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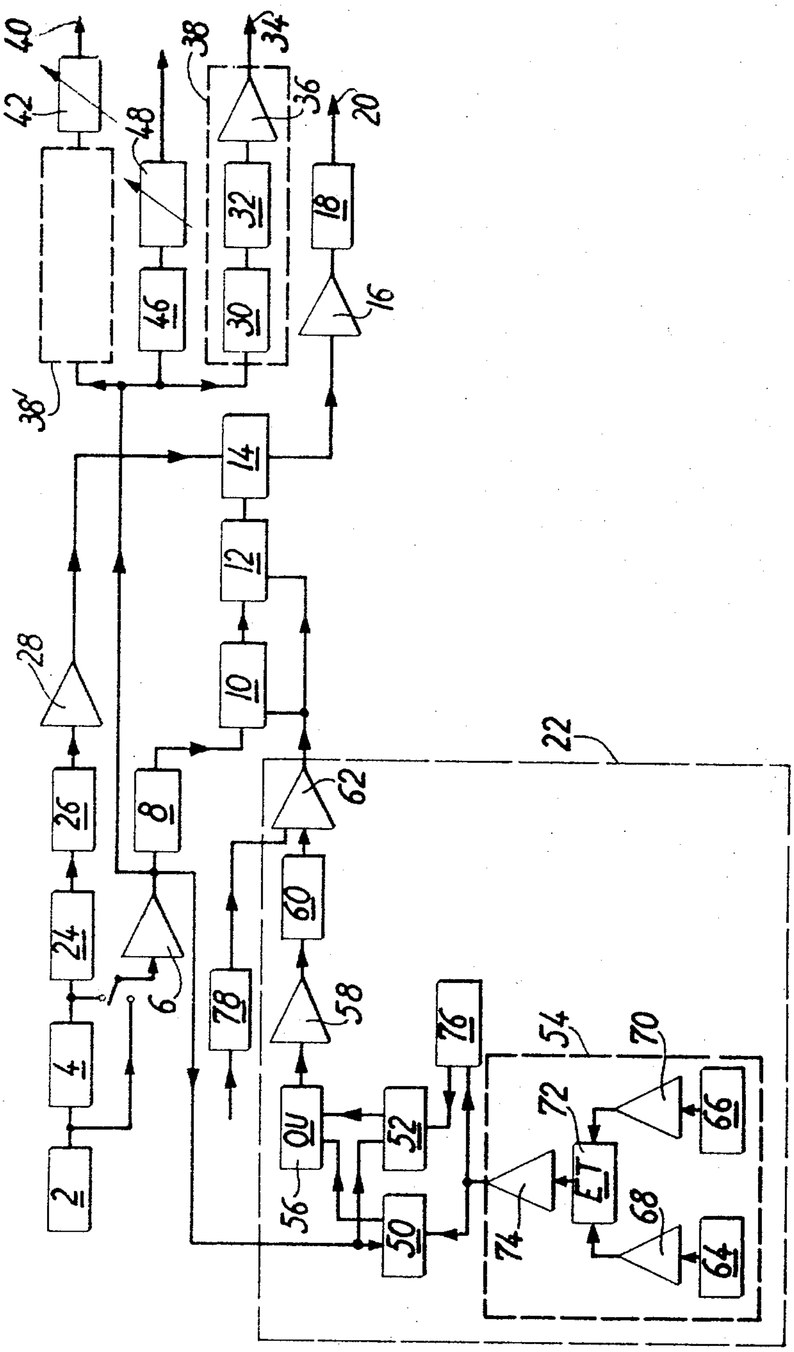

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METHOD AND DEVICE FOR PROVIDING PROTECTION AGAINST ACCIDENTAL BEAM DEVIATION IN LINEAR PARTICLE ACCELERATORS

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ABSTRACT OF THE DISCLOSURE

A high frequency linear accelerator is protected against damage due to abnormal deviations of the beam by detecting the beam at least in the neighborhood of the end of the trajectory each time the beam is injected. A new beam is then automatically injected at a frequency of several thousand hertz (NkHz.) if the detector has not registered a deviation of the beam. If a deviation of the beam is noted the frequency of injection is reduced to a low frequency of repetition.

The present invention is concerned with a method of protecting a high-frequency linear particle accelerator against abnormal beam deviations as well as a device for the practical application of said method.

In an accelerator of this type which is designed to impart a very high energy to the particles forming the beam, any accidental deviation of said beam is liable to result in bombardment of one section and therefore to cause very extensive damage. As a consequence, the mean power of the beam must be considerably reduced when the beam deviates from the axis of the accelerator to any substantial extent. In order to obtain this result, the repetition rate of the high-frequency pulses is reduced. It is then possible to determine the cause of the malfunction and to take appropriate remedial action.

The method in accordance with the invention makes it possible to carry out this protection operation automatically and is carried into practice by means of a positive safety system which provides highly reliable operation.

Accordingly, the method consists in detecting the beam from at least one point each time the beam is injected, in permitting a further automatic injection of said beam at a relatively high frequency as long as the beam is found to be present at the said detection point or all detection points for at least n consecutive periods, and in reducing the injection frequency to a substantial extent when said beam is not found to be present at any one detection point.

The device for the practical application of said method is of particular interest in the case of high-frequency accelerators, the operation of which is controlled by a clock pulse generator.

Said device is characterized in that it comprises two bistable multivibrators for generating pulses which serve to open a gate system so as to permit the transmission of clock pulses to the injection unit. The first input of each bistable multivibrator is directly coupled to the clock pulse generator whilst the second input of the first bistable multivibrator is directly coupled to a unit which detects the presence of the beam at two points and the second input of the second bistable multivibrator is also coupled to the same unit by means of a device which is capable of retarding the detection signal by 1, 2, 3 and $n-1$ clock periods.

The detector unit comprises two simple devices for detecting the presence of the accelerator beam at two points. These detectors are respectively coupled to the inputs of an AND circuit, the output of which is coupled to the second inputs of the multivibrators.

The clock pulse generator drives dividers and consequently serves to produce two series of pulses, one series having a high repetition frequency and the other series having a low repetition frequency.

A mixing device receives for the purpose of subsequent transmission to the beam-injection element on the one hand the pulses which have a relatively low repetition frequency and on the other hand the pulses which have a relatively high repetition frequency which are transmitted by the gate system, said gate system being opened by the signals produced by both multivibrators.

Finally, the gate system comprises two series-connected gate circuits which are controlled separately by both multivibrators.

Aside from these main arrangements, the invention is also concerned with a number of secondary arrangements which will be disclosed hereinafter and which relate in particular to one embodiment of the device for the practical application of the method according to the invention.

It can be noted that, in the device which is proposed, the existence of any one pulse is dependent on the existence of the preceding pulses.

Should one of the detectors find that no beam is present during two successive cycles of operation of the accelerator, the repetition frequency of the high-voltage pulses is automatically reduced, thereby protecting the operation of the modulating elements of the accelerator, namely the driving klystron and power klystrons.

In other words, it can be stated that the beam itself controls the operation of the accelerator; both detectors are placed near the end of the beam path, one of said detectors being even placed as a rule in the vicinity of the collector. Each time the beam is detected by one of the detectors, said detector produces a pulse. As has already been stated, the two detectors are coupled respectively to the two inputs of an AND circuit which produces a signal only if the beam is detected by each detector.

Should the beam be accidentally deviated after it has been normally injected as a result of the transmission of a clock pulse, then the said beam is not detected by the detectors and the AND circuit does not produce any signal. By virtue of the delay device which is coupled to the second input of one of the multivibrators, the following clock pulse will again trigger the injection of the beam. However, if the AND circuit fails to produce a signal during two successive clock periods, the safety system trips or, in other words, the injection pulse repetition frequency is reduced to a considerable extent.

In order that the technical characteristics and advantages of the present invention may more readily be understood, there will now be described a system for controlling a high-frequency linear particle accelerator which is illustrated in the accompanying drawings by a single figure, said system comprising a safety device for the practical application of the method which is covered by this invention. It is understood that this safety system is not intended to set any limitation on the modes of operation and applications of the invention which may be contemplated.

The figure to which reference is made represents a block diagram of the control system, the injection chain of which will first be described.

The clock **2**, or clock pulse generator, which has a frequency of the order of several thousand cycles per second, controls an amplifier **6** either directly or by means of a divider **4** which divides by a number m less than 10. The output voltage which is produced by said divider is transmitted by means of a delay line 8 and two gate circuits 10–12 which are coupled in series with the first input of a mixer 14, the function of which will be explained hereinafter.

The pulses which are transmitted by the mixer are again amplified and re-shaped by a device 16 which drives a monostable multivibrator 18. This latter delivers the basic pulse required for producing the drive pulse applied to the modulator which constitutes the injection control element 20, not shown in the figure.

The gate circuits 10–12 are controlled by the beam-detecting safety device 22 which will be described hereinafter.

The pulses produced by the divider 4 are transmitted to a second divider 24 which divides the input by a number p which is greater than m and therefore delivers pulses having a very low repetition frequency. These pulses are transmitted via a delay line 26 and an amplifying and shaping device 28 to the second input of the mixer 14. It should be noted that the delays introduced by the devices 8 and 26 are so determined that the pulses applied to the second input of the mixer 14 are synchronous with a number of pulses applied to the first input of said mixer.

When the safety device 22 has normally detected the beam during a clock period, the gates 10 and 12 are opened during the following period and the amplifier 16 receives a series of pulses which do not all have the same amplitude, which is of no importance inasmuch as said pulses are employed for the purpose of triggering a monostable multivibrator 18.

On the other hand, when the gate circuits are not open, the device 14 transmits only those pulses which have a low repetition frequency. This frequency becomes the beam injection frequency and consequently the mean power of this latter is substantially reduced.

The pulses produced by the amplifier 6 are also transmitted to a monostable multivibrator 30. Said pulses are applied to a second device 32 which is of the same type but which produces shorter pulses, a delay line being provided in the output circuit of the second stage of said device. The pulses produced by said second monostable multivibrator 32 have a very precise duration and are transmitted to the power modulators 34 via an amplifier 36. The elements 30, 32 and 36 constitute the channel 38.

The pulses which are transmitted to the control channel 38 of the power modulators are also applied to an identical channel 38′, and said channel produces pulses which are delivered to the control modulator 40 (not shown) by a potentiometer which performs the function of a phase shifter 42 for the purpose of regulating the positions of the pulses transmitted to the control modulator 40 with respect to the positions of the pulses which are transmitted to the power modulators 34.

A channel 46 associated with a potentiometer 48 which performs the function of phase shifter serves to produce synchronization pulses for different physical apparatuses which are associated with the accelerator.

There will now be described the device 22 which permits the practical application of the method according to the invention and accordingly ensures protection against accidental beam deviations.

The pulses produced by the amplifier 6 are applied to the first inputs 50_1 and 52_1 of two bistable multivibrators and establish the state of equilibrium A of these latter whilst the pulses derived from the beam detector unit 54 are applied to the second inputs 50_2 and 52_2 of said multivibrators and establish their state of equilibrium B.

The outputs of said multivibrators are coupled to the inputs of an OR circuit 56 which is coupled to a peak-limiting or "clipper" amplifier 58 which drives a monostable multivibrator 60, a delay line being connected into the output circuit of the second stage of said multivibrator. The pulses produced by the delay line have a precise duration and are transmitted by the amplifier 62 which initiates the opening of the gates 10 and 12.

The detector unit 54 comprises two beam detectors 64–66 which are disposed near the end of the accelerator, one of said detectors being usually located at the collector whilst the second detector is located in the vicinity of this latter. Said detectors produce high-frequency waveform pulses which are respectively amplified by the pulse amplifiers 68 and 70; these two devices are coupled to the two inputs of an AND circuit 72 which produces pulses transmitted by the amplifier 74 to the bistable multivibrators 50 and 52.

In accordance with one of the essential features of the invention, the amplifier 74 is directly coupled to the second input of the bistable multivibrator 50 whereas it is coupled to the second input of the bistable multivibrator 52 by way of a delay device 76 having a number of taps corresponding to delays of 1, 2, 3 . . . and $n-1$ repetition periods of the pulses transmitted by the amplifier 6, whereupon the safety device 22 stops the operation of the accelerator after 2, 3, 4, n consecutive periods during which the unit 54 has not detected the beam.

When it is desired to start up the accelerator, the monostable multivibrator 78 is triggered and produces a pulse which is amplified by the device 62 and opens the gate circuits 10–12 for a sufficient period of time to permit the passage of a few pulses which are transmitted by the amplifier 6.

When the apparatus is in operation and the amplifier 6 transmits a clock pulse I_r to the bistable multivibrators 50 and 52, said multivibrators both achieve the state of equilibrium A. There appears at the output thereof a step which constitutes the leading edge of the pulses which are produced. These steps are shunted by the OR circuit 56 which comprises in particular an assembly consisting of a resistor, a capacitor and a diode. The pulse which appears at the output of said assembly is clipped and amplified by the device 58 which trips the multivibrator 60. After it has been amplified by the device 62, the aforesaid pulse opens the gates 10 and 12 for a time interval which is short compared with the clock period and said gates accordingly transmit the pulse I_r which is suitably retarded by the delay line 8.

So far as concerns the remainder of the beam injection, said beam is detected by the detectors 64–66, the amplifiers 68 and 70 drive the AND circuit 72, said circuit produces a pulse which is amplified by the amplifier 74 and transmitted to the second inputs of the multivibrators 50 and 52. It should be noted that, inasmuch as the multivibrators have previously been put into state A, the multivibrator 50 then changes over to state B and again permits the injection of the beam when it receives the pulse I_{r+1}.

If, as a result of the injection of the beam (pulse I_r), said beam is not detected by the detectors 64–65, the amplifier 74 does not produce any pulse but, during 1, 2 and $n-1$ periods, the device 76 delivers a pulse to the multivibrator 52 which changes over to state B. The beam injection will again be permitted when the multivibrators receive from the amplifier 6 the clock pulses I_{r+1}, I_{r+2} . . . I_{r+n-1}.

On the other hand, as and when the pulse I_{r+n} is received, the two multivibrators will again be in state A. They will not be able to trip, the gates 10–12 will remain closed and the injection will not take place.

The use of two gates connected in series has for its object to provide a greater degree of safety in the improbable event that, as a result of the short circuit of a single gate, the clock pulses are transmitted in spite of the non-delivery of an opening pulse.

In the case of an accelerator control system which has been constructed by the present applicant, the clock pulse generator 2 has a frequency of 2 kc./s. The frequency of the pulses transmitted to the amplifier 6 is 2 or 1 kc./s. The device 24 is a divider which divides by the number 64, with the result that the low repetition frequency is in the vicinity of 16 c./s. The device 76 has only one output and creates a delay of 1 period of repetition of the pulses derived from the amplifier **6**. Finally, the monostable multivibrator **78** produces pulses of 2.5 ms., with the result that the gates **10–12** permit the passage of two pulses at a frequency of 1 kc./s. and four or five pulses at a frequency of 2 kc./s.

It should be noted that it is feasible to employ a detector unit **54** which comprises either one detector alone or more than two detectors.

What we claim is:

1. A method of protecting a high-frequency linear particle accelerator against abnormal beam deviations, said method consisting in detecting the beam from at least one point each time the beam is injected, in permitting a further automatic injection of said beam at a relatively high frequency as long as the beam is found to be present at said detection point or all detection points for at least n consecutive periods, and in reducing the injection frequency to a substantial extent when said beam is not found to be present at any one detection point.

2. Device for the protection of a high frequency linear accelerator producing a beam and including an injection control element against abnormal deviations of the beam comprising a clock pulse generator producing pulses having a repetition frequency of several thousand cycles per second, a plurality of gate circuits in series, a beam detecting safety device including a plurality of beam detectors which open the gate circuits when there is no abnormal deviation of the beam as determined by one of said beam detectors, for at least n successive periods, a mixer, two inputs for said mixer, said mixer following and being connected to said gate circuits, an output for said mixer connected to said injection control element and a divider connecting said clock pulse generator to the second input of said mixer producing impulses of low frequency repetition.

3. The device as described in claim **2**, said beam detecting safety device comprising a monostable multivibrator, an OR circuit preceding said monostable multivibrator, two bistable multivibrators, the outputs of said bistable multivibrators being connected to the inputs of said OR circuit, the first input of each of said bistable multivibrators being connected to said clock pulse generator, a beam detector unit including said beam detectors detecting the presence of the beam adjacent the extremity of its trajectory and at another part of the beam, the output of said unit being connected directly to the second input of the first of said bistable multivibrators and a delay device slowing the detection signal by 1, 2 . . . $n-1$ periods, the input of said delay device being connected to the output of said beam detector unit with the $n-1$ outputs connected to the second input of the second of said bistable multivibrators.

4. Device as described in claim **3**, said beam detector unit comprising two beam detectors detecting the presence of the beam adjacent the extremity of its trajectory and at another location of the beam, and an AND circuit, two inputs for said AND circuit respectively connected to the outputs of said beam detectors and the output of said AND circuit being connected to the output of said beam detector unit.

5. Device as described in claim **2**, in which said plurality of gate circuits include two gate circuits.

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