Sept. 23, 1958 R. C. MOBLEY 2,853,645

ELECTRON CONCENTRATING AND ENERGY TRANSDUCING DEVICE

Filed Nov. 16, 1953 2 Sheets-Sheet 1

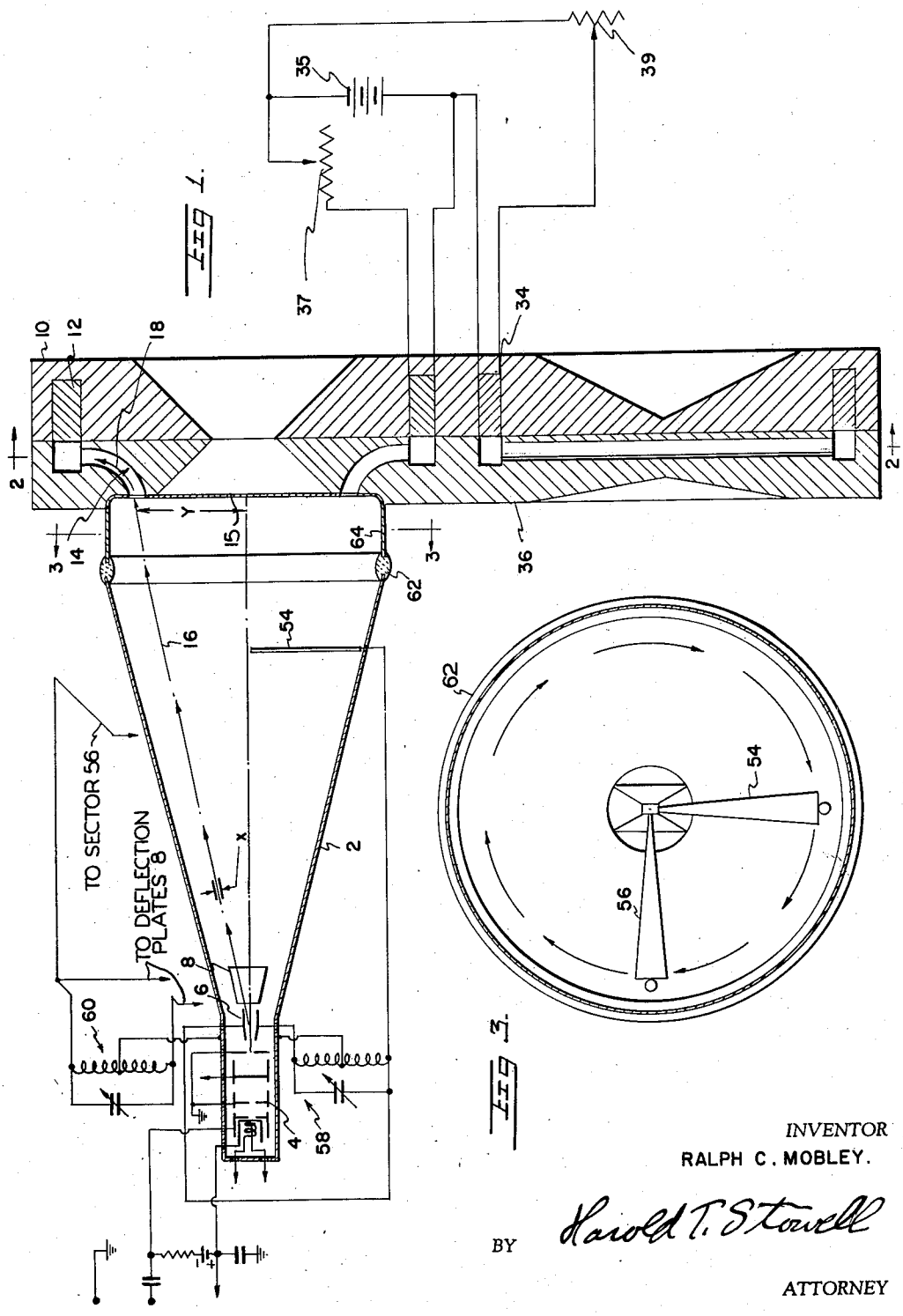


Fig. 1.

Fig. 3.

INVENTOR
RALPH C. MOBLEY.

BY Harold T. Stowell

ATTORNEY

Sept. 23, 1958 R. C. MOBLEY 2,853,645

ELECTRON CONCENTRATING AND ENERGY TRANSDUCING DEVICE

Filed Nov. 16, 1953 2 Sheets-Sheet 2

Fig 2.

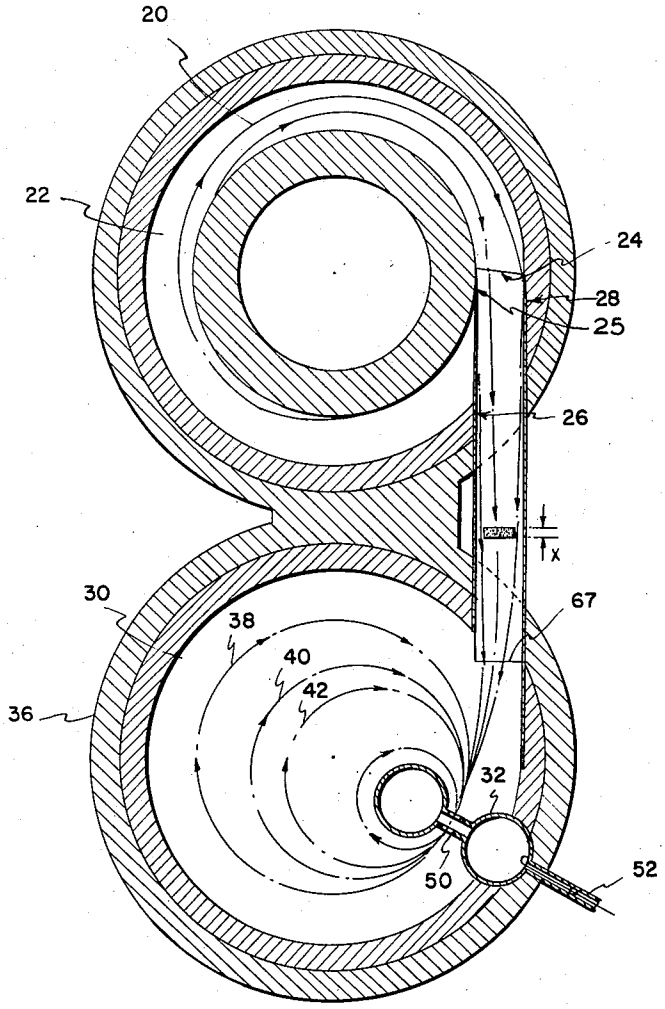
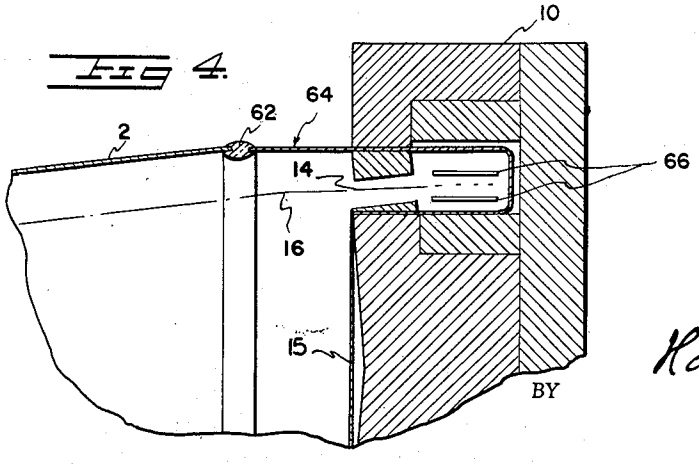


Fig 4.



INVENTOR
RALPH C. MOBLEY.

Harold T. Stowell

BY

ATTORNEY

United States Patent Office 2,853,645 Patented Sept. 23, 1958

2,853,645

ELECTRON CONCENTRATING AND ENERGY TRANSDUCING DEVICE

Ralph C. Mobley, Baton Rouge, La., assignor to Research Corporation, New York, N. Y., a corporation of New York

Application November 16, 1953, Serial No. 392,124

8 Claims. (Cl. 315—5.18)

This invention relates to electron concentrating and energy producing devices, and more particularly to improved electron tube structures for producing and utilizing densely concentrated groups or bunches of high energy electrons. The invention relates to electron discharge devices of the electron beam or cathode ray type and has for a primary object the provision of means for concentrating substantially all of the electrons of a continuous electron beam into highly concentrated successive bunches of electrons of substantially equal energy. Another object is the extraction of energy from such electron bunches in a utilization device for the production of very high frequency electrical oscillations at high power.

Still another object is the provision of relatively simple, readily controlled means for concentrating at a single point and at a single time the energy of the electrons produced by a cathode ray beam over an appreciable period of time. A further object is the provision of means for sufficiently extracting the energy of a concentrated bunch of high velocity electrons into a high frequency electrical circuit.

It is also an object of the invention to provide self contained means for producing a continuous circular sweep of a cathode ray beam by extracting energy from said beam to control the sweep timing.

The nature of the invention, as well as other objects and advantages thereof, will clearly appear from a description of a preferred embodiment as shown in the accompanying drawings in which:

Fig. 1 is a diagrammatic view, partly in section, illustrating the constructional features and sweep circuitry of a preferred embodiment of the invention;

Fig. 2 is a sectional view taken on line 2—2 of Fig. 1;

Fig. 3 is a sectional view taken on line 3—3 of Fig. 1; and

Fig. 4 is a fragmentary sectional view showing part of the field portion of a modification of the invention.

Referring to Fig. 1, a suitably evacuated chamber 2 contains a conventional electron gun 4 for producing a monoenergetic electron beam which passes through deflectors 6 and 8 which are activated to provide a circular sweep of the beam as will be more fully explained below. At the end of the tube is a magnetic field structure 10 of annular shape activated by coil 12 to produce a magnetic field across annular gap 14 which terminates at face 15 of the tube 2 at the locus of the circular sweep of electron beam 16. The electrons thus enter the gap 14 as they sweep around their circular path. Considering the beam 16 at the moment shown in Fig. 1, that is, with the beam substantially in the plane of the drawing, an electron entering the gap 14 is deflected substantially 90° so as to stay within the gap as indicated by arrow 18. This, however, represents only one component of the path of the electron; it also acquires another component of motion which causes it to spiral clockwise with reference to Fig. 2 along the lines generally indicated by paths 20 of Fig. 2. The circular sweep velocity of the electron beam entering gap 14 is adjusted to be equal to the circular velocity of the electrons in paths 20 so that as the electrons sweep angularly around the gap additional electrons are added to form a group or bunch of electrons whose length in the direction of angular motion is only as great as the original width of the beam (shown as X in Fig. 1). All successive electrons entering gap 14 during a single revolution of the electron beam are added to this bunch revolving in chamber 22. Such additions increase the radial spread of the group but not its length along its direction of motion. At the end of every revolution of the electron beam sweep in gap 14 the electron bunch so formed leaves chamber 22 along line 24 which represents the edge of the magnetic field and is formed by suitably shaped magnetic field members, and enters the field free tube 26. This is brought about by terminating the magnetic field in gap 14 as close as possible to lines 24, 25 and 28.

As a result of the constant and repetitive nature of the electron beam circular sweep velocity in gap 14, electron bunches emerge from chamber 22 uniformly separated in time at a frequency equal to the sweep repetition rate.

It will be apparent that the magnetic field in gap 14 must have a strength and configuration such that the electrons while changing their direction by 90° as indicated by arrow 18 in Fig. 1 will also follow spiral paths as indicated by arrows 20. Upon emerging from the magnetic field along line 24, if the edge of the field at this line is properly shaped the electron bunch will pass throuh field free tube 26, enter the uniform magnetic field in chamber 30 along line 67, pass through aperture 50 and be brought to a focus at the center of resonant cavity 32. By tuning cavity 32 to a frequency equal to an integral multiple of the sweep repetition rate and by adjusting the magnetic field produced in chamber 30 by coil 34 and circular field member 36 to a value where the time for an electron to make one complete circle within this magnetic field is equal to the time for an integral number of oscillations of the cavity, then each electron bunch entering the cavity from chamber 22 will be so timed with respect to the oscillations set up in the cavity that it will deliver energy to the cavity and furthermore, by making this energy loss to the cavity by the electron bunch large enough, the electron bunch after passing through the cavity will circle in a path of small enough diameter to remain within the magnetic field in chamber 30 and thus make many passes through the cavity so timed as to deliver energy to the cavity on each pass. This progressive loss of energy of an electron bunch on each successive pass through the cavity causes each successive path, indicated as 38, 40, 42 etc. in Figure 2 to be progressively of smaller diameter until the electron bunch is finally collected on the cavity. Energy delivered to the cavity by the electron bunches in passing through the cavity is transferred through appropriate coupling to power output 52.

With this arrangement, where a given electron bunch can make many passes through the resonant cavity in delivering its energy to the cavity, the coupling between the electron bunch and cavity need not be very large for efficient energy transfer and furthermore by appropriate adjustment of the uniform magnetic field in chamber 30 the circulating electron bunches can be made to pass through resonant cavity 50 at equally spaced intervals between the arrival of new pulses from chamber 22 thus permitting the cavity to oscillate at a high harmonic of the sweep repetition rate and deliver essentially constant power to the power output 52 without making extreme demands on the Q of the resonant cavity.

Alternatively, the second magnetic field provided by coil 34 could be omitted and each pulse caught in a resonant cavity or circuit. If the resonant cavity or circuit were tuned to a very high harmonic of the sweep

repetition rate, however, such a scheme would not be as effective as the one outlined in the figure because of the difficulty of obtaining sufficient coupling between the resonant cavity or circuit and the electron bunch to remove all the energy from the electron bunch in a single pass through the resonant structure and also because of the very high Q which would be necessary for the resonant circuit or cavity if it were to deliver power at a uniform rate to the power output without undue modulation at the sweep repetition rate. For adjusting the strength of the magnetic fields a conventional battery **35** is shown with variable resistors **37** and **39** for coils **12** and **34**, respectively.

If the diameter of the electron beam on entering gap **14** is x, the radius of the entrance to gap **14** is y and the intensity of the electron beam I_0, then the current density in the electron bunch passing through cavity **50** is approximately

$$\frac{2\pi y}{x} I_0$$

and the time duration D of the electron pulse at **50** is

$$\frac{x}{v}$$

where v is the velocity of the electron beam. For y=3.5 cm., x=.1 cm., and an electron energy of 25 k. e. v. at gap **14** the current density in the electron bunch would be 220 I_0. The velocity of a 25 k. e. v. electron is about 9.4×10^9 cm./sec. and the minimum theoretical electrical pulse duration at **50**, neglecting any space charge spreading effects, would be 1.07×10^{-11} sec. Based on a Fourier analysis of an assumed square electrical pulse at **50** of 1.07×10^{-11} sec. and very large coupling to the resonant cavity, the efficiency of energy transfer from the electron bunch to the resonant cavity should be approximately 100% for frequencies much less than 5×10^{10} cycles/sec., 63% for a frequency of 5×10^{10} cycles/sec., and 5.8% for a frequency of 5.4×10^{11} cycles/sec. (λ=½ mm.).

More specifically if new electron bunches from chamber **22** arrive at **50** with a frequency r_0 and if it is assumed that the coupling between resonant cavity **32** and these electron bunches is very large causing the electron bunches to lose all of their energy in a single pass through the cavity, and if the resonant frequency f of the resonant cavity **50** is chosen equal to nr_0, where n is an integer such that

$$1\leq n\frac{1}{r_0D}, \frac{1}{r_0D}<n<\frac{2}{r_0D}, \frac{2}{r_0D}<n<\frac{3}{r_0D}$$

etc., then the cavity will be set into electrical oscillations at its resonant frequency with an amplitude proportional to

$$\frac{2}{n\pi}\sin(n\pi Dr_0) \text{ for } 1\leq n\leq\frac{1}{r_0D}$$

but proportionately somewhat less than this for n progressively greater than

$$\frac{1}{r_0D} \text{ i. e. } \left(f=\frac{1}{D}\right)$$

due to non-uniformity in the electron beam density and/or space charge spreading of the electron bunches. The efficiency of energy transfer from the electron bunch to the resonant cavity has a theoretical maximum of 100% for

$$n<<\frac{1}{2r_0D} \text{ i. e. } \left(f<<\frac{1}{2D}\right), 63\% \; n=\frac{1}{2r_0D} \text{ i. e. } \left(f=\frac{1}{2D}\right)$$

21% for

$$n=\frac{3}{2r_0D} \text{ i. e. } \left(f=\frac{3}{2D}\right)$$

and neglecting non-uniformity and space charge effects in the electron pulse, 5.8% for

$$n=\frac{11}{2r_0D} \text{ i. e. } \left(f=\frac{11}{2D}\right)$$

Some energy would be available in principle at even higher frequencies, but at lower efficiencies.

It is to be understood that the efficiencies given are based on several approximations and can therefore serve only as guides to the actual performance of such an oscillator. Furthermore, the sin ($n\pi Dr_0$) amplitude dependence given is true only for the conditions assumed and will not apply where the electron bunches make multiple passes through the resonant cavity in the manner previously outlined.

A useful application for this oscillator is for the generation of amplitude modulated signals in the

$$f<<\frac{1}{2D}$$

region, which in the preceding example would be for frequencies less than 50,000 megacycles, although frequencies corresponding to wave lengths of a fraction of a millimeter appear to be theoretically possible. Amplitude modulation of the high frequency electrical power output can easily be achieved by intensity modulation of the electron beam.

The oscillator with its circular sweep is self exciting and the sweep amplitude is self regulatory. Sectors **54** and **56** (Fig. 3) intercept a small portion of the electron beam as the sweep revolves. The current so intercepted is used to excite resonant circuits **58** and **60**. These resonant circuits are in turn attached to the deflecting plates **6** and **8** respectively and cause the circular deflection of the electron beam. Proper phasing of the two resonant circuits, both resonant to the same frequency, is obtained by placing sectors **54** and **56** at right angles to each other. The diameter of the sweep circle is limited by designing the deflecting plates so that they intercept part of the electron beam when it tends to sweep in a circle of radius greater than y. The loading that thus results prevents the peak to peak tuned circuit deflecting voltages from attaining larger values than desired.

The pulse repetition rate r_0 is governed by the tuned deflecting circuits **58** and **60**. For a given electron beam energy at gap **14** it is then necessary to appropriately adjust the deflecting tuned circuits and the strength of the magnetic field in **14** to obtain good bunching. For a given velocity v of the electrons entering gap **14** the sweep frequency r_0 is given by the expression

$$\frac{v}{2\pi y}$$

For 25 k. e. v. electrons and y=3.5 cm. as used in the preceding example this turns out to be about 430 megacycles, which is still within the range of the simple lumped constant tuned circuits shown. The second magnetic field at **30** must also be properly adjusted to give proper phasing of the multiplicity of circulating electron pulses.

To minimize the maximum necessary deflecting voltage and yet permit a high final electron energy an insulating section **62** is inserted between sections **2** and **64** and the largest portion of the accelerating voltage can then be made to appear across this gap if so desired. Signals for intensity modulation of the electron beam are applied between grid and cathode of the electron gun.

An alternative arrangement for accomplishing electron bunching is indicated in Fig. 4. In this figure the magnetic field merely produces a deflection of approximately 90° to the plane of the paper in the entering electron beam, and a pair of circular electrostatic deflecting plates **65** cause the then tangentially moving electron beam to follow a circular path until a point corresponding to a point on line **24** (Fig. 2) is reached. At this

point a gap is left in the circular electrostatic deflecting plates 66 so that the electron bunch, formed between the circular plates in much the same manner as described above, may enter the field free tube 26. The electron bunch in this case instead of spreading out radially will spread out axially. By varying the width of gap 14 so as to vary the deflection of the electron beam in passing through the gap, all electrons can be made to come to a common focus at a point such as the center of resonant cavity 32.

The arrangement of Fig. 2 has the advantage over the above arrangement in that once the correct field configuration has been established, only the strength of the magnetic field need be adjusted to obtain proper bunching whereas in the modification of Fig. 4, both the magnetic and electrostatic fields must be adjusted.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of my invention as defined in the appended claims.

I claim:

1. An electron beam bunching device comprising means for producing an electron beam, cyclically energized deflector means for deflecting said beam to sweep a uniform circular trace in a plane perpendicular to the central axis of the sweep, means defining an annular gap spanning the circular trace of the deflected beam, means for producing an electron deflecting field in said gap to deflect the electron beam entering the gap into a spiral path substantially in a plane perpendicular to the original axis of said beam, and means for synchronizing the circular velocity of the electron beam entering said gap with the velocity of the electrons in said spiral path whereby the electrons in said spiral path are concentrated in bunches having lengths in the direction of angular motion thereof approximately equal to the width of the electron beam entering said gap.

2. The invention according to claim 1 wherein the electron deflecting field is a magnetic field.

3. The invention according to claim 1 including means for directing said axially bunched electrons into an energy extracting means.

4. The invention according to claim 3 wherein the energy extracting means comprises an internally resonant chamber having an aperture in the path of travel of said electron bunches and tuned to a resonant frequency synchronous with the rate of passage of the electron bunches through said aperture, power outlet means electrically coupled to said resonant chamber, and means for producing about said chamber a magnetic field of such configuration and intensity as to redirect the electron bunches passing through said aperture into arcuate paths leading back to said aperture of such length that the returning electron bunches pass through said aperture in synchronism with oscillations of said resonant chamber for the further extraction of energy from said electron bunches.

5. The invention according to claim 1, said beam producing means comprising a cathode-ray tube having two deflection control means for respectively controlling the beam sweep in two mutually perpendicular directions, pick-up electrode means in the circular path of said beam, means for deriving two ninety-degree-phase-displaced sweep timing signals from said pick-up means, and means for feeding back said signals to said respective deflection control means for energizing said last means to produce a circular sweep of said beam.

6. The invention according to claim 5, said pick-up electrode means comprising two pick-up electrodes in the circular path of said beam at positions ninety degrees displaced along said circular path.

7. The invention according to claim 6, said pick-up electrodes being sector-shaped.

8. Electron beam bunching device as defined in claim 1 wherein the said means for producing an electron deflecting field in said gap comprises a magnetic member and an electrostatic member, said magnetic field member being of such configuration as to deflect electrons of said beam in one direction and the electrostatic field member being of such configuration as to deflect the electrons of said beam in a curved path in another direction.

References Cited in the file of this patent

UNITED STATES PATENTS

2,368,328	Rosencrans	Jan. 30, 1945
2,454,094	Rosenthal	Nov. 16, 1948
2,528,541	Pajes et al.	Nov. 7, 1950
2,559,582	Bailey	July 10, 1951