Lewis

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REPLY TO ATTN OF: GP

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TO: KSI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,764,850

Government or Corporate Employee : Government

Supplementary Corporate Source (if applicable) : —

NASA Patent Case No. : LEW-11,617-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes [ ] No [X]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter

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Enclosure
Copy of Patent cited above

United States Patent [19]

Kosmahl

[11] **3,764,850**

[45] **Oct. 9, 1973**

[54] **ELECTRON BEAM CONTROLLER**

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[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**

[22] Filed: **June 27, 1972**

[21] Appl. No.: **266,832**

[52] **U.S. Cl.** **315/5.38,** 315/5.35
[51] **Int. Cl.** **H01j 23/02**
[58] **Field of Search** 315/5.35, 5.38

[56] **References Cited**

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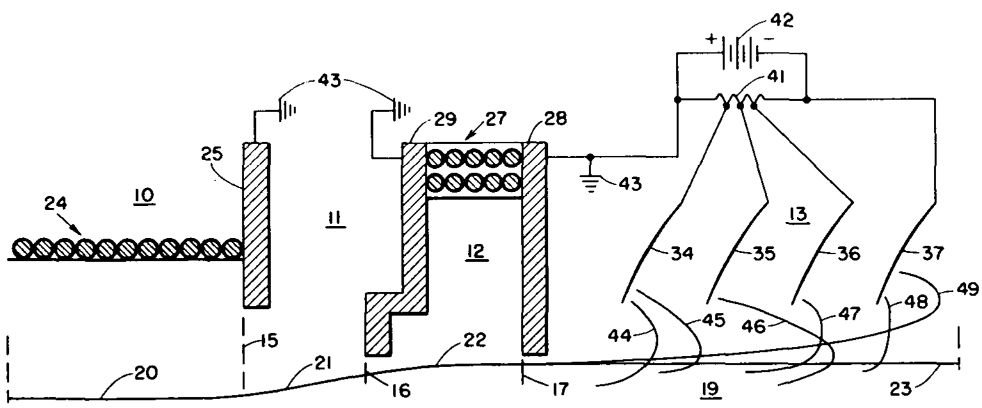
[57] **ABSTRACT**

A magnet applies a magnetic field of predetermined intensity and shape to a spent electron beam over an axial distance having a predetermined relationship to the frequency of operation of a utilization device which has extracted energy from the electron beam and at a predetermined axial distance after the beam has left the magnetic field of the utilization device and entered the beam expansion region and beam stabilization region. The stabilizing magnetic field is terminated abruptly before the electron beam enters a collector apparatus.

12 Claims, 2 Drawing Figures



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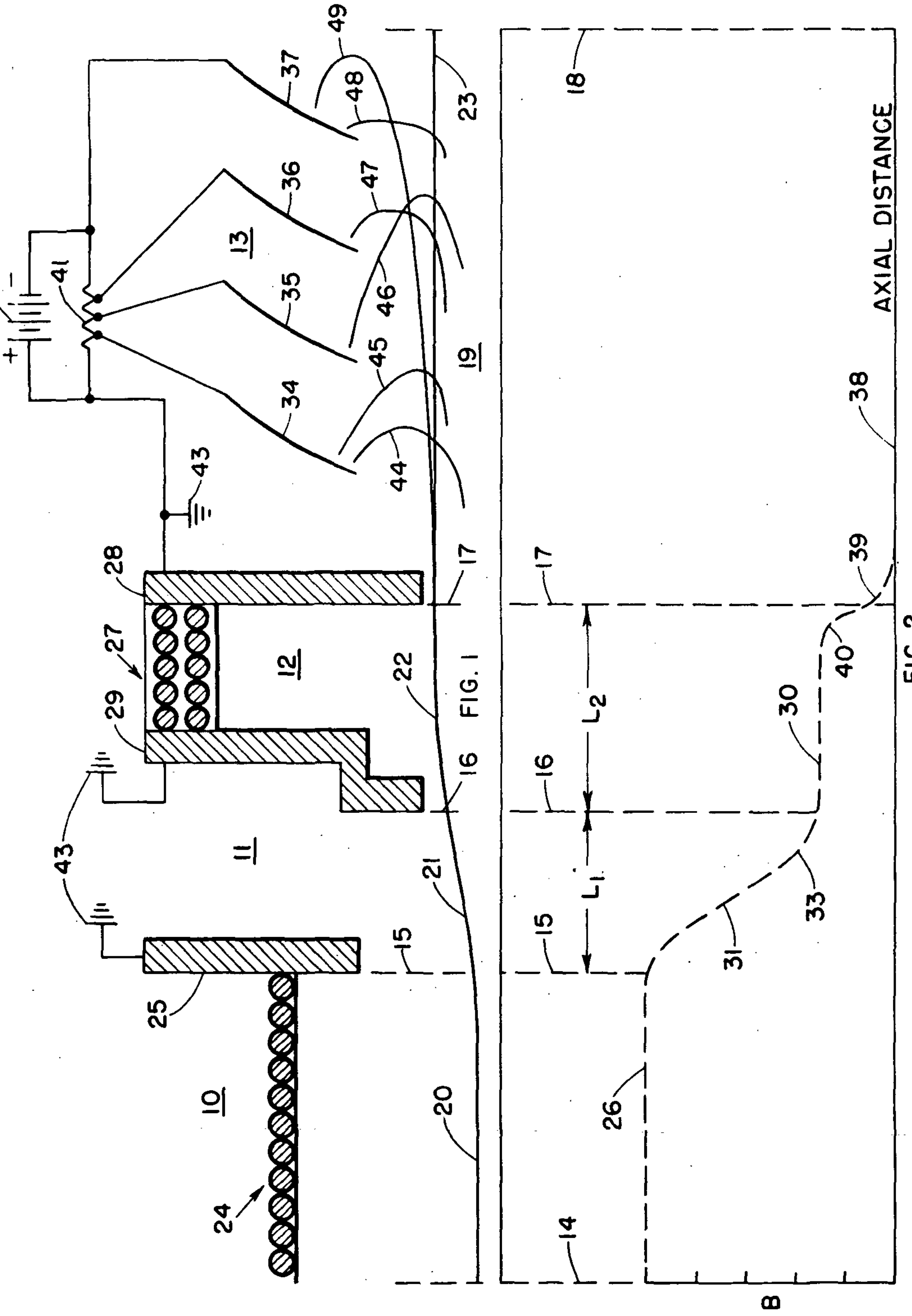
FIG. 1
FIG. 2
AXIAL DISTANCE
B
L_1
L_2

ELECTRON BEAM CONTROLLER

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government of the United STates for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to electron beam devices and is directed more particularly to apparatus wherein energy is extracted from an electron beam before the electrons of the beam are captured by a collector apparatus.

Modern space communication system require the highest possible efficiency from transmitting devices not only to conserve the primary power but also to minimize the heat dissipation which may occur in space due to poor efficiencies. Aside from high internal efficiencies, called electronic efficiencies, depressed-type collectors offer a solution for achieving high overall efficiency in microwave tubes. It can be shown, however, that the realization of energy recovery of such collectors depends strictly and critically upon the degree of disorder in the spent beam. Theoretically, 100 percent efficiency should be possible in a well-designed collector operating in relationship to a point source electron beam having only an axial velocity spread.

In actual practice, however, spent beams have a very complex velocity spectrum including radial and azimuthal velocities and radial position distribution in addition to the spectrum of axial velocities. Furthermore, at high microwave frequencies and at kw power ranges, current densities in the electron beam may be as great as 20 to 1200 amperes per square centimeter. It is known that such beams explode radially after the focusing fields have been removed and, accordingly, are not suitable for injection into many collectors, and particularly in a depressed collector. Consequently, it is apparent that a substantial dilution of current densities down to a few A/cm² must take place before the electron beam is injected into certain type collectors if a high efficiency is to be achieved. In addition to diluting the current densities, transverse velocity components should be eliminated or minimized.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the invention to provide a method and apparatus for minimizing the transverse velocity components in a spent electron beam.

It is another object of the invention to provide for a spent electron beam apparatus for refocusing the beam, which apparatus is easily adaptable to a microwave electron tube.

Still another object of the invention is to provide a method and apparatus for refocusing a spent electron beam utilizing negligible power or no power at all.

Yet another object of the invention is to provide a method for refocusing a spent electron beam for injection into a collector at high efficiency without any complex monitoring or programming steps being required.

A still further object of the invention is to provide apparatus for refocusing a spent electron beam with a minimum of parts.

It is an additional object of the invention to provide a method for refocusing a spent electron beam which

is applicable to solenoid, permanent magnet or permanent periodic magnet focused tubes.

In summary, the invention produces refocusing of a spent electron beam by minimizing transverse elctron velocities in the beam whereby the electrons having a multiplicity of axial velocities are sorted at high efficiency by collector electrodes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is the upper half of a longitudinal cross-sectional view of a microwave oscillator tube embodying the invention.

FIG. 2 is a graph whose abcissa is proportional in length to the length of the tube of FIG. 1 and which is a plot of magnetic field strength versus axial length of the tube.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, it will be seen that a microwave tube embodying the invention may be divided generally into an interaction region **10**, a refocusing region **11**, a beam stabilization region **12** and a collector region **13**. The foregoing four regions are defined by vertical lines **14, 15, 16, 17** and **18**.

An electron beam **19** will, in accordance with the instant invention, have the general shape as shown in FIG. 1 wherein the spent beam from which energy has been extracted in region **10** has a relatively constant diameter as indicated at **20** in the interaction region **10** of the tube, increasing radius as indicated at **21** in refocusing region **11**, stabilization of the radial velocities as shown at **22** by limiting of the velocities and of the radius to a maximum average fixed value as indicated at **23** in the collector region **13**. Focusing and refocusing, as used herein, indicate that the transverse velocities of electrons comprising an electron beam are reduced. Consequently, although an electron beam may be expanding, a limiting or decreasing of the amount of expansion will reduce the transverse velocity components of electrons in the beam. This causes the axial velocity of the electrons to increase, as may be shown by the well-known adiabatic expansion.

The interaction region **10** may include a solenoid comprising a current carrying winding **24** and a pole piece **25** which produce a magnetic field of constant value as indicated at **26** in FIG. 2. Downstream of the first solenoid is a second solenoid comprising current carrying windings **27**, a rear pole piece **28** and a front pole piece **29**. The second solenoid produces a constant magnetic field in stabilization region **12** as indicated at **30** in FIG. 2 and of much lower intensity than the magnetic field of the first solenoid.

In stabilization region **12** the transverse velocity components of the beam are minimum. Advantageously, the groups having slower axial velocities drift preferentially to the edge of the beam thus providing a natural velocity-position sorting which reduces the sorting which must be done subsequently in the collector region **13**. This presorting increases the collector efficiency because less energy is expended by the collector in sorting.

It will be seen that the magnetic field in the refocusing region **11** of FIG. 1 decreases smoothly but not necessarily linearly, as indicated at **31** in FIG. **2**, from its intensity as produced by the first solenoid to its lower intensity as produced by the second solenoid. The ratio of the magnetic field as given by **26** to that indicated by **30** in FIG. **2** is determined by the degree of the required dilution of the current density in the spent electron beam. Since the average beam radius is inversely proportional to the local magnetic field, the dilution is approximately given by the factor $(B_T/B_S)^2$, where B_T and B_S designate the values of the magnetic fields in the tube region **10** and the stabilization region **12**, respectively. Because the current density J_T in the tube region is known from the tube design, and the current density J_C at the entrance into the collector should not exceed the amount of approximately 10A/cm², we have for the ratio

$(B_S/B_T)^2 = J_C/J_T$. A pole piece **32** of smaller diameter than the pole piece **29** may be disposed on the front of the pole piece **29** so as to produce a smooth, gradual change of the magnetic field to its stabilizing value.

This smooth change is shown at **33** in FIG. **2**.

In the collector region **13** the electrons comprising electron beam **19** are all collected and, as shown in **38** in FIG. **2**, there is no magnetic field in this region except for a residual amount as shown at **39** after the magnetic field beings an abrupt decrease towards 0 as at **40**. The collector mechanism of the collector region **13** may comprise apertured dished plates **34, 35, 36** and **37**. However, it will be clear to those skilled in the art, that other suitable collectors of the prior art such as those used for microwave electron tubes may be used. To apply an increasingly negative voltage to each of the collectors **34** through **37** in a direction away from the electron source, the collectors are connected to a voltage divider **41** which is energized by suitable d-c source **42**. The positive side of the d-c source **42** is grounded as at **43** as are the pole pieces **25, 28, 29** and **32**. Numerals **44** through **49** indicate some of the paths which may be followed by various electrons in the electron beam as they travel toward the collector plates.

Referring again to FIG. **2**, L_1, the distance between vertical dash lines **15** and **16**, and L_2, the distance between the vertical dash lines **16** and **17**, represent the length of the refocusing region and the stabilization region, respectively. In accordance with the invention, L_1 has a length from about one cyclotron wavelength to about three cyclotron wavelengths while L_2 has a length from about one-half cyclotron wavelength to about 1 cyclotron wavelength, where a cyclotron wavelength is defined as $\lambda_c = {}_2\pi[\overline{u}/(e/m)\ B]$, where $\overline{u}$, e/m and B designate the average electron velocity, the electronic charge to mass ratio equal to 1.76×10 inch Coul/Kg and the local magnetic field B, respectively. It will be understood by those skilled in the art of electron beam dynamics in microwave amplifiers, that the optimum lengths L_1 and L_2 can be determined exactly only through complex complications such as to produce least transverse velocity at the entrance into the collector. However, the present invention gives the magnitude of the required fields the range of suitable lengths L_1 and L_2 and the method and shape of the refocusing fields.

It will, of course, be understood by those skilled in the art that permanent magnets may be used in place of the solenoids described in FIG. **1**.

If the tube is of a type utilizing permanent magnets for focusing in the interaction region to minimize weight and power consumption, then the magnets for the stabilizing region will preferably be also of the permanent type. In this case one single permanent magnet can be constructed such as to produce the required profile of the refocusing fields by a proper placement of pole pieces **25, 29** and **28** and proper shaping of the magnet itself.

What is claimed is:

1. A method of minimizing transverse velocity components in an expanding spent electron beam comprising the steps of:

restricting the expansion of said beam within predetermined limits for an axial distance of from about one cyclotron wavelength to about three cyclotron wavelengths to reduce the radial velocity of electrons in the beam;

then stabilizing said beam for an axial distance of from about one-half cyclotron wavelength to one cyclotron wavelengths; and

collecting said electron beam.

2. A method of conditioning a spent electron beam after it emerges from a first magnetic field of a utilization device comprising the steps of:

subjecting said electron beam to a gradually decreasing magnetic field which tapers to a stabilizing intensity, said decreasing magnetic field having an axial length of from about one cyclotron wavelength to about three cyclotron wavelengths, subjecting said beam to said stabilizing intensity for an axial length of from about one-half wavelength to one cyclotron wavelength after which it becomes zero; and

collecting the electrons comprising said electron beam downstream of the point at which the stabilizing intensity drops to zero.

3. *The method of claim 2 wherein said stabilizing in*tensity is from about ¼ to 1/10 as great as the intensity of said first magnetic field.

4. Apparatus for focusing an electron beam comprising:

means for limiting the expansion of said electron beam within a predetermined limit for an axial distance from about one cyclotron wavelength to about three cyclotron wavelengths:

means for substantially eliminating further expansion of said electron beam for an axial distance of from about one-half cyclotron wavelength to one cyclotron wavelength; and

means for collecting the electrons of which the beam is formed, each of said means being positioned in order as named in a direction away from said source of electrons.

5. An improved microwave tube comprising means for producing a beam of electrons;

means for extracting energy from said beam;

first magnetic means for focusing said beam;

second magnetic means disposed downstream of said first magnetic means to provide a constant magnetic field of lower intensity than that of said first magnetic means;

the fields of said first and second magnetic means merging to provide a refocusing field which decreases gradually in a downstream direction from the intensity produced by the first magnetic means to the intensity produced by the second magnetic means; and

means for collecting the electrons of said beam downstream of said second magnetic means.

6. The apparatus of claim 5 wherein said first and second magnetic means are solenoids.

7. The apparatus of claim 6 wherein said second solenoid includes a front pole piece including an upstream extending annular step portion of smaller diameter than said pole piece.

8. The apparatus of claim 5 wherein said first and second magnetic means are permanent magnets.

9. The apparatus of claim 5 wherein said collector is of the depressed type.

10. The apparatus of claim 5 wherein said second magnetic means includes auxiliary magnetic means disposed at the downstream surface of said second magnetic means to provide a smooth gradual change as the decreasing magnetic field between said first and second magnetic means merges into said lower intensity field produced by said second magnetic means.

11. The apparatus of claim 5 wherein said second magnetic means produces a magnetic field having an intensity 1/10 to ¼ as great as the intensity produced by said first magnetic means.

12. The apparatus of claim 5 and including means for abruptly terminating the field produced by said second magnetic means upstream of said collecting means.

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