Feb. 6, 1968 A. SAHARIAN 3,368,102

COLLECTOR STRUCTURE OPERATING AT A DEPRESSED POTENTIAL FOR COLLECTING A HOLLOW ELECTRON BEAM

Filed June 9, 1965 2 Sheets-Sheet 1

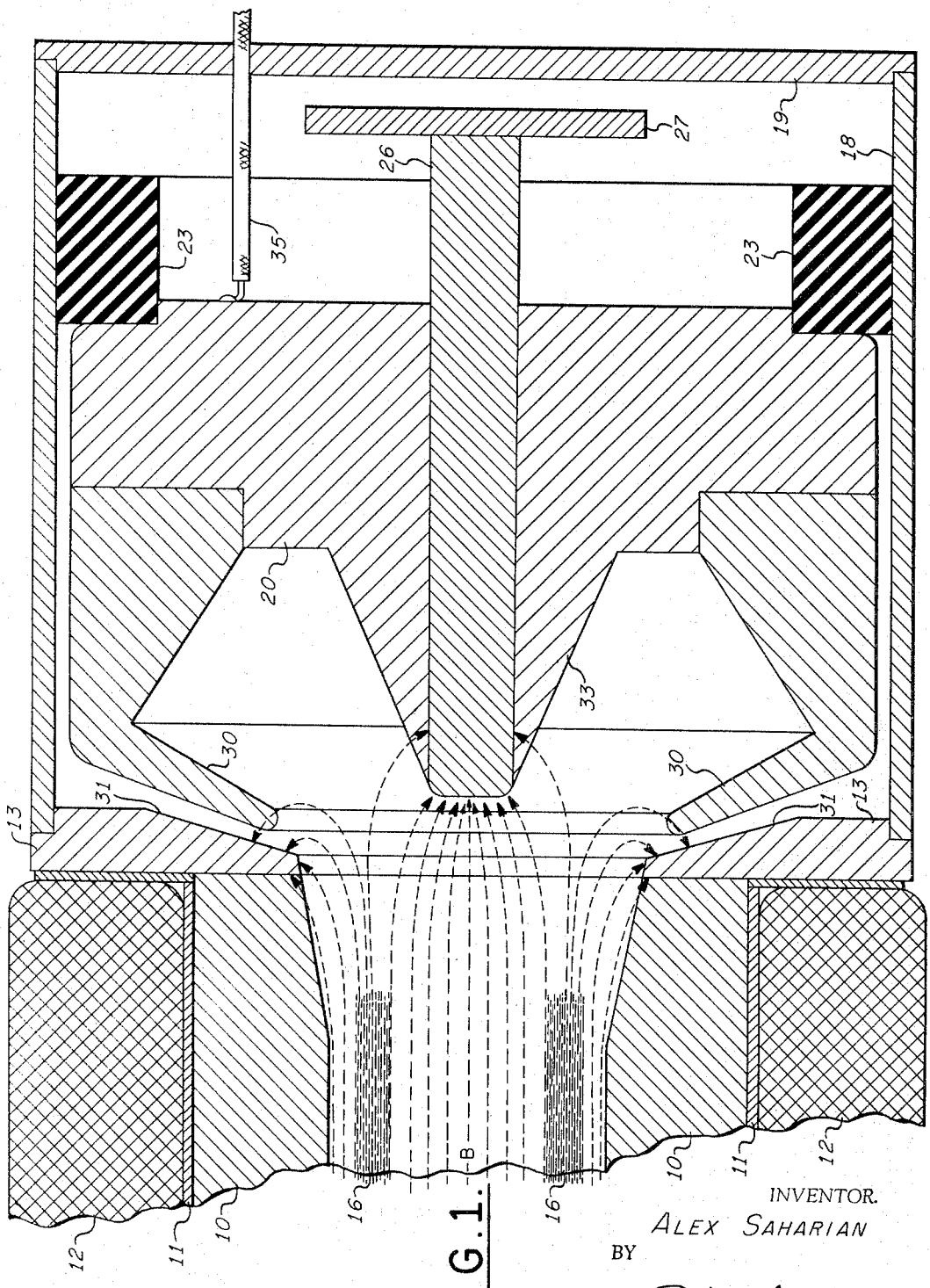


FIG. 1.

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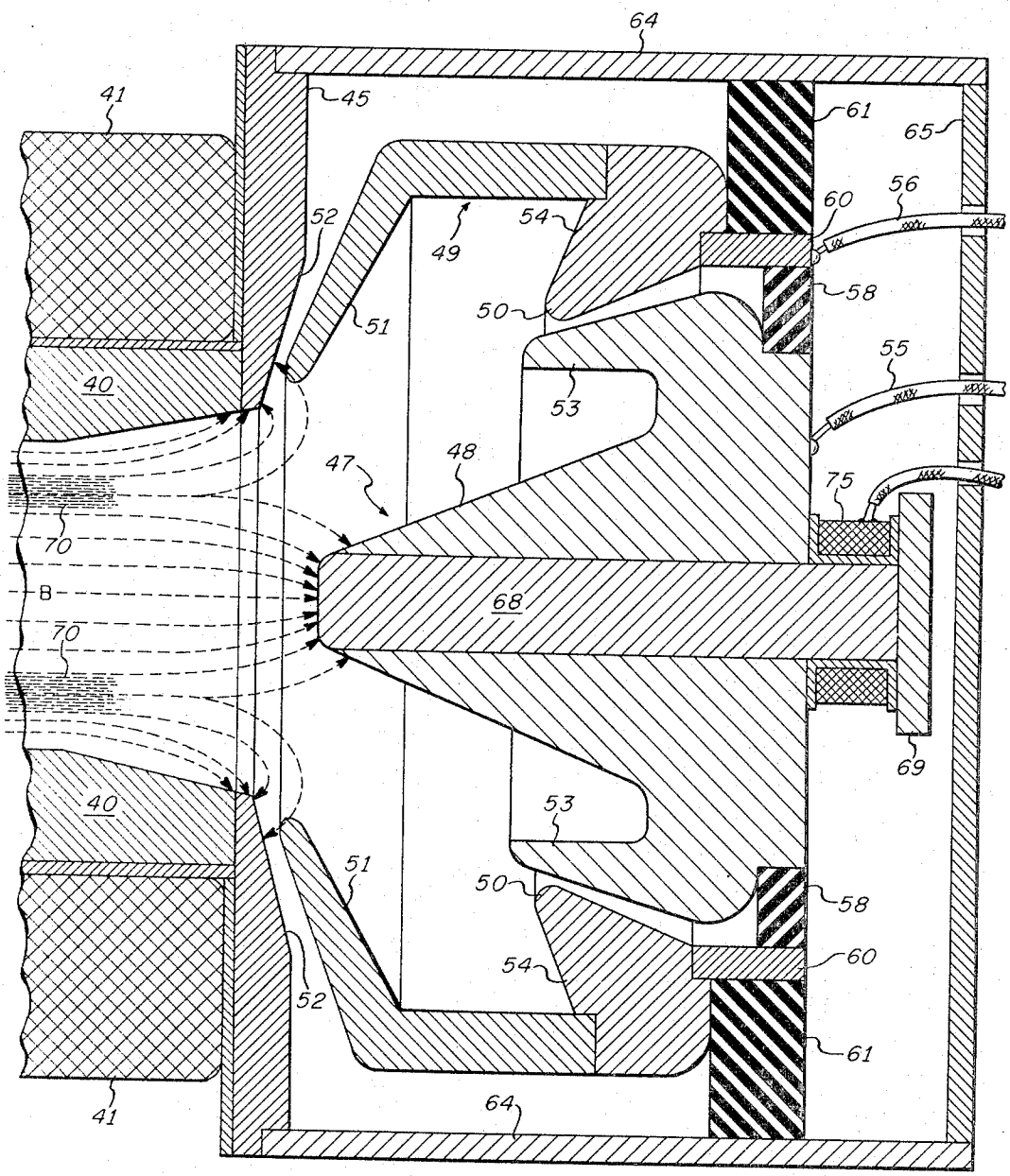


FIG. 2.

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COLLECTOR STRUCTURE OPERATING AT A DEPRESSED POTENTIAL FOR COLLECTING A HOLLOW ELECTRON BEAM

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8 Claims. (Cl. 315—3)

The invention herein described was made in the course of, or under a contract or subcontract thereunder, with the Department of the Air Force.

This invention relates to a collector electrode structure for an electron tube device and more particularly it relates to a collector that is particularly useful for collecting a hollow electron beam.

An electron beam in the form of a thin hollow tube, referring to most commonly as a hollow beam, long has been considered attractive for use in electron beam tubes because it affords greater efficiency of interaction between the beam electrons and waves propagating on a slow wave propagating structure. This means that for a given value of gain the tube may be made shorter. Further, higher beam currents are obtainable in hollow beams before problems arising from space charge forces set in. It is customary to confine the electrons within the hollow beam by means of an axially extending magnetic field. Typically, this magnetic field is terminated in the region of the tube immediately in front of the collector electrode by an annular magnetic pole piece which forms part of the body portion of the tube. It has been found in the operation of hollow beam traveling wave tubes having this type of arrangement and with the collector structure in the form of a hollow cup which is electrically biased at a depressed potential, i.e., a potential considerably lower than the potential of the interaction structure and the body portion of the tube, that a large portion of the beam electrons were being collected on the pole piece in front of the collector rather than in the collector itself. This led to the creation of undesirable localized "hot spots" on the pole piece and this is undesirable because it affects the magnetic characteristics of the pole piece and leads to cooling problems that are difficult to contend with. The reason why a large portion of the electrons was being collected on the pole piece was due to the fact that all of the flux lines of the focussing magnetic field curved outwardly as they terminated on the annular pole piece, thus causing all but the very highest energy electrons to be forced outwardly from the hollow beam so that they came close enough to the tube body to be collected by the pole piece which is at a higher potential than the collector. To overcome this problem, one approach that was tried was to remove the pole piece from in front of the collector and make provisions so that all of the magnetic field flux lines terminated in the cup-shaped collector, the hope being that the beam electrons would follow along or about the magnetic flux lines directly into the collector. Under these conditions, however, the combination of the depressed potential on the collector and the space charge forces in the high current hollow beam caused a large number of the beam electrons to reverse their direction and follow back along the magnetic field flux lines to the interaction structure of the tube, where together with the secondary electrons from the collector that found their way back to the interaction structure, they caused a disturbing effect on the operation of the tube.

In accordance with an illustrated embodiment of the present invention, I am able to efficiently collect a hollow electron beam in a depressed potential collector by employing a structure in which the conventional annular

magnetic pole piece is positioned immediately in front of the collector electrode and a second pole piece in the form of a rod extends axially through the center of the collector in such a manner as to form a reentrant nib that falls within the hollow portion of the beam. The collector is a concave member having a diameter considerably larger than that of the hollow beam and is electrically biased at a potential considerably below that of the body portion and interaction structure of the tube. A low reluctance magnetic circuit encloses the collector and is electrically insulated therefrom to provide a low reluctance magnetic path between the two pole pieces. With this arrangement of the two pole pieces, the central portion of the magnetic field will terminate on the second pole piece at the center of the collector so that the electrons in the inner portion of the hollow beam and the most energetic electrons elsewhere in the beam may proceed along or about the magnetic flux lines that extend into the central region of the collector and thereby be collected at the lower potential collector. The end of the collector that faces toward the first pole piece has a centrally apertured cap which is positioned closely adjacent to the back surface of the first pole piece so that not only does the cap of the collector form a Faraday cage type of arrangement for the collector, but it also partially shields the back of the first pole piece and collects primary and secondary electrons that might otherwise collect on the back surface of the pole piece.

The invention will be described by referring to the accompanying drawings wherein:

FIG. 1 is a longitudinal cross sectional view of the collector region of an electron tube, such as a traveling wave tube, which is constructed in accordance with the teachings of this invention; and

FIG. 2 is an illustration of an alternative embodiment of the invention in which the collector is a multi-stage collector having portions thereof that are at different depressed potentials.

Referring now in detail to FIG. 1, and assuming for example, that the tube in which this collector is used is an otherwise conventional traveling wave tube, the tubular member **10** of a conductive nonmagnetic material is at the end region of the body portion of the tube immediately following the output coupler (not illustrated) from which the amplified waves are extracted. The vacuum envelope **11** of a nonmagnetic material and the solenoid **12** surround the body portion **10**, and when the solenoid is energized it establishes within the tube a longitudinally directed magnetic focussing field B whose flux lines are illustrated in the drawings by the dashed lines. Annular magnetic pole piece **13**, which is made of a material such as cold rolled steel, is positioned at the end of the body portion of the tube and provides a low reluctance magnetic path for terminating the outermost magnetic flux lines. The hollow electron beam **16** is relatively well focussed as it enters the end region of the tube, having been confined throughout its traversal of the tube by the axially extending magnetic field B. Cylinder **18** of a low reluctance magnetic material is secured to pole piece **13** and to end plate **19**, also of a low reluctance magnetic material, in a vacuum tight manner to form an enclosure about the collector electrode **20**. An annular dielectric member **23** supports collector electrode **20** in spaced-apart relationship with respect to cylinder **18**. Collector electrode **20** is made of a nonmagnetic conductive material such as copper and is centrally apertured to receive the rod **26** of a low reluctance magnetic material which serves as a second pole piece for terminating the magnetic flux lines in the central region of the magnetic field B. A disc **27** of magnetic material is secured at the right end of the central rod **26** to improve the coupling of the magnetic flux lines from center rod **26** to the end plate

19. The left end of collector electrode 20 is provided with a centrally apertured cap portion 30 which is inclined inwardly and positioned in close proximity to and electrically isolated from the back surface 31 of annular pole piece 13. The cap portion 30 of collector electrode 20 thus establishes a Faraday cage type of configuration for collector electrode 20 and also serves as a shield for the back surface 31 of pole piece 13 by collecting at least some of the primary and secondary electrons that otherwise might be collected on pole piece 13. The central region of collector electrode 20 has a cone-shaped nib 33 that extends about the central magnetic rod 26. It may be seen that collector electrode 20 is electrically isolated from the remainder of the tube by the dielectric support ring 23 and collector electrode 20 is maintained at a depressed potential with respect to the body portion of the tube and with respect to annular pole piece 13 by means of a biasing voltage that is applied by a conductor 35 attached to the back surface of the collector.

As the hollow electron beam 16 enters the collector region, the lower velocity electrons that are located about the exterior of the beam will be forced outwardly by the curving magnetic field flux lines that terminate on annular pole piece 13 and will be collected by this pole piece which is at a relatively high potential with respect to collector 20. However, the electrons in the interior region of the hollow beam and the higher energy electrons elsewhere in the beam will tend to follow along or about the magnetic flux lines that they had pursued throughout their traversal of the tube and will continue through the aperture in the cap portion 30 of the collector electrode 20. Because the collector 20 and the center magnetic rod 26, which is at the same potential as the collector 20, are at a lower potential than the body portion 10 and annular magnetic pole 13, an electrostatic field gradient will exist between the collector and the pole piece 13 and body portion 10. This electrostatic field gradient will tend to draw the electrons radially outwardly from their tubular configuration so that they will enter the recessed portion of collector 20 and be collected therein. It will be noted that the left end of the magnetic rod 26 is positioned to the right of a plane passing through the right edge of pole piece 13. This arrangement is provided to further assure that the nib 33 and magnetic rod 26, which are at the depressed potential, will permit the electrons to enter the recessed portion of collector 20 and will not divert them onto annular magnetic pole piece 13, thereby preventing the formation of the troublesome "hot spots" that were referred to above. It will be noticed that magnetic field flux lines do not terminate in the region of the collector 20 where the electrons are actually collected. This is quite desirable in a depressed potential collector because it avoids "back focussing" of secondary electrons back to the interaction structure of the tube.

In the design of the collector structure illustrated in FIG. 1, the axial position of the center magnetic rod 26 relative to annular magnetic member is important because their relative positions have an effect on both the electrostatic and magnetic fields in the collector region. Since a position of magnetic rod 26 that would satisfy the requirements of one field may not satisfy the other, it may be desirable to provide some additional control on the magnetic field distribution in the collector region. For example, a magnetizing winding may be placed about the right end of the central magnetic rod 26 in order to provide means for controlling the amount of the magnetic field B that terminates on the center magnetic rod 26. Alternatively, a permanent magnet could be placed at the right end of magnetic rod 26.

It will be apparent from the above description that because at least some of the lower energy electrons will have been collected on the annular pole piece 13, the beam density will have been reduced within the hollow beam 16 as the beam enters the collector, thereby reducing the possibility that a virtual cathode will form in front of, or within the collector, and thereby increasing the probability that the remaining beam electrons will be collected in the depressed potential collector.

In some instances it has been found that greater flexibility of design and greater control of the beam may be achieved by collecting it in several stages. Such a multistage collector is illustrated in FIG. 2 wherein the collector structure is comprised of two separate stages that have different depressed potentials with respect to the interaction structure and the body portion of the tube. The end of the body portion of the tube is illustrated as the tubular member 40 about which is disposed the solenoid 41 which produces the longitudinally directed magnetic focussing field B whose flux lines are represented by the broken lines along the central portion of the tube. An annular magnetic pole piece 45 is positioned at the end of the body portion of the tube and at the entrance to the collector region. The collector is comprised of inner and outer electrically isolated portions that are made of a conductive nonmagnetic material such as copper. The inner portion 47 is comprised of the tapered inner member 48 which is disposed about the central axis of the tube, and the outer portion 49 is comprised of the back annular member 50 and the centrally apertured cap portion 51 which extends in close proximity to the back surface 52 of pole piece 45. It will be seen that the inner portion 47 and the outer portion 49 of the collector have the respective reentrant portions 53 and 54 which serve to help trap the electrons and prevent their reentry back to the interaction portion of the tube. The tapered inner member 48 of the collector is maintained at a first depressed potential by means of the lead 55, and the outer portion 49 of the collector is maintained at a second and less depressed potential by means of the lead 56. The ring 58 of a dielectric material supports the inner portion of the collector and maintains it in electrical isolation from the remainder of the collector. The short conductive tubular member 60 is secured to the back annular member 50 of the outer portion of the collector and also is secured to the outer dielectric support ring 61. Tubular member 60 provides conductive continuity between lead 56 and the back annular member 50. Dielectric ring 61 is secured to the shell 64 of a magnetic material, and the magnetic end plate 65 is secured to shell 64 and encloses the collector region of the tube. A rod 68 of magnetic material is disposed axially within the tapered inner member 48 and serves as the second pole piece in the same manner as the rod 26 described in connection with FIG. 1. The end disc 69 of magnetic material is secured to the second pole piece 68 and aids in establishing the low reluctance magnetic circuit between the two pole pieces.

Illustrated in this embodiment of the invention is an auxiliary magnetizing coil 75 that is employed to control the distribution of the magnetic field in the collector region. By varying the current through the separately excited coil 75 the amount of flux B that terminates on the inner magnetic rod 68 can be controlled. As mentioned previously, a permanent magnet could be used as an alternative.

In the operation of this multi-stage collector of FIG. 2, the least energetic electrons of the hollow beam 70 will spiral outwardly as they encounter the outwardly curving flux lines and at least a portion of them will collect on annular pole piece 45 and body member 40. Some electrons with slightly more energy will be collected on the end region of the cap portion 51 of the outer collector 49. The remainder of the electrons will follow along or about the magnetic flux lines that terminate on the second pole piece 68 and will enter the collector region of the tube and will undergo a velocity sorting experience in which the most energetic electrons will be collected on the tapered inner member 48 and the remaining group of less energetic electrons will be deflected outwardly from the hollow beam 70 as a result

of the electrostatic field between the first pole piece 45 and the depressed potential on the inner and outer portions of the collector, and these electrons will be collected on the outer portion of the collector 49.

Although the collectors of this invention are intended to collect a hollow electron beam, it should be understood that their use is not restricted to a hollow beam but they also may be utilized to collect a solid electron beam. Furthermore, although the collector structures illustrated in FIGS. 1 and 2 have been described as operating at depressed potentials, they also may be used at potentials that are the same as the potential of the body portion of the tube.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

What is claimed is:

1. In a device employing a stream of charged particles that is magnetically focussed by a longitudinally extending magnetic field, means for collecting said stream comprising the combination,

an annular magnetic pole piece positioned to encircle said stream and to terminate a portion of said magnetic field,

a conductive collector electrode of nonmagnetic material positioned along said stream beyond said pole piece,

a member of magnetic material disposed within said collector electrode for terminating the remainder of said magnetic field.

2. In a device employing a hollow stream of charged particles that extends along an axis and is magnetically focussed by an axially extending magnetic field, means for collecting said hollow stream comprising the combination,

an annular magnetic pole piece disposed about said hollow stream to terminate a portion of the flux lines of said magnetic field,

a conductive collector electrode of non-magnetic material positioned along said axis beyond said pole piece,

a member of magnetic material disposed within said collector electrode in a region within the hollow portion of said stream of charged particles for terminating the remainder of the flux lines of the magnetic field.

3. In a device employing a hollow stream of charged particles that extends along an axis and is magnetically focused by an axially extending magnetic field, means for collecting said hollow stream comprising the combination,

an annular magnetic pole piece disposed about said hollow stream to intercept a portion of the flux lines of said magnetic field,

a conductive collector electrode of non-magnetic material positioned along said axis beyond said pole piece, said collector electrode having a front apertured portion that extends in close proximity to said pole piece and having a back portion extending transversely to the direction of said stream,

a rod of magnetic material positioned within the back portion of the collector electrode and extending in the direction of said pole piece for terminating the remainder of the flux lines of said magnetic field, said rod being positioned to lie within the hollow portion of said stream of charged particles.

4. In a device employing a hollow stream of charged particles that extends along an axis and is magnetically focused by an axially extending magnetic field, means for collecting said stream comprising the combination,

an annular magnetic pole piece disposed about said hollow stream to intercept a portion of the flux lines of said magnetic field,

a conductive collector electrode of non-magnetic material positioned along said axis beyond said pole piece, said collector electrode having a front apertured portion that extends inwardly toward said stream and in close proximity to said pole piece and having a back portion extending transversely to the direction of said stream,

a rod of magnetic material positioned axially within the back portion of the collector electrode and extending axially in the direction of said pole piece for terminating the remainder of the flux lines of said magnetic field.

5. The combination claimed in claim 4 and further including means for electrically biasing said collector electrode at a potential that is different from the potential of said pole piece.

6. The combination claimed in claim 4 and further including means for providing a low reluctance magnetic path between said pole piece and said rod.

7. In a device employing a hollow stream of charged particles that extends along an axis and is magnetically focused by an axially extending magnetic field, means for collecting said stream comprising the combination,

a centrally apertured magnetic pole piece disposed symmetrically about said stream in a manner to terminate a portion of the flux lines of said magnetic field,

a conductive collector electrode of non-magnetic material positioned along said axis beyond said pole piece, said collector electrode being concave in a direction away from said pole piece and having a diameter greater than that of the central aperture of said pole piece, said collector being comprised of a front apertured portion that is inclined inwardly toward said stream and in close proximity to an adjacent side of said pole piece, and being further comprised of a back portion that is disposed transversely to said axis,

an axially-protruding central portion of said collector coaxially disposed about said axis and extending in the direction toward said pole piece,

a rod of magnetic material extending axially through the central portion of said collector electrode for terminating the remainder of the flux lines of the magnetic field,

means for providing a low reluctance path between said rod and said pole piece, and

means for electrically isolating the collector electrode from the pole piece.

8. The combination claimed in claim 7 wherein the axially-protruding central portion of said collector is electrically isolated from the remainder of said collector electrode and is adapted to be electrically biased at a depressed potenital that is different from the potential of the remainder of the collector.

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JAMES W. LAWRENCE, *Primary Examiner.*