United States Patent

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[72] Inventor **Hal Clarence Becker**
New Orleans, La.

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[73] Assignee **X-Scope Corporation**
Philadelphia, Pa.
a corporation of Delaware. by mesne assignments

[54] **METHOD AND APPARATUS FOR CALIBRATING A CARDIAC X-RAY SYNCHRONIZER**
9 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **250/93,** 250/65
[51] **Int. Cl.** **H05g 1/26**
[50] **Field of Search** ..... 250/93, 102, 65; 128/2.05, (Inquired)

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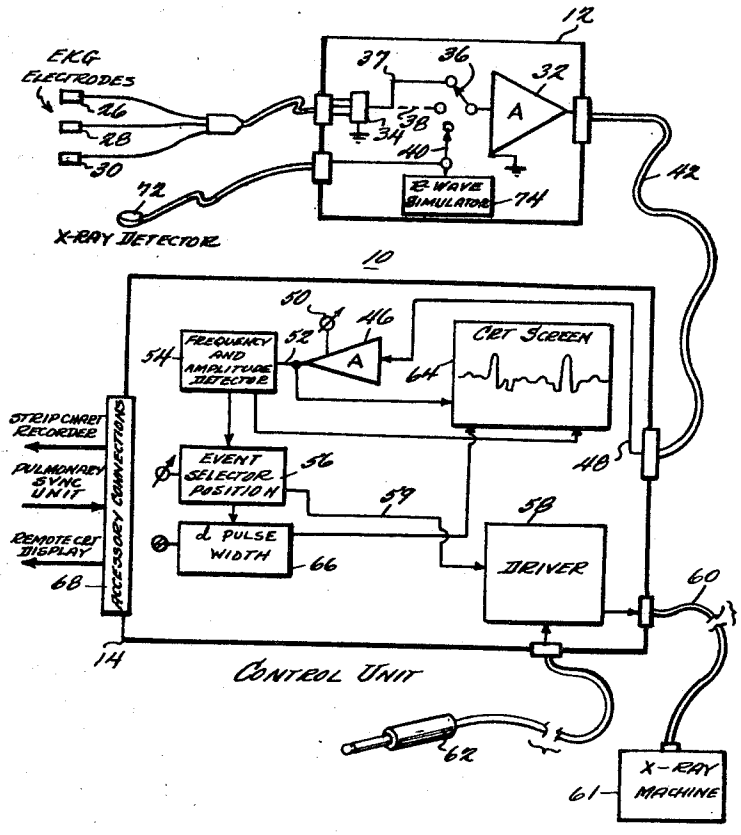
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Primary Examiner—Archie R. Borchelt
Assistant Examiner—C. E. Church
Attorney—Cushman, Darby and Cushman

ABSTRACT: Method and Apparatus for calibrating a cardiac X-ray synchronizer which causes an X-ray machine to produce an X-ray burst at a given adjustable point in the cardiac cycle of a person disposed in the burst path by detecting each R-wave peak and producing a signal actuating the machine at a given adjustable time after the peak and which displays the cardiac waveform and a pulse having a duration equal to the inherent time delay between actuation and burst production so that the operator can set the trailing edge of the pulse on the point. Calibration is accomplished by placing an X-ray detector in the burst path and utilizing a simulated R-wave signal to actuate the synchronizer so that the X-ray burst signal, the simulated R-wave and the pulse are displayed. The pulse width is then adjusted so that the trailing edge coincides with the X-ray burst signal.



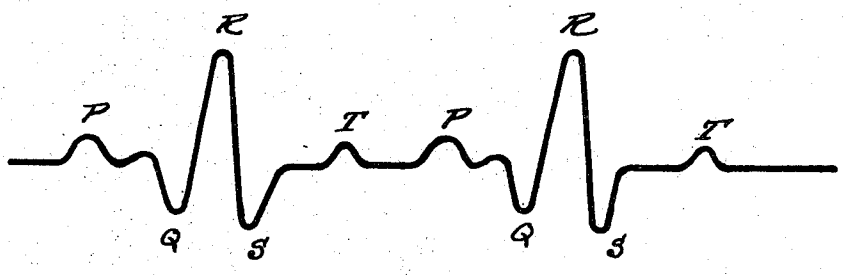


Fig. 1

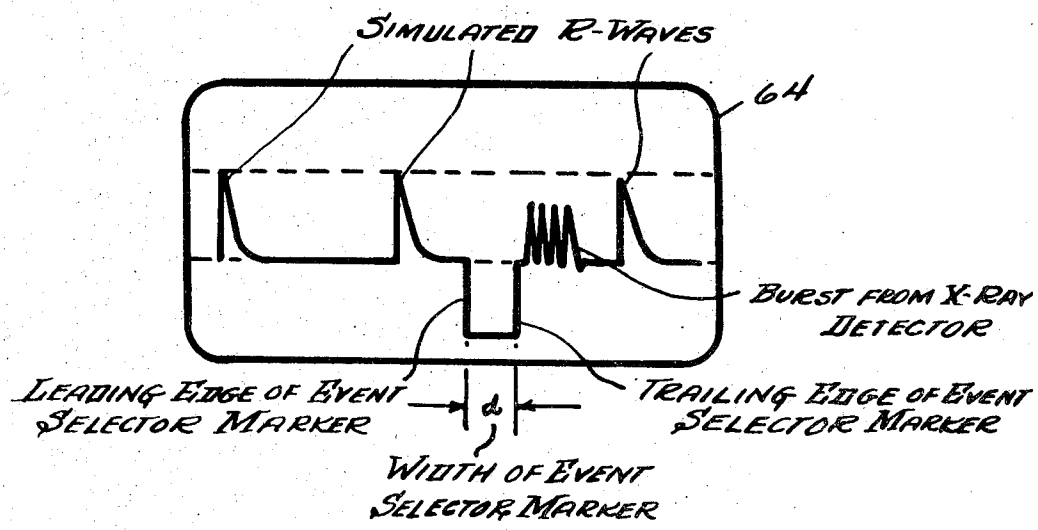
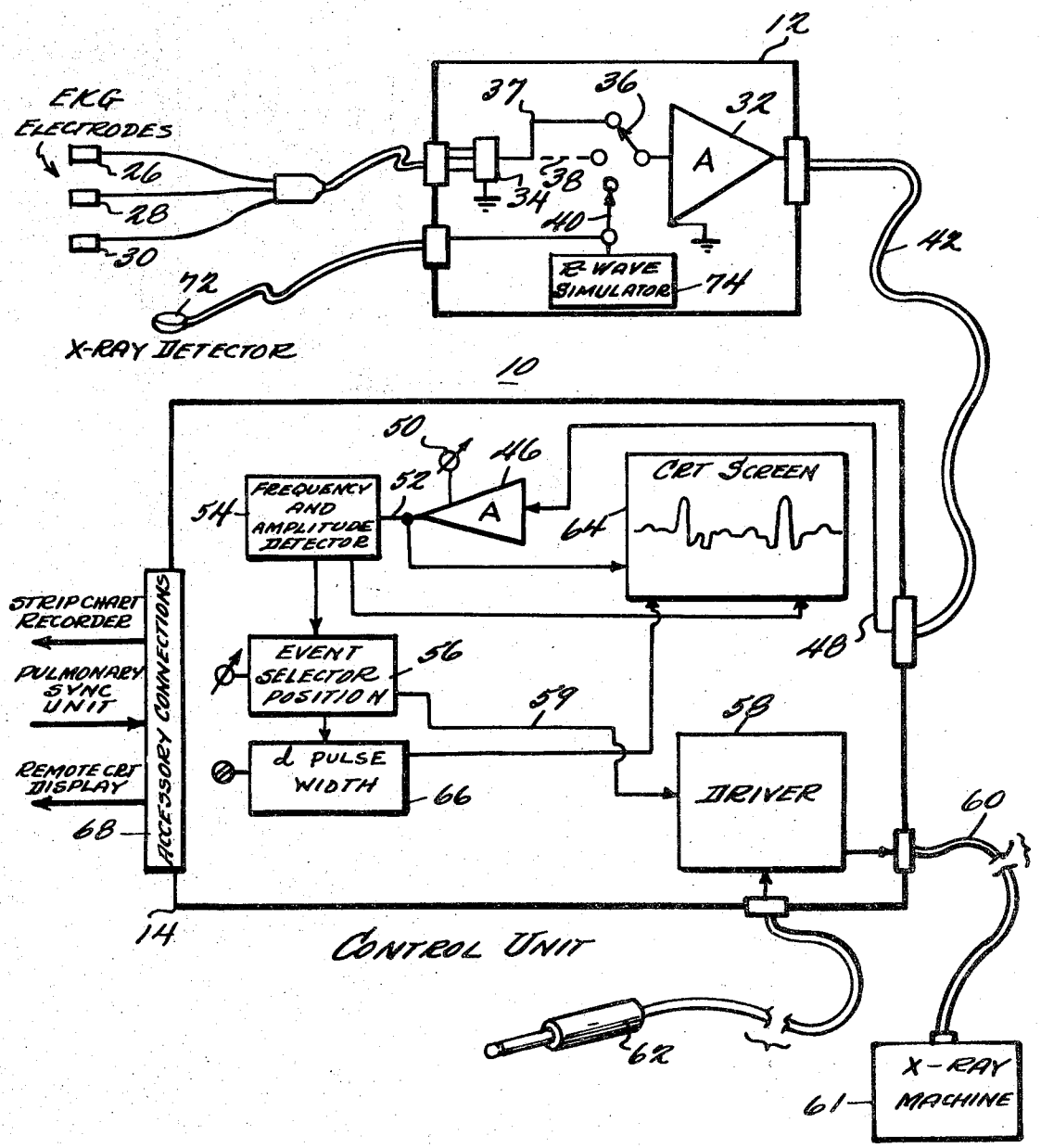


Fig. 3

INVENTOR
HAL C. BECKER

BY Cushman, Darby & Cushman
ATTORNEYS

Fig. 2



INVENTOR
HAL C. BECKER

BY Cushman, Darby & Cushman
ATTORNEYS

METHOD AND APPARATUS FOR CALIBRATING A CARDIAC X-RAY SYNCHRONIZER

DESCRIPTION OF THE PRIOR ART AND SUMMARY OF THE INVENTION

The invention relates to a method and apparatus for compensating for the time delays inherent in activating an X-ray machine and for calibrating an X-ray synchronizer so that it can be used with any given X-ray machine.

A cardiac synchronizer is a device for causing an X-ray picture to be taken at any predetermined point in the cardiac cycle thereby enabling the clinician to follow changes in the size of the heart of a given patient from time to time in an exact manner and to examine the size of the heart at different points during the cycle. The conventional procedure for taking X-ray pictures is simply to manually activate the X-ray machine wherever the subject is in the desired physical position without reference to the cardiac cycle. Since the heart size may vary as much as 2 to 3 centimeters in width between maximum contraction and maximum dilation, it is impossible, with the conventional procedure to extract any meaningful information relating to changes in heart size over a period of time or during a given cycle by comparing X-ray photographs taken at different times. However, using a cardiac synchronizer allows these changes to be detected and evaluated.

Several techniques have been developed for detecting heart disease from such changes or lack of them in the heart size. One such technique is described in an article entitled "Roentgenographic Exercise Test" in the Oct. 23, 1967 issue of the Journal of the American Medical Association and utilizes the two step Master test or a walk of a given distance such as 100 yards. In a normal heart, a decrease in heart diameter after such exercise can be detected by comparing X-ray pictures taken at any given point in the cardiac cycle before and after the exercise, but the heart in most patients with certain types of coronary disease shows either no change at all in heart size or an actual increase in size. Furthermore, this technique is apparently capable of detecting abnormal conditions which no other test can. Therefore, photographing the heart at any given point in the cardiac cycle before exercise and then after exercise can then serve as an effective test to determine the presence of certain abnormal cardiac conditions which might otherwise be undetectable.

One method of photographing the heart at a given point in the cycle used in cardiac synchronizers is to produce an electrical signal delayed for an adjustable time with respect to some prominent characteristic of the electrical waveform produced by the heart, such as the R-wave peak, and use this delayed signal to activate the X-ray machine. However, since a certain amount of time is required between the activating of the X-ray machine and the actual burst of X-rays, the total time between the R-wave peak and the actual photographing is the sum of the adjustable delay and the inherent delay in the X-ray machine itself.

In order to illustrate the time at which the actual burst occurs, superimposed upon the cardiac waveform, for example on an oscilloscope, so that the operator can choose the point in the cycle when firing is to occur without actually taking an X-ray, a pulse having a time width equal to the inherent delay can be produced and displayed. The leading edge of this pulse then represents the instant at which the X-ray machine is activated and the trailing edge then when the actual burst is produced.

However, the delays inherent in activating the X-ray machine vary greatly among the different types of machines and particularly between those devices actuated by a mechanical relay and those operated by solid state electronic circuits. Even different machines of a given model display some time variation which is sufficient to disturb the results of delicate tests. Furthermore, this inherent time delay may change as the machine ages or after repair.

The present invention sets forth an apparatus and method whereby the width of this pulse representing the inherent time delay within the X-ray machine itself between actuation and firing can be easily calibrated to exactly equal that inherent time delay which varies from machine to machine, after the cardiac synchronizer has been completely installed.

First, an X-ray detector, which produces an electrical signal when X-rays impinge upon it, is placed in the line of fire of the X-ray machine and connected into the same electronic circuit which receives the EKG. signals from the heart. Another electrical circuit which produces a signal simulating the R-wave peak is also so connected so that both the simulated R-wave and the X-ray bursts are displayed on the oscilloscope.

The cardiac synchronizer can then be adjusted to fire at any point in the cycle and then reacts to the simulated R-wave in the same manner as it reacts to an actual R-wave peak, by activating the X-ray machine at the proper time after operation of a manual control and displaying the pulse imitating the inherent delays on the oscilloscope. To calibrate the synchronizer then it is only necessary to operate the manual control and then to adjust the width of the pulse imitating the inherent delay so that the trailing edge of the pulse coincides with the displayed burst of X-rays. After this calibration the R-wave simulator and the X-ray detector can be removed, the actual EKG. waveform connected to the synchronizer, and an X-ray photograph taken at any point in the cycle by adjusting the time between the R-wave peak and the actuation of the machine until the trailing edge of the pulse coincides with that point and then simply operating the manual control.

Other objects and purposes of the invention will become apparent from the following detailed description of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows the electrical signals produced by the act of the heart pumping the blood and detected by attaching electrodes to the body.

FIG. **2** shows a cardiac X-ray synchronizer with calibrating apparatus.

FIG. **3** shows the CRT screen of the cardiac X-ray synchronizer while the synchronizer is being calibrated.

DETAILED DESCRIPTION OF THE DRAWINGS

Reference is now made to FIG. **1** which shows the waveform of the electrical signals produced by the heart during a complete cycle, along with the conventional letter representations of the prominent characteristics. Diastole normally occurs upon the trailing edge of the R-wave peak, and systole upon the trailing edge of the T-wave. Since the R-wave peak represents the maximum amplitude of the signal produced it is convenient to utilize it as a reference point from which the time to any other point in the cycle can be measured, and this arrangement is preferred for this embodiment. However, any of the other characteristics of the cycle can alternately be used as such a reference is desired.

Reference is now made to FIG. **2** which shows an X-ray synchronizer **10**, including calibrating apparatus, and made up of a preamplifier unit **12** and a control unit **14** which are each disposed in a separate cabinet. The EKG. electrodes **26**, **28** and **30** can be placed on the patient as desired but preferably they are affixed to the thorax at the auxiliary regions since there is little muscular activity in these areas and therefore practically all muscular displacement artifacts and action potential artifact interference are eliminated. These electrodes can be quickly and easily affixed by applying electrode jelly (or pad) and using adhesive tape over the electrodes to hold them in place. Although only two are normally used, the third can be attached to a leg, or other suitable location, if severe external electrical interference is present.

The three electric leads **26**, **28** and **30** lead into the preamplifier unit **12** where they are connected to a conventional amplifier **32** via a fuse **34** and a three position switch **36**. During normal operation, the switch **36** connects line **37** to the ampli-

fier **32** as shown. However, for those occasional persons whose axis is inverted so that their EKG. Waveform is the negative of the waveform shown in FIG. **1**, an inverted signal is made available on line **38** and switch **36** can be connected to this line in a second position. The third position of switch **36** connecting line **40** to the amplifier **32** is used to calibrate the X-ray synchronizer **10** as described below.

A cable **42** connects the preamplifier unit **12** with the main control unit **14**, which may be mounted on or near the control console of the X-ray machine **61** for easy viewing by the X-ray machine operator. The preamplifier unit **12** may be located on or near the chest film rack so that a cable length of 35 to 50 feet may be necessary.

The signal received in the control unit **14** from the cable **42** is first carried to another amplifier **46** via line **48**. The amplifier **46** is equipped with an amplitude control **50** which can be used to adjust the output signal level on line **52** so that the R-wave peak is sufficient to operate the detector **54** and not enough to result in blocking in amplifier **46**. This adjustment may be made for each individual subject, preferably during maximum inspiration. The output of amplifier **46** on line **52** is then applied to frequency and amplifier detector **54** which produces a short electrical triggering pulse or other appropriate signal coinciding with the leading edge of the R-wave and eliminates the remainder of the waveform shown in FIG. **1** representing the cardiac cycle.

This short pulse is then passed to an event selector device **56** which delays it for a given and variable amount of time, or produces a similar short triggering pulse a given time after the pulse from detector **54** is received. At the end of this given time, the triggering pulse is conveyed to a driver **58** on line **59**, which actuates the X-ray machine **61** by imposing a suitable electrical signal on cable **60** whenever the manual control **62** is operated.

This manual control **60** may be simply a hand held unit with a button which the operator presses when he wishes to take an X-ray exposure. The cardiac synchronizer **10** will then trigger the machine **61** at the next chosen and appropriate point in the cardiac cycle.

In every X-ray machine a definite time will elapse between the time that the machine is activated and when an actual burst occurs. With conventional methods, this delay is inconsequential but if the photograph is to be taken at a definite point in the cardiac cycle the burst itself must coincide with that point and not simply the activation of the machine. This requires that the X-ray machine be activated at a time before the given point equal to this inherent time delay.

The proper time for activating the X-ray machine **61** can be simply determined by displaying on a CRT or oscilloscope screen in conjunction with the cardiac wave a pulse having a width equal to this inherent delay and produced by the signal actuating the machine **61** so that the leading edge represents the time at which the X-ray machine **61** is actuated and the trailing edge the time at which the X-ray burst is actually produced. Therefore, the operator of the machine **61** can visually select and ascertain at what point in the cycle the actual photograph will be taken by setting the trailing edge of this pulse, hereforth called the *d* pulse, on the event.

In this embodiment, the *d* pulse is produced by pulse generator **66** and has a given adjustable width which is varied as described below to calibrate the synchronizer **10**. The generator **66** is activated by the production of the triggering pulse by the event selector **56** which serves to activate the X-ray machine **61** via driver **58**. The generator **66** is connected to the CRT screen **64** which may be of the long persistence type so that both the *d* pulse and the cardiac wave will appear on the screen **64** continuously before, during and after actuation of the X-ray machine **61**.

To take an exposure, the operator merely attaches the electrodes **26**, **28** and **30** to the subject and applies a suitable source of electrical energy (not shown) to the synchronizer **10**. The cardiac waveform shown in FIG. **1** and the *d* pulse produced by each R-wave peak then appear on the CRT screen **64**. Then the trailing edge of the *d* pulse can be merely adjusted without altering the width of the *d* pulse, which merely represents the inherent and unchanging delay in the X-ray machine **61**, to coincide with the event at which the X-ray burst is chosen to occur by adjusting the event selector **56**. Finally, the manual control **62** is operated so that an X-ray burst results from the signal produced by the driver **58** at the time of the event selected.

The synchronizer **10** can be associated with other devices to perform different functions and this capability is represented in FIG. **2** as an input terminal **68** with two arrows carrying electrical signals outward and one carrying signals inward. One of the outwardly directed arrows represents a connection to a strip chart recorder which can produce a permanent record for later study of the cardiac waveform and the *d* pulse. Furthermore, the strip chart recorder can also be used to record the X-ray burst on the strip chart recorder by disposing an X-ray detector in the path of the X-ray bursts. The other of the outward directed arrows represents the connection to another remote display such as another oscilloscope or CRT screen.

The inwardly directed arrow represents a possible connection to a pulmonary synchronization unit which can be used to ensure that triggering of the X-ray machine occurs only at some level of inspiration, normally maximum inspiration or exhaustion. For example, the U.S. Pat. No. 2,967,944, to Lusted, describes one such system for triggering upon some level of inspiration. Of course, many other exterior devices can be attached and these three are only exemplary.

Reference is now made to FIG. **3** which shows the signals which are displayed on CRT screen **64** during calibration, and the calibrating operation will now be described in detail. To calibrate the cardiac synchronizer **10**, so that the width of the *d* pulse is exactly equal to the inherent delay in the X-ray machine **61**, the switch **36** is first shifted so as to contact line **40**. Connected to line **40** is an R-wave peak simulator **74** which produces an electrical signal which is similar to the R-wave peak of the normal cardiac cycle and an X-ray detector **72**. It is in this embodiment not necessary to attempt to imitate the entire cardiac waveform since only the R-wave is used as a reference. Of course, if another portion of the cycle such as the Q or S valleys where utilized as the reference then that portion would be limited during calibration.

This simulated R-wave signal is then amplified by amplifier **32**, conveyed to the control unit **14** on the cable **46** and properly amplified by the amplifier **42** in the same manner as the ordinary cardiac waveform. The simulated R-wave then passes the frequency and amplitude detector **54**, and operates on the event selector **56** to trigger the driver **58** after a given time has elapsed, which in turn activates the X-ray machine **61** in the same manner as a genuine R-wave peak, whenever the manual control **62** is operated. Since for the purpose of calibration of the *d* pulse it makes no difference which event is selected, the event selector **56** can be arbitrarily set to produce an X-ray burst at any arbitrary time during the cardiac cycle. The passage of a simulated R-wave through the control unit **14** then operates to trigger the X-ray machine **61**, producing a burst of X-rays.

The X-ray detector **72** is disposed so as to intercept a portion of this burst and to produce an electrical signal characteristic of it which can be passed through amplifiers **32** and **46** and displayed on the CRT screen **64**. The detector may be simply a fluorescent screen optically coupled to a solid-state photocell encased in epoxy resin disc and may be taped to the X-ray tube cone to intercept the beam, providing an electrical signal proportional to, and in phase with, the emitted X-ray intensity. This signal is shown in FIG. **3** and labeled "Burst from X-ray Detector." Alternatively, any other suitable device for producing an electrical signal indicating a burst can be employed.

The *d* pulse, the simulated R-wave, and the X-ray bursts will then appear on the CRT screen **64** as shown in FIG. **3** and to calibrate the synchronizer, it is only necessary to alter the

width of the *d* pulse so that its trailing edge coincides with the initiation of the pulse of the X-ray as shown. When this adjustment is completed the width of the *d* pulse will then be exactly equal to the inherent time delay between the actuation of the X-ray machine **61** and the actual production of an X-ray burst. Since this time may change slightly over a period of time, this simple calibration can be made as often as desired to ensure accurate results.

The above embodiment merely represents one example of the invention and any changes and modifications are possible without departing from the spirit of the invention. Consequently, the scope of the invention is limited only by the scope of the appended claims.

I claim:

1. Apparatus for calibrating an X-ray cardiac synchronizer for use with an X-ray machine for causing an X-ray burst to be produced at a given point in the cardiac cycle of a person disposed in the path of said burst having means for receiving the electrical waveform representing said cardiac cycle of said person, means for actuating an X-ray machine an adjustable time after a given portion of said waveform is received, means for producing a pulse beginning when said machine is actuated and having a duration equal to the time between when said machine is actuated and when said burst is produced, so that the time of occurrence of the trailing edge of said pulse coincides with the time of production of said burst, and means for displaying said pulse and said waveform as a function of time, comprising:

an X-ray detector disposable in the path of said burst for producing an electrical signal characteristic of said burst when said burst is produced;

means for connecting said electrical signal to said displaying means so that said electrical signal is displayed with said pulse and said waveform as a function of time;

means for adjusting said duration of said pulse so that the trailing edge of said pulse coincides with said electrical signal on said display means so that the duration of said pulse is equal to the time between when said X-ray machine is actuated and when said burst is produced; and

means for producing a simulated cardiac waveform, and means for connecting said simulated waveform to said synchronizer in the same manner as said waveform of said person so that said simulated waveform is displayed on said displaying means as a function of time and said actuating means actuates said X-ray machine an adjustable time after a given portion of said simulated waveform is received.

2. Apparatus as in claim **1** wherein said given portion of said waveform of said person is the R-wave peak and said simulated signal is sufficiently similar to said R-wave peak to cause said actuating means to actuate said X-ray machine.

3. Apparatus for causing an X-ray burst from an X-ray machine to be produced at a chosen point in the cardiac cycle of a person disposed in the path of said burst comprising:

means for detecting said cardiac cycle and for producing the electrical waveform representing said cycle;

means connected to said detecting means for amplifying said waveform;

means for detecting the R-wave peak of the amplified waveform;

means for actuating said X-ray machine at a given adjustable time after said R-wave is detected;

pulse generating means for producing a pulse with its leading edge occurring at the time said X-ray machine is actuated and its trailing edge at the time said burst is produced;

display means for displaying said pulse and said waveform as a function of time so that the trailing edge of said pulse coincides with the point in said waveform at which said burst is produced;

means for altering said given adjustable time to alter said chosen point;

manual operated means for causing said actuating means to activate said X-ray machine;

X-ray detecting means disposable in the path of said burst for producing an electrical signal representing said burst;

means for connecting said electrical signal to said displaying means so that said electrical signal is displayed as a function of time;

means for producing a simulated R-wave signal for causing said actuating mans to actuate said X-ray machine;

switch means for connecting said producing means to said amplifying means and disconnecting said detecting means from said amplifying means so that said simulated signal causes said actuating means to actuate said machine and is displayed on said displaying means as a function of time; and

means for adjusting the width of said pulse so that when said simulated signal, said electrical signal; and said pulse are displayed on said displaying means the trailing edge of said pulse coincides with said electrical signal.

4. Apparatus as in claim **3** including an X-ray machine.

5. Apparatus as in claim **4** including means connected to said detecting means for inverting said waveform and wherein said detecting means includes a plurality of electrodes attached to said person and said switch means includes a three position switch having a first position connecting said amplifying means to said detecting means, a second position connecting said amplifying means to said inverting means and a third position connecting said amplifying means to said means for producing a simulated R-wave.

6. Apparatus as in claim **5** including further amplifying means connected to said amplifying means, a first housing containing said means for producing a simulated R-wave, said inverting means, said amplifying means and said three position switch, and a second housing containing said further amplifying means, said detecting means, said actuating means, said pulse generating means, and said display means.

7. A method of calibrating a cardiac X-ray synchronizer for use with an X-ray machine for causing an X-ray burst to be produced at a given point in the cardiac cycle of a person disposed in the path of said burst and having means for receiving the electrical waveform representing said cycle, means for actuating an X-ray machine an adjustable time after a given portion of said waveform is received, manual control means operable to cause said actuating means to actuate said machine, means for producing a pulse beginning when said machine is actuated and having a duration equal to the time between when said machine is actuated and the time said burst is produced so that the time of occurrence of the trailing edge of said pulse coincides with the time of production of said burst, and means for displaying said pulse and said waveform as a function of time, comprising the steps of:

connecting said receiving means to means for producing a signal simulating said given portion of said waveform and to an X-ray detector disposed in the path of said burst so that said signal simulating said portion causes said actuating means to actuate said machine and produce said pulse, so that said signal simulating said portion and said signal representing said burst are displayed on said display means when said manual control means is operated;

operating said manual control means so that said pulse, said signal simulating said portion and said signal representing said burst are displayed on said displaying means; and

adjusting the width of said pulse so that the trailing edge of said pulse coincides with said signal representing said burst.

8. A method of calibrating a cardiac X-ray synchronizer for use with an X-ray machine for causing an X-ray burst to be produced at a given point in the cardiac cycle of a person disposed in the path of said burst and having means for receiving the electrical waveform representing said cycle, means for actuating an X-ray machine an adjustable time after a given portion of said waveform is received, manual control means operable to cause said actuating means to actuate said machine, means for producing a pulse beginning when said machine is actuated and having a duration equal to the time between when said machine is actuated and the time said burst

is produced so that the time of occurrence of the trailing edge of said pulse coincides with the time of production of said burst, and means for displaying said pulse and said waveform as a function of time, comprising the steps of:

placing in the path of said burst an X-ray detector which produces an electrical signal representing said burst when said burst is detected;

producing an electrical signal simulating said given portion of said waveform;

connecting said electrical signal representing said burst and said electrical signal simulating said given portion to said receiving means;

disconnecting said waveform from said receiving means;

operating said manual control means so that said pulse, said signal simulating said portion and said signal representing said burst are displayed on said displaying means; and

changing the width of said pulse so that the trailing edge of said pulse coincides with said signal representing said burst.

9. A method of calibrating an X-ray synchronizer of the type which causes an X-ray burst to be produced at a given point in the cardiac cycle of a person disposed in the path of the burst by detecting each R-wave peak and producing a signal actuating a said machine at an adjustable time after said peak provided a manual control is operated and which displays the cardiac cycle and a pulse triggered by the actuation of said machine and having a duration equal to the inherent time delay of said machine between said actuation and said production of an X-ray burst so that the trailing edge of said pulse marks the point in said cycle at which said burst is produced to allow choosing said point by changing said adjustable time, comprising the steps of:

placing in the path of said burst an X-ray detector which produces a signal representing said burst;

producing an electrical signal simulating said R-wave peak;

operating said manual control to produce an X-ray burst;

displaying said pulse, said signal representing said burst and said signal representing said R-wave peak; and

adjusting the width of said pulse so that the trailing edge of said pulse coincides with said signal representing said burst so that the width of said pulse is exactly equal to said inherent time delay of said machine.