

[54] **ELECTROMAGNETIC LENS FOR HIGH SPEED ELECTRON BEAMS**

[72] Inventor: **Rolf Wideroe**, Nussbaumen, Switzerland

[73] Assignee: **Aktiengesellschaft Brown, Boveri & Cie**, Baden, Switzerland

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[30] **Foreign Application Priority Data**

June 27, 1968 Switzerland .....9636/68

[52] U.S. Cl.....**315/14, 315/5**

[51] Int. Cl.....**H01j 29/46**

[58] Field of Search.....315/5, 5.35, 14, 84, 85

[56] **References Cited**

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*Primary Examiner*—Carl D. Quarforth

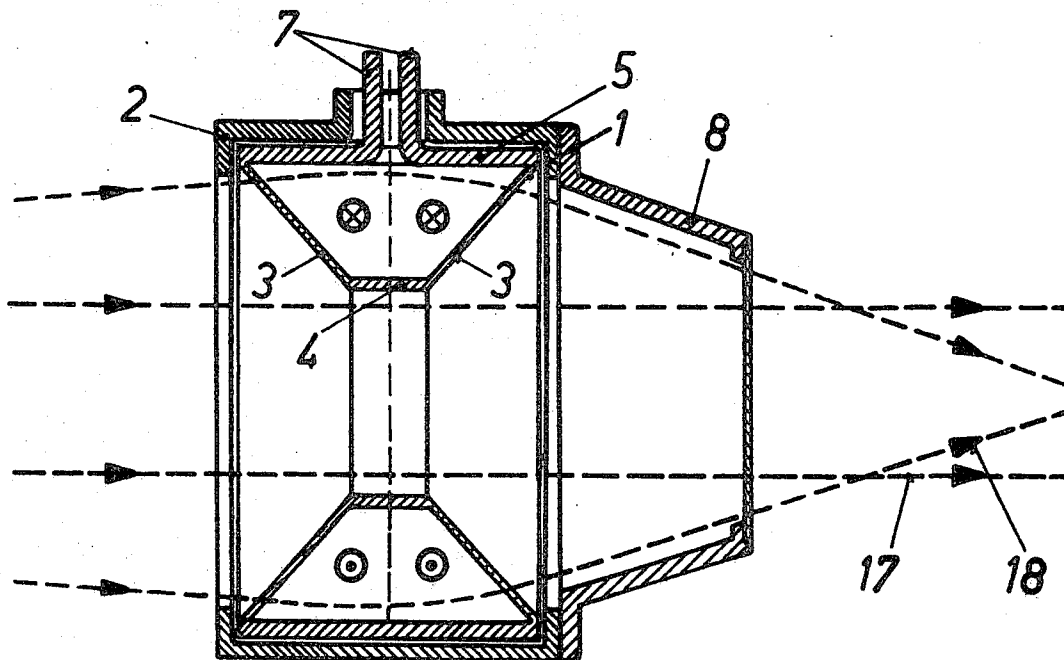
*Assistant Examiner*—J. M. Potenza

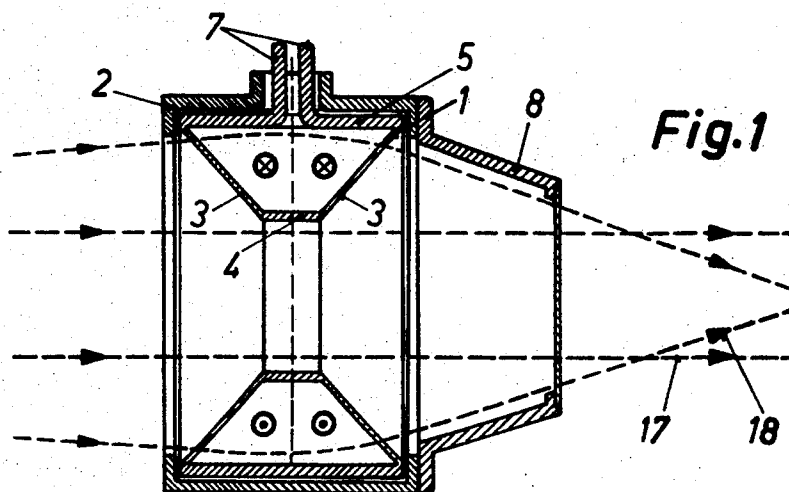
*Attorney*—Pierce, Scheffler & Parker

[57] **ABSTRACT**

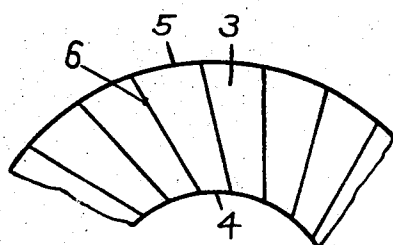
A lens of the magnetic field type for high speed electron beams such as those which emerge from an electron accelerator comprises a multi-turn toroidal coil having a trapezoidal configuration, which is energized by pulse currents. The coil is wound from ribbon-form conductor material, such as aluminum and the conductor parts on the conical surface zones of the coil which are traversed by the electron rays have a smaller thickness than the conductor parts at the inner and outer peripheral surface portions of the coil. Cooling means in the form of fins in contact with a fluid coolant can be provided in heat transfer relation with those conductor parts of the coil which are not traversed by the electron rays.

**12 Claims, 5 Drawing Figures**

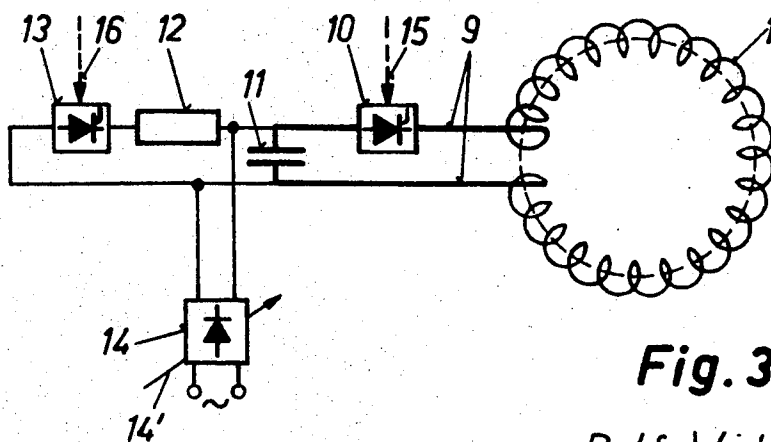




**Fig. 1**



**Fig. 2**



**Fig. 3**

Inventor

Rolf Wideroe

By *Pierre, Scheffler & Parker*  
Attorney

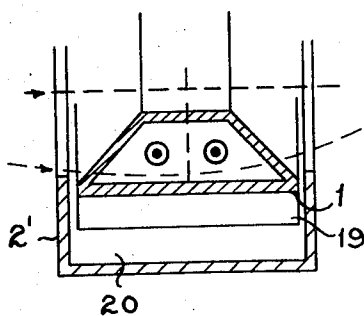


Fig. 4

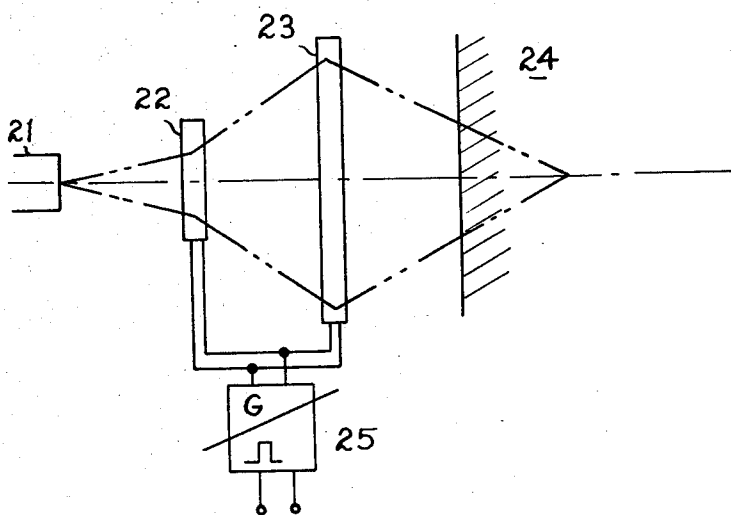


Fig. 5

# **ELECTROMAGNETIC LENS FOR HIGH SPEED ELECTRON BEAMS**

The traversed invention relates to a magnetic lens for high speed electron beams in which an axially symmetrical and azimuthally orientated magnetic field is produced in a toroidal chamber, disposed coaxially relative to the lens axis and being transversed by part of the rays of the pencil of electron rays.

A magnetic lens of the kind heretofore described is disclosed in the Swiss Patent Specification 351,037. It is used in a preferred embodiment for increasing the depth dose when irradiating the human body by means of high speed electrons. To this end, and in order to maintain the greatest possible ratio of depth dose to surface dose, said lens is disposed directly on the surface of the body to be irradiated.

The known magnetic lens comprises a hollow toroidal metallic member within which is disposed a toroidal iron core provided with a magnet winding. By feeding said winding with current pulses a current is induced in the wall of the hollow member to generate therewithin an axially symmetrical, azimuthally orientated magnetic field. Parts of the wall of said hollow member, constructed from relatively thin aluminum plate, serve as windows for the passage of part of the rays of the pencil of electron rays, said part being focusingly deflected by the magnetic field which is established in the toroidal chamber.

The known magnetic lens, however, has certain disadvantages. Firstly, the effective inductance of the magnet coil is relatively high so that short excitation current pulses with a duration of, for example 100  $\mu$  sec can be produced only with a relatively substantial effort. Furthermore, the losses in the known magnetic lens due to remagnetization of the iron core are relatively high.

The object of the invention is to provide a magnetic lens which does not have the aforementioned disadvantages, which permits better focusing of the electron rays and which moreover has a lower weight or is less expensive to produce than the known magnetic lens.

The magnetic lens according to the invention is characterized in that the toroidal chamber is surrounded by a toroidal coil with a plurality of turns, serving as excitation winding for the azimuthally orientated magnetic field. The invention will be explained hereinbelow by reference to the accompanying drawings in which a preferred embodiment is illustrated.

In these drawings, FIG. 1 is a view of the improved magnetic lens in longitudinal section;

FIG. 2 is a fragmentary view showing a sector of a toroidal coil shown in FIG. 1;

FIG. 3 is a circuit diagram illustrating one suitable circuit for supplying the toroidal coil in FIG. 1 with pulsed excitation current;

FIG. 4 illustrates a modified construction wherein cooling means are provided for the coil producing the magnetic field; and

FIG. 5 illustrates a modified construction wherein a pair of magnetic lenses are located along the axis of the beam to effect first a divergence of the beam and then a convergence.

With reference now to the drawings, FIG. 1 shows a section of the magnetic lens. It comprises a toroidal coil 1 of aluminum and being of approximately trapezoidal

cross-section, mounted in electrically insulated manner in a housing 2. The toroidal coil 1 itself comprises a ribbon form conductor of aluminum. The conductor parts 3 on the conical surface zones of the toroidal coil 1 are of smaller thickness (for example 1 mm) than the remaining conductor parts 4,5. FIG. 2, which illustrates a sector of the toroidal coil 1 in plan view, parallel to the coil axis, discloses the individual turns of the coil which are disposed adjacently and are closely spaced. The joints 6 between two adjacent coil turns are filled with insulating compound. The coil is fed via a cable which is connected to the ends 7 of the toroid coil 1. An interchangeable, non-conductive irradiation tube 8 is mounted on the ray exit side of the magnetic lens.

Since most accelerators such as linear accelerators, betatrons, microtrons and the like suitable for co-operation with such a magnetic lens for producing a pencil of electron beams operate by the impulse method, the magnetic lens is accordingly advantageously excited by pulse currents which are synchronized with the electron ray pulses delivered by the accelerator.

The aforementioned pulsed excitation currents are produced by a supply apparatus whose circuit diagram is illustrated in FIG. 3. The toroid coil 1 is connected via a low-induction cable 9 and a controllable discharge rectifier 10 to a low-inductance capacitor 11. A serial connection, comprising an inductance 12 and a controllable charging rectifier 13, also the output of an adjustable rectifier stage 14, whose input is supplied from the A.C. mains, is connected in parallel to the aforementioned capacitor 11. The adjustable voltage output characteristic of the rectifier is indicated schematically by the arrow 14'.

The method of operation of the apparatus described hereinabove is as follows: after switching on the supply unit the capacitor 11 is charged by the variable rectifier stage 14 to a specified and pre-determined D.C. potential. Simultaneously with the control pulse which initiates the delivery of a pencil of electron rays from the accelerator, the discharge rectifier 10 is supplied via its control input 15 with an opening or gating pulse thus causing the capacitor 11 to be connected via the cable 9 to the toroid coil 1 and for said capacitor to discharge via the aforementioned coil. Owing to the effect of inductance which tends to maintain the coil current, the charge polarity of the capacitor 11 is reversed. During said reversal, a pulsed excitation current will flow in the toroid coil 1. After polarity reversal has taken place, the charging rectifier 13 is supplied via its control input 16 with an opening or gating pulse so that the capacitor 11 is re-charged to its original polarity via the charging inductance 12. The reduction of capacitor voltage due to circuit losses is compensated by additional charging from the rectifier stage 14.

By appropriate dimensioning of the charging inductance it is possible for the period of the second charge reversal to be extended so that it is completed immediately prior to the initiation of the next excitation current pulse. In this way, the maximum power drawn from the mains is minimized.

The control pulses which serve to control the discharge rectifier are timed relative to associated control pulses which cause the pulse delivery of electrons from the accelerator so that the pencils of highly mag-

netic electrons traverse the magnetic lens only if at least approximately the maximum excitation current flows in the toroid coil 1. The central rays 17 (FIG. 1) of the pencil of electron rays traverse the central opening of the magnetic lens in substantially un-changed form. A part 18 of the rays of the pencil of rays however traverse the cavity surrounded by the toroid coil 1 in which cavity there exists an axially symmetrical, azimuthally orientated magnetic field whose field strength is proportional to the excitation current. The thin-walled conductor parts 3 of the toroid coil 1 are traversed by high-energy electrons which are substantially un-attenuated.

Owing to the presence of the magnetic field in the aforementioned cavity, the electrons are deflected proportionally to the magnetic field strength and proportionally to the length of path traversed by them within said cavity. To obtain precise focusing, it would be necessary for the angle of deflection to be approximately proportional to the distance of the electron beam to be deflected from the lens axis. Since, however, the magnetic field strength in the cavity is inversely proportional to the distance from the lens axis, the distances traversed by the electrons in the cavity would have to diminish approximately in accordance with a square law with a decreasing distance from the lens axis. The square law relationship is approximated in the magnetic lens by the conical construction of the flanks of the toroid coil 1. The focal length of the magnetic lens can be varied within relatively wide limits by altering the maximum excitation current, that is to say by varying the output voltage of the rectifier 14.

The excitation current required for higher electron energies and accordingly the losses in the toroid coil become so large that it is not possible to dispense with separate cooling means. In an advantageous embodiment of the lens with cooling means the toroid coil may, for example, as illustrated in FIG. 4 be provided at its cylindrical circumference with cooling fins 19 which extend into an annular cooling duct 20 between the toroid coil 1 and the housing wall 21 through which cooling air is blown by means of a suitable blower, not illustrated.

According to a further embodiment of the lens, the remaining parts of the conductor of the toroid coil are additionally supplied with blown cooling air.

In a lens of the kind heretofore described, for example, having a toroid coil of 16 cm diameter and a maximum thickness of 12 cm and comprising 30 turns, a focal length of 30 cm is obtained for electrons having an energy of 35 MeV and a divergence angle of  $3.82^\circ$ , for example, with a coil current of 4,300 Amperes. With an excitation current pulse duration of 100  $\mu$  sec and a frequency of 50 pulses/s, the 1 mm thick conductor parts of the coil will have a mean power loss of 410 watts which can be easily dissipated by the air cooling system.

In the dimensioned example described hereinabove the inductance of the toroid coil amounts to approximately  $8.5 \cdot 10^{-6}$  henries. A capacitor having a capacitance of 119  $\mu$  farad is required to produce excitation current pulses of 100  $\mu$  sec duration. The maximum capacitor voltage amounts to approximately 1,200 V. A charging inductance 12 of 0.237 henries provides a charging half wave whose duration cor-

responds to a frequency of 30 cycles and a charging current having a maximum peak value of 27 amperes.

When using such magnetic lenses in conjunction with linear accelerators which deliver electron ray pencils with very small divergence angles, two serially disposed lenses are required for producing a pencil of sufficiently large diameter, the first of said lenses being disposed as dispersion lens at the output of the accelerator to increase the divergence of the emergent pencil of rays, while the second lens, disposed on the object to be irradiated, focuses said pencil of rays. The two lenses are advantageously operated from the same supply unit. To this end, the excitation current pulses supplied to the lenses and therefore the focal length thereof must be individually adjustable but must be proportional relative to each other.

FIG. 5 illustrates an arrangement of two magnetic lenses as described above, in conjunction with a linear accelerator 21 which delivers an electron ray pencil having a very small divergence angle. For producing a pencil of sufficiently large diameter, lenses 22, 23 are serially disposed in spaced relation along the axis of the pencil or beam, the lens 22 being disposed, as a dispersion lens, at the output of the accelerator 21 to increase the divergence of the emergent pencil of rays, while lens 23 disposed at the object 24 to be irradiated, focuses the pencil of rays. The two lenses 22, 23 are advantageously connected to the same electrical supply source 25, the excitation current pulses of which are individually adjustable but proportional relative to each other and the coil currents being in opposite directions.

I claim:

1. In a magnetic lens structure for producing an axially symmetrical, azimuthally oriented magnetic field serving to control a beam of high energy electrons, and wherein said lens structure includes a toroidal space disposed co-axially with the lens axis and through which space the outer rays of the electron beam are passed, the improvement wherein said magnetic field is produced within said toroidal space by a coil having a plurality of turns surrounding said space, said coil having a trapezoidal cross-sectional configuration and in which the minimum dimension thereof in the axial direction faces towards said lens axis.

2. A magnetic lens as defined in claim 1 wherein said trapezoidally coil is wound from ribbon-form conductor material and wherein those conductor parts which are traversed by the electron rays have a smaller thickness than the remaining conductor parts of said coil.

3. A magnetic lens as defined in claim 1 wherein said trapezoidally coil is wound from ribbon-form conductor material, the conductor parts on the conical surface zones of the coil traversed by the electron rays having a smaller thickness than the remaining conductor parts at the inner and outer peripheral surface portions of the coil.

4. A magnetic lens as defined in claim 1 and wherein further includes cooling means in heat transfer relation with those conductor parts of the coil which are not traversed by the electron rays.

5. A magnetic lens as defined in claim 4 wherein said cooling means are constituted by fins provided on the outer circumference of said coil and located in an annular cooling duct between said coil and the internal wall surface of the housing in which said coil is located.

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6. A magnetic lens arranged as defined in claim 1 and which further includes an excitation circuit for said trapezoidally coil, said excitation circuit delivering adjustable pulse currents and which are produced by the charge reversal of at least one capacitor.

7. A magnetic lens arrangement as defined in claim 6 wherein said excitation circuit includes at least one controllable discharge rectifier for effecting the charge reversal of said capacitor.

8. A magnetic lens arranged as defined in claim 7 10 wherein said excitation circuit includes a charging inductance and controllable charging rectifier for effecting reverse charge reversal of said capacitor after charge reversal.

9. A magnetic arrangement as defined in claim 8 15 wherein an electron accelerator is utilized for producing the electron beam, and wherein the control pulses which serve to control the rectifiers for discharging and recharging said capacitor have a predetermined time

relationship to associated control pulses which cause the discharge of electrons from said accelerator.

10. A magnetic lens arrangement wherein an electron accelerator is utilized for producing the electron beam which passes through first and second magnetic lenses each as defined in claim 1 and arranged in series, said first lens serving to increase the divergence of the electron beam emerging from the accelerator and said second lens serving to focus the divergent beam.

11. A magnetic lens arrangement as defined in claim 10 wherein the excitation current pulses for said first and second lenses and hence the focal lengths thereof are individually adjustable and are proportional relative to each other.

12. A magnetic lens arrangement as defined in claim 10 wherein the excitation currents for the coils of said first and second lenses are produced from the same current supply circuit.

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UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 3,689,796 Dated September 5, 1972

Inventor(s) ROLF WIDEROE

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 2, line 2:

Claim 3, line 2:

Claim 6, line 3:

--- configured -- should have been inserted after  
"trapezoidally: --

Claim 4, line 1: "wherein" should be ---which ----

Signed and sealed this 23rd day of January 1973.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.  
Attesting Officer

ROBERT GOTTSCHALK  
Commissioner of Patents