Jan. 31, 1961 A. H. IVERSEN 2,970,240

LIQUID-COOLED TRAVELING WAVE TUBE

Filed Oct. 1, 1958 2 Sheets-Sheet 1

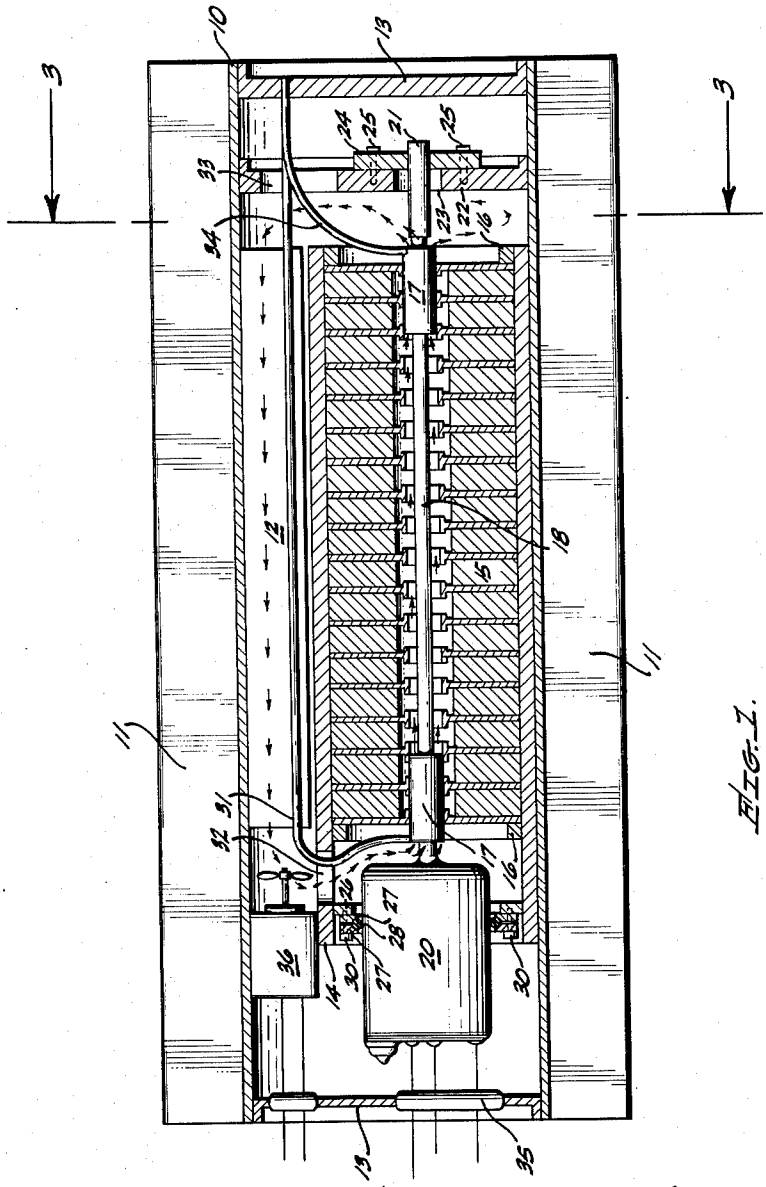


FIG. 1.

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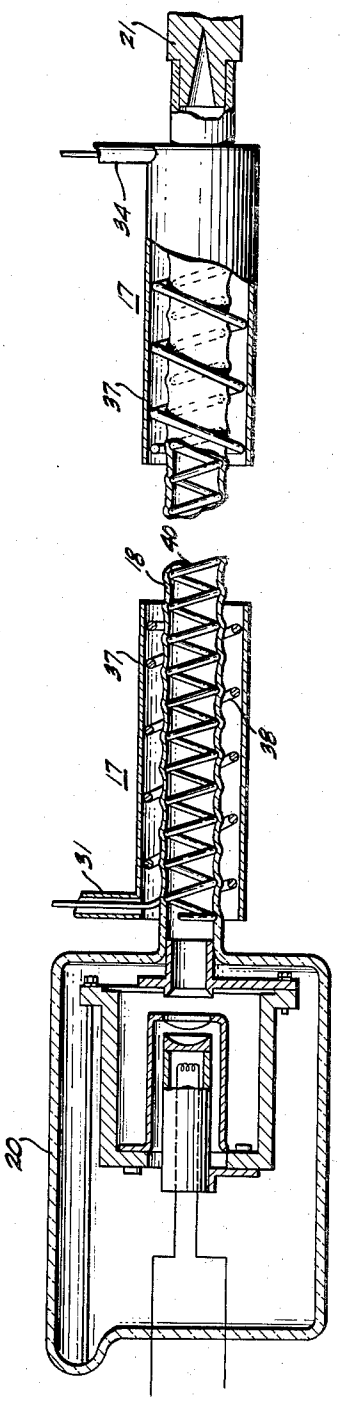


FIG. 2.

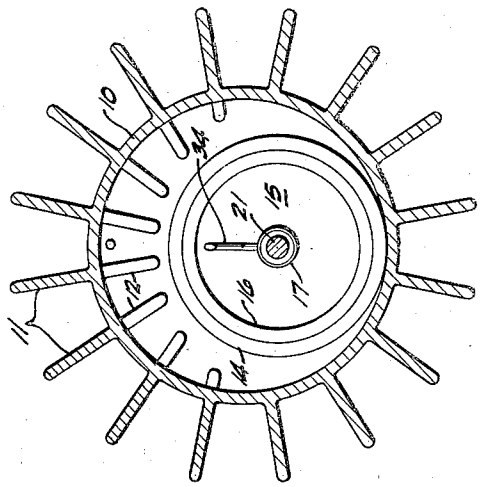


FIG. 3.

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LIQUID-COOLED TRAVELING WAVE TUBE

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4 Claims. (Cl. 315—3.5)

The present invention relates to a traveling wave tube, and more particularly, to an arrangement for cooling helix-type traveling wave tubes.

It is well-known that the power-dissipation capabilities of a traveling wave tube helix structure severely limit the output power from a helix-type traveling wave tube. For example, portions of an S-band helix have been brought to red heat by 12 watts of power dissipation. For this reason, most helix-type traveling wave tubes are limited to about 10 watts average output power. Further, overheating of the helix materially shortens tube life due to the development of a gassy condition and causes a slump in power output as the tube warms up due to losses in the helix causing heating which increases the resistance of the helix resulting in increased losses and increased heating.

All-metal traveling wave tubes, such as those having a folded-waveguide type of slow-wave structure, are capable of high power output without overheating. However, such tubes are heavy, long and bulky. In addition, non-helical tubes can only be operated over a narrow band of frequencies, cannot be easily periodically focused by permanent magnet focusing structures and are inefficient when operating below 1,000 watts peak power output.

Thus, it may be seen that a small, light, broad-band, periodically focused traveling wave tube for providing a power output in the range from 10 to 1,000 watts should be of a type having a cooled helical structure. Attempts have been made to cool the helix by passing a coolant around the vitreous envelope surrounding it. However, this method is inefficient because the helix is in a vacuum and only a small amount of heat is effectively transmitted to the envelope by radiation.

One prior art device is provided with a helically wound hollow conductor through which a coolant is circulated. Such a tube is limited to use at lower frequencies due to the physical size of hollow conductor which must be employed. Further, such a helix is difficult to wind and is subject to operating anomalies due to surging of the coolant.

Another prior art tube utilizes a helix supported by several sections of small-diameter, non-conductive tubing through which a coolant is circulated. Such an arrangement has some disadvantages in that periodic focusing cannot be used because the support tubing prevents the focusing magnet structure being in close proximity to the electron beam.

Yet another prior art traveling wave tube is provided with a combined helix and envelope in which the helical conductor has a vitreous material hermetically sealed between the turns thereof to provide a vacuum-tight helix serving as an envelope. A coolant is passed over the outside of the combined helix and envelope and is in direct contact with the outside surface of the helical conductor. A disadvantage of this arrangement is that any expansion of the helical conductor due to heat causes fracturing of the vitreous material between the turns, thereby breaking the vacuum-tight seal of the envelope. Another disadvantage is that the presence of the vitreous material between the turns of the helix leads to high dielectric losses.

Accordingly, it is an object of the present invention to provide traveling wave apparatus which is small, light, and operates efficiently in the range from 10 to 1,000 watts average power output over a broad frequency band.

Another object of the invention is the provision of apparatus for efficiently cooling a helical slow-wave structure without inducing high dielectric losses and while permitting the use of a permanent magnet periodic focusing structure.

A further object of the present invention is to provide apparatus for efficiently cooling all of the heat-dissipating components of a traveling wave tube while also increasing the resistance of the tube to internal voltage breakdown.

In accordance with the invention there is provided a hermetically sealed outer metallic envelope having internal and external cooling fins. A permanent magnet periodic focusing structure is located inside the outer envelope and eccentric therewith. Inside each end of the focusing structure are microwave energy coupling helices. A vitreous slow wave envelope extends concentrically through the focusing structure and the coupling helices and is spaced apart therefrom to define a passage for a liquid coolant along the vitreous envelope. The vitreous envelope is shrunken about a helical slow wave structure but not bonded thereto to provide a slidable, heat-conductive contact therebetween. A liquid coolant having favorable electrical properties is circulated along the vitreous envelope to the outer metallic envelope by means of a pump. An electron collector is disposed at one end of the vitreous envelope and is provided with a metallic heat-conductive path to the outer metallic envelope. Thus heat is removed from the slow wave structure by conduction through the wall of the vitreous envelope where it is absorbed by the coolant and transported to the internal fins of the outer metallic envelope and radiated from the external fins thereof to the atmosphere.

For a better understanding of the invention together with other and further objects thereof reference is made to the following description taken in connection with the accompanying drawings in which an embodiment of the invention is illustrated by way of example only, like reference characters designating like parts throughout the figures thereof, and wherein:

Fig. 1 is a side view, partly in section, of an embodiment of a traveling wave tube in accordance with the invention;

Fig. 2 is an enlarged view of a portion of the traveling wave tube shown in Fig. 1; and

Fig. 3 is a sectional view taken across the line 3—3 of Fig. 1.

Referring now to Figs. 1 and 3 of the drawings, there is provided an outer metallic case or envelope 10 for enclosing the traveling wave tube and radiating the heat developed thereby. The outer envelop 10 is made of a light, strong, heat-conductive metal such as aluminum formed into a cylindrical shape and provided with external cooling fins 1. These fins 11 may be integral with the outer envelope 10, extending radially outward therefrom along the length thereof, and regularly spaced therearound. Internal fins 12 are also provided to receive the heat developed in the traveling wave tube and conduct it to the outer envelope 10. The internal fins 12 may be integral with the outer envelope 10, extending radially inward therefrom along the length thereof, and regularly spaced around a portion of the inner wall thereof. The internal fins 12 extend less than the full length of the outer envelope 10 in order to allow sufficient space at each end of the envelope 10 for elements yet to be described. In addition, the internal fins 12 only extend

approximately half way around the internal surface of the envelope 10 and are progressively shortened in radial length from the middle one of the fins 12 to the outermost ones thereof to define a cylindrical space eccentrically disposed with respect to the envelope 10 to receive the traveling wave tube and provide, within an overall minimum diameter, space for a circulation pump as described below. The cylindrical outer envelope 10 is closed at both ends by means of circular closure members 13 which may be fastened in place by any convenient means, such as brazing.

A cylindrical inner case or support member 14 is provided for supporting and enclosing the traveling wave tube and is eccentrically located within the outer envelope 10 in the cylindrical space defined by the internal fins 12. A cylindrical permanent magnet focusing structure 15 for periodically focusing an electron beam is secured within the support member 14 by means of rings 16 which are fixed thereto by any convenient method, such as brazing. Microwave members 17 are located in each end of the focusing structure 15 for coupling microwave energy into and out of the traveling wave tube.

Extending through the coupling members 17 and the focusing structure 15 is an elongated, hermetically sealed inner envelope 18 which is made of a vitreous material, such as glass. An electron gun structure 20 is provided at one end of the inner vitreous envelope 18 to develop an electron beam and an electron collector 21 is provided at the other end thereof to receive the electron beam. A circular plate 22 which is made of a metallic, heat-conductive material is provided at the collector end of the inner vitreous envelope 18 to provide support therefor and to conduct heat away from the collector 21. A hole 23 is provided in the circular plate 22 through which the collector 21 extends. The hole 23 is of a greater diameter than the diameter of the collector 21 in order to provide for centering of the envelope 18 within the focusing structure 15 and the coupling members 17. A collector centering ring 24 surrounds the end of the collector 21 and is fixed thereto. The centering ring 24 is secured to the circular plate 22 by means of screws 25 through oversized holes provided in the centering ring 24.

The electron gun structure 20 is secured to a support ring 26 which is fixed to the support member 14, as by brazing. The electron gun 20 is clamped to the support ring 26 by means of clamping rings 27 which compress an O-ring 28 against the gun structure 20. This is accomplished by means of screws 30 which pass through oversized holes provided in the clamping rings 27 into threaded holes in the support ring 26. The clamping rings 27 are provided with chamfered edges and are disposed with their chamfered edges adjacent to form a V-groove for the O-ring 28. Thus, as the screws 30 are tightened, the clamping rings 27 are forced together, which narrows the V-groove and thereby compresses the O-ring 28.

The oversize holes for screws 30 and 25 permit the envelope 18 to be centered inside the focusing structure 15 and the coupling members 17. After the envelope 18 has been centered, the envelope securing members may be spot welded or brazed in place. The coupling member 17 located at the gun end of the traveling wave tube is connected to a coaxial cable 31 which extends through a hole 32 provided in the wall of the cylindrical support member 14, passes between the internal fins 12, through a hole 33 provided in the circular plate 22 to a hermetically sealed connector in the outer closure member 13. The coupling member 17 at the collector end of the tube is connected to a coaxial cable 34 which also passes through the hole 33 in the circular plate 22 to a hermetically sealed connector in the outer closure member 13. Electrical connections to the electron gun structure 20 are brought out through the outer closure member 13 by means of a hermetically sealed glass connecting structure 35.

A small pump 36 is provided and disposed in the eccentric space between the outer envelope 10 and the member 14 for circulating a liquid coolant within the outer envelope 10 which is completely filled with a liquid coolant and hermetically sealed thereafter. Thus an enclosed, self-contained system including its own cooling means is provided. An expansion chamber for the coolant may be provided in the outer envelope 10, if desired.

The coolant must have good electrical properties in order to be used in conjunction with a traveling wave tube. Specifically, it should have a low dielectric constant to prevent loading of the RF circuit, low loss to prevent lowering of the efficiency and gain of the tube, and good cooling properties. It also should have low viscosity to provide ease of pumping and low surface tension to prevent the development of hot spots within the tube. Additionally, the dielectric strength should be high to prevent voltage breakdown. While many fluids may be used, it has been found that an inert fluorochemical identified by the number FC–43 and manufactured by the Minnesota Mining and Manufacturing Company is satisfactory.

Referring now to Fig. 2, the coupling members 17 are each provided with a cylindrical outer shell 37 which encloses a coupling helix 38. The wire of the coupling helix 38 and the coaxial cables 31 and 34 is provided with a tough, heat resistant insulation such as Teflon. Space is provided between the coupling helices 38 and the vitreous envelope 18 to allow for passage of the cooling fluid along the entire length of the vitreous envelope 18 for efficient cooling thereof.

Within the vitreous envelope 18 there is provided a helical slow wave structure 40. The envelope 18 is uniformly collapsed or shrunken about the helical structure 40. The shrinkage is slight so as not to allow the glass to extend between the turns of the helical structure 40 but is sufficiently great to insure that the outer surface of the helical structure 40 uniformly contacts the vitreous envelope 18. Thus, any heat developed in the helical structure 40 will be conducted through the wall of the vitreous envelope 18 where it may be carried away by the liquid coolant. The helical structure 40 is not permitted to become fused or bonded to the envelope 18 so that if the helical structure 40 expands, it is free to rotate and thereby does not fracture the vitreous envelope 18. If desired, attenuation may be provided by coating the inside or outside of the vitreous envelope 18 with a resistive material such as aquadag.

Inasmuch as the separation between the focusing structure 15 and the electron beam must be kept as small as possible in order to permit satisfactory focusing of the beam, there is only limited space available for the flow of coolant along the vitreous envelope 18. It has been found that .020 inch is adequate spacing between the outside of the vitreous envelope 18 and the inside of the coupling members 17 and the focusing structure 15 to provide satisfactory focusing and yet still permit an adequate flow of coolant along the envelope 18.

In operation, heat is developed in the electron gun structure 20, the coupling members 17, the helical slow wave structure 40, the attenuator and the collector 21. The circulating coolant maintains all of the internal elements of the traveling wave tube, and particularly the helical slow wave structure 40, at a temperature such that an average output power on the order of 1 kilowatt may be obtained. The collector 21 is mainly cooled by conduction through the centering ring 24 and the circular plate 22 directly to the outer envelope 10 but is also cooled somewhat by the liquid coolant. Although the internal fins 12 are located only on one side of the outer envelope 10, due to the conductivity of the outer envelope 10, the heat spreads evenly and is radiated from all the external fins 11. In addition, since the outer envelope 10 is hermetically sealed, the tube is ideally

suited for use at high altitudes where present day aircraft frequently operate. The coolant prevents voltage breakdown within the traveling wave tube at high power levels and at high altitudes.

As indicated by the arrows in Fig. 1, the coolant flows along a path defined by the inner surface of the outer envelope **10** and the outer surface of the focusing structure **15** toward the pump **36**. It then flows through the hole **32** in the wall of the cylindrical support member **14** and around the gun structure **20**. The fluid passes between the inner surface of the first coupling member **17** and the outer surface of the vitreous envelope **18**, and traverses the entire length of the vitreous envelope **18** inside of the focusing structure **15**. The flow of the fluid therealong will be turbulent due to the ripples in the envelope **18** caused by the shrinking and also due to the internal configuration of the focusing structure **15**. The fluid passes between the second coupling member **17** and the envelope **18** and along the circular plate **22** to complete the path back to the inner surface of the outer envelope **10**.

Thus, there has been described a cooling arrangement for traveling wave tubes which efficiently cools a helical slow wave structure while permitting the use of a permanent magnet periodic focusing structure, and which is small, light, and operates efficiently in the range from 10 to 1,000 watts average power output over a broad frequency band and in which all the heat dissipating components of the traveling wave tube are cooled, while the resistance to internal voltage breakdown is increased.

What is claimed is:

1. A high power traveling-wave tube comprising: a slow wave structure including an external slow wave structure envelope extending longitudinally along said tube; means including input and output coupling helices encompassing and radially separated from said slow wave structure envelope located at different points therealong; a cooling envelope encompassing said coupling helices and said slow wave structure envelope and having a central longitudinal axis which is eccentrically displaced with respect to said slow wave structure envelope, said cooling envelope defining a closed volumetric path for a circulating cooling medium, which path extends between said input coupling helix and said slow wave structure envelope, along said slow wave structure envelope and between said output coupling helix and said slow wave structure envelope; and means including a liquid coolant having a sufficiently high boiling point to operate without vaporization, circulating within said cooling envelope.

2. A high power, liquid cooled traveling-wave tube comprising: a slow wave structure having a longitudinal axis; a vitreous envelope concentrically encompassing and being at least partially in contact with said slow wave structure; microwave energy coupling means concentrically encompassing and positioned along said vitreous envelope, a magnetic focusing structure extending along said vitreous envelope and concentrically encompassing said coupling means and said vitreous envelope, said coupling means and said focusing structure being radially outwardly separated from said vitreous envelope, the heat developed in said slow wave structure being conducted through the wall of said vitreous envelope, the points of greatest heat concentration being in the proximity of said coupling means; a collector coupled to one end of said slow wave structure, said collector developing appreciably higher heat energy in operation than said slow wave structure; means including an elongated substantially cylindrical cooling envelope eccentrically enclosing said focusing structure and a liquid coolant within said cooling envelope for conducting the heat developed in said slow wave structure away from said vitreous envelope, the inner surface of said cooling envelope and the outer surface of said focusing structure defining a nonannular closed cooling path which extends between the inner surface of said coupling means and said focusing structure and the outer surface of said vitreous envelope and which is spaced apart from the principal portion of said collector; and means including a metallic conductor in registry with said collector and coupled to said cooling envelope for conducting heat developed in said collector to said cooling envelope.

3. A high power traveling wave device comprising a vitreous envelope having a longitudinal axis, an electron gun disposed at one end of said envelope for projecting an electron stream along an axial path within said envelope, a permanent magnet structure coaxially disposed about and apart from said envelope for periodically focusing said stream along said path, a helical slow wave structure disposed coaxially within said envelope and adjacent said path for propagating radio frequency energy in interacting relationship with the electrons of said stream, input coupling means coaxially disposed about and apart from one end of said slow wave structure for coupling radio frequency energy thereto, output coupling means coaxially disposed about and apart from the other end of said slow wave structure for removing radio frequency energy therefrom, said envelope being uniformly collapsed about said slow wave structure for providing heat-conductive contact therebetween, said slow wave structure being slidable within said envelope for permitting expansion of said slow wave structure by slidable movement thereof, an elongated, substantially cylindrical, hermetically sealed chamber disposed eccentrically about said traveling wave device for defining a nonannular hollow cylindrical reservoir, a liquid coolant disposed within said chamber, and means disposed within said chamber for circulating said coolant through said traveling wave device along said envelope between said envelope, said input coupling means, said permanent magnet structure and said output coupling means.

4. In combination, an elongated hermetically sealed cylindrical metallic outer envelope having a plurality of heat-conductive fins extending therealong and radially inwardly and outwardly therefrom, said inwardly extending fins being located solely on a portion of the inner surface of said outer envelope and being progressively shortened in length from the central one of said fins to the outer ones of said fins to define a cylindrical opening eccentrically displaced with respect to said outer envelope, an elongated cylindrical permanent magnet focusing structure disposed within the eccentric opening defined by said inwardly extending fins, input and output coupling helices concentrically located within said focusing structure, an elongated hermetically sealed cylindrical vitreous inner envelope extending concentrically through said coupling helices and said focusing structure but being spaced apart therefrom to form a cylindrical passage therebetween, a helical slow wave structure within and in slidable heat conductive contact with said inner vitreous envelope, an electron collector disposed at one end of said vitreous envelope and being provided with a metallic heat conductive path to said outer envelope, a liquid coolant disposed within said outer envelope, and means for circulating said coolant through said passage to said internal fins of said metallic outer envelope.

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