United States Patent [19]

McMaster et al.

[11] **3,719,824**

[45] **March 6, 1973**

[54] **PULSE X-RAY WITH PULSE FIELD ENHANCEMENT OF FILM RESPONSE**

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[73] Assignee: **The Ohio State University,** Columbus, Ohio

[22] Filed: **June 8, 1971**

[21] Appl. No.: **150,956**

[52] **U.S. Cl.** .....**250/65 R,** 250/65 ZE
[51] **Int. Cl.** **G03b 41/16**
[58] **Field of Search** .....250/65 R, 65 ZE; 310/8.7

[56] **References Cited**

UNITED STATES PATENTS

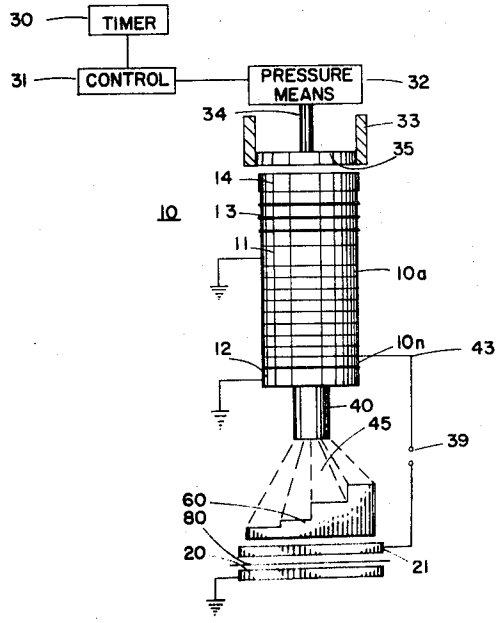
3,148,276	9/1964	Rothstein	250/65 R
2,692,948	10/1954	Leon	250/65 ZE
3,466,473	9/1969	Rhoten	310/8.7
3,551,677	12/1970	Brewster	250/102

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Assistant Examiner—C. E. Church
Attorney—Cennamo, Kremblas & Foster

[57] **ABSTRACT**

Apparatus to enhance the speed of radiographic exposures utilizing pulse X-ray generators of the stacked piezoelectric assembly type. Intense electric fields are applied simultaneously across the thickness of the photographic or X-ray film to produce electron avalanches at each center of latent-image response to exposure. The application of the voltage pulse is synchronized with the pulse of X-rays for the attainment of film speed and contrast enhancement.

9 Claims, 3 Drawing Figures



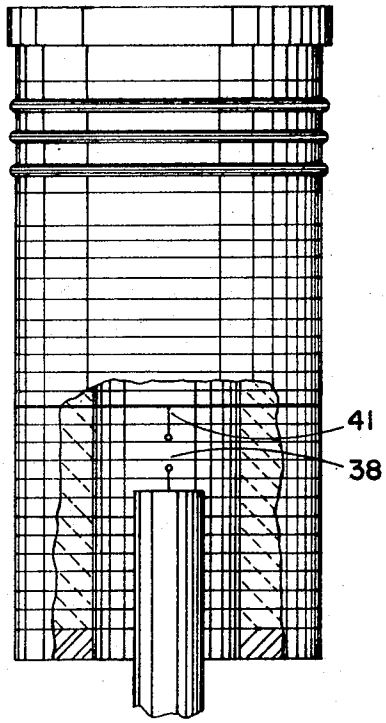


FIG. 2

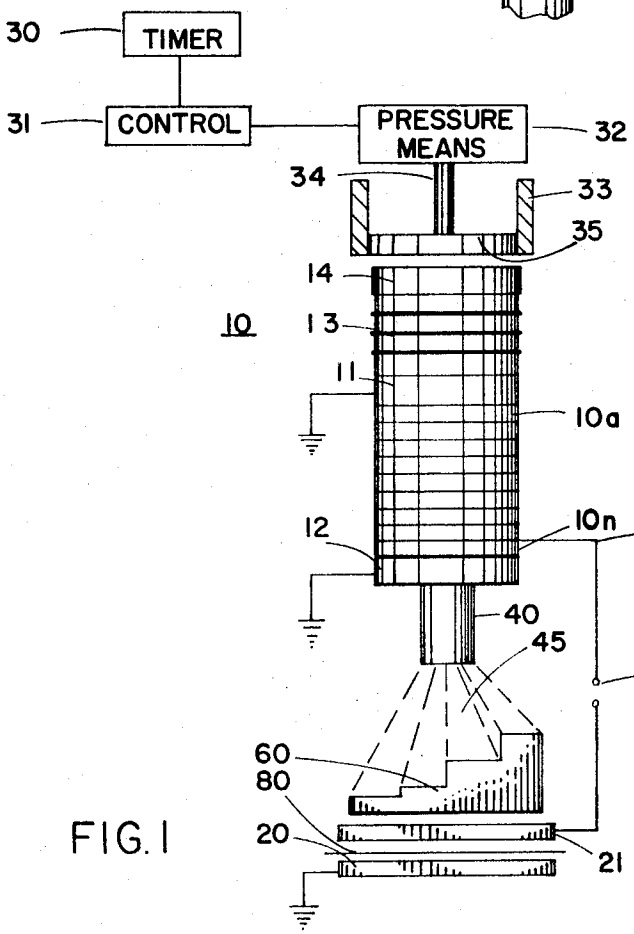


FIG. 1

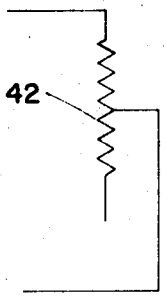


FIG. 1A

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PULSE X-RAY WITH PULSE FIELD ENHANCEMENT OF FILM RESPONSE

BACKGROUND

In the U.S. Pat. to Merle L. Rhoten, No. 3,466,473, there is disclosed a pulse generator comprising a plurality of piezoelectric crystal assemblies in a stacked relationship. The assembly is a piezoelectric wafer in radial compression to prevent fracturing when high voltages or high forces are applied. The pulse generators have been developed in ratings of 150, 200, 300, 600 and 1,000 kvp, and produce waveforms of the order of 30 to 40 nanoseconds in duration.

In general, the practical radiographic application of the aforementioned generators has been deterred by their relatively low output radiation per pulse. Conventionally, to compensate for this limited output radiation the use of high-speed combinations of X-ray films and intensifying screens has been used. This resulted in limited contrast and radiographic detail resolution.

In the U.S. Pat. to J. Rothstein, No. 3,148,276, there is disclosed a method of applying intense electric fields across the thickness of photographic or X-ray films. There is produced electron avalanches at each center of latent-image response to exposure. In this way the electric field intensity is enhanced in regions of higher incident radiation.

As indicated in the Rothstein patent, the shorter the pulse durations, the higher the voltage that can be applied to the film or emulsion without puncturing or breakdown of the emulsion. And, the voltage must be of sufficient amplitude to provide the desired increase in response. Thus, a very large E_{bb} must be used, but cannot be applied for a time longer than its corresponding f_{bb}. But yet, the Rothstein method uses pulses having times of 10–100 microseconds. Accordingly, with the pulse generator utilized by Rothstein there has been reached a limitation as to film speed and contrast response that may be obtained with high voltage excitation.

As further pointed out by prior art, it is necessary that extremely high electric fields be applied during the time the photographic emulsion (or X-ray film) is responding to the impingement of radiation thereupon. The time durations used — relatively speaking — were exceedingly long. To further increase the response phosphor intensifying screens are suggested.

SUMMARY OF THE INVENTION

The present invention utilizes the combination of the pulse X-ray generator of the aforementioned Rhoten patent together with the method of applying simultaneously a high voltage to the X-ray film. To achieve this unique combination, the aforementioned Rhoten X-ray pulse generator has been modified to become a dual pulse generator, a generator to pulse the flash X-ray tube and a generator for providing simultaneously the high voltage for the film enhancement. The voltage pulse applied to the film enhancement electrodes therefore is synchronized with the pulse of X-ray for exposure, since it is part of the same system. Similarly, the "during" exposure requirement is met for the attainment of film speed and contrast enhancement effect.

Specifically, a stack of piezoelectric assemblies is utilized with a midpoint terminal for spark gap coupling of the flash X-ray tube. A second intermediate terminal is connected to the stack of piezoelectric elements for film enhancement. A force applied to the stack of assemblies results in the simultaneous production of high voltage pulses.

Of real significance to the generator of the present invention is that the dual generated pulses are in the order of 10^{-3} times shorter in duration than that of the prior art systems. With this very short time pulse a much higher voltage gradient is applied across the film emulsions without breakdown. With the increase in film response in speed in the order of 100 – 1,000 times the apparatus of the present invention is adaptable to industrial uses.

OBJECTS OF THE INVENTION

It is accordingly a principal object of the present invention to provide a new and improved X-ray system having improved speed in response and contrast.

It is another object of the invention to provide an improved generator for simultaneously providing a pair of high voltage pulses.

A further object of the invention is to generate a high voltage pulse of such short duration that much higher voltage grandients may be applied across the film emulsions without breakdown.

Further objects and features of the invention will become apparent when taken in conjunction with the drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is the preferred embodiment of the present invention shown partly pictorially and partly schematically;

FIG. **1***a* is an alternative resistor connection between the electrode and the generator; and,

FIG. **2** illustrates the stack of piezoelectric assemblies with a cutaway section to illustrate one of the improvements found in the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1** generally, there is shown the pulse generator **10** described in the aforementioned Rhoten patent utilizing a stack of piezoelectric assemblies **10***a* x x x **10***n*. The number of assemblies in the stack **10** are of course dependent upon the parameters required by the particular application. Coupled to a terminal **41** — defining a first pulse generator — of the pulse generator **10** is the flash X-ray tube **40**. This X-ray source is operative in a conventional manner to emit X-ray beam **45** on the workpiece **60**. The X-rays penetrating the workpiece **60** expose the X-ray film **80**. To increase the response of the X-ray film to the X-radiation the high voltage at terminal **43** — defining a second pulse generator — is applied to the electrode **20** positioned beneath the workpiece **60**.

Referring now specifically to FIG. **1** the piezoelectric assemblies **10***a* x x x **10**n are stacked in a vertical arrangement and operative as heretofore described as a high voltage pulse generator **10**. Each of the piezoelectric assemblies is that shown and claimed in the U.S. Pat. to Hildegarde M. Minchenko, No. 3,396,285, utilized therein in an electromechanical transducer. The

assemblies are particularly unique for high voltage applications since the piezoelectric wafer rings are placed under radial compression. This prevents the piezoelectric wafer rings from fracturing when a high voltage or force is applied thereto. At both ends of the column of piezoelectric elements **10***a* x x x **10***n* there is positioned metal rings **11** and **12** preferably brass that make up the two electrical electrodes, in this embodiment the electrodes **11** and **12** are grounded. Also in the embodiment of the present invention there is positioned at the intermediate point of the stack of assemblies **10***a* x x x **10***n* an electrode or terminal **41** and a second terminal **43** positioned near the grounded end of the stack of assemblies. Mounted to the upper end of the stack of assemblies is an insulator **13** which in turn has mounted thereon the metal disc **14** adaptable to receive high pressure blows. All of the components in the stacked generator **10**, the electrodes **11** and **12**, terminals **41** and **43**, insulator **13**, and metal ring **14** have approximately the same diameter as that of the piezoelectric assemblies **10***a* x x x **10***n*.

The physical impact to the piezoelectric pulse generator **10** may be simply a hammer blow or alternatively a pressure controlled impact or a release of pressure. Across the electrodes **11** and **41**, and also across electrodes **12** and **41** a high voltage pulse of extremely short duration is taken for utilization. The insulator **13** is to preserve electrical insulation between the assemblies and the metal impact ring **14**.

With continued reference to FIG. **1** illustrating the preferred embodiment of the generator X-ray exposure/enhancement system of the present invention, the output voltage and/or current from the pulse generator **10** is dependent upon the size of the crystals and the number of crystal assemblies in the stack. Accordingly, the first and most important parameter to be determined is the necessary voltage-current required by the X-ray source **40** and the voltage-current film enhancement. Once this is established the size of the crystals **10***a* x x x **10***n* and the number of assemblies in the stack **10** are determined. The size of the crystals and the number of assemblies are next correlated with the amount of pressure necessary to yield the power output, specifically the work effort required from the pressure source **30** is dictated by the desirable electrical characteristics. The work effort of the pressure source **30** is controlled by the stroke distance of the rod **34** within cylinder **33** as well as the size of the impact means **35**. The stroke distance of the rod **34** is in turn controlled through the controller **31**.

The frequency of the output voltage from the stack of crystal assemblies that is required by the system is controlled through timer **31** to the pressure device **32**. That is, the number of strokes per minute of rod/impact means is time. A single pressure impulse or release can also be used.

It is also to be noted that the pulse X-ray system of the present invention permits two methods of operation, (a) on rising pressure and (b) on release of high pressure. For interchange between these two modes, the crystal stacks have each crystal reversed (top for bottom).

The particular device that constitutes the pressure means **32** has taken alternate arrangements. In one embodiment, utilized in a permanent type of installation, the pressure means is a hydraulic press. In another embodiment, utilized in a portable installation, an explosive type of pressure means is utilized. Still other installations may comprise a gasoline reciprocating engine utilized as the pressure means; sonic motor impact coupling; and hydraulic pressure from oil pumps, switched on and off by fast-acting solonoid valves.

As pointed out above, pulse generators as that shown in FIG. **1** have been developed in ratings of 150, 200, 300, 600, and 1,000 kvp. Each of these generators is operative to produce a pulse waveform of the order of 30 – 40 nanoseconds in duration. However, despite the power rating and extremely short pulse, the pratical radiographic application of these generators for pulse X-ray has been deterred by their relatively low output radiation per pulse.

One solution — known to the art — to compensate for this limited output radiation is the use of high-speed combinations of X-ray films and intensifying screens. The present invention teaches a far more improved technique for increased response. Particularly the use of electrical high voltage pulses simultaneously applied to the X-ray film.

It is acknowledged that the use of electrical means to increase the response of a photographic process has been suggested. Intense electric fields have been applied across the photographic emulsion or X-ray film to produce electron avalanches at each center of latent-image response to exposure. The electron multiplication has lead to increased exposure speed and improvements in contrast.

In the prior studies relative to application of electrical fields to the process, certain requirements have been established, (1) extremely high electrical fields are applied directly to the emulsion or film, (2) the application of the electrical fields must be during the time that the photographic emulsion or film is responding to the impingement of radiation thereupon, and (3) the duration of application of the electric field must be sufficiently short in time to avoid dielectric breakdown. Thus, a very large E_{bb} must be used, but cannot be applied for a time longer than its corresponding f_{bb}.

Continuing with reference to the configuration of FIG. **1** there is shown the arrangement of apparatus and components in a system configuration for pulsing the X-ray **40** source simultaneously with the application of a very short timed high voltage to the X-ray film **80**. The process is made possible by the present invention by modification of the generator **10** to a dual high voltage pulse generator. The modification also shown partly in FIG. **2** comprises a spark gap coupling means **38** intermediately positioned adjacent an intermediate terminal **41** in the stack **10**, of the piezoelectric assemblies. The X-ray source — flash X-ray tube **40** — is energized from the spark gap coupling means **38** and ground **11**. The high voltage electrical pulse is applied to the X-ray film **80** from the electrodes **12** and **43** connected to the high voltage plate **20** and the grounded plate **21**.

When radiation **45** from the X-ray source **40** impinges upon film **80**, electrons are freed within the grains of film emulsion according to the intensity of the variations of the incident radiation passing through the target material **60**. The electrons produced aid the response of the X-ray film in the applied field.

When the electrons are being freed in the X-ray film **80** the very high electric field is applied directly by way of the pair of plates **20–21** as heretofore described. Under the influence of the very high voltage short duration pulse, the electrons acquire energy and make ionizing collisions within X-ray film **80**. A large number of electrons are thereby produced which further assists the exposure process.

If the time duration of the electric field were lengthened, a dielectric breakdown would occur (X-ray film being considered a dielectric). It is believed the breakdown is a result of heating that accompanies ionic conduction. Because of the very short voltage pulses — such as the 30–40 nanoseconds produced by the stacked piezoelectric generator **10** — considerably higher electric fields may be applied to the dielectrics.

In order that the pulse applied to the X-ray film be applied at the time of spark-gap **38** breakdown of the main X-ray pulse generator **40**, a supplementary spark gap **39** (adjusted to fire at the same time instant as the gap in the main power supply) may be added in the lead from terminal **43** to the electrode **20** which applies the pulse field to the X-ray film. Otherwise, the leakage of charge from the one or two piezoelectric rings connected to terminal **43** might (a) start dielectric breakdown of the X-ray film when the pressure pulse starts and long before the main spark gap breaks down and applies voltage to the pulse X-ray tube, and (b) the piezoelectric rings connected between terminal **43** and ground might be discharged by the leakage current through the film electrode circuit, so that no voltage, or less voltage, would appear across them when the X-ray tube spark gap fired and the X-ray pulse occurred.

An alternative system for energizing electrode **43**, which supplies the voltage to the film electrode **20** would be to utilize the chain of resistors **42** (used to bleed off the reverse voltage of the piezoelectric rings during unidirectional pulse operation of the self-rectifying X-ray tube) to feed the pulse voltage to the electrode **20** which applies an electric field across the film. The connection of electrode **43** to this chain of bleed-off resistors could be located to select the desired portion of the total X-ray pulse voltage needed to excite the film.

The piezoelectric pulse generators of the aforementioned patent can produce penetrameter sensitivities of the order of 3 percent. This fails to meet the normal industrial requirements for penetrameter sensitivities in the range from 1 to 2 percent. To attain exposures adequate for standard (Class I or Class II0 X-ray films without screens, it would be necessary to apply a sequence of pulses from the present pulse X-ray systems. This possibly may be 10 to 100 or more pulses, depending upon test object density and thickness, and source-object or source-film distances. On the other hand, with the increases of 100 times obtained in film response speed by the pulse electric field enhancement of the present invention, the pulse X-ray generators are adaptable to many critical industrial and medical applications.

Specific applications of the system of the present invention is in medical and industrial radiography, X-ray diffraction and stress analysis studies. Application is also found in fluoroscopy since the enhancement effects are found in phosphors used in fluorescent or intensifying screens.

Although certain and specific embodiments have been shown, it is to be understood that modifications may be made without departing from the true spirit and scope of the invention.

What is claimed is:

1. Apparatus for radiographic recording utilizing an emulsion film comprising:

a high voltage pulse generator, a penetrating radiation source, means for supporting radiographic film in the path of radiation from said source and adjacent an object to be radiographed and film enhancement high voltage electrode positioned adjacent said film;

said high voltage pulse generator comprising a stacked piezoelectric assembly and operative to produce simultaneously a pair of high voltage pulses of extreme short duration in the range of from 30 to 40 nanoseconds,

means applying the first of said pair of pulses to said radiation source so as to generate radiation,

means for synchronizing said pair of pulses for simultaneously applying the second of said pair of pulses to said electrode and for increasing the fim response several orders of magnitude.

2. Apparatus as set forth in claim **1** wherein said radiation source is an X-ray source and said film is X-ray film.

3. Apparatus as set forth in claim **1** wherein said means for applying said pulses to said radiation source is a spark gap.

4. Apparatus as set forth in claim **1** wherein said high voltage generator is of the stacked piezoelectric assembly type and said pulses are generated across said stack by force impact.

5. Apparatus as set forth in claim **1** wherein said high voltage generator is of the stacked piezoelectric assembly type and said pulses are generated across said stack by pressure release and wherein said first and second means for applying comprises means coupled to said stack.

6. Apparatus as set forth in claim **4** wherein said stack of piezoelectric assemblies includes a terminal for deriving a first high voltage pulse and an intermediate terminal and coupling means for deriving a second high voltage pulse.

7. Apparatus as set forth in claim **5** wherein said coupling means is a spark gap.

8. Apparatus as set forth in claim **1** wherein said last-named means comprises a spark gap.

9. Apparatus as set forth in claim **1** wherein said last-named means comprises a series of tapped resistors.

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