24 shown in FIG. 2 and the voltage supplied across the resistor 78A to the base of the transistor 82A corresponds to the shutter reference voltage \( V_{\text{sh}} \) as shown in FIG. 2. The various voltages provided to the pole of the switch 54A, either from the manually adjustable potentiometer 56A or through the switch 58A, correspond to the voltage on the movable arm 16A of the potentiometer 16 shown in FIG. 2. In view of the expla-
nation of the operation of such a circuit in connection with Fig. 2, it is not believed necessary to repeat it again. Suffice it to say that the potential provided at the base of the transistor 82A is proportional to a desired shutter opening in one dimension corresponding to a desired image field size in the corresponding dimension. The same explanation, of course, is applicable to channel B, where the voltage provided on the base of the transistor 82B is proportional to a desired shutter opening in another dimension corresponding to a desired image field size in that same dimension.

The differential amplifier 32A provides a signal to the power amplifier 34A to cause the motor driven by the power amplifier to rotate in the proper direction to adjust the shutter opening to a desired size. The power amplifier will provide no power to the motor if the shutter is correctly adjusted. The differential amplifier 32A comprises the transistors 82A and four NPN transistors 84A, 86A, 88A, 90A. The collector of the transistor 82A is connected directly to the collector of the transistor 84A and to the positive potential line 36 through a load resistor 92A. The emitter of the transistor 82A is connected directly to the base of the transistor 84A. The collectors of the transistors 86A, 88A are connected together and to the line 36 through a load resistor 94A. The base of the transistor 86A is connected directly to the emitter of the transistor 82A. The emitters of the transistors 84A, 86A are connected together and to the collector of the transistor 90A. The base of the transistor 90A is connected directly to ground, and the emitter of that transistor is connected to the negative potential line 46 through a load resistor 96A. The transistor 90A serves as a fixed current source for transistors 84A, 86A, 88A. The base of the transistor 88A is connected to the potentiometer 98A, which is connected in series through a variable calibration resistor 100A and a fixed resistor 102A to the line 42. The output from the differential amplifier 32A is taken directly from the collector of the transistor 94A and supplied through an "anti-hunt" resistor 104A to the base of an amplifier transistor 106A in the power amplifier 34A. The movable arm of the potentiometer 98A that supplies potential to the base of the transistor 88A is mechanically connected to be positioned by the motor that drives the shutter corresponding to the dimension controlled by channel A. Thus, the voltage present on the movable arm of the potentiometer 98A, which is directly proportional to the actual or existing opening of the shutter in the chosen single dimension. Similarly, in channel B, the voltage present on the movable arm of the potentiometer 98B is directly proportional to the actual or existing opening of the second shutter in the second dimension.

The power amplifier 34A comprises the transistor 106A, an NPN transistor 108A, and two PNP transistors 110A, 112A. As previously noted, the base of the transistor 106A is connected to receive the output signal from the differential amplifier 32A. The emitter of the transistor 106A is connected directly to the positive potential line 36. The collector of the transistor 106A is connected directly to the bases of the transistors 108A, 110A and to the negative potential line 46 through a load resistor 114A. The collector of the transistor 106A is connected directly to the base of the motor 122A through a diode 124A. The diode 124A is connected to the limit switches 118A, 120A, respectively, when the shutter reaches its full-open and full-closed positions. The purpose of the diodes 124A, 126A shunting the limit switches is to permit the motor 122A to move in its closing direction after the full-open limit switch has been opened, and to permit the shutter to move in its opening direction after the full-closed limit switch has been actuated. For example, if the limit switch 118A is open, the motor 122A may still be energized through the limit switch 120A and the diode 124A to cause it to move the shutter in a closing direction to close the limit switch 118A. Similarly, if the limit switch 120A is open, the motor may be energized through the limit switch 118A and the diode 126A to move the shutter in an opening direction and thus close the switch 120A.

In operation, the potentials on the bases of the transistors 82A, 88A in the differential amplifier 32A will be equal to each other when the shutter opening is of the proper size in the dimension controlled by channel A. In this condition, the transistors 82A, 84A, 86A, 88A are all conducting to some extent. The potential on the collector of the transistor 84A which is somewhat less than +13 volts because of the voltage drop across the resistor 92A, is supplied to the base of the transistor 106A in the power amplifier 34A. This potential causes the transistor 106A to be partially conductive, so that its collector is essentially at ground potential. This places the bases of the transistors 109A, 110A also at ground potential, and causes both of those transistors to be non-conductive. The variable calibration resistor 100A is adjusted to obtain this condition when the shutter opening is correct. When the transistor 110A is non-conductive, the transistor 112A assumes the same condition. It is seen that when both transistors 108A and 112A are non-conductive, no current can flow in either direction through the motor supply line 116A. Thus, the motor 122A has no power supplied to it and it does not rotate. The opening in the shutter 118A and the position of the arm of the potentiometer 98A remain fixed.

If now the potential applied to the base of the transistor 82A becomes more positive than the voltage on the base of the transistor 88A, it may be concluded that a change in the desired field size dimension or in the distance of the spot filmer from the X-ray tube, the differential amplifier 32A becomes unbalanced. The transistors 82A, 84A will go into full conduction, and the transistors 86A, 88A will be cut off. When the transistors 82A, 84A go into full conduction, the potential on the collector of the transistor 84A drops, which causes the transistor 106A to go into full conduction. When the transistor 106A is fully conducting, the base of the transistor 108A goes positive and causes that transistor to become fully conductive. At the same time, the base of the transistor 110A goes more positive, which causes the transistors 112A, 112A to remain cut off. Current thus flows from the +13 volt line 36 through the transistor 108A, through the motor supply line 116A, and through the armature of the motor 122A to ground to cause the motor to rotate at full speed in a first direction. As the motor 122A rotates to change the opening in the shutter 128A, it also causes the movable arm of the potentiometer 98A to move until the voltage on the base of the transistor 88A is the same as that on the base of the transistor 82A. When this occurs, the differential amplifier is again in a balanced condition and no further change in size of the image will occur until the differential amplifier 32A is again unbalanced.

Assume now the condition wherein the voltage on the base of the transistor 82A becomes less positive than that on the base of the transistor 88A. In that case, the transistors 86A, 88A go into full conduction, which causes the transistors 82A, 84A to be cut off. When the tran-
sistor 82A, 84A are cut off, the potential provided to
the base of the transistor 106A rises to +13 volts be-cause there is no voltage drop across the resistor 92A,
and conduction through the transistor 106A is cut off.
When the transistor 106A is cut off, the potential on
the bases of the transistors 108A, 110A drops to -13 volts.
This causes the transistor 108A to remain cut off, and
causes the transistors 110A, 112A to become fully
conductive. Thus, current flows from ground through the
armature of the motor 122A, the line 116A and the
transistor 112A to the -13 volt line 38. The motor 122A
rotates at full speed in a second direction to vary the
opening of the shutter 128A and simultaneously to re-
position the arm of the potentiometer 98A until the dif-
ferential amplifier 32A is again in a balanced condition.
When that balanced condition is obtained, the transistors
110A, 112A will become non-conducive and rotation of
the motor 122A will stop.
If for some reason the circuit should not operate prop-
erly and tend to drive the shutters beyond their full-
closed positions, one of the limit switches 118A, 120A
will be opened to prevent further movement of the
shutter 128A in that direction. However, as previously
noted, because of the diodes 124A, 126A, the motor
122A can be driven in a reverse direction to correct the
overdriving condition.
The circuitry of channel B operates in the same man-
ner as that of channel A to energize the motor 122B to
vary the opening in the shutter 128B and move the arm
of the potentiometer 99B until the potentials on the
bases of the transistors 82B, 88B are equal and the dif-
ferential amplifier 32B is balanced. Of course, channel
B controls the shutter opening in a second dimension
at right angles to the dimension controlled by channel
A. The shutters 128A, 128B act together to define a
square or rectangular shutter opening. If the shutter
opening is always to be square, one of the channels A,
B may be eliminated and a single motor used to control
both shutters.
It is apparent from the foregoing explanation that
the invention attains its general objective in providing a
shutter control for adjusting a shutter opening automatically
as the distance from an image plane to a shutter plane is varied.
Although an embodiment of the invention has been shown and described in detail, it is apparent that
many variations and modifications may be made by one
skilled in the art without departing from the true spirit
and scope of the invention.
What is claimed is:
1. In X-ray apparatus having a source of X-rays for
forming an image of predetermined image size in
an image plane, said image plane being variable in
distance from said source, a shutter system comprising:
(a) shutter means defining a variable size shutter
opening therefor, said shutter means being interposed be-
tween said source and said image plane whereby
some of said X-rays pass through said shutter open-
ing in a shutter-defined beam, said shutter means
defining a shutter plane a distance from said source;
(b) power means for varying the size of said shutter
opening and hence the size of said shutter-defined
beam;
(c) a voltage source;
(d) variable impedance means connected directly
across said voltage source for providing a first volt-
age signal proportional to said predetermined image
field size;
(e) first and second impedance means connected in
series to receive said first voltage signal;
(f) said first impedance means being proportional
in value to distance from said shutter plane to said image
plane;
(g) said second impedance means being propor-
tional in value to distance from said shutter plane to said source;
(f) a connection across one of said first and second
impedance means for providing a second voltage
signal proportional to a desired shutter means open-
ing size to provide a proper shutter-defined beam
size for said predetermined image field size and said
distance of said image plane from said source;
(g) third impedance means for providing a third volt-
age signal proportional to actual shutter means
opening size; and
(h) comparison means for comparing said second and
third voltage signals and providing a fourth signal
to said power means for varying the size of said
shutter means opening to vary said actual shutter
means opening size until said second and third sig-
nals are equal.
2. Apparatus according to claim 1, wherein said compa-
ration means includes a differential amplifier.
3. Apparatus according to claim 1, wherein said compa-
ration means includes differential amplifier means and
power amplifier means, an output of said differential
amplifier means controlling said power amplifier means.
4. In X-ray apparatus having a source of X-rays for
forming an image of predetermined image field size in
an image plane, said image plane being variable in dis-
tance from said source, a shutter system comprising:
(a) shutter means defining a variable size shutter
opening therein, said shutter means being interposed be-
tween said source and said image plane whereby
some of said X-rays pass through said shutter open-
ing in a shutter-defined beam, said shutter means
defining a shutter plane a distance from said source;
(b) power means for varying the size of said shutter
means opening and hence the size of said shutter-
defined beam;
(c) selector switch means for selectively providing a
first signal from a predetermined plurality of signals
that are correspondingly proportional to said plu-
rality of predetermined image field sizes;
(d) first impedance means for providing a second
signal proportional to said distance of said image
plane from said source;
(e) second impedance means responsive to said first
and second signals for providing a third signal pro-
portional to a desired shutter means opening size
for said predetermined image field size and said
distance of said image plane from said source;
(f) third impedance means for providing a fourth sig-
nal proportional to actual shutter means opening
size; and
(g) comparator means for comparing said third and
fourth signals and providing a fifth signal to said
power means for varying the size of said shutter
means opening to vary said actual shutter means opening size until said third and fourth signals are
equal.
5. Apparatus according to claim 4, wherein said compa-
ration means includes a differential amplifier.
6. Apparatus according to claim 4, wherein said compa-
ration means includes differential amplifier means and
power amplifier means, an output of said differential
amplifier means controlling said power amplifier means.
7. Apparatus according to claim 6, wherein said power
amplifier means provides power to said power means
for varying the size of said shutter means opening.
8. Apparatus according to claim 7, wherein said power
means for varying the size of said shutter means open-
ing comprises reversible motor means.
9. In X-ray apparatus having a source of X-rays for
forming an image of predetermined rectangular image
field size in an image plane, said image plane being
variable in distance from said source, a shutter system
comprising:
(a) first and second adjustable shutters respectively
defining length and width of a variable size, rectan-
gular shutter opening, said shutters being interposed
between said source and said image plane whereby some of said X-rays pass through said shutter opening in a shutter-defined beam, said shutters lying substantially in a shutter plane fixed in distance from said source;
(b) first and second power means connected to said first and second shutters for respectively varying said length and width of said shutter opening; and hence the size of said shutter-defined beam;
(c) first and second selector switch means for respectively providing first and second signals from a predetermined plurality of signals that are correspondingly and respectively proportional to length and width of said plurality of predetermined rectangular image field sizes;
(d) first impedance means for providing a third signal proportional to said distance of said image plane from said source;
(e) second impedance means responsive to said first and third signals for providing a fourth signal proportional to a desired shutter opening length for said predetermined image field length and said distance of said image plane from said source;
(f) third impedance means responsive to said second and third signals for providing a fifth signal proportional to a desired shutter opening width for said predetermined image field width and said distance of said image plane from said source;
(g) fourth impedance means for providing a sixth signal proportional to actual shutter opening length;
(h) fifth impedance means for providing a seventh signal proportional to actual shutter opening width;
(i) first comparator means for comparing said fourth and sixth signals and providing an eighth signal to said first power means to adjust said first shutter until said fourth and sixth signals are equal; and
(j) second comparator means for comparing said fifth and seventh signals and providing a ninth signal to said second power means to adjust said second shutter until said fifth and seventh signals are equal.
10. Apparatus according to claim 9, wherein said first and second comparator means each include differential amplifier means and power amplifier means, an output of said differential amplifier means controlling said power amplifier means.
11. Apparatus according to claim 10, wherein the two power amplifier means respectively provide power to said first and second power means for adjusting the length and width of said shutter opening.
12. Apparatus according to claim 11, wherein said first and second power means each comprise reversible motor means.

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