Sept. 13, 1966 I. ITZKAN 3,273,081

FLUID-COOLED SLOW-WAVE STRUCTURE HAVING ALTERNATING LONGITUDINAL AND TRANSVERSE EXTENDING PORTIONS

Filed May 31, 1962 2 Sheets-Sheet 1

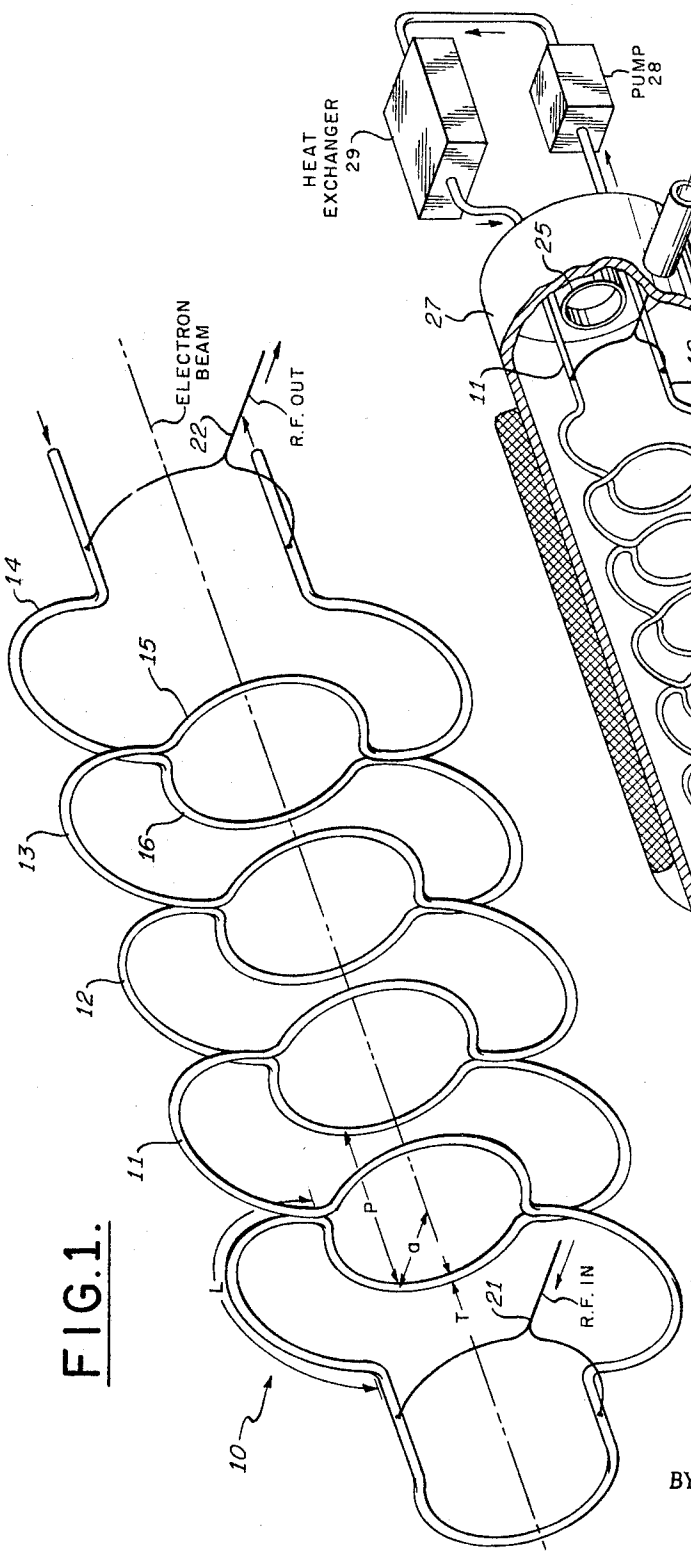


FIG. 1.

FIG. 2.

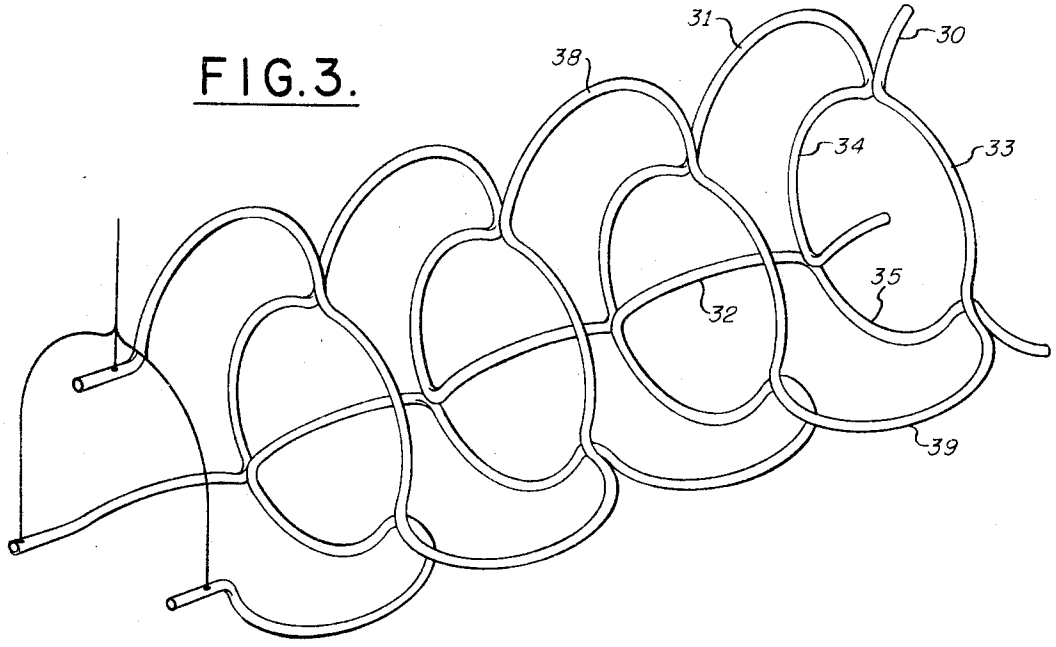
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FIG.3.



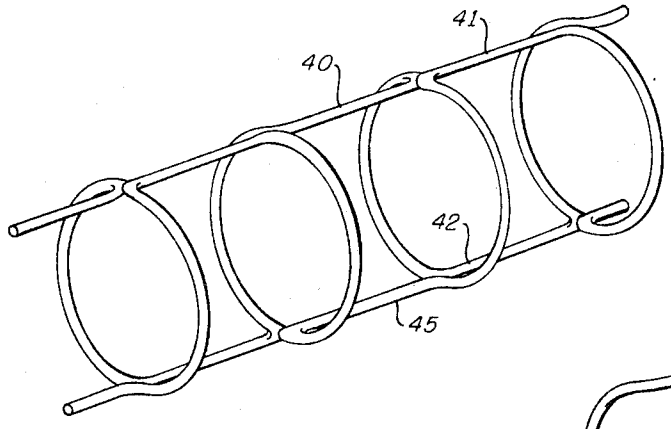


FIG.4.

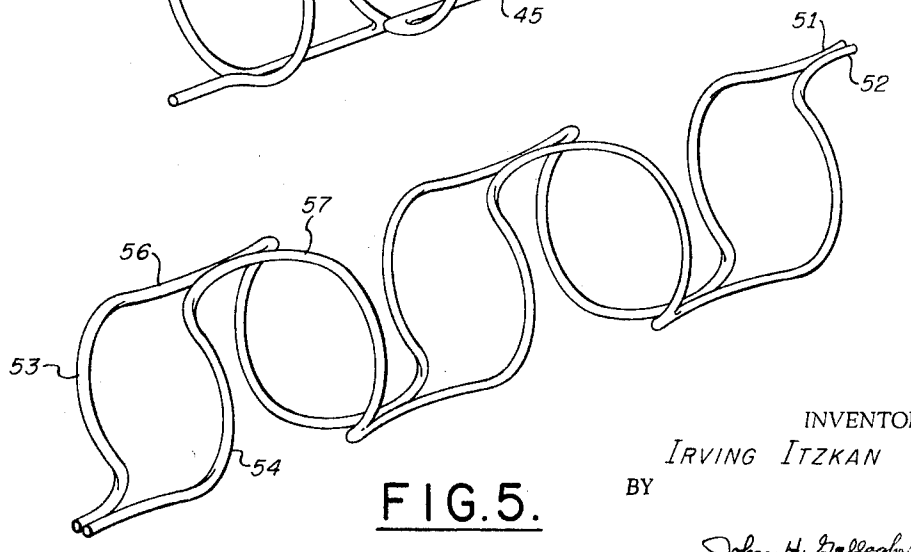


FIG.5.

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United States Patent Office 3,273,081 Patented Sept. 13, 1966

3,273,081

FLUID-COOLED SLOW-WAVE STRUCTURE HAVING ALTERNATING LONGITUDINAL AND TRANSVERSE EXTENDING PORTIONS

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Filed May 31, 1962, Ser. No. 198,997
5 Claims. (Cl. 333—31)

This invention relates to fluid-cooled high-power electron beam-electromagnetic wave interaction structures for use in traveling wave tube types of electron discharge devices.

It has been found that in the higher power traveling wave tubes presently being developed, the well known slow wave interaction structures commonly used in lower-power tubes, such as helices and related structures, are not entirely satisfactory. Considerable effort has been expended to develop slow wave interaction structures that exhibit the desired electrical characteristics in the high-power tubes. A number of structures have been developed, but most of these have limited applications and many of them suffer the disadvantages that they are relatively complicated to construct and are difficult to cool. The cooling problem is a primary consideration in the higher-power tubes because both the primary electrons in the electron beam and the secondary electrons produced at the collector electrode and at the interaction structure itself have considerable energy and generate a considerable amount of heat when they strike the interaction structure. Additionally, the high electric field strengths of the waves propagating in the tube also significantly contribute to the heating of the structure.

Generally, slow wave interaction structures can be divided electrically into two classes, open structures and closed structures. Open structures guide the electromagnetic waves down both the outside and inside of the structure. Helices, and ring-and-bar circuits are examples of open structures. Because the outside of the circuit in the open structure is essential to the interaction process, it must be spaced from the surrounding envelope and the other exterior metallic portions of the tube. The physical spacing and rigidity of the open-type structures are usually provided by dielectric materials which are poor heat conductors. Therefore, cooling problems are of a primary consideration in high-power tubes using open type interaction structures. Closed structures, on the other hand, guide the electromagnetic waves down the axis of an enclosed cylindrical interaction structure. The mass of metal in this type of structure provides both a good heat-conducting path and good mechanical rigidity. This reduces the severity of the cooling problems, but the frequency bandwidth and interaction impedance characteristics of these types of structures are less favorable than those of the open structures. Therefore, the open type of slow wave interaction structures are preferred over the closed structures in view of their superior electrical characteristics, provided that satisfactory means can be found for cooling the open type of structures. The present invention is particularly directed to providing open types of interaction structures that possess good electrical characteristics and may be readily cooled without adversely affecting the electrical characteristics.

It therefore is an object of this invention to provide a fluid-cooled interaction structure for use in high-power electron discharge devices.

A further object of this invention is to provide a fluid-cooled slow wave propagating structure that is easily fabricated by relatively unskilled labor.

Another object of this invention is to provide high-power slow wave propagating structures of the type classified as open structures.

It is another object of this invention to provide fluid-cooled high-power electron beam-electromagnetic wave interaction structures having relatively broad bandwidths, and high interaction impedances.

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

FIG. 1 is a schematic illustration of a fluid-cooled ring-loaded meander line type of slow wave interaction structure constructed in accordance with the present invention;

FIG. 2 is a simplified illustration of a traveling wave tube amplifier incorporating a slow wave interaction structure constructed in accordance with the present invention, and

FIGS. 3–5 illustrate other types of fluid-cooled slow wave interaction structures constructed in accordance with the present invention.

The slow wave interaction structures constructed in accordance with the present invention are of the type which have been called ring-line circuits, specific examples being the ring-loaded meander line structure described by I. Itzkan and P. J. Crepeau on page 525, Proceedings of the I.R.E., February 1961, and the ring and bar circuit described in U.S. Patent 2,836,758.

Referring now in particular to FIG. 1, the interaction structure **10** illustrated therein is of the ring-loaded meander line type and is comprised of two fluid conduits **11** and **12** of a conductive material, each conduit having sinuous bends of uniform periodicity throughout its length. The axial extending portions **13** and **14** of the two conduits lie substantially in a longitudinally extending plane which passes through the electron beam. The transversely extending portions **15** and **16** of the two conduits **11** and **12** project outwardly and are shaped to conform to the circumference of a circle. The transversely extending portions **15** and **16** of the conductive conduits are aligned in parallel transverse planes throughout the length of the structure and form circular cross-sectional configurations in the respective planes. The axially extending portions **13** and **14** of the sinuously bent conduits form conductive connectors which join the successive circular configurations at diametrically opposite points thereon. In assemblying the structure of FIG. 1, the two similar conduits **11** and **12** are merely rotated 180° with respect to each other and are secured together at the necessary regions. Another way of considering the resultant configuration of the structure of FIG. 1 is to consider that the two conduits **11** and **12** are placed adjacent each other with their outwardly projecting portions **15** and **16** aligned in parallel transverse planes, and with the two conduits having a one-half period axial displacement.

As may be seen, the outwardly projecting portions **15** and **16** simulate rings and the axially extending portions **13** and **14** simulate meander lines extending throughout the length of the structure. It has been found that the closer the sinuously bent conduits approximate true parallel-aligned rings and meander lines, the better the electrical performance of the structure.

Fluid conduits **11** and **12** desirably are made of copper or are of copper coated steel tubing. The two conduits **11** and **12** may be either spot-welded or brazed together at the regions where the axially extending portions **13** and **14** and the outwardly projecting portions **15** and **16** come together.

Another possibility of joining together the two conduits **11** and **12** is to place them adjacent each other, but with a small transverse separation therebetween. Short transverse conductive bars then may be secured to the two

conduits to secure them together and to rigidify the structure.

As may be seen at the left end of the structure illustrated in FIG. 1, the conductive conduits **11** and **12** are joined together to make a continuous fluid path at that end of the structure. At the right end of the structure, each of the conduits **11** and **12** extends axially and passes through the envelope of the tube so that they may be connected to lines of a fluid system that supplies fluid coolant to the interaction structure **10** so as to maintain its temperature below a maximum temperature limit.

Electrical connectors **21** and **22** are respectively connected to the left and right ends of interaction structure **10** and provide means for coupling electromagnetic waves into and out of the structure.

A simplified schematic illustration of a traveling wave tube incorporating the slow wave structure **10** of FIG. 1 is illustrated in FIG. 2 and is comprised of an electron gun assembly **24**, which may be of any conventional design, and a collector electrode **25**, which similarly may be of any conventional design. Slow wave interaction structure **10** is disposed coaxially about the electron beam that is established between electron gun **24** and collector **25**. A magnetizing coil **26** may be disposed about the envelope **27** in the conventional manner. As may be seen, fluid conduits **11** and **12** are joined to the external fluid system that includes the pump **28** and heat exchanger **29**.

As shown in FIG. 1, the periodicity of the interaction structure is uniform throughout its length. However, the periodicity may be varied, if desired, in accordance with known practices to achieve desired electrical characteristics in the structure.

In the matter of physically supporting the open type structure illustrated in FIG. 1, for the lower frequency structures wherein the diameters of the fluid conduits **11** and **12** are relatively large, the structure is self-supporting. In higher frequency tubes in which the conduits **11** and **12** are of considerably smaller size, they may be supported by longitudinally extending dielectric rods as is standard practice in the art.

The important dimensions of the interaction circuit illustrated in FIG. 1 include the axial spacing p between the circular cross-sectional configurations formed by transversely extending portions **15** and **16**, the length L of the meandering sections formed by axially extending portions **13** and **14**, the thickness t of the conduit, and the radius a of the cross sectional configuration formed by outwardly projecting portions **15** and **16**, In evaluating the performance of the type of interaction structure illustrated in FIG. 1, it is found that as the period p of the structure is decreased the phase velocity of the waves propagating thereon is decreased because the loading effect of the ring-like portions of the circuit is increased. At the same time, both the frequency bandwidth and interaction impedance are decreased. As the lengths L of the axially extending meandering portions **13** and **14** are increased the phase velocity is decreased and the interaction impedance and bandwidth are increased. Increasing the thickness t of the conduits **11** and **12** decreases the phase velocity and increases the bandwidth without appreciably affecting the interaction impedance. From this it may be seen that it is desirable to use conduits of as small an outer diameter as possible.

Interaction structures having three or more meander lines disposed about the circumference of the circular cross-sectional portions of the structure also may be constructed in accordance with the present invention. For example, the structure illustrated in FIG. 3 has three meandering lines symmetrically disposed about the ring-like portions of the structure. This structure is comprised of three identically shaped conduits **30**, **31** and **32**, each of which is sinuously bent throughout its length, and is further bent so that each of the transversely extending portions **33**, **34** and **35** form an arcuate section of substantially 120°, so that when joined together they form circular configurations in parallel transverse planes throughout the length of the structure. The axially extending portions which form the meandering lines, portions **38** and **39** of conduit **30**, for example, lie in longitudinal extending planes that are disposed at 120° with respect to each other. It may be seen that the three identically shaped conduits **30**, **31** and **32** are angularly disposed at 120° with respect to each other and have their corresponding transversely extending sections joined together to form the fluid-cooled ring-loaded meander line of FIG. 3. Structures having a greater number of meander lines may be constructed by utilizing a number n of identically shaped conduits, wherein n is equal to the number of desired meander lines, and by forming each of the transversely extending outwardly projecting sections to conform to an arc of a circle having an angular extent substantially equal to $360°/n$, and by joining together the plurality of bent conduits which are disposed at an angle of $360°/n$ with respect to each other.

A ring-loaded two wire transmission line type of interaction structure also may be formed in accordance with the principles of this invention. This type of structure is illustrated in FIG. 4 and is comprised of two sinuously bent conduits **41** and **42** that are similar in shape to the sinuously bent conduits **11** and **12** of FIG. 1, with the exception that the axially extending portions **44** and **45** extend substantially parallel to the central axis of the structure rather than being of an arcuate shape as the axially extending portions **13** and **14** are in the structure of FIG. 1.

An interaction structure simulating the ring-and-bar interaction structure also may be readily fabricated in accordance with this invention, as illustrated in FIG. 5. In this structure the two conductive conduits **51** and **52** have outwardly projecting transversely extending portions **53** and **54** that are each shaped in a semicircular bend to form substantially circular cross-sectional configurations in uniformly spaced transverse planes throughout the length of the structure. The axially extending portions **56** and **57** of the two conduits are secured together to form the axially extending bar members that join successive pairs of ring-like configurations at diametrically opposite regions.

All of the structures illustrated in the drawings are readily constructed with the use of relatively simple twisting forms and bending jigs or dies, and may be constructed by relatively unskilled labor from commercially available hollow tubes. Thus, by utilizing the relatively simple procedures and readily available materials, slow wave propagating structures of the open type having the most desirable electrical characteristics may be readily fabricated in a form which permits fluid cooling without requiring appreciable design and construction effort in the remaining portions 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 of 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. A fluid-cooled slow wave propagating structure comprised of

a plurality n of tubular conduits of conductive material symmetrically disposed about an axis and each lying substantially entirely within a respective angular sector that extends parallel to said axis, n being an integer,

each of said conduits being comprised of alternately disposed longitudinally-extending and transversely-extending portions that are arranged to form a serpentine-like configuration throughout the length of its respective angular sector,

each transversely-extending portion traversing a given angular extent about said axis and the longitudinally-extending portions at the two ends of a transverse portion lying in respective axially-extending planes that intersect along said axis at an oblique angle,

the n conduits being disposed about said axis with the transverse portions located in successive transverse planes in a manner to form successive closed configurations about said axis.

2. A fluid-cooled slow wave propagating structure comprised of,

a plurality n of tubular conduits of conductive material symmetrically disposed about an axis and each lying substantially entirely within a respective angular sector that extends parallel to said axis, n being an integer,

each of said conduits being comprised of alternately disposed longitudinally-extending and transversely-extending portions,

each transversely-extending portion conforming to a $360°/n$ arc of a circle and the longitudinally-extending portions at the two ends of a transverse portion lying in respectively longitudinally-extending planes that intersect along said axis at an angle of $360°/n$,

the n conduits being disposed about said axis with corresponding transverse portions arranged in successive transverse planes in a manner to form circular configurations.

3. The combination claimed in claim **2** wherein the longitudinally-extending portions of the n conductors are angularly disposed at $360°/n$ with respect to each other between each adjacent pair of said circular configurations.

4. A fluid-cooled slow wave propagating structure comprising,

a plurality of n fluid conduits of electromagnetic wave propagating material disposed about an axis and each extending longitudinally in a respective one of n coextensive angular sectors that extend parallel to said axis, n being an integer,

each conduit being comprised of arcuate portions that extend longitudinally and transversely-extending portions that are disposed intermediate said arcuate portions,

the transverse portions conforming to a $360°/n$ arc of a circle and the longitudinally-extending arcuate portions at the two ends of each transverse portion lying in respective axially extending planes that intersect along said axis at an angle of $360°/n$,

the transverse portions of the conduits being positioned to form circular configurations in successive transverse planes along said axis and the arcuate portions extending between adjacent circular configurations being angularly disposed at $360°/n$ relative to each other, and

means for passing a fluid coolant through said conduits.

5. A fluid-cooled slow wave propagating structure comprising,

first and second fluid and electrical conductors extending parallel to an axis and each lying substantially entirely on a respective side of a longitudinal plane through said axis,

each conductor being comprised of a succession of arcuate sections that extend alternately longitudinally and transversely,

the transversely extending sections of the two conductors being aligned in successive transverse planes and each being arched approximately 180° about said axis to form a circular configuration in each transverse plane,

the longitudinally-extending sections of the two conductors arching outwardly relative to the axis and the conductors being positioned relative to each other so that respective longitudinally-extending sections of the two conductors extend between adjacent circular configurations at diametrically opposite regions.

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