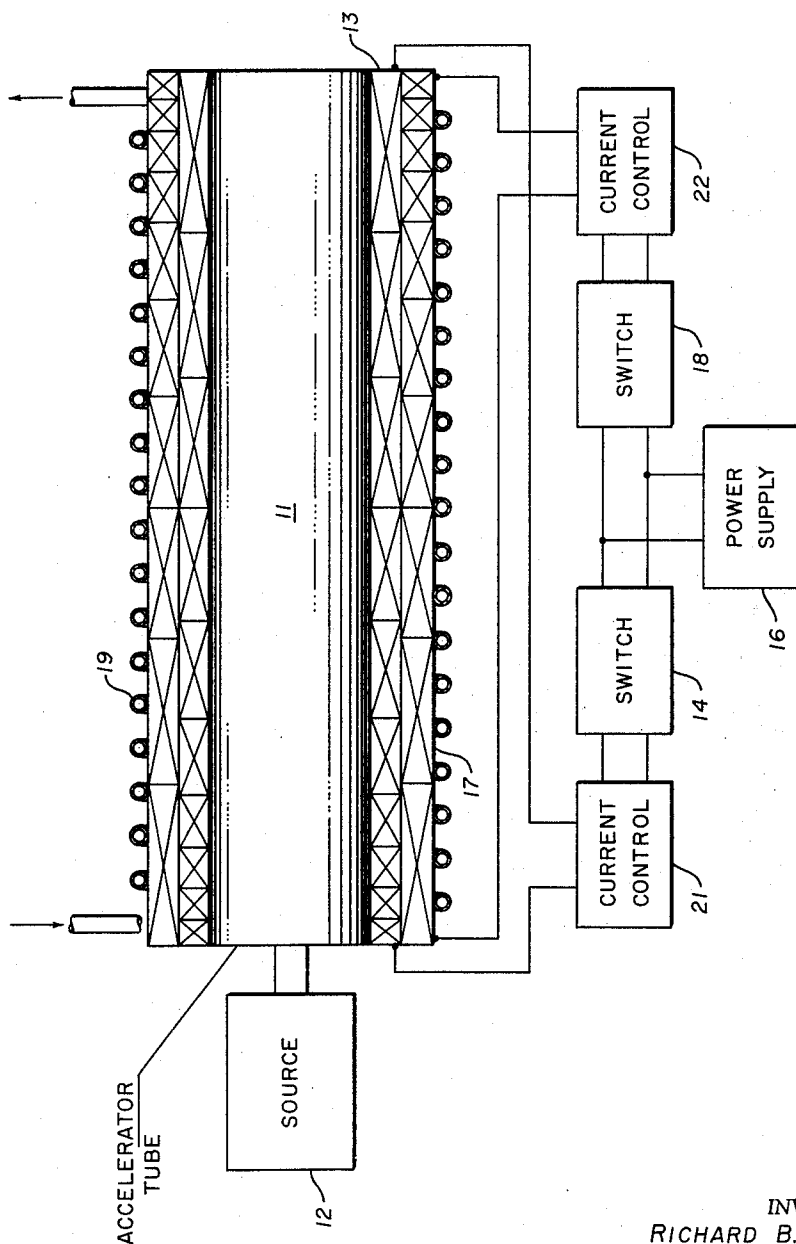


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PARTICLE ACCELERATOR AND METHOD OF CONTROLLING
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PARTICLE ACCELERATOR AND METHOD OF CONTROLLING THE TEMPERATURE THEREOF

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The present invention relates to method and means for controlling the temperature of a particle accelerator and more particularly to the maintenance of a constant temperature throughout a particle accelerator.

Inasmuch as the present invention is intimately concerned with particle accelerators and the control thereof, it is of prime importance to define the scope of the term accelerator, and as herein employed the term "accelerator" or "particle accelerator" is taken to mean a device for accelerating atomic particles, such as electrons or ions, to a relatively high energy as, for example, by the application thereto of time-varying electrostatic fields. Although the present invention is equally applicable to all types of particle accelerators falling within the foregoing definition, for the sake of clarity and simplicity the following disclosure is referenced to a linear electron accelerator wherein radio-frequency power is employed to excite a succession of resonant cavities whereby an electron beam of a pulsed nature directed therein receives energy from the excited cavities to increase the resultant bunched beam energy.

Aside from the better-known difficulties encountered in the field of particle accelerators, other no less serious and somewhat less understood difficulties are also present in that the initiation and cessation of operation of a particle accelerator is commonly accompanied by various electrical and physical phenomena that require a substantial period of time to complete. Thus, for example, in the starting up of a particle accelerator of the linear type as herein taken as an example, it is first necessary to highly evacuate the accelerator tube formed by the succession of resonant cavities and in this process of evacuation it is not only required that pumping be employed but also that a heat treatment be used to bake out the structure to the end of removing occluded gases from the structural members whereby the resultant vacuum may be maintained. Additionally, it is necessary, or at least of advantage, to employ means for maintaining a constant temperature in the accelerator during operation for reasons set forth in more detail below. Numerous improvements and developments have been made to the end of shortening the period required for starting up a particle accelerator and in this respect materially improved targets have been developed whereby same may be changed without affecting the vacuum within the accelerator tube.

Considering specifically the temperature difficulties regarding not only the starting up of a linear accelerator but also of the operation thereof, it is as previously noted first necessary to bake out the accelerator tube for the purposes of maintaining adequate vacuum conditions therein. Additionally, it is necessary to place the accelerator tube at a substantial temperature closely related to that which it will reach during operation, for with temperature changes the structural size of the resonant cavities in the accelerator tube vary and consequently the electrical characteristics thereof vary. It is not possible to have satisfactory accelerator operation under

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varying temperature conditions, inasmuch as relatively slight frequency variations brought about by changes in the size of the resonant cavities will cause unsatisfactory results in that somewhat out-of-phase relationships are thereby introduced between the entering electron beam and the energizing electromagnetic fields established within those resonant cavities. At the time that the radio-frequency energy is applied to the accelerator tube for energizing the cavities thereof, a certain portion of this energy is converted into heat and this heat therefore operates to raise the temperature of the cavity walls whereby the dimensions thereof vary. In order to preclude this circumstance, it is necessary to in some manner maintain constant the temperature of the accelerator tube either by cooling or heating of same.

It has in the past been the practice to energize the resonant cavities of the accelerator tube with radio-frequency energy sometime prior to admission of an electron beam for acceleration therein for the purpose of raising the temperature of the accelerator tube by the radio-frequency energy losses therein. Additionally, there have been employed cooling tubes soldered to the outside of the accelerator tube and carrying water or the like for the purpose of removing heat from the accelerator tube. It has been found that this technique of employing cooling tubes, which are normally soldered to the exterior of the accelerator tube, is unsatisfactory inasmuch as the soldered connection of the cooling tubes melts during the bake-out procedure noted above wherein quite high temperatures are encountered. In this respect, it is common to heat the accelerator tube to a temperature in the range of 400° C. to drive out occluded gases from the structure thereof and this elevated temperature is sufficient to damage normal solder connections.

A possible further solution to the temperature difficulties encountered in particle accelerators lies in the application of excessive heat to the accelerator tube to the end that the overall temperature variation produced by the radio-frequency energy losses form only a minor portion of the heat in the accelerator tube. This solution is also unsatisfactory inasmuch as the radio-frequency energy losses in a high powered accelerator tube are considerable and, furthermore, are unequally distributed throughout the length of the tube so that despite auxiliary heating of the tube, there yet is produced a temperature variation from one end to the other and this temperature variation will, as above noted, cause dimensional variation in the resonant cavities whereby improper frequency responses are obtained.

The present invention is directed to the solution of the above-noted problems in relation to the temperature control of a particle accelerator. Apparatus of the present invention may be operated to bake out an accelerator structure for removing occluded gases therefrom and is not, in itself, damaged by the temperatures reached during this bake-out procedure. The invention is particularly applicable to the rapid establishment in a particle accelerator of temperature conditions suitable for initiation of operation, including not only the radio-frequency energization thereof but the injection of an electron beam therein. In transition from the warm-up period to the steady state operating condition, the present invention is likewise highly advantageous inasmuch as the invention operates to maintain the same temperature throughout the accelerator during operation as is established during warm-up, even though there is produced in the accelerator an exponentially varying heating of the structure by losses from the radio-frequency driving energy. Finally, the invention is equally applicable to the maintenance of a constant accelerator temperature during and following shut-down thereof wherein the driving radio-frequency

power is shut off and the present invention operates to prevent any change in the temperature conditions of any portion of the accelerator during such period.

It is an object of the present invention to provide improved method and means for precise temperature control of a particle accelerator.

It is another object of the present invention to provide method and means for compensating for the non-uniform heating of a particle accelerator by the driving energy applied thereto so as to maintain a uniform temperature throughout the accelerator.

It is a further object of the present invention to provide through a single instrumentality means for baking out a particle accelerator and maintaining uniform the temperature of the accelerator during periods in which radio-frequency driving power is applied thereto.

It is yet another object of the present invention to provide means for applying to a particle accelerator heat in the exact distribution thereof as is applied thereto by the losses in radio-frequency driving power and further to apply to the accelerator additional heat in an inverse relationship to the foregoing for maintaining at all times a uniform temperature throughout the accelerator.

A still further object of the present invention is to provide method and means for counteracting frequency variations in the resonant cavities of an electron accelerator normally produced by temperature variations thereof arising from driving power losses in the accelerator.

Numerous other possible objects and advantages of the present invention will become apparent to those skilled in the art from the following description taken together with the accompanying drawing, wherein the sole figure is a schematic representation of a linear electron accelerator including heating means constructed in accordance with the present invention and illustrating one manner of carrying out the improved method of this invention.

Considering now details of the present invention, it is first to be noted that in the acceleration of electrons, for example through a plurality of resonant cavities, it is conventional to apply radio-frequency energy to these cavities to establish electromagnetic waves therein for the successive acceleration of electrons as a bunched beam thereof is passed through the cavities. Such a device may be employed for a variety of purposes and, for example, suitable target means may be disposed to intercept the accelerated electron beam to produce desired target reactions. In the application of the radio-frequency energy to the linear accelerator, there are encountered unavoidable losses in the energy and these losses are evidenced in the form of heat absorbed in the structural portions of the accelerator. This heating of the walls of the resonant cavities through which the radio-frequency energy travels is unequal inasmuch as the losses are greater at the input end of the accelerator. Such unequal heating of the accelerator causes unequal expansions of the resonant cavities with a consequent variation in the volumes thereof whereby the frequency characteristics of the successive resonant cavities become unequal. Any undue heating of the accelerator will produce dimensional variations in the cavity sizes which are highly undesirable; however, unequal heating as occurs in actual practice produces an even more undesirable result in that the resulting frequency responses of the successive cavities are thereby made unequal. This circumstance causes the radio-frequency energy to become out-of-phase with the accelerated electrons whereby improper acceleration occurs and a net defocusing effect of the beam results as well as an inefficient utilization of the accelerating energy. It is contemplated by the method of the present invention first that the accelerator tube, and by this it is herein meant the succession of resonant cavities, shall be at all times maintained at the same elevated temperature. With a constant and

predeterminable temperature it is then possible to determine the exact frequency response of the resonant cavities and to operate the accelerator accordingly.

The method of the present invention includes a step of providing along the length of an accelerator tube an exponentially varying heat transfer. Application of heat to the accelerator tube is accomplished in this instance to exactly duplicate the heating of the accelerator tube that results from the radio-frequency power losses in the tube during operation thereof. As pointed out above, the radio-frequency driving energy suffers maximum losses to the tube at the injection end thereof, i.e., the end in which the radio-frequency energy is applied, and these radio-frequency losses diminish exponentially along the tube toward the target end thereof. By the application of heat to the accelerator tube in this manner the tube is then heated to exactly the same conditions as would be the case with the radio-frequency power applied to the tube. As a further step of the present invention, there is applied additional heat to the tube with the maximum amount thereof being supplied to the target or discharge end of the tube and diminishing toward the input end. The heat applied in the second step is supplied in a manner inversely proportional longitudinally of the tube as regards the heat applied in the first step. The two heating steps set forth above are individually controlled and are not interrelated, except insofar as the magnitude and distribution thereof, so that either or both may be employed according to the circumstances of accelerator operation. Insofar as the times of application of the heat in accordance with the above-stated heating steps, there is first to be considered the situation wherein the accelerator is to be initially operated following, for example, a period of inoperation during which the interior thereof has not been maintained under high vacuum. In such a circumstance it is necessary, in addition to evacuating the tube by mechanical or other means, to insure that all gas which may have been absorbed by the tube walls be driven therefrom in order that they will not give up gas to the tube interior during operation of the accelerator. This is accomplished by "bake-out" of the accelerator structure wherein the accelerator tube is raised to an elevated temperature and maintained thereat for a substantial period during which continued evacuation of the tube is carried out so that gases occluded in the tube walls will be driven therefrom. During the bake-out procedure both of the above-noted heating steps of the present invention are employed so that there is produced a substantially uniform heating of the tube throughout the length thereof. Additionally, these heating steps are carried out at an elevated temperature well above that necessary during other tube operating circumstances. After the tube has been adequately evacuated and it is desired to energize the tube with radio-frequency energy and to inject therein a pulsed electron beam for acceleration of same, the first heating step wherein the tube is heated to supply an exponentially decreasing heat content thereto from the inlet end toward the target end is terminated and the radio-frequency power is applied to the tube. As was stated in the description of the first heating step above, the amount of heat and heat distribution provided thereby exactly equals the heat supplied by the radio-frequency power losses in the tube so that by terminating the first heating step and initiating radio-frequency energization of the tube, no heat variation occurs within the tube from the condition wherein both heating steps are carried out. It will be appreciated that immediately prior to the application of radio-frequency energy to the tube the two heating steps thereof are adjusted to maintain within the tube exactly the temperature at the input end of the tube which would be established by losses from the radio-frequency energy. With the substitution of the first heating step by the radio-frequency energy losses and the consequent retention by

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the tube of exactly the same temperature throughout same as previous thereto, it is then possible to immediately commence injection of electrons and full scale operation of the accelerator in a conventional manner. Throughout operation of the accelerator wherein same is energized by radio-frequency energy applied at the input end thereof, no temperature variations occur in the accelerator for the second heating step is continued and a suitable exterior cooling operation is employed to carry away excess heat whereby the accelerator maintains constant the temperature therein despite the continued and, in this case, even application of heat along the length of the accelerator. In the circumstance wherein it is desired to cease operation of the accelerator for some short period of time, as for example in the changing of targets therein, the first heating step is recommenced at the time the radio-frequency energizing power for the accelerator is turned off so that the heat generated in the accelerator by radio-frequency power losses is still added in like quantity and relation to the accelerator by the first heating step. The two heating steps complement each other to maintain a substantially even temperature throughout the accelerator during the period under discussion so that no unequal expansion or contraction of cavity elements in the accelerator tube are possible and it is then possible to immediately re-energize the accelerator and operate same merely by turning on the radio-frequency driving power and at the same time ceasing the first heating step.

It will be seen from the foregoing that the method of the present invention includes the application to a particle accelerator of heat in a like quantity and distribution to the heat generated therein by power losses from the radio-frequency driving power of the accelerator and additionally providing heat in an inverse distribution thereto for complementing the heat provided in the first step, whereby it is possible to maintain a substantially constant temperature throughout the accelerator whether same is being energized by radio-frequency energy or not. A further step in the method of the present invention comprises the removal from the exterior of the accelerator excess heat in a uniform manner over the length thereof merely to prevent excessive temperatures therein during prolonged accelerator operation. It will be appreciated that a certain amount of heat loss by radiation from the accelerator normally occurs and that herein the main problem to be combatted is that of unequal temperature distribution and variation throughout the accelerator rather than the removal of heat from the accelerator. Thus, the third step of the method, wherein heat is removed from the accelerator, need only be employed in those instances wherein insufficient heat radiation occurs from the accelerator owing to particular circumstances, such as for example very extended periods of operations thereof. In determining the exact amount of heat and the distribution thereof to be applied to the accelerator by the heating steps of the method of this invention, it will be appreciated that the particular accelerator characteristics are of importance. Thus, inasmuch as individual accelerators differ in various aspects insofar as their constructional characteristics are concerned and insofar as their driving power and consequent heat absorption therefrom are concerned, modifications of the amounts of heat to be supplied by the first and second heating steps are necessary for individual accelerators. It is contemplated that the heat gain by an individual accelerator from radio-frequency power losses therein shall be initially determined as by the determination of temperature rise throughout the length of the accelerator during powered operation thereof and that this heat distribution relationship with accelerator length shall be employed as the heat curve upon which the first heating step is determined. The second heating step shall then be determined from the first in order that it shall add thereto to the end of raising the accelerator

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structure temperature to a constant level throughout the length thereof. This may be thought of very roughly as the determination of a triangle with the accelerator length as the base thereof and the accelerator temperature as the height with the original triangle being then determined from the operation of the accelerator, wherein the radio-frequency power raises the accelerator temperature to decreasing levels along the length thereof. A second triangle representing the second heating steps of the present method is then determined so that it will, upon addition to the first, produce a rectangle wherein the height thereof is constant over the entire length of the accelerator. It will be appreciated that this rough analogy is only that, for the actual curves are not triangles; however, they may be readily determined for any particular accelerator and basically the two heating steps provide heat in such quantity and at such location along the accelerator that they add together to produce the same temperature in the accelerator throughout the length thereof.

Considering now one particular means for carrying out the method described above and referring to the drawings, there will be seen to be illustrated therein an accelerator tube structure 11 wherein there may be disposed a plurality of aligned communicating resonant cavities having a central aperture axially through the tube for accommodating the passage of an electron beam. Source means 12 are provided in attachment to the input end of the accelerator and include means for generating radio-frequency energy and coupling same into the accelerator tube for energizing the resonant cavities therein at the resonant frequency of the cavities. This source 12 further includes means for generating and focusing a bunched electron beam into the accelerator tube together with means for accelerating same substantially to the velocity of light so that in passage through the accelerator tube the electron beam is substantially in phase with the radio-frequency energy exciting electromagnetic waves within the resonant cavities thereof. All of the foregoing is quite conventional in the art of linear electron accelerators and thus details of construction and operation are omitted herefrom. In accordance with the present invention there is provided a first heating coil 13 wound about the accelerator tube 11 over the length thereof and connected through switching means 14 to a power supply 16 whereby electrical current may be passed therethrough to raise the temperature thereof and conduct heat to the accelerator structure. This heating coil 13 is adapted to provide heat to the accelerator tube in the same manner as heat is applied thereto by losses in the radio-frequency energization of the tube during operation thereof and, consequently, the coil is particularly wound about the accelerator tube with a decreasing number of turns per unit length thereof from the point of entry of the radio-frequency energy to the opposite end of the accelerator tube. Although it is herein contemplated that the radio-frequency energy shall be applied at the same ends of the accelerator tube as is the electron beam, it is appreciated that various other modes of resonant cavity energization are possible, as for example back wave energization wherein the radio-frequency waves are applied from the opposite end of the accelerator tube relative to the end thereof wherein the electron beam is introduced. In such instance it is, of course, this opposite end wherein maximum heat losses occur to the accelerator structure from the radio-frequency energy end; thus it would be at such end that the maximum number of turns of the heating coil would be disposed. The reduction in number of turns of the heating coil along the length of the accelerator tube is determined by the desired temperature variation therealong in order to produce the same temperature variation as would be produced by the radio-frequency energy losses therein. Inasmuch as this loss is generally exponential, the reduction in coil turns is likewise expo-

nential. A second heating coil 17 is also wound about the accelerator structure in close contact therewith for providing heat thereto and this coil also has a non-uniform number of turns along the length of the accelerator tube in order to provide to the tube the complement of the heat supplied by the first coil. Inasmuch as heating of the accelerator tube with a like current flowing through all turns of both coils is proportional to the number of turns, it then follows that after a determination of the coil configuration of the first coil for any particular accelerator, it remains only to align thereupon the second coil with the number of turns of the second coil and first coil at all points along the accelerator tube length adding up to the number of coils at the large end of the first coil. This second coil 17 is likewise connected through switching means 13 to the power supply 16. Suitable cooling means such as a coil 19 is wound about the structure to circulate a cooling medium for removing heat from the tube.

Operation of the above-described apparatus of the present invention is accomplished by closing the first coil switching means 14 to provide a predetermined current flow through the turns of this coil whereby a predeterminable amount of heat is conducted to the accelerator tube at each individual point along the length thereof. Likewise closing of the switching means 18 to produce a predeterminable current flow through the individual turns of the second coil 17 will cause same to apply a predeterminable amount of heat to each unit length of the accelerator tube. Heat from each of the coils add together to raise the temperature of the accelerator structure a predetermined and uniform amount through the length thereof owing to the fact that the two coils together provide a uniform number of turns per unit length of the accelerator. Suitable control means 21 and 22 are provided in the circuits of the coils 13 and 17, respectively, for the purpose of controllably establishing the current flowing through the coils. In order to bake out the accelerator structure, these control means are adjusted to provide a relatively large current flow through the coils whereby the temperature of the accelerator structure is materially raised, as for example to a temperature of 400° or more. At such temperatures gas occluded within the accelerator structure is driven therefrom for evacuation from the accelerator tube. Following bake out of the accelerator tube, the control means are adjusted to reduce the current flowing through the two coils so that a much lower temperature is maintained in the accelerator tube and in this condition the accelerator is then available for immediate use. Operation of the accelerator requires only that the radio-frequency power be directed into the accelerator and that an electron beam also be directed therein for acceleration, while at substantially the same time the current to the first heating coil 13 is cut off by opening the switch 14. In this situation the second coil 17 continues to supply heat to the accelerator tube for complementing or adding to the heat supplied thereto by the radio-frequency energy losses within the accelerator so that there is maintained the same temperature through the accelerator length. Circulation of a cooling medium through the coil 19 uniformly removes heat from the tube to maintain a substantially constant temperature therein.

It will be seen from the foregoing that whatever operation is desired of the accelerator 11, energization of the first coil 13 is alternated with the application of radio-frequency driving energy to the accelerator whereby the heating effect of each serves to substitute for one another. Thus in those circumstances wherein the accelerator is operating and thereby absorbing heat from the losses in the driving energy, the first coil 13 is de-energized and, in those circumstances wherein the radio-frequency power is shut off so that no heat losses occur within the accelerator therefrom, the first coil 13

is energized to substitute a like amount of heat in the same distribution as would be provided by the radio-frequency heat losses. With this apparatus it is thereby possible to turn on and off the accelerator much like a light switch without difficulties normally accompanying such action, for it is not necessary with this apparatus to proceed through lengthy and complicated procedures for raising the accelerator structure to an operating temperature as is the case in conventional linear accelerators not employing the present invention. By the present invention the flexibility and utility of particle accelerators are thereby materially enhanced.

Although there is described in the immediately preceding paragraphs of this patent application particular apparatus for accomplishing the objects of the present invention, it will be appreciated that other apparatus may be designed to carry out the method of the present invention. Thus, for example, the heating coils 13 and 17 described above may be replaced by other heating means supplying heat in the manner set forth in the above description of the method of this invention. As an example of suitable apparatus capable of carrying out the steps of the present invention, there may be employed a fluid heat transfer system wherein a heated liquid or gas is circulated about the accelerator tube with a maximum heat transfer being accomplished from one fluid system in the manner of coil 13 and heat transfer from a second fluid system being accomplished in the manner of coil 17. There may be employed in this respect a molten metal passing through exterior heat exchange apparatus for absorbing a substantial quantity of heat in passing therethrough and giving up this heat in controlled quantities to the accelerator tube in accordance with the magnitude of contacting surface and available fluid volume at any particular point along the accelerator structure. A further alternative is the provision of a heat conducting path laterally of the accelerator and having variable heat conduction properties therealong to provide the desired heat transfer to the accelerator structure as described above. Such a system may comprise two separate heating means by intertwining fluid flow paths with each having heat conducting surfaces of variable conductivity in opposite directions along the accelerator with said paths being disposed about the accelerator structure. Although the alternative proposals set forth above appear not to be of great utility or practicality in the type of particle accelerator herein taken as an example for application of the present invention, yet certain advantages pertain thereto, as for example in the use of molten metal as a heat source about an accelerator wherein radioactive emanations are produced, for in such instance the heat source may itself serve as a shield about the accelerator for protection of equipment and personnel in the vicinity and thus take the place of bulky and expensive shielding normally associated with such accelerators.

It will be seen from the foregoing that there is presented by the present invention highly advantageous method and means for controlling the temperature of a particle accelerator to the end of enhancing the flexibility and utility thereof and it is not intended to limit the present invention to the terms of the foregoing description but rather reference is made to the following claims for a precise delineation of the scope of the present invention.

What is claimed is:

1. A method for maintaining constant the frequency response of a particle accelerator employing radio-frequency driving power comprising a first application of heat to an accelerator over the length thereof in exact duplication of the accelerator heating resulting from radio-frequency energy losses therein, the further application of heat to said accelerator structure over the length thereof in an amount equal to the difference between heat applied by said first step at any point therealong

and the amount of heat applied by said first step at the point of maximum heating thereby, and the cessation of said first heating during energization of the accelerator.

2. A method of maintaining uniform and constant temperature of a particle accelerator throughout the length thereof comprising the steps of (1) applying heat to said accelerator over the length thereof with a heat distribution substantially equal to accelerator heating from losses in the driving power of the accelerator, (2) applying to said accelerator a further heating over the length thereof and in a quantity to maintain with said first heating a temperature over the entire accelerator length equal to the accelerator temperature attained through said first heating at the point of maximum application thereof, and (3) applying said first heating only during the periods in which said accelerator is not energized by driving power.

3. A method of maintaining a uniform and constant temperature distribution over the length of a particle accelerator both during periods of energization and of de-energization thereof comprising the steps of applying heat to said structure in varying amounts from a maximum at the end thereof whereat driving power is normally applied to the accelerator to a minimum at the opposite end of the accelerator and said heat varying exponentially therein in accordance with the driving power losses through the accelerator whereby said heat reproduces the accelerator heating through driving power losses therein, controlling the application of said heat to apply same only during those periods in which driving power is not applied to the accelerator, and applying further heating to said accelerator in varying amounts from a maximum at the accelerator end opposite the driven end to a minimum at the driven end of the accelerator and varying therebetween to provide together with said first heating a constant accelerator heating throughout the length thereof.

4. Means for maintaining constant and uniform the temperature of a particle accelerator including an elongated accelerator tube having a driven end at which radio-frequency energizing power is supplied for accelerating particles therein and comprising a first heating coil wound about said accelerator tube with a maximum number of turns at the driven end of same and decreasing in the number of turns per unit length of said accelerator toward the opposite end thereof, and a second heating coil wound about said accelerator tube with a maximum number of turns at the undriven end thereof and decreasing in turns toward the driven end to establish together with said first heating coil an equal number of turns per unit length of said accelerator tube, and means for individually energizing said heating coils to pass electrical current therethrough for heating said accelerator tube to maintain a constant temperature over the entire length thereof.

5. Apparatus for stabilizing the resonant frequency of a linear electron accelerator including a plurality of communicating resonant cavities defining an accelerator tube together with means introducing radio-frequency

driving energy at a driven end of said tube and comprising a first heating coil wound about said accelerator tube with a maximum number of turns at the driven end thereof and reducing in number to a minimum at the opposite end, a second heating coil wound about said accelerator tube with a minimum number of turns at the driven end thereof increasing to a maximum number of turns at the opposite end thereof and providing with said first heating coil an equal number of turns per unit length over the entire length of said accelerator tube, power supply means for energizing said heating coils to pass current therethrough, and switching means for individually controlling the electrical energization of each of said coils.

6. Apparatus as defined in claim 5 further characterized by the number of turns per unit length of said first coil diminishing exponentially from the driven end of said accelerator tube along the length thereof whereby said coil provides heat to said tube in substantially the same amounts and distribution as is provided said tube by losses in the radio-frequency driving power of the accelerator.

7. Apparatus as defined in claim 5 further characterized by cooling means providing a flow of coolant over the exterior of said accelerator tube for removing excess heat therefrom whereby said accelerator is maintained at a constant and uniform temperature throughout the length thereof.

8. An improved particle accelerator comprising an elongated accelerator tube adapted to receive a beam of charged particles at a driven end thereof whereat radio-frequency driving power is applied, first heating means about said tube over the length thereof with a decreasing heat transfer to said tube away from the driven end thereof, second heating means about said tube substantially over the length thereof with a decreasing heat transfer to said tube toward the driven end thereof and combining with said first heating means in providing a constant and uniform heat over the tube length, and control means switching said heating means on and off and controlling the amount of heat supplied by each of same.

9. A particle accelerator as claimed in claim 8 further defined by said first and second heating means comprising electrical windings about the accelerator tube, and said control means including current switches connected to each coil and current control means connected to each coil whereby a zero temperature gradient is maintained lengthwise of said tube during power energization and de-energization of the accelerator.

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