This invention relates to particle accelerators and their synchronization, and more particularly to the use of such particle accelerators to make stroboscopic X-ray pictures or radiographs of a moving object.

It is well known that the energy of a certain number of million electron volts or higher may be imparted to charged particles such as electrons by accelerating the particles with a magnetic induction or electrostatic field. One example of an apparatus for producing this result is disclosed in U. S. Patent No. 2,394,071, granted on February 5, 1946 to W. F. Westendorp and assigned to the General Electric Co., the assignee of this present invention.

Such a machine is commonly referred to in the art as a betatron and comprises field generating means for providing a time-varying magnetic flux which links an orbital path to accelerate charged particles introduced into the path, and a time-varying magnetic guide field which traverses the locus of the orbital path for constraining the particles thereto. Moreover, further energy may be imparted to the charged particles by subjecting them to the repetitive action of a cyclically-varying electric field after they have been accelerated to a desired energy level by the above-mentioned betatron apparatus. Suitable apparatus for achieving this purpose is disclosed in U. S. Patent No. 2,485,409, granted on October 18, 1949 to H. C. Pollock and W. F. Westendorp and also assigned to the assignee of this invention. This latter apparatus is commonly referred to in the art as a synchrotron utilizing betatron start. It generally comprises means such as a high frequency resonator coupled to the charged particle orbital path for providing a localized cyclically-varying electric field to accelerate the particles after they have been accelerated by betatron action, and means for producing a time-varying magnetic guide field traversing the locus of the orbital path for constraining the particles thereto during the application of the electric field.

It is also common in the art, when using either of the above-mentioned forms of apparatus for accelerating particles, to employ iron core magnets to provide suitable magnetic fields and fluxes. However, the iron cores of these magnets may saturate extremely rapidly since the central flux through the is approximately twice that present at the orbital path of the accelerated particles. As suggested by D. W. Kerst and R. Server in vol. 60 of the Physical Review, pg. 53 (1941), this situation may be dealt with by biasing the core of the magnet with a direct current for producing an initial field that is opposite in direction to the final field. Thus the central flux can be made twice its normal value without increasing the saturation of the iron. Particle accelerators that utilize or do not utilize such direct currents are respectively called biased or unbiased machines in the art.

Both biased and unbiased betatrons and synchrotrons can be used to produce short bursts that are short enough to adequately stop the motion of fast moving objects and produce a sharp image upon a film. This may be done by diverting the moving particles after their acceleration has proceeded to the desired degree and directing them at an X-ray producing target. One such X-ray producing betatron is shown in U. S. Patent No. 2,394,072, issued to W. F. Westendorp on February 5, 1946, and assigned to the assignee of the present invention; and a suitable X-ray producing synchrotron is shown in the aforementioned Pollock and Westendorp patent. Since each burst of X rays produced in such betatrons and synchrotrons is small in quantity, it is necessary to direct repeated bursts of X rays toward the moving object for a large interval of time in order that a satisfactory image may be obtained and recorded upon film. However, because the object is moving, the X rays must be directed at it stroboscopically; that is, in order to ensure that the X rays will always be directed toward the moving object at the same point in its cyclically repeating path of movement until a sharp image is recorded on film, the occurrence of the X-ray bursts must be synchronized with the motion of the moving object.

However, the production of X-ray bursts in betatrons and synchrotrons now known to the art is synchronized with their power supply frequency, and heretofore there has been no known means for synchronizing their occurrence with the motion of an object being radiographed. This situation has existed due to the fact that a betatron or synchrotron the acceleration of particles can be accomplished only during the portion of the power supply cycle when the magnetic flux in the magnet is increasing in one direction, from zero guiding flux at the particle orbit to a maximum. In a biased machine this occurs over a little less than 180 electrical degrees from zero flux, or a half cycle of the alternating current power supply potential, and in an unbiased machine over a little less than 90 electrical degrees, or a quarter cycle of the alternating current power supply potential. The injection of particles during the accelerating cycle must always occur at a time shortly after zero flux, as is made clear in an article entitled, "Electronics Applied to the Betatrons," written by T. W. Dietze and the present inventor, and published in vol. 37, No. 10, October 1949, pages 1171 to 1175, of the Proceedings of the I. R. E. However, the termination of the acceleration may be caused to occur at any time after the acceleration starts, so long as it is during the acceleration period. This adjustment is used in the art to vary the energy of the particle accelerator output by varying the acceleration time. The present invention uses this adjustment together with a novel method and apparatus to synchronize the occurrence of the X-ray bursts from a betatron or synchrotron with a moving object.

It is, therefore, one object of this invention to provide a method and apparatus for synchronizing the output of a particle accelerator with any given frequency.

It is another object of this invention to provide a method and apparatus for synchronizing an X-ray output from a particle accelerator with the motion of a recurrently moving object so as to enable a radiograph of said object to be made.

Other objects and advantages will appear as the description of the invention proceeds.

In accordance with the invention, a method is disclosed for synchronizing the output pulses of a betatron or synchrotron with the repetitive motion of an object, while maintaining the accelerating cycles of the machine synchronous with the supply voltage of its alternating current field. This is accomplished by deriving electric signal pulses synchronous with the moving object, injecting particles to be accelerated in the particle accelerator only during an accelerating cycle, and adjusting the time interval after the beginning of one of said signal pulses, deriving an output, such as X rays, from the machine at...
the end of said time interval, and irradiating the object and an X-ray sensitive film with the X-rays so as to make a picture of a portion of the object. The apparatus for practicing the above method comprises a gating switch activated for a given time interval or duration by first signal pulses synchronous with the repetitive movement of the object past a given point, and a coincidence switch receptive of both (1) second signal pulses which are synchronous with said accelerating cycles, and (2) the output of the gating switch. If the second signal pulses occur during the given time intervals when the gating switch is open, they pass through the coincidence switch and serve to inject particles into the particle accelerator. The gating switch output is also used to generate an ejection signal pulse at the termination of each time interval for causing any particles in the accelerator to strike an X-ray emitting target. If desired, the apparatus may be modified by also feeding the pulse signal output of the coincidence switch through a second gating switch to a second coincidence switch. The second coincidence switch also receives the ejection pulse output of the first named gating switch. Only when the two inputs to the second coincidence switch coincide does this switch permit an ejection pulse to pass, thereby insuring that ejection pulses will pass only when particles have been injected and accelerated. Moreover, by varying the time of the intervals of given duration in accordance with any variation in speed of the moving object, exact synchronization between the particle accelerator output and said moving object can be attained. The achievement of such a synchronization has made it possible to use high powered X-ray machines to scan any fast moving object stroboscopically, and make a radiograph or even a motion picture thereof. Such an ability to photograph enclosed moving objects is of extremely great importance in that it now becomes possible to observe the causes of failure within any motor or pump, for example, without opening the motor or pump.

The features of this invention which are believed to be novel and patentable are pointed out in the claims which form a part of this specification. For a better understanding of the invention, reference is made in the following description to the accompanying drawings, wherein like parts are indicated by like reference numerals, in which:

Fig. 1 is a circuit diagram showing one embodiment of the invention:

Fig. 2 is a circuit diagram showing a second embodiment on the invention; and

Fig. 3 comprises seven graphs showing the wave forms appearing at various portions of the circuits of Figs. 1 and 2.

Referring now to Fig. 1, there is shown the basic elements of the novel apparatus needed for practicing the novel method of this invention. In this figure, a block 1 is shown, which block may be a motor containing therein an object having a recurrent motion which it is desired to study stroboscopically by means of X-rays. An X-ray betatron or synchrotron 2 is also shown for producing an X-ray beam 3 which irradiates the moving object to produce upon a film 4 a picture thereof. The moving object is connected to a shaft 5 to which is affixed a disk 6 having a tooth 7 thereupon. This disk is not permanently attached to shaft 5 but may be loosened and turned relative thereto, and then fixed in position. Displaced opposite tooth 7 is a permanent magnet core 8 having a winding 9 thereabout for producing a voltage every time tooth 7 is adjacent thereto and cuts through the lines of flux of said magnetic core. Core 8 and its winding 9 may be replaced by a magnetic pick-up impulse generator such as is made by Electro Products Laboratories, Inc., of Chicago, Ill., for example. There is, therefore, produced in winding 9 a voltage wave form whenever tooth 7 passes core 8, and this voltage is recurrent and synchronous with the motion of the recurrently moving object. The circuits shown within a pair of blocks 11 and 12 are used to synchronize the output of X-ray betatron or synchrotron 2 with the voltages produced in the winding 9. The circuit of block 11 comprises a gating switch, while the circuit of block 12 comprises a coincidence switch. Gating switch 11 is triggered by said voltages and produces square wave pulses synchronous with the repetitive movement of the moving object, each of which has a given duration. These square waves are fed into the coincidence switch of block 12. Also fed into said coincidence switch are pulses from the X-ray betatron or synchrotron and causing them to strike an X-ray target and emit the X-ray beam 3.

It will thus be apparent that the system shown in Fig. 1 causes an output pulse to be generated for each tooth passing core 8, the voltage being recurrent and synchronous with the movement thereof, while the accelerating cycle of the X-ray betatron or synchrotron remains synchronous with the frequency of its supply voltage. A more detailed description of the elements of Fig. 1 and their exact mode of operation now follows.

The voltages induced in coil 9 are differentiated in a differentiating network which includes a capacitor 13 coupled between one end of said coil and a resistor 14, the other end of said coil being connected to ground. The resultant sharp signal pulses are pictured in Fig. 3b and labelled B. Pulses B' in Fig. 3b are obtained by means of a capacitor 16 for the first time. This will be explained below. Pulses B' are then fed into the gating switch 11, which may comprise a one-shot multivibrator 15. This multivibrator includes a triode 16 which is normally conducting due to a positive potential applied to its control grid through a resistor 17 coupled to a positive terminal 18 of a source of positive potential. Multivibrator 15 also includes a triode 19 having its cathode coupled to the cathode of tube 16, both cathodes being coupled to ground through a common resistor 21. The bias developed across resistor 21 due to the conduction of current therethrough when the output of the tube 16 serves to maintain tube 19 normally nonconducting. As is usual in such one-shot multivibrators, the anode of tube 19 is coupled through a capacitor 22 to the control grid of tube 16, and the anode of tube 16 is coupled through a resistor 23 to the control grid of tube 19. The anodes of tubes 16 and 19 are also coupled through respective anode resistors to positive terminal 18 of the source of potential. A positive pulse B is applied to the control grid of normally nonconducting tube 19, and causes it to conduct; whereas its anode potential drops in a negative direction, producing a negative-going voltage pulse. This negative voltage pulse is transmitted through capacitor 22 to the control grid of tube 16 and serves to cut off normally conducting tube 16 and thereby produce in this latter tube a resultant rise in anode potential. The anode of tube 16 will rise at its positive peak for the interval of time that it takes the charge upon capacitor 22 to fall to zero. The anode resistor 17 and the anode resistor of tube 19, after which time the control grid of tube 16 will again become sufficiently positive to cause this tube to conduct. Conduction of tube 16 then produces a negative pulse that is transmitted through resistor 23 to the control grid of tube 19 to cut off this latter tube and return the system to its original condition wherein tube 16 is normally conducting and tube 19 normally nonconducting. The resultant potential rise at the anode of tube 16 has the form of a square wave and is depicted in Fig. 3c as wave forms C. Similar square
waves are also produced simultaneously at the anode of tube 19, but these waves are negative in polarity. The negative going voltage output of tube 19 is applied to a differentiating network comprising a capacitor 24 and a resistor 25, and the resultant differentiated signal pulses, having a wave shape shown in Fig. 3d, are supplied through a conductor 26 to the X-ray producing device. The positive going voltage pulses of the differentiated output signal of tube 19 are indicated at D in Fig. 3d.

The positive square wave signal C from the anode of tube 16 is applied to the third grid of a coincidence switching tube 27 through a coupling capacitor 28. Tube 27 has five grids wherein of the second and fourth are connected together and the fifth is connected to the cathode thereof. Applied to the control grid of tube 27 by a lead 29 through a capacitor 31 is a series of signal pulses labelled A and shown in Fig. 3a. Both the control grid and the third grid respectively of tube 27 have negative biases applied thereto through respective resistors 32 and 33 which are connected to a negative terminal 18 of the supply voltage. The cathode of tube 27 is connected to ground, the second and fourth grids are connected to the positive source of potential through positive terminal 18, and the anode is also connected to the terminal 18 of the positive source of potential through an anode resistor 34. The aforementioned negative biases upon the first and third grids of tube 27 are so chosen that this tube can only conduct when a positive pulse A from lead 29 coincides with a positive square wave C from the anode of tube 16. Upon the conduction of tube 27, a negative pulse is produced in its anode circuit which is coupled through a capacitor 34 to a lead 35; this negative pulse is depicted in Fig. 3e and is labelled E. An examination of Figs. 3a to 3e will readily disclose that pulse E on lead 35 coincides with a pulse A on lead 29 and only appears when this latter pulse coincides with a square wave C. Each square wave C of course is started by a pulse B coincident with the moving object. Further, pulse D also coincides with the termination of the aforementioned square wave C.

Leads 26, 29 and 35 are respectively connected to an ejection circuit 36, an injection timing circuit 37, and an injection circuit 38 of X-ray betatron or synchrotron 2. The betatron and synchrotron may be those respectively noted above as being shown in the Westendorp 2,394,072 patent and the Pollock and Westendorp patent. The injection timing circuit 37 is used to derive the pulses A which serve as injection timing pulses timed with respect to the zero flux time of the betatron or synchrotron, as is explained in the aforementioned article by T. W. Dietze and the present inventor. Such pulses may be obtained by placing a peeker strip in a betatron as shown in U. S. Patent No. 2,553,305, issued to the present inventor on May 15, 1951 and assigned to the assignee of the present invention. The use of a peeker strip in a synchrotron to obtain such injection timing pulses is disclosed in the aforementioned Pollock and Westendorp patent.

Lead 35 is connected to the injection circuit 38 of the betatron or synchrotron and serves to couple negative injection trigger pulses E, to said injection circuit. These negative pulses are timed with respect to the zero flux condition previously noted, and cause particles to be injected into the betatron or synchrotron to be accelerated therein. Suitable injection circuits activated by negative pulses from both the betatron and synchrotron are respectively shown in the aforementioned article by the present inventor and in the Pollock and Westendorp patent.

As noted above, pulses D are fed by lead 26 into an ejection circuit 36 of the betatron or synchrotron. This ejection circuit responds only to the positive pulses D of the pulses shown in Fig. 3d and serves to cause the accelerated particles to strike an X-ray emitting target in response thereto. These X-rays are shown as beam 3, and they are directed through moving object 1 to strike film 4 and produce a radiograph. Suitable ejection circuits for a synchrotron and a betatron are respectively shown in the aforementioned Pollock and Westendorp patent and in Westendorp Patent 2,394,072.

Examining now Figs. 1 and 3 in order to explain the operation of the invention, it will be apparent that synchronizing pulses B derived from moving object 1 have a different frequency than injection timing pulses A derived from injection timing circuit 37, which latter pulses are synchronized with the aforementioned accelerating cycles. Pulses B are used to generate positive square waves C, and also negative square waves from which positive pulses D can be derived. The square waves have a given time duration which is preferably slightly less than one-half the period of time between pulses A if the particle accelerator is unbiased and slightly less than one-half said period if the accelerator is biased, thus ensuring against accidental ejection due to contraction of the particle stream at the end of an acceleration cycle. Positive square waves C serve as injection gate pulses for coincidence tube 27, insuring that this tube will only conduct when injection gate pulses C and injection timing pulses A coincide. Upon this coincidence, an injection trigger pulse E is produced to cause particles to be injected in the betatron or synchrotron so that they can be accelerated thereby. Consequently, it will be apparent that particles are injected in the betatron or synchrotron only when an injection timing pulse A from the injection timing circuit occurs within said given time interval after a synchronizing pulse B. A short time thereafter, at the end of said given interval of time, a pulse D appears upon lead 26 and causes the accelerated particles to strike the X-ray target. The interval between pulse D and pulse A is labelled x and corresponds to the acceleration time of the particle in the betatron or synchrotron.

From the foregoing it will be apparent that the present invention has made it possible to synchronize the motion of a moving object with the output of an X-ray betatron or synchrotron without changing the accelerating cycle synchronization of the betatron or synchrotron with its flux supply voltage. This feature has made it possible to obtain internal stroboscopic radiographs of machines having recurrently moving internal objects. Further, by successively moving disk 6 relative to moving object 1 on shaft 5 and then fixing its position successively shifting the phase of pulses B, successive points of an internal moving part can be stroboscopically radiographed and the results can then be placed upon a continuous film to provide a motion picture of the movement of the object.

While the circuit and method disclosed in Fig. 1 enables the foregoing advantages to be obtained, it will be noted that the ejection circuit 36 is pulsed by the first pulse D even when no injection trigger pulse E is present to inject particles into the betatron or synchrotron. This pulsing of the ejection circuit, while it has no effect on the X-ray output, may have a deleterious effect upon the ejection circuit power supply in that excessive current flow may ensue with resultant damage to the equipment. To prevent this condition, the circuit of Fig. 1 has been modified in the manner shown in Fig. 2 by the addition of a second one-shot multivibrator gating switch shown in Figs. 39 and a second coincidence switch tube 40. Corresponding elements in Figs. 1 and 2 are correspondingly numbered and perform the same functions in the same way. In Fig. 2, when coincidence switch tube 27 conducts, it is expected to provide an injection trigger pulse E for injection circuit 38. This injection pulse is now also conducted through a rectifier 43 and a capacitor 44 to the control grid of a normally conducting triode 45 of multivibrator gating switch 39. Tube 45 has a positive bias applied to its control grid by a resistor 42 coupled to the positive terminal 18 of the source of potential, and the
The cathode of this tube is coupled to the cathode of a tube 46 of the multivibrator, both cathodes being coupled to ground through a resistor 47. The current flow through normally conducting tube 45 develops a potential across cathode resistor 47 which serves to bias tube 46 to cutoff so that this latter tube is normally nonconducting. The anode of tube 46 is connected to the control grid of tube 45 through the aforementioned capacitor 44, and the anode of tube 45 is connected to the control grid of tube 46 through a resistor 48. Tubes 45 and 46 respectively correspond to tubes 16 and 19 of the multivibrator 15 and operate in exactly the same way. The anode of tube 45 is connected through a capacitor 49 to the third grid of a five grid second coincidence switch tube 41. The grids of tube 41 are connected in the same way as those previously described in connection with first coincidence tube 27, and the cathode of tube 41 is grounded. A negative bias is applied to the respective first and third grids of tube 41 by means of resistor 25 and a resistor 51 which are coupled to negative terminal 18 of the source of potential. The anodes of tubes 41, 45 and 46 are connected through respective resistors to the source of potential at positive terminal 18. A capacitor 52 is connected to the anode of tube 41 and serves to couple the output therefrom through a phase inverter 53 such as a transformer, to lead 26 and ejection circuit 36. Since the anode of tube 16 is connected through capacitor 28 to the third grid of tube 27, it will be seen that multivibrator 15 and coincidence tube 27 operate in this figure in exactly the same manner as they did in Fig. 1 to produce an injection trigger pulse E on lead 35 whenever an injection timing pulse A appears on lead 29 that coincides with the square wave G generated by synchronizing pulse B from the moving object. However, the pulse appearing on lead 26 and activating the ejection circuit 36 is no longer pulse D, as will be described below.

Now will be described the operation of the above-mentioned portions of Fig. 2 which differ from Fig. 1. The negative injection trigger pulse E derived from the anode of tube 27 and depicted in Fig. 3e passes through rectifier 43 and capacitor 44 and serves to cut off normally conducting tube 45 to conduct due to multivibrator action. A resultant positive square wave appears at the anode of tube 45 having a duration determined by the rate of discharge of capacitor 44 through resistor 43 and the anode resistor of tube 45, and a similar negative square wave appears simultaneously at the anode of tube 46, rectifier 43 having a polarity such that this negative square wave cannot pass therethrough and to injection circuit 38. This positive square wave is depicted in Fig. 5f and labelled F, and it only can occur when an injection trigger pulse E has simultaneously gone to injection circuit 38 and caused particles to be injected into the betatron or synchrotron 2. Positive square wave F will cause coincidence tube 41 to conduct only when a positive pulse D, derived from the negative square wave at the anode of tube 19, is produced and simultaneously applied to the control grid of tube 41. At this time, tube 41 conducts to produce a negative pulse G depicted in Fig. 3g, and this negative pulse then passes through capacitor 52 to be reversed in polarity by phase inverter 53 and applied as a positive pulse to lead 26 and ejection circuit 36 of the betatron or synchrotron. It will be seen from the operating diagram of Fig. 2 described above and from Fig. 3 that now an ejection trigger pulse G for causing accelerated particles to strike the X-ray target only can occur when particles have actually been injected into the betatron synchrotron and have been accelerated. The time x between waveforms E and G is the accelerating period of particles in the betatron or synchrotron and it determines the amount of acceleration of these particles. This time equals the time x between waveforms A and D since the former ejection pulse D coincides with pulse G, but now an ejection pulse G is produced only when particles are injected, thus effectively eliminating the deleterious effects of the first occurring pulse D in Fig. 3d.

The circuit of Fig. 2 also differs from that of Fig. 1 in one other respect. The above discussion in connection with Figs. 1, 2 and 3 proceeded upon the assumption that the positive ejection pulse G coincides with pulse D, the speed, thereupon tooth 7 of disk 6 would pass core 8 at regular intervals and the same point on moving object 1 would be periodically scanned by X-ray beam 3. However, under actual operating conditions, the speed of the moving object may easily vary by more than 1 or 2 percent of its normal speed, causing the image upon tooth 7 to be slightly blurred due to the fact that different points of the moving object are being scanned. In order to compensate for any speed variation in moving object 1, a further modification has been made in Fig. 2. A second tooth 10 has been added to disk 6 and a triode 20 has been inserted between differentiating network 13, 14 and multivibrator 15 with the control grid of tube 20 being connected to the junction of capacitor 13 and resistor 14. The tube 20 is self biased to cutoff by means of a resistor 30 and a capacitor 40 which couples the cathode of tube 20 to ground, and which is placed at positive terminal 18 of the source of potential through a resistor 50. The anode of tube 20 is also connected to a pair of rectifiers 54 and 55, rectifier 54 being connected to the anode of normally conducting tube 16 of multivibrator 15, and rectifier 55 being connected to the anode of normally nonconducting tube 19 of said multivibrator. Also, in order to speed the action of this multivibrator, a capacitor 56 has been placed across resistor 23 between the anode of tube 16 and the control grid of tube 19 which is coupled to ground through a resistor 57. The values of capacitor 22, resistor 17, and the anode resistor of tube 19 are so chosen that the square wave produced by multivibrator 15 now exceeds slightly the 90 electrical degrees time interval previously noted if using an unbiased X-ray betatron or synchrotron, or slightly exceeds 180 electrical degrees if the machine is biased.

Now will be described the operation of the last mentioned portions of Fig. 2 which differ from Fig. 1. Assuming a counterclockwise rotation of disk 6, when tooth 7 cuts the line of flux of core 8, a potential is induced in winding 9 which is differentiated by capacitor 13 and resistor 14 to produce a positive pulse B, as shown in Fig. 3b, which is sufficient to overcome the bias of tube 20 and cause this tube to produce a negative pulse at its anode. Due to the high positive potential at the anode of normally nonconducting tube 19, this negative pulse passes through rectifier 55 to the anode of tube 19 and then through capacitor 56 to the control grid of normally conducting tube 16, causing this tube to be cut off. Because normally conducting tube 16 has a low anode potential, this negative pulse cannot pass through rectifier 54 to the anode of tube 16, and therefore tube 19 is unaffected thereby. When normally conducting tube 16 is caused to be cut off by the said negative pulse, due to multivibrator action, tube 19 is then caused to conduct. With the triggering of multivibrator 15, as previously described, particles to be accelerated will be injected by injection circuit 38 into the X-ray betatron or synchrotron 2 if a pulse A occurs during multivibrator 15 is in operation. Now however, instead of supplying an ejection trigger pulse G at the natural conclusion of multivibrator square wave output C, the multivibrator action is terminated when tooth 19 cuts the lines of flux of core 8. The positive pulse generated when tooth 10 is opposite core 8 is depicted in Fig. 2b and labelled B'. Pulse B' causes a negative pulse to appear at the anode of tube 20 and since tube 19 is now conducting and tube 16 is now cut off, the above described action of these tubes is reversed and this negative pulse can only affect tube 19, while it can have no effect upon
tube 16. Pulse B', therefore, serves to operate the multi-
vibrator and restore the original condition where tube 16 is conducting and tube 19 is nonconducting. It will thus be apparent that by means of tooth 10, if the motion of moving object 1 speeds up, square wave C will have a shorter duration than if moving object 1 slows down, in view of the fact that pulse B' will occur closer or farther away from pulse B. Since the termination of the square wave C determines the time when ejection trigger pulse G will cause the accelerated particles to strike an X-ray target and emit an X-ray beam 3, it will be apparent that X-ray beam 3 is now perfectly syn-
chronized with any speed of moving object 1. Thus it is now possible to insure against any blurring of the image of the moving object upon film 4.

In connection with Figs. 1 and 2, it should be under-
stood that if so desired an X-ray integrator may be placed behind film 4 to determine when the film has been suf-

ciently exposed to the X rays to produce a picture. Such
integrators are well known in the art, one such suitable instrument being called the Integron IV and being manu-
factured by the Victoreen Instrument Co. of Cleveland,
Ohio. The output of the X-ray integrator when the pic-
ture is complete may be used to stop the particle ac-

celerator and then used to take a new picture; said output may also be used to turn slainly disk 6 with respect to shaft 5 and insert a new film 4 in addition to turning off particle accelerator 2, thereby automatically providing a motion picture record of the moving object 1.

It should be understood that the present invention is
not limited to any particular type of particle accelerator, since any particle accelerator that is synchronized with a separate supply voltage can be adapted for use with this invention. Further, this invention is not limited to any particular device for obtaining synchronizing pulses, since any device which will allow any type of recurrent motion of a moving object can be used to derive suitable synchronizing pulses, regardless of whether the motion is circular or reciprocal. Moreover, the present in-

vention is not limited to any particular type of switching
arrangement but can utilize any circuits which will assure that only injection timing pulses occurring a short time before the ejection pulses will be permitted to pass through and inject particles into a betatron or synchro-
tron, and that the particles will be ejected at the conclusion of said time interval.

From the foregoing it is believed apparent that a novel method and apparatus have been disclosed which make it possible for the first time to study the movements of enclosed moving objects by means of X-ray betatrons or synchrotrons without changing the synchronization of these pieces of apparatus with their power supply. While there have been described what are at present considered preferred embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from this invention; and it is aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Apparatus for deriving output pulses from a par-
iclusterator that are synchronous with input pulses of a first frequency, said particle accelerator having an ac-

celerating cycle which recurs at a rate equal to a second
frequency, comprising means for injecting particles to be accelerated into said particle accelerator only during an accelerating cycle and within a given time interval after the beginning of a pulse in said series of pulses, and means for deriving an output pulse from the accelerated particles at the end of said given time interval.

2. The apparatus of claim 1, further including means for varying the duration of said given time interval in accordance with any variation of said first frequency.

3. The apparatus of claim 1, wherein said particle ac-
celerator includes an X-ray target, and said means for


deriving an output pulse includes means for directing the accelerated particles against said X-ray target to produce X-rays.

4. Apparatus deriving output pulses from a particle accelerator that are synchronous with input pulses of a first frequency, said particle accelerator having an acceler-
ating cycle which recurs at a rate equal to a second fre-

quency, comprising means for generating a series of in-

jection pulses each of which respectively occurs during a respective accelerating cycle, means for injecting par-
ticles to be accelerated into said particle accelerator by means of said injection pulses only when an injection pulse occurs within a given time interval after the begin-
ning of an input pulse, and means for deriving an output pulse from the accelerated particles at the end of said given time interval.

5. Apparatus for deriving output pulses from a particle accelerator that are synchronous with a first frequency, said particle accelerator having an accelerating cycle which recurs at a rate equal to a second frequency, comprising means for producing a series of pulses having a frequency equal to said first frequency, means for injecting particles to be accelerated into said particle accelerator only during an accelerating cycle and within a given time interval after the beginning of a pulse in said series of pulses, and means for deriving an output pulse from the accelerated particles at the end of said given time interval.

6. Apparatus for deriving output pulses from a particle accelerator that are synchronous with a first frequency, said particle accelerator having an accelerating cycle which recurs at a rate equal to a second frequency, comprising means for producing a first series of pulses hav-
ing a frequency equal to said first frequency, means for producing a second series of pulses having a frequency equal to said second frequency and each pulse of which respectively occurs during a respective accelerating cycle, means for injecting particles to be accelerated into said particle accelerator by means of said second series of pulses only when a pulse of said second series of pulses occurs within a given time interval after the beginning of a pulse in said first series of pulses, and means for de-


riving an output pulse from the accelerated particles at the end of said given time interval.

7. Apparatus for making stroboscopic radiographs of an object moving recurrently at a first frequency by means of an X-ray producing particle accelerator having an ac-

celerating cycle which recurs at a rate equal to a second
frequency, comprising means for generating a series of pulses having a frequency equal to said first frequency, means for injecting particles to be accelerated into said particle accelerator only during an accelerating cycle and within a given time interval after the beginning of a pulse in said series of pulses, and means for directing the accelerated particles at the end of said given time interval against an X-ray target to produce X rays, and means for recording the X-ray image of said object when said X rays are directed thereat.

8. The apparatus of claim 7, further including means for varying the duration of said given time interval in accordance with any variation of said first frequency.

9. The apparatus of claim 7, wherein a pulse of said series of pulses occurs whenever a point on said moving object passes through a given point in space, and further including means for varying the phase of said series of pulses relative to said point on said moving object.

10. The apparatus of claim 9, further including means for varying the duration of said given time interval in accordance with any variation of said first frequency.

11. Apparatus for making stroboscopic radiographs of an object moving recurrently at a first frequency by means of a particle accelerator having an accelerating cycle which recurs at a rate equal to a second frequency, said
particle accelerator including ejection means for directing accelerated particles at an X-ray target to produce X rays, comprising means for producing a first series of square wave pulses having a frequency equal to said first frequency, each of said square waves having a given time duration, means for producing a second series of pulses having a frequency equal to said second frequency and each pulse of which respectively occurs during a respective accelerating cycle, means for injecting particles to be accelerated into said particle accelerator by means of said second series of pulses only when a pulse of said second series of pulses coincides with any square wave of said first series of pulses, means for producing a third series of pulses respectively coinciding with the termination of the respective square waves of said first series of pulses, means for activating said ejection means in response to said third series of pulses to irradiate said object by means of X rays, and means for recording the X-ray image of said object.

12. The apparatus of claim 11, wherein the accelerated particles are directed toward the X-ray producing target only by pulses of said third series of pulses occurring at the termination of the square waves that coincide with the pulses of said second series of pulses.

13. The apparatus of claim 11, further including means for producing a fourth series of square wave pulses each of which is generated only when a pulse of said second series of pulses coincides with a square wave of said first series of pulses, and means for activating said ejection means in response to said third series of pulses only when a pulse of said third series of pulses coincides with a pulse of said fourth series of pulses.

14. The apparatus of claim 13, further including means for varying said given time interval in accordance with any variation of said first frequency.

15. The apparatus of claim 13, wherein a pulse of said first series of pulses occurs whenever a point on said moving object passes through a given point in space, and further including means for varying the phase of said first series of pulses relative to said point on said moving object.

16. The apparatus of claim 15, further including means for varying the duration of said given time interval in accordance with any variation of said first frequency.

17. The apparatus of claim 14, wherein said moving object is coupled to a disk having at least one tooth thereof and each pulse of said first series of pulses is generated only when said tooth passes through a given point in space, the coupling of said disk relative to said moving object being such that said disk can be advanced to vary the phase of said first series of pulses.

18. The apparatus of claim 17, further including a second tooth upon said disk for producing a fifth series of pulses synchronous with said first frequency but respectively separated in time from the beginning of the respective pulses of said first series of pulses for changing the duration of said given time interval in accordance with any variation of said first frequency.

19. Apparatus for making stroboscopic radiographs of an object moving recurrently at a given frequency by means of a particle accelerator having an accelerating cycle which recurs at a rate equal to another frequency, said particle accelerator including ejection means for directing accelerated particles at an X-ray target to produce X rays, comprising means for producing a first series of pulses having a frequency equal to that with which a given point on the moving object passes a given point in space, square wave generator means receptive of and responsive to said first series of pulses for producing a second series of square wave pulses having a frequency equal to that of said first series of pulses, means for producing a third series of pulses having a frequency equal to the accelerating cycle recurrence rate of said particle accelerator and each pulse of which respectively occurs during a respective accelerating cycle, coincidence switch means receptive of said second and third series of pulses for passing only the pulses of said third series of pulses that coincide with pulses of said second series of pulses, the pulses so passed being coupled to said particle accelerator and serving to inject therein particles to be accelerated, means for deriving from said second series of pulses which respectively coincide with the termination of the respective square waves of said second series of pulses for activating said ejection means to produce X rays for irradiating said moving object, and means for recording the X-ray image of said object.

20. The apparatus of claim 19, further including square wave generator means receptive of and responsive to the pulses of said third series of pulses that are passed by said coincidence switch for producing a fifth series of square wave pulses, and coincidence switch means disposed between the means for deriving said fourth series of pulses and said ejection means and receptive of and responsive to both said fourth and fifth series of pulses for only passing those pulses of said fourth series of pulses that coincide with square waves of said fifth series of pulses, only the pulses so passed serving to activate said ejection means.

21. The apparatus of claim 19, further including means for generating a series of pulses equal in frequency to that of first series of pulses but separated therefrom by intervals of time which vary in accordance with any variation in speed of said moving object for terminating the duration of each square wave of said second series of pulses.

22. In combination: X-ray particle accelerator means with an accelerating cycle which recurs at a rate equal to a given frequency and having injection timing circuit means for generating a first series of electrical pulses having a frequency equal to its accelerating cycle recurrence rate and each pulse of which respectively occurs during a respective accelerating cycle, injection circuit means responsive to electrical pulses for injecting particles to be accelerated therein, and ejection circuit means responsive to electrical pulses for causing accelerated particles to strike an X-ray target; means for producing a second series of electrical pulses having a frequency equal to that with which a given point on a recurrently moving object passes a given point in space, one-shot multivibrator means receptive of and responsive to said second series of pulses for producing a third series of square wave electrical pulses having a frequency equal to that of said second series of pulses, coincidence tube switch means receptive of said first and third series of pulses for passing only the pulses of said first series of pulses that coincide with square wave pulses of said third series of pulses, the pulses so passed being coupled to and activating said injection circuit means of said X-ray particle accelerator, differentiating means for deriving from said third series of pulses a fourth series of electrical pulses which respectively coincide with the termination of the respective square waves of said third series of pulses and being coupled to and activating said ejection circuit means to produce X rays for scanning said object and means for recording the X-ray image of said object.

23. The apparatus of claim 22, further including one-shot multivibrator means receptive of and responsive to the pulses of said first series of pulses that are passed by said coincidence tube switch means for producing a fifth series of square wave electrical pulses, and coincidence tube switch means disposed between said differentiating means and said ejection circuit means and receptive of and responsive to both said fourth and fifth series of pulses for only passing those pulses of said fourth series of pulses that coincide with square waves of said fifth series of pulses, only the pulses so passed serving to activate said ejection circuit means.

24. The apparatus of claim 23, further including means coupled to the first-named multivibrator means for gen-
erating a sixth series of electrical pulses equal in frequency to that of said second series of pulses but separated therefrom by intervals of time which vary in accordance with any variation in speed of said moving object and for terminating the operation of said first-named multivibrator means to vary the duration of each square wave of said third series of pulses.

25. The apparatus of claim 24, wherein the means for generating said second series of pulses and the means for generating said sixth series of pulses comprise a rotatable disk coupled to said moving object and having a pair of teeth thereupon, and magnetic pick-up means disposed adjacent to said disk for producing a pulse each time a tooth of said disk passes thereby.

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