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Thompson, Jr. et al.

[11] **3,908,160**

[45] **Sept. 23, 1975**

[54] **FILAMENT SUPPLY CIRCUIT FOR PARTICLE ACCELERATOR**

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[73] Assignee: **Radiation Dynamics, Inc.**, Westbury, N.Y.

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[52] **U.S. Cl.** **321/15**; 313/63; 321/16; 328/233

[51] **Int. Cl.** **H02m 7/00**

[58] **Field of Search** 321/15, 16; 328/233; 313/63

[56] **References Cited**

UNITED STATES PATENTS

2,875,394 2/1959 Cleland 321/15

OTHER PUBLICATIONS

"Silicon Zener Diode and Rectifier Handbook," Motorola, Inc., Third Edition, 1961, pages relied upon 69–72.

Primary Examiner—R. N. Envall, Jr.

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[57] **ABSTRACT**

In a particle accelerator of the type employing AC primary power and a voltage multiplication apparatus to achieve the required high DC accelerating voltage, a filament supply circuit is powered by a portion of the AC primary power appearing at the last stage of the voltage multiplier. This AC power is applied across a voltage regulator circuit in the form of two zener diodes connected back to back. The threshold of the zeners is below the lowest peak-to-peak voltage of the AC voltage so that the regulated voltage remains constant for all settings of the adjustable acceleration voltage. The regulated voltage is coupled through an adjustable resistor and an impedance-matching transformer to the accelerator filament.

10 Claims, 4 Drawing Figures

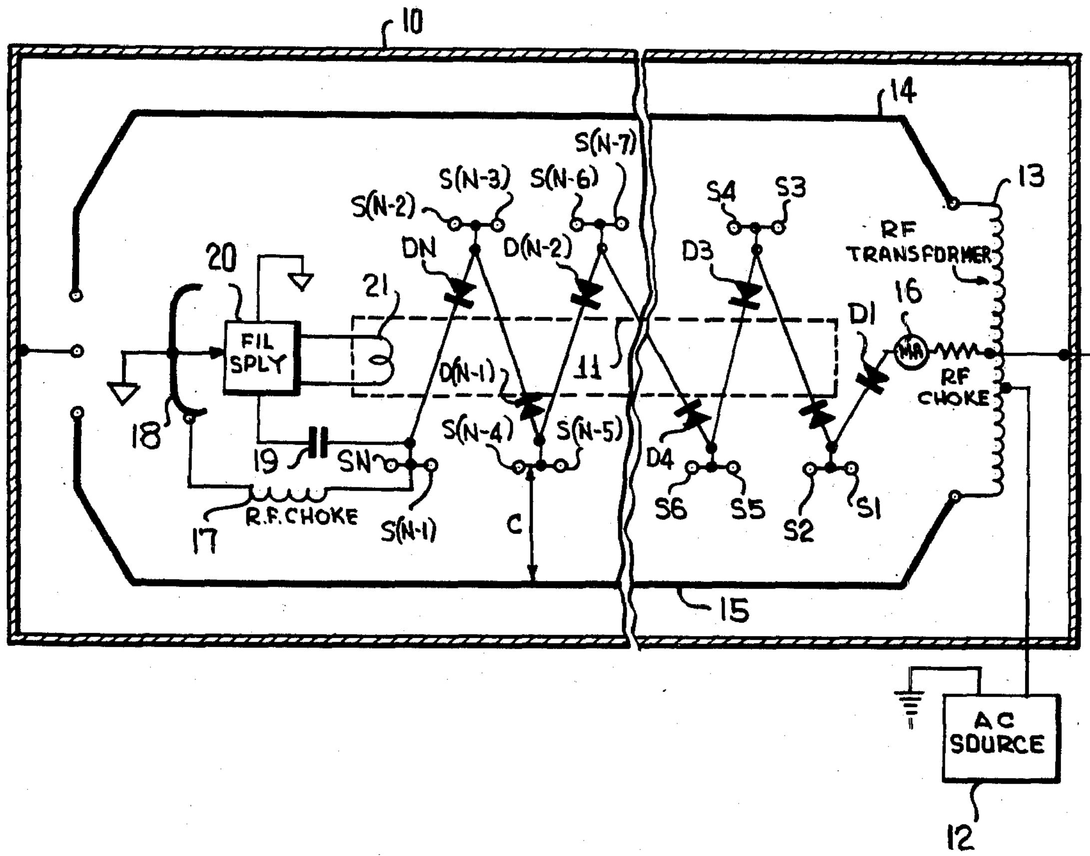


FIG.1

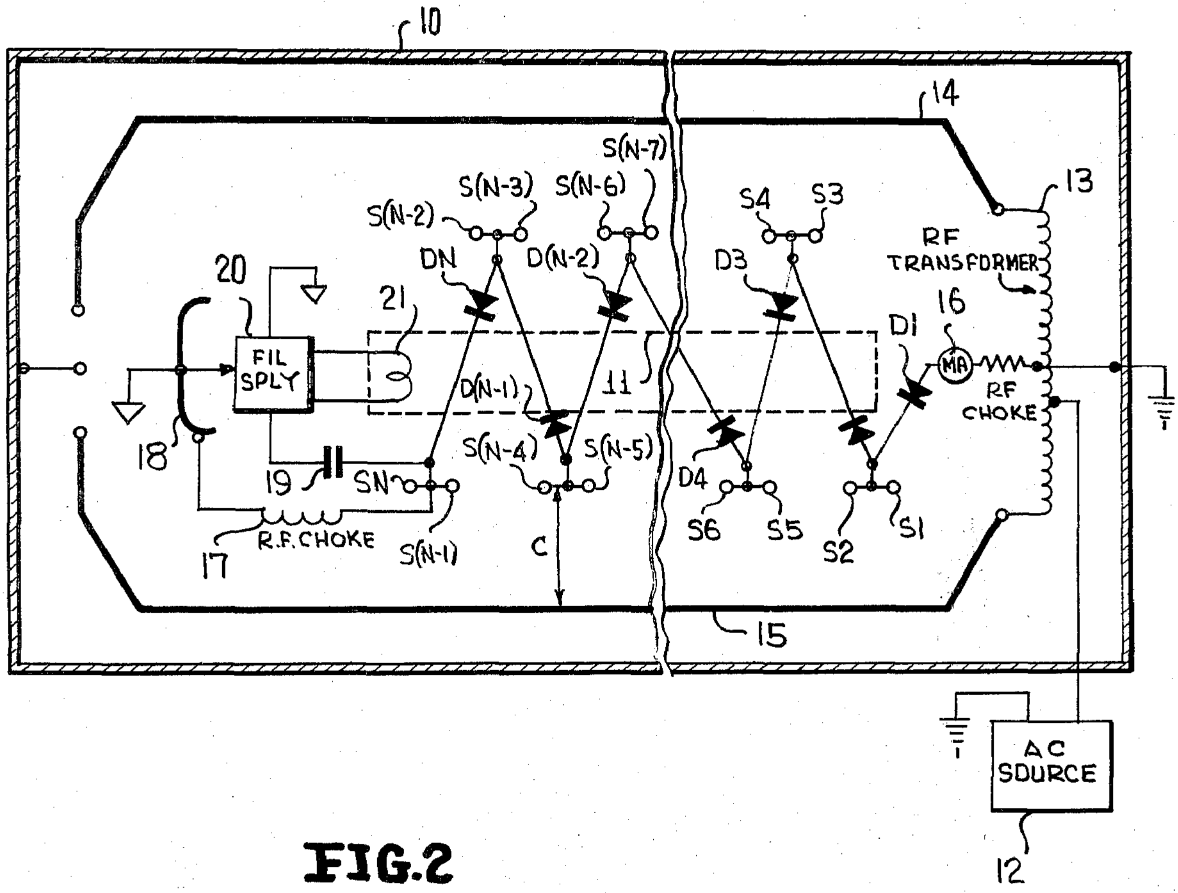
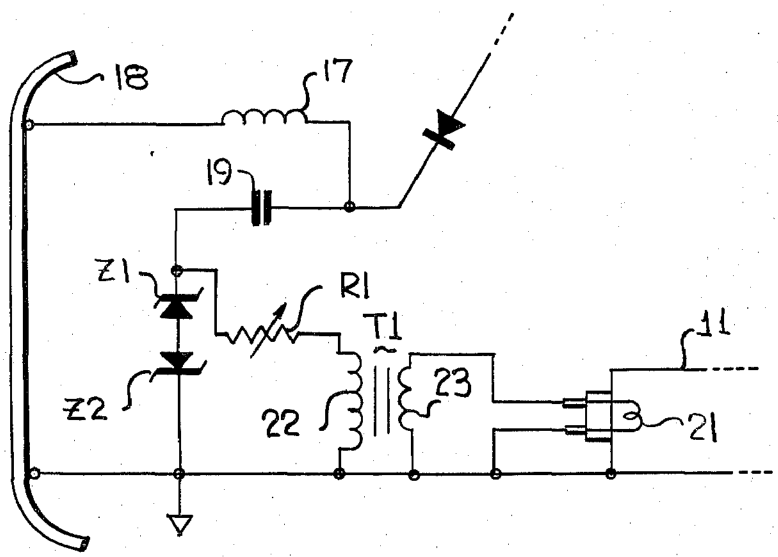

10
14
13
S(N-7)
S(N-3)
S(N-6)
S(N-2)
S4
S3
RF TRANSFORMER
DN
D(N-2)
D3
20
21
16
D1
FIL SPLY
MA
RF CHOKE
D(N-1)
11
18
19
SN
S(N-4)
S(N-5)
D4
S(N-1)
R.F. CHOKE
17
C
S6
S5
S2
S1
15
AC SOURCE
12

FIG.2


18
17
19
Z1
R1
T1
Z2
22
23
11
21

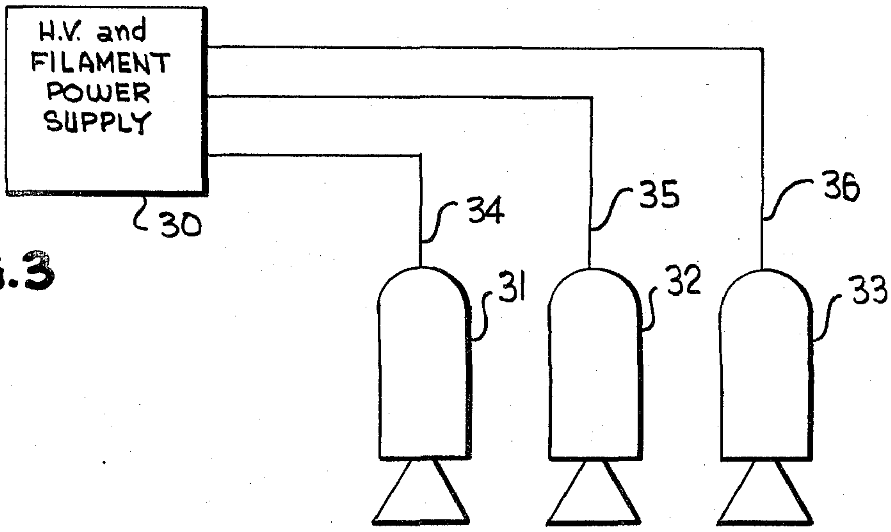
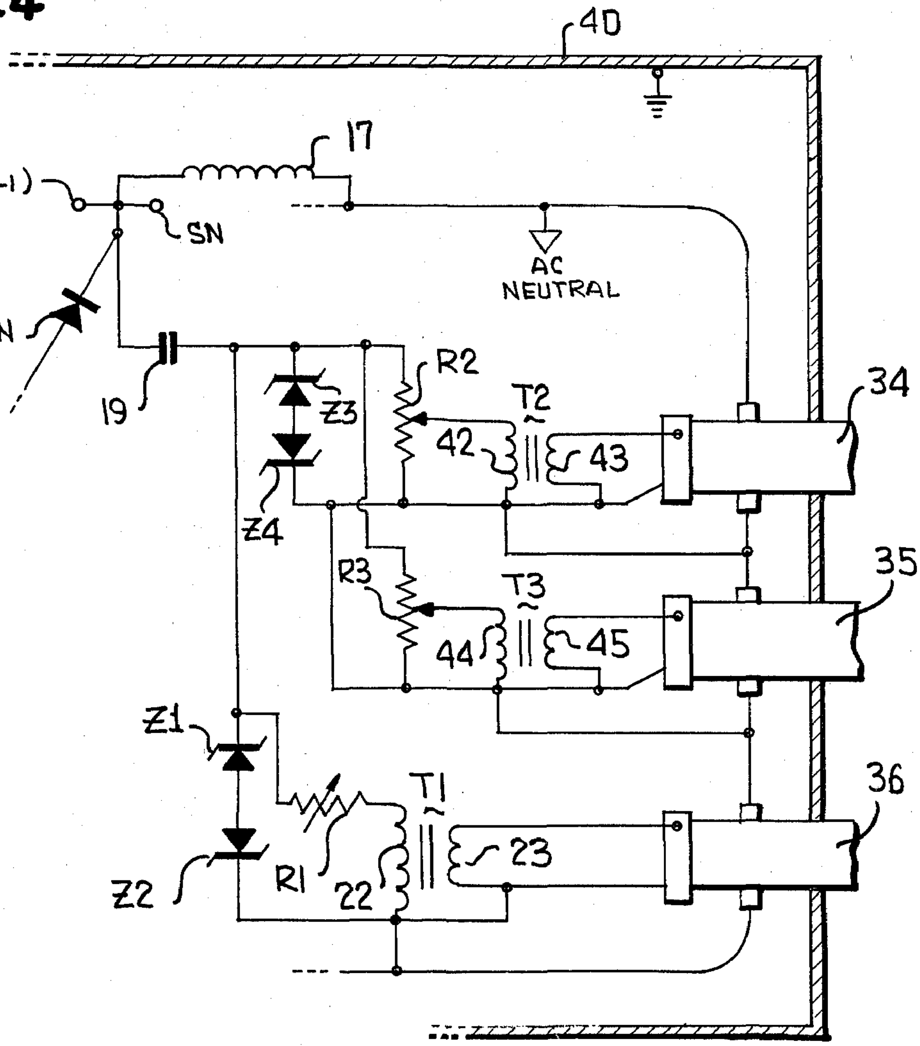

H.V. and
FILAMENT
POWER
SUPPLY
30
34
35
36
31
32
33

FIG.3

FIG.4


40
17
S(N-1)
SN
DN
AC
NEUTRAL
19
R2
Z3
Z4
T2
42
43
34
R3
T3
44
45
35
Z1
R1
T1
22
23
Z2
36

FILAMENT SUPPLY CIRCUIT FOR PARTICLE ACCELERATOR

BACKGROUND OF THE INVENTION

The present invention relates to high voltage particle accelerators and, more particularly to improvements in filament power supplies for such accelerators.

It is conventional in the field of high voltage accelerators to employ filament power supplies which are separate and apart from the high voltage supply. It is possible, of course, to drop the high voltage to a low enough level for the filament; however, many accelerators provide the capability of adjustable beam intensity be permitting adjustment of the high voltage, and this would cause variations in the filament voltage.

Many particle accelerators (such as the Dynamitron manufactured by Radiation Dynamics, Inc., Westbury, New York, and described in U.S. Pat. No. 2,875,394) utilize power in the radio frequency (RF) range in conjunction with a voltage multiplier to achieve a high DC accelerating voltage. These accelerators, too, require separate filament supplies because the primary RF power is usually adjustable to permit adjustment of the accelerating voltage. Moreover, at RF the problem of impedance matching the filament supply to the filament becomes a consideration which precludes merely dropping the RF voltage to a suitable level and coupling it to the filament.

It is therefore an object of the present invention to provide a particle accelerator which does not require a filament power supply which is separate and apart from the high voltage supply.

It is another object of the present invention to derive the filament voltage in a particle accelerator from the high voltage power supply.

It is still another object of the present invention to provide a filament power supply circuit in a particle accelerator wherein the filament voltage is derived from the high voltage power supply but is not subject to variations when the accelerating voltage is adjusted.

It is yet another object of the present invention to employ the RF primary power of a high voltage supply for supplying filament voltage through a circuit which matches the filament impedance and is insensitive to variations in the RF voltage amplitude.

SUMMARY OF THE INVENTION

In accordance with the present invention, filament voltage is derived from the RF voltage appearing at the output stage of the voltage multiplication circuit employed to derive the accelerating voltage. The RF voltage is applied to a limiter circuit whose output voltage is maintained constant over the entire adjustment range of the RF supply voltage. The limited output voltage is passed through an impedance matching circuit, including a variable resistor and a transformer, to the accelerator filament.

Plural accelerator tubes driven from the same high voltage supply employ the same technique, with each tube being supplied filament voltage through its own impedance matching circuit. The filament voltages in such case are superimposed on the DC accelerating voltages and applied to the various accelerator tubes through respective high voltage cables.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of specific embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic diagran of a particle accelerator employing a filament power supply according to the present invention;

FIG. 2 is a schematic diagram of a filament power supply circuit according to the present invention;

FIG. 3 is a schematic diagram of plural particle accelerators served by a single HV and filament power supply according to the present invention; and

FIG. 4 is a schematic diagram of the filament supply portion of the power supply in FIG. 3.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring specifically to FIG. 1 of the accompanying drawings, there is schematically illustrated a particle accelerator and voltage multiplication apparatus of the type described in U.S. Pat. No. 2,875,394 to Cleland, modified by the filament power supply arrangement of the present invention. Only those components essential to an understanding of the present invention are illustrated in FIG. 1 and described herein; for a fuller understanding of the accelerator and voltage multiplication apparatus, reference is made to the aforementioned Cleland patent.

An electrically-grounded gas-tight container **10** houses a particle accelerator tube **11** and a voltage multiplication apparatus. The latter, as disclosed in the aforesaid patent, includes a plurality of series connected rectifier units D1 through DN. The diodes D1 through DN define a generally zig-zag configuration about accelerator tube **11**. A series of corona shields S1 through SN are spaced along the length of the unit on opposite sides of the accelerator tube. Adjacent pairs of these corona shields are electrically tied together and serve as contact points for respective diode junctions in the voltage multiplication apparatus.

A primary power source **12** supplies RF voltage from outside container **10**. The voltage from source **12** is preferably on the order of 50,000 to 150,000 volts peak, and the frequency is preferably in the range of 20 KHz to 200 KHz. A voltage adjustment may be provided at source **12** to vary the RF voltage amplitude and, thereby, the accelerator voltage level. The RF voltage is applied across an inductor **13** located inside container **10** proximate one end thereof. For purposes of the voltage multiplication apparatus, inductor **13** can be considered the source of the RF or primary power. Opposite ends of the inductor are electrically connected to respective electrodes **14** and **15**. These electrodes are in the form of shells located on opposite sides of accelerator **11** and the voltage multiplication apparatus.

The center tap of inductor **13** is connected through a millimeter **16** to the first diode unit D1 in the voltage multiplication unit. In addition the center tap of the inductor is connected to the grounded container **10**.

The RF voltage applied across electrodes **14** and **15** is capacitively coupled through the inherent (stray) capacitance existing between electrodes **14** and **15** and adjacent corona rings S3 to S(N-2) and S1 to SN, respectively. In consequence, the same RF potential is applied across each of the rectifier units except the first and last which have, in this example, half the potential of the others applied thereacross.

The filtering action of the inherent capacitance provided between the corona shields S1 to SN and the electrodes **14** and **15** and the rectifier interelectrode capacitance is adequate to provide a substantially constant DC voltage of the desired value with adequate regulation even at relatively high beam currents.

The high DC voltage provided at the output stage DN of the voltage multiplication apparatus is DC-coupled through RF choke **17** to a high voltage terminal **18** disposed at the end of container **10** remote from inductor **13.** Terminal **18,** though at the high DC voltage, is connected to AC neutral.

The voltage across the last stage of the multiplication unit (at stage DN) is also AC-coupled through capacitor **19** to a filament supply circuit **20** which supplies filament heater power to the filament or cathode **21** of accelerator tube **11.** Capacitor **19** serves to couple the RF voltage to the filament supply circuit. Filament supply circuit **20** is illustrated in greater detail in FIG. **2.**

Referring to FIG. **2,** the RF voltage passed by capacitor **19** is applied across two back-to-back zener diodes Z1 and Z2 connected in series between capacitor **19** and AC neutral. A series circuit, comprising an adjustable resistor R1 and the primary winding **22** of a step-down transformer T1, is connected between capacitor **19** and zener diode Z1. The secondary winding **23** of transformer T1 is connected across the filament **21** of accelerator tube **11,** with one side of the secondary winding connected to AC neutral. The high voltage appearing on high voltage terminal **18** is coupled to accelerator tube **11** via the AC neutral connection between terminal **18** and the filament supply circuit **20.**

Back-to-back zener diodes Z1 and Z2 serve as a voltage limiter or regulator circuit which provides an RF output voltage at a constant amplitude, irrespective of variations in the amplitude of the RF voltage received from rectifier unit DN in the voltage multiplication system. In this regard, zener diodes Z1 and Z2 are selected to have threshold levels which are below the minimum peak-to-peak voltage applied across the zener diodes. Thus, if it is desired to adjust the high voltage (i.e. — accelerator voltage) level by adjusting the amplitude of the RF voltage delivered from source **12** (FIG. **1**), the limited voltage amplitude at the junction of zener diodes Z1 and Z2 remains unaffected, even though the voltage amplitude at rectifier unit DN changes.

Adjustable resistor R1 and transformer T1 serve as impedance matching components for filament **21** to maximize power transfer to the filament. Specifically, resistor R1 is adjusted to vary the power to the filament to allow variablility of the accelerator current.

The filament circuit of FIG. **2** thus provides a stable supply voltage for the accelerator tube filament and properly matches the impedance of the filament at the supply voltage frequency. The AC nature of the filament voltage does not modulate the accelerator beam because the RF is too fast for the time constant of filament **21.** Filament supply circuit **20** thus eliminates the need for an external supply, independent of the high voltage supply.

The invention described in relation to a single high voltage accelerator of FIGS. **1** and **2** is also applicable to plural accelerators powered by a common supply. The general arrangement is illustrated in FIG. **3** wherein a common filament and high voltage supply **30** serves three accelerator tubes **31, 32** and **33,** via respective high voltage cables **34, 35** and **36.** The filament supply circuitry within the common supply **30** is illustrated in detail in FIG. **4.**

Referring specifically to FIG. **4,** the high voltage power supply includes an RF source and voltage multiplication arrangement of the type illustrated in FIG. **1,** with only the output rectifier stage DN of the voltage multiplier being illustrated in FIG. **4.** The entire supply is enclosed in a pressure-tight grounded casing **40.** The output stage DN of the voltage multiplier is DC-coupled to a high voltage terminal **41** via RF choke **17;** stage DN is AC-coupled to plural filament supply circuits via coupling capacitor **19.** The three filament supply circuits serve the three accelerator tubes **31, 32** and **33,** respectively, of FIG. **3.** Different embodiments of the filament supply circuit are illustrated in FIG. **4** for purposes of the present disclosure; it should be understood, however, that all three filament circuits may be identical.

The filament circuit servicing accelerator tube **33** via high voltage cable **36** is identical to filament supply circuit **20** illustrated in FIG. **2,** and like reference numerals are employed for both circuits. The constant-amplitude RF filament voltage produced across the secondary winding **23** of transformer T1 is applied across the high voltage conductors of cable **36** so that the filament voltage can "ride" on the high voltage. Transformer T1, must be designed to match the impedance of cable **36.** A similar transformer located at accelerator tube **33** matches the impedance of the filament to the cable. Resistor R1 allows variability of the power to the filament.

The filament supply circuits for accelerator tubes **31** and **32** share the same pair of back-to-back zener diodes Z3 and Z4, although separate diode pairs could be used for each filament circuit. Variable resistors R2 and R3 are connected in parallel across the back-to-back zener diodes Z3 and Z4. Resistor R2 serves accelerator **31** via cable **34** and has its adjustable contact arm connected to one side of the primary winding **42** of transformer T2. The other end of winding **42** is connected to AC neutral at high voltage terminal **41.** Secondary winding **43** of transformer T2 is connected across the high voltage conductors of cable **34,** with one end of winding **43** connected to AC neutral at terminal **41.**

Resistor R3 serves accelerator **32** via cable **35** in the same manner, with the center arm of resistor R3 connected to primary winding **44** of transformer T3. Secondary winding **45** of transformer T3 applies RF filament voltage across the high voltage conductors of cable **35.**

It is noted that transformers T1, T2 and T3 provide individual impedance matching capabilities for each filament circuit, thereby assuring proper impedance matching for each accelerator filament. A single limiter circuit (zener diodes) can be shared by all three filament circuits if desired.

Although back-to-back zener diodes provide the preferred form of voltage limiting circuit, other known voltage limiters may be used. The important point is that the filament voltage amplitude remain constant even though the amplitude of the primary power RF voltage is changed.

The resistor R1 of FIG. **2** or resistors R1, R2 and R3 of FIG. **4** utilized for varying the power to the filament(s) may be replaced by variable reactor(s) such as capacitors or inductors.

While I have described and illustrated specific embodiments of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

I claim:

1. In conjunction with a particle-accelerating device of the type having a filament and in which a beam of accelerated charged particles is supplied by a high DC voltage being generated by means of a rectifier-capacitor voltage multiplier unit driven by an RF primary voltage which is adjustable over a predetermined operating voltage range to adjust the beam energy, a filament power supply comprising:

voltage limiting means AC-coupled to said voltage multiplier unit for receiving RF primary voltage from said voltage multiplier unit and providing a limited RF voltage having a peak-to-peak amplitude which remains constant for adjustment of said primary voltage over said entire predetermined operating voltage range; and

filament impedance-matching means for coupling said limited RF voltage from said voltage limiting means to said filament.

2. The combination according to claim **1** wherein said impedance matching means comprises:

a transformer having a primary winding and a secondary winding connected across said filament for impedance matching said filament to said voltage limiting means; and

an adjustable resistance for coupling said limited RF voltage to said primary winding, said adjustable resistance being adjustable to vary the heating current to said filament.

3. The combination according to claim **2** wherein said voltage limiting means comprises a pair of series-connected zener diodes connected back-to-back.

4. The combination according to claim **3** wherein said RF voltage is connected across said series-connected zener diodes, and wherein said adjustable resistor and said primary winding are connected in series across said zener diodes.

5. The combination according to claim **3** wherein said RF voltage is connected across said series-connected zener diodes, and wherein said adjustable resistor is connected in parallel with said series-connected zener diodes and includes a movable contact arm connected to one end of said primary winding, the other end of said primary winding being connected to the cathode of one of said zener diodes.

6. The combination according to claim **1** wherein said voltage-limiting means includes a pair of zener diodes connected in back-to-back series relationship across said RF voltage.

7. A common power supply for providing both high DC voltage and filament voltage for a plurality of particle accelerators via respective high voltage cables, said cables connected across the filaments of respective particle accelerators, said common power supply comprising:

means for providing a high DC accelerating voltage, including source means for providing primary RF voltage, and a voltage multiplier responsive to said primary RF voltage for providing said high DC accelerating voltage; and

filament supply means AC coupled to said voltage multiplier to receive RF voltage therefrom, said filament supply means including:

voltage-limiting means connected to receive said RF voltage and provide a peak-to-peak limited RF voltage; and

impedance matching means for connecting the limited RF voltage to respective high voltage cables while matching the filament supply impedance to the impedance of each cable and the filament to which that cable is connected.

8. The combination according to claim **7** wherein said voltage-limiting means comprises a common voltage limiter for a plurality of said particle accelerators, and wherein said impedance-matching means comprises a plurality of impedance-matching circuits, one for each particle accelerator.

9. The combination according to claim **8** wherein said common voltage limiter comprises a pair of series-connected back-to-back zener diodes connected across said RF voltage.

10. The combination according to claim **8** wherein said voltage limiting means comprises an adjustable resistor and a transformer having a primary winding connected to receive said peak-to-peak limited RF voltage via said adjustable resistor and a secondary winding connected across a filament through high voltage cable.

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