

*off in response to charge
being electrode* PA

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2,844,706

METHOD OF PRODUCING MINUTE PERFORATIONS IN
SOLID BODIES BY THERMAL IMPACT EXERTED BY
CONCENTRATED CORPUSCULAR RAYS

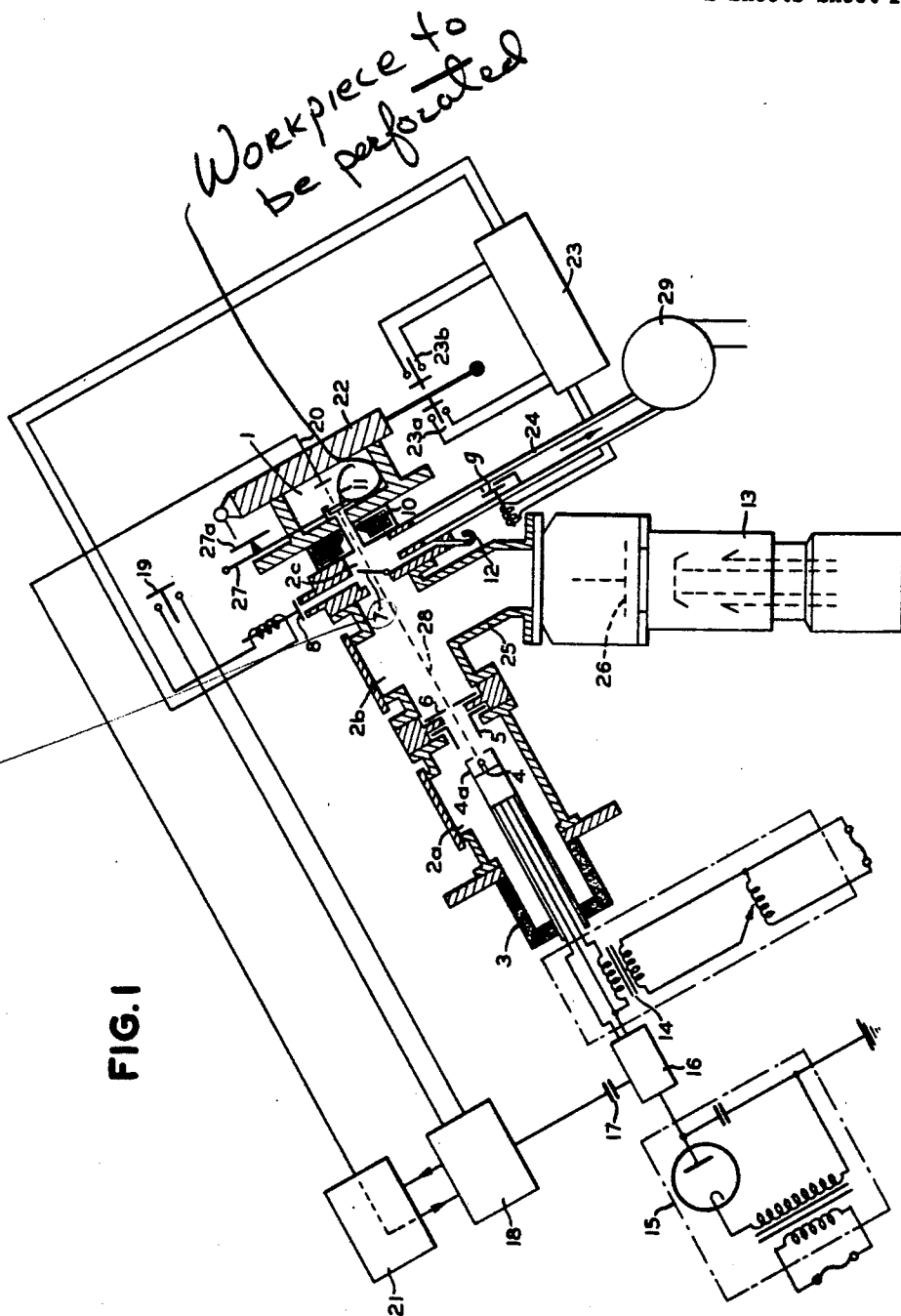
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2 Sheets-Sheet 1

*Workpiece to
be perforated*

FIG. 1

*valve
means*



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FIG. 2

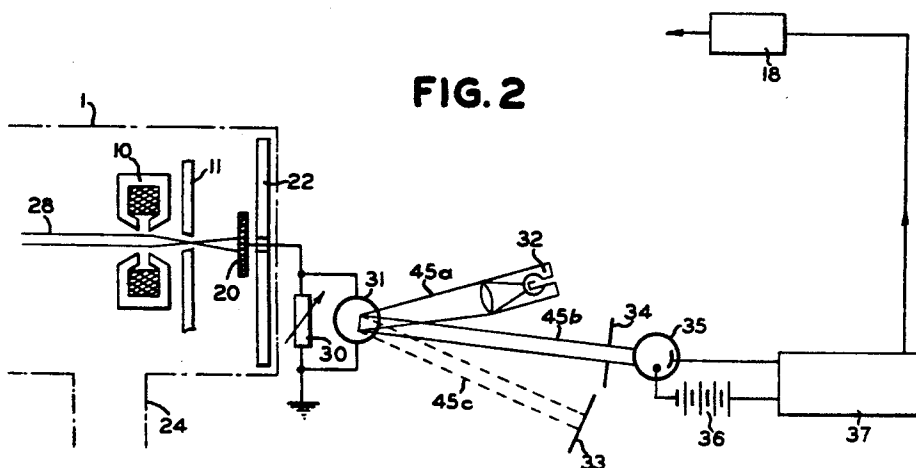
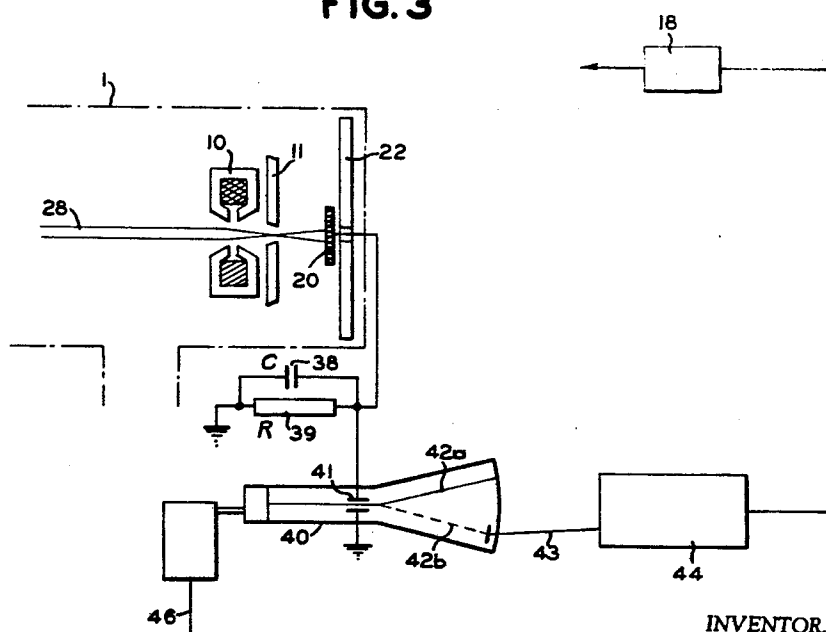


FIG. 3



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9 Claims. (Cl. 219—69)

The present invention relates to an improvement in the method of producing minute perforations in solid bodies by means of concentrated corpuscular rays. In this method, electrically charged corpuscular rays, electronic or ionic rays, produced in a high vacuum, are accelerated to high velocities by electrical tension and concentrated, focussed and directed on to the workpiece to be perforated. At the point of impact, the kinetic energy inherent in the corpuscular ray is converted into thermal energy, so that over an extremely limited area a powerful heating effect is produced which is sufficient to fuse and vapourise the material of the workpiece. In this way, minute holes or foramina of any desired depth can be produced in the workpiece. For this purpose, the workpiece may be located in a chamber subject to reduced pressure or to normal atmospheric pressure.

A particular requirement in connection with this method is that it be possible to control the diameter of the minute perforations produced by corpuscular ray, more particularly by accurate timing of the duration of the action of the corpuscular ray used. This task is particularly important when it is desired to produce, in succession, a large number of perforations as nearly as possible identical with each other, that is to say to obtain accurately reproducible results. This requirement is of particular significance in the production of synthetic fibre spinnerets.

Theoretically it is possible, with the aid of known electrical means, to keep constant the accelerating voltages and the current strength used in the generation of the corpuscular ray, as also the electrical and magnetic fields used to concentrate and focus the ray, and appropriate apparatus for this purpose is described in our co-pending application.

It has been found, however, that even when these factors are kept constant to a high degree, considerable difficulty is encountered in observing narrow limits of accuracy as to size and shape and particularly the diameter of the perforations produced, this being mainly due to circumstances concerned with the prevailing physical conditions, the material to be perforated and the apparatus used. Inter alia, the quality of the vacuum, the composition of the residual gas present in the apparatus and particularly its water vapour constant which is dependent on climatic conditions, the extent of the heating effect produced by ray impact and the alteration of physical conditions attendant thereon, and, finally, variations in the material itself, all play an important part in this connection.

The immediate task is therefore to obtain uniform perforating performance, irrespective of ambient conditions and of the perforating equipment, so that all the perforations in a series have at least the same outlet orifice diameter. More particularly, the shape of the perforation should be independent of the quality of the vacuum, com-

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position of the gas present in the apparatus, heating effect produced by ray impact and variations in the material used.

The problem thus presented is advantageously solved in a novel manner, in accordance with the invention, by the provision of means whereby a variable involved in the perforating operation itself actuates, on the attainment of a predetermined stage of perforation, a switching device to interrupt the corpuscular ray.

The preferred procedure is to provide beneath the workpiece an electrical absorber which becomes charged by the corpuscular ray emerging from the perforation and which responds on the attainment of a predetermined potential, thereby initiating the operation of magnetic or electronic switching mechanism.

It has been found desirable to use switching mechanism for this purpose which cuts off, with an adjustable amount of time lag, the current required to produce the corpuscular ray. A particularly effective solution of the problem presented, instead of cutting off the corpuscular ray in dependence on a predetermined time lag, directly integrates the current emerging on perforation of the workpiece and represented by the corpuscular ray, and effecting the switching-off operation on the attainment of a predetermined integral value of the resulting charge.

In the ensuing description of the invention, reference will be made to the accompanying diagrammatic drawings, in which:

Fig. 1 shows the lay-out of electrical equipment for producing minute perforations in workpieces by the application of concentrated corpuscular rays, in accordance with the invention.

Fig. 2 is a diagrammatic representation of a preferred embodiment of the control circuit arrangement according to the invention for interrupting the corpuscular ray; while

Fig. 3 shows an electronic device with the aid of which the switching-off of the corpuscular ray used in perforating a workpiece can likewise be effected in dependence on total throughput.

In the method according to the invention for producing minute perforations in workpieces, particularly in the form of plates or discs, for example spinneret apertures in spinning nozzle heads, use is made of the arrangement shown diagrammatically in Fig. 1, with the aid of which a high-intensity ray 28 of electrically charged corpuscular particles, namely either an electron or an ion ray, can be produced, accelerated, focussed and directed on to the workpiece 11 to be perforated. Since arrangements of this kind, so far as the actual ray production is concerned, are in themselves known, the following description will be limited to the parts and features essential to the present invention, it being assumed that the structural details and the coaction of the individual parts of the equipment are familiar to anyone conversant with the art to which the invention pertains.

A known type of high tension generator and rectifier are so used to produce a high tension, rectified electric current that an electron ray 28 of suitable strength can form a known type of hot cathode 4 located in a high vacuum chamber 2a and ray-concentrating Wehnelt cylinder 4a on the one hand and an earthed, adjustable anode 5 on the other hand, which ray, after traversing an adjustable apertured diaphragm 6 and further intermediate parts of the equipment to be described in due course, impinges upon the workpiece 11 located in perforating chamber 1 and supplies the energy requisite to vapourise the material and produce a minute perforation therein. The hot cathode is fed by a heating current circuit connected to mains through an insulating transformer 14. A separate unit 16 generates and regulates the initial

electrical tension required for the Wehnelt cylinder, which is vital to the concentrating and accelerating of the ray, and also renders it possible for the ray to be switched on and off. By capacitive coupling through condenser 17, the regulating device 16 is connected with switching device 18 and with a control device 21 which is essential to the practising of the invention and which will be described in the further course of this specification with reference to Figs. 2 and 3, so that either by direct operation of push-button 19 or by impulses proceeding from the absorber electrode 20 in response to the impinging of the electron ray thereon, the corpuscular ray and with it the perforating operation can be switched on and off. The high tension components of the equipment are inserted in the high vacuum chamber through a high tension insulator 3. Chambers 2a and 2b must be maintained under a high vacuum of at least 10^{-3} mm. Hg if flash-over and dispersal of the electron beam on the way from its point of origin and the perforating chamber are to be prevented from occurring. To maintain the high vacuum required, the intermediate chamber 2b is connected, by means of a flanged tube 25 of large diameter and a plate valve 26, to a diffusion pump 13.

This arrangement has the advantage that gases or impurities that may possibly enter the high vacuum chamber 2b from the perforating chamber or the valves are immediately drawn off by the diffusion pump and thereby prevented from passing directly into the chamber 2a containing the highly sensitive ray producing equipment. A certain degree of separation of the two vacuum chambers from each other is also achieved by means of the adjustable apertured diaphragm 6 located in an intermediate member pertaining to the housing, which otherwise serves to intercept straying particles of the electron beam. The high vacuum chambers are adapted to be sealed off by an intermediate valve 7 operated automatically in dependence on the gas pressure obtaining in chamber 2c, for which purpose this chamber communicates with a gas-pressure switch 12, for example a mercury tube containing two contacts by which electrical impulses for the operation of valve 7 are generated in a manner familiar to those skilled in the art and therefore not needing to be described in detail. When the cover 22 of the perforating chamber 1 is opened, a flooding valve 8, which is preferably electrically operated and connected with cover 22 and which serves to establish communication with the outside atmosphere, is simultaneously opened, while at the same time the intermediate valve 7 is automatically closed by the increase of pressure. For the purpose of establishing the reduced pressure required for the perforating operation, the intermediate chamber 2c communicates, through a branch pipe 24 and suction valve 9, with an exhausting pump 29. In the embodiment shown, the electron beam 28 traverses, shortly before reaching the perforating chamber, an electromagnetic lens 10 having an adjustable magnetic field and serving for the focussing of the beam. The workpiece to be perforated, which may be for example a spinning nozzle head made of metal or glass, and particularly of quartz glass, is introduced into the perforating chamber 1, with cover 22 open, valve 8 flooded and valve 7 closed, and placed upon a supporting device 27 adapted to be actuated and controlled from outside. As soon as the exhausting pump 29, after closing of the cover 22 and of the flooding valve 8 coupled therewith, has established a sufficiently low gas pressure in the perforating chamber 1 and in the intermediate chamber 2c, the intermediate valve 7 opens automatically and the electron beam can then be switched on by operating the push-button 19. Thus, together with the cover 22, the flooding valve 8 and the intermediate valve 7 are both so coupled to the switching device 23, by means of contacts 23a and 23b, that the flooding valve 8 can not be opened as long as the intermediate valve 7 is open. Moreover, with the aid of known electrical interlocking means, the pressure

switch 12 and the associated control device (not shown) are so interlocked with the intermediate valve 7 that this latter cannot be opened until the pressure switch has responded. The intermediate valve 7 is also so coupled with the suction valve that this latter closes as soon as the former opens. These features ensure completely reliable operation of the equipment, inasmuch as faulty operation is rendered incapable of damaging the apparatus or endangering its proper functioning.

At the same time, in order to obtain the desired uniformity of perforation irrespective of variations in circumstances other than electrical quantities, even when these latter remain constant, means are provided according to the invention for intercepting the electron beam, after piercing the workpiece 11, by an electrically absorbent element 20. The resulting charge releases electric impulses which are imparted to the control device 12 and which automatically switch off the electron beam through the intermediary of the switching device 18.

To this end the switching device 12 may be so arranged that the electron beam actuates a preadjustable, precision time switch mechanism which cuts off the electron beam after the lapse of a certain period of time starting from the emergence and initial impact of the beam. The size of the outlet orifice of the perforation is thereby rendered to a very considerable extent independent of the thickness of the workpiece and of variations in the structure of the material of which it is composed.

In accordance with the invention, a two-stage procedure may be adopted, in the first of which a preliminary, tapered perforation is produced which just pierces the prescribed thickness of wall, while in the second stage, which normally follows immediately upon the first, the outlet orifice is expanded to the required extent by the application of an apportioned amount of energy.

In order to fulfill still further requirements in regard to compliance with extremely close limits, for instance in the size of the outlet orifice of a spinning nozzle bore, the method according to the invention may be carried to a still higher pitch of accuracy and discrimination. Instead of predetermining the length of time for which re-perforating is carried out, that is to say, the time that elapses between the emergence and initial impact of the electron beam on the one hand and the switching-off of the electron beam on the other hand, it is possible to absorb in a suitable manner the electric charge entrained by the corpuscular beam (in the case of an electron beam the negative charge), to integrate the charge current and to arrange for this latter, when it has built up to a predetermined quantity, to impart an impulse which initiates the switching operation. In this case, the duration of the perforation finishing operation is regulated automatically in accordance with the progress of this operation and continues automatically until the required size of outlet aperture is obtained and is then automatically terminated. The extent of the technical progress achieved in this way will be understood when it is considered that, in the case of spinnerets, outlet orifices of a diameter as small as 1μ are often called for. At degrees of fineness of this order, mechanical or manual control of the switching operations is clearly quite out of the question if uniform repetition work is to be accomplished.

A preferred form of construction of the means provided in accordance with the invention for this purpose, which are merely indicated diagrammatically in Fig. 1 and which consist of switch gear connected with the absorber electrode 20, is shown in Fig. 2. After piercing the workpiece 11, the electron beam impinges on the absorber electrode 20 which is connected, through the cover 22 of the perforating chamber 1, with a mirror galvanometer 31 the sensitivity and damping of which is suitably adjusted by means of a variable resistance 30. As the charge grows, the mirror galvanometer is deflected, whereby a light beam 45a thrown on to the mirror of the galvanometer by the light source 32

equipped with beam-concentrating optical means, is reflected back in the direction 45b. In the position of rest, the beam reflected by the mirror of galvanometer 31 points in direction 45c where a screen 33 is suitably mounted, having a mark indicating the position of rest. When discharging has reached a certain predetermined stage, the emergent beam 45b is allowed to fall, through a narrow slit in the diaphragm 34 on to a photo electric cell 35 located behind this diaphragm. The emitted photo electric current, or an electric current supplied for example from a source 36 and admitted by reduction of the resistance offered by the photo electric cell, can then be amplified in known manner by means of an amplifier 37 and the amplified current fed to the switching device 18 shown diagrammatically in Fig. 1, which in its turn effects the switching-off of the electron beam.

The galvanometer 31, by virtue of the fact that the damping resistance 39 is connected in parallel therewith, acts as a leakage galvanometer, so that the extent of its deflection is at all times proportional to the integral of the current. Its zero position can be so adjusted that the required size of the outlet orifice of the perforation produced by the electron beam is obtained.

Another possible mode of controlling the switching-off of the electron beam so as to obtain the required result consists in arranging for the electric current supplied by the absorbing electrode 20 to charge a condenser which initiates the switching operation as soon as the tension of the charge has built up to a predetermined figure.

Fig. 3 illustrates an embodiment of this purely electrical procedure. After piercing the workpiece 11 placed in the perforating chamber 1, the electrically charged corpuscular beam impinges on the absorbing electrode 20, thereby charging a condenser 38 provided with a parallel-connected resistance 39. Connected to condenser 38 are the deflecting electrodes 41 of a known type of cathode ray tube (Braun's tube) to which, as indicated diagrammatically, current is supplied through device 46. In the position of rest, the cathode ray produced by tube 40 is emitted in the direction indicated at 42a. However, as soon as the electric field between electrodes 41 reaches a certain value as a result of the charge building up on condenser 38, the first cathode ray is deflected in direction 42b, impinges on a further absorbing electrode 43 thereby releasing in an amplifier unit 44 a switching current which effects, through switching device 18, the switching-off of the electron beam 28 at the main control device.

More particularly the two last described variants of the method according to the invention ensure an ideal uniformity of all perforations produced in this way in a workpiece. Owing to the fact that only the central portion of the electron beam actually pierces while the remainder impinges on the tapering inner surface of the perforation producing a charge thereon, no variations can occur in the perforating process. The charge at the perforation wall varies greatly with the nature of the material and its temperature. Other chance circumstances may also play a part, for example of a small particle of the material breaks away. All such variations, however, are compensated for by the method according to the invention, because only the actually piercing portion of the electron beam is utilised for controlling the switching-off mechanism, irrespective of how large the remainder of the beam may be, which becomes lost and dissipated after producing a charge on the material of the workpiece.

It is also possible to combine the method operating with a predetermined time lag with the method operating in dependence on the traversing charging current, by governing the re-perforating operation according to some functional dependence on the time required for the current difference to reach a certain predetermined value. This procedure can be of advantage in cases in which slight alterations of the integral value of the

electric current are not quite proportional to the corresponding variation of the diameter of the outlet orifice of the perforation produced.

The method according to the invention also compensates for minor variations in the intensity of the electron beam which may be brought about by the conditions obtaining at the source of the beam.

When the workpiece consists of insulating material, the switching-off signal may become falsified by slip or influence charges which are generally apt to produce premature initiation of the switching operation. It has proved effective for the purpose of eliminating this imperfection, to apply a conductive coating consisting for instance of a vapourised metal layer on a layer of graphite to one side or both sides of the workpiece and to earth such layer on layers during the perforation operation in order to disperse any charge that may collect.

After the beam has been cut off, the workpiece can either be removed by opening the cover 22 which thereby trips contact 23b to produce an electric impulse through switch device 23, which opens the flooding valve 8, or alternatively, in the event of a number of perforations having to be made, as is generally the case with spinneret heads, the workpiece is first moved into the position required for making the next perforation, by means of device 27 operable from outside, after which the electron beam can be switched on again by operating the push-button 19.

For the purpose of reproducing accurately a prescribed arrangement of perforations in a given workpiece, it is expedient to use a preferably enlarged template or diagrammatic stencil 27a on which the positions of the individual perforations can be followed by means of a stylus. The arrangement may be such that a single vacuum-tight lead-through accommodates the means for enabling the workpiece to be moved controllably in two or even in three dimensions, while the movement control mechanism is snap-located into position for each perforation of the workpiece. In this way, a perforation pattern can be exactly reproduced or otherwise transmitted.

Operation of the equipment is facilitated if all controls are grouped in a desk type housing and, as indicated in Fig. 1, the corpuscular beams are inclined from below upwards, so that a person standing in front of the perforation chamber 1 can conveniently carry out the inserting and removal of workpieces with the aid of an inspection window (not shown) provided at the side of the apparatus, through which the interior of the perforation chamber and the progress of the perforating operation can be effectively observed.

The method according to the invention has a particularly valuable application in perforating heads of spinning nozzles, in view of the fact that the production of artificial fibres from fully synthetic organic materials, particularly fine spinneret apertures of a high degree of uniformity are required. Spinnerets of this kind often comprise many thousands of minute and closely grouped orifices distributed over a small area. With other methods it would hardly be possible to obtain even distribution.

I claim:

1. In the method of producing minute perforations through a solid body by means of thermal impact provided by a directed and concentrated corpuscular beam electrically generated in vacuum, comprising maintaining said concentrated beam on said body until a perforation is produced therethrough, permitting said beam to pass through said perforation onto a chargeable electrode until said perforation attains predetermined dimensions, and terminating said beam automatically by means of response of said electrode, said electrode response activating a switch means for terminating said beam.

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2. The method according to claim 1, whereby said beam is permitted to impinge on said electrode for a predetermined time effected by means of an adjustable time delay means.

3. The method according to claim 1, comprising terminating said beam by utilizing said electrode response to activate a mirror galvanometer and causing said galvanometer to activate a photoelectric switch means.

4. The method according to claim 1, comprising terminating said beam by utilizing said electrode response to charge a condenser which upon discharge energizes a beam terminating switch means.

5. The method according to claim 4, comprising utilizing said electrode response to activate and deflect the ray of a cathode ray tube, said deflected ray being directed to energize a second electrode which is caused to energize a beam terminating switch.

6. In an apparatus for producing minute perforations through a solid body by means of thermal impact provided by a directed and concentrated corpuscular beam electrically generated in vacuum, a chargeable electrode positioned rearwardly of said body, said chargeable electrode being electrically connected to a switch means, and an adjustable time delay means electrically connected between said electrode and said switch means, said switch means being electrically connected to a source of said corpuscular beam.

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7. In an apparatus according to claim 6, wherein said time delay means comprises a mirror galvanometer connected to said electrode and responsive to the charge of said electrode, and a photocell positioned to intercept light deflection of said mirror.

8. In an apparatus according to claim 6, wherein said time delay means comprises a condenser electrically connected to said electrode and to said switch means.

9. In an apparatus according to claim 8, comprising a cathode ray tube containing ray deflecting means, said means being connected to said condenser, and a second electrode positioned to intercept deflected rays of said cathode tube said second electrode being electrically connected to an amplifier means and said amplifier means being electrically connected to said switch means.

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