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B. T. KERNS ETAL

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METHOD AND APPARATUS FOR FABRICATING SLOW-WAVE STRUCTURES

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FIG. 1

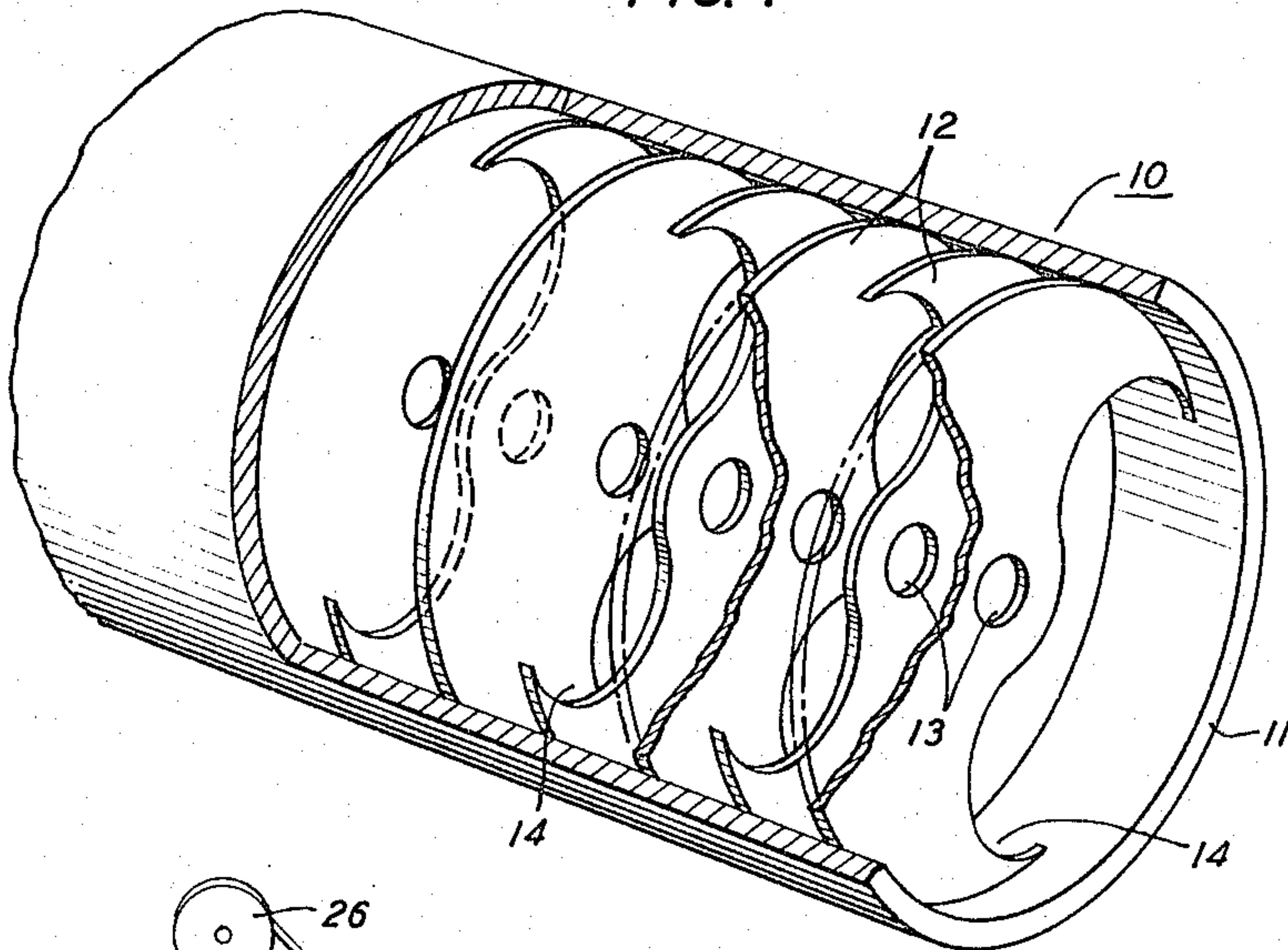


FIG. 2

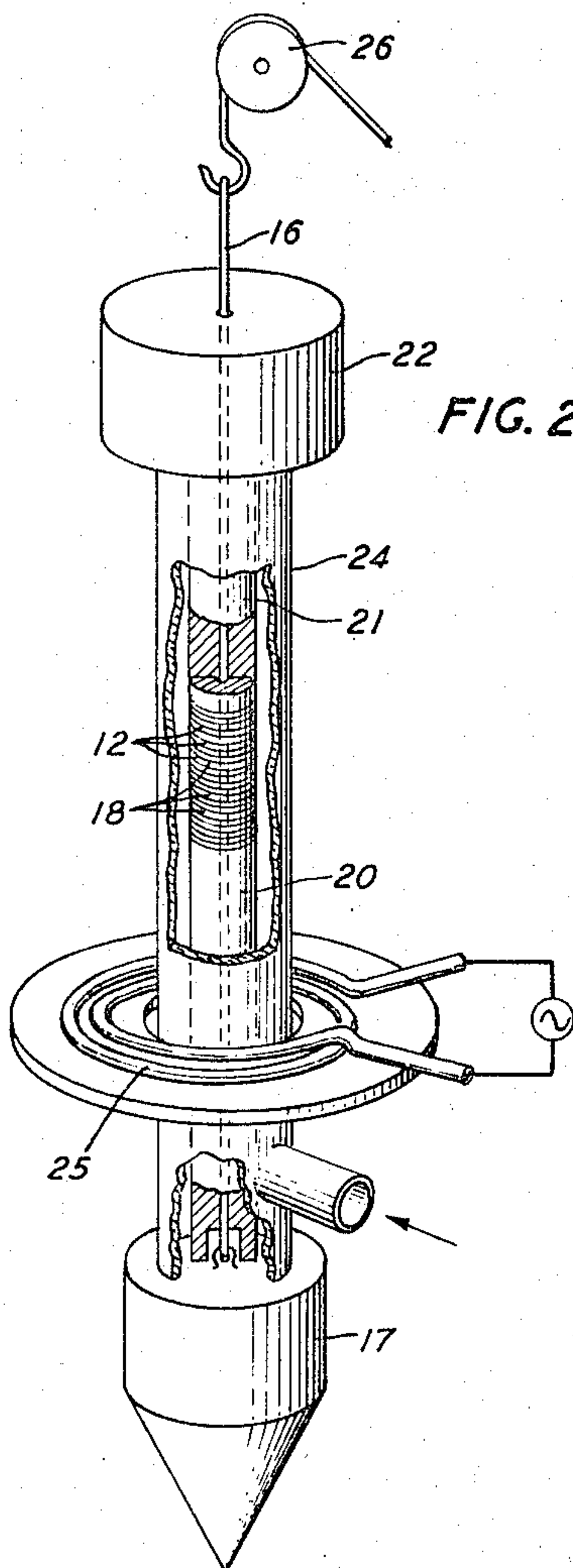
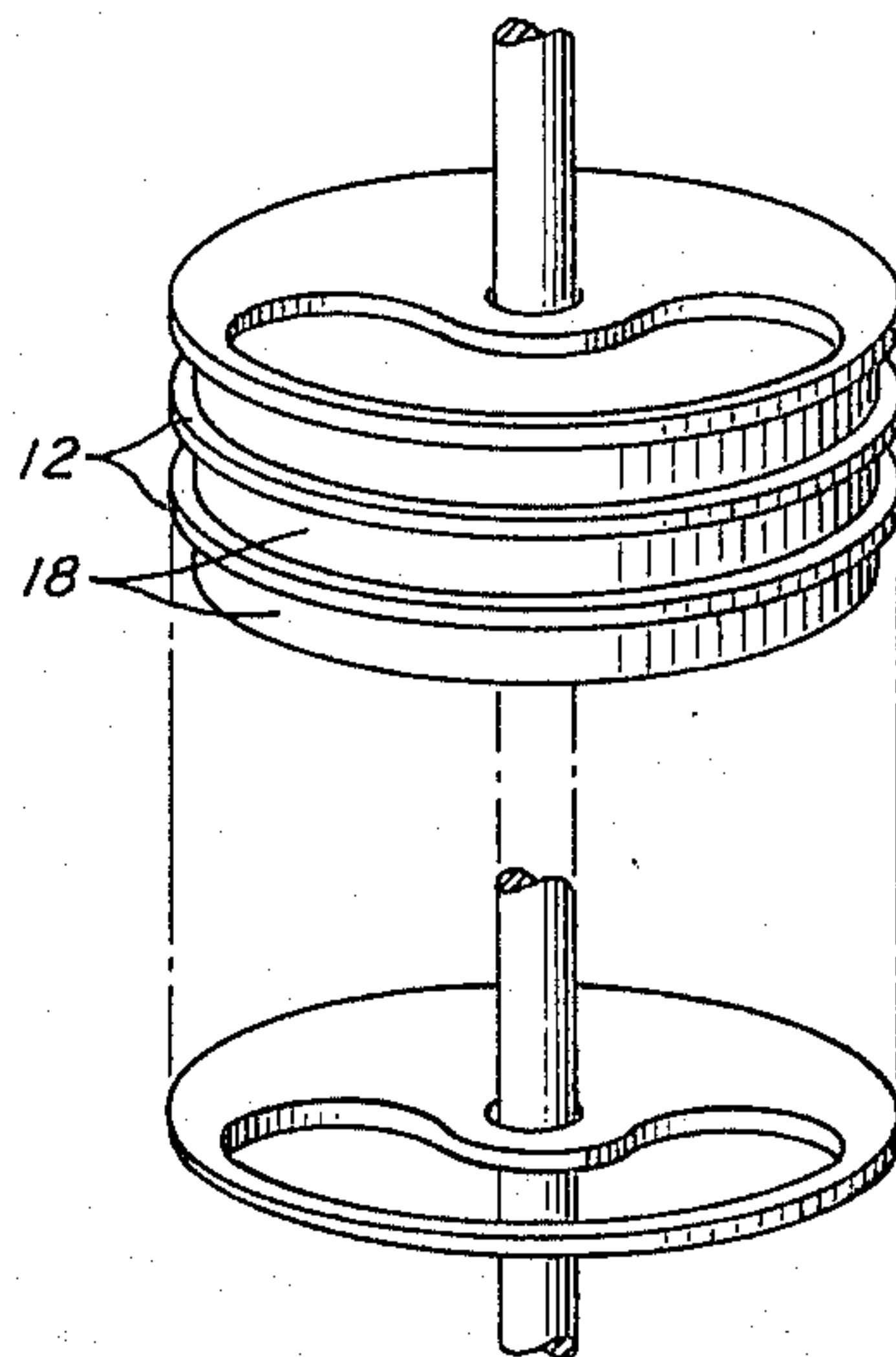


FIG. 3



INVENTORS B. T. KERNS  
D. E. KOONTZ  
BY

Roderick B. Anderson  
ATTORNEY



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## METHOD AND APPARATUS FOR FABRICATING SLOW-WAVE STRUCTURES

Becky T. Kerns and Donald E. Koontz, Summit, N.J., assignors to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York  
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3 Claims. (Cl. 29—155.5)

This relates to methods and apparatus for fabricating slow-wave structures, particularly slow-wave structures of the type comprising a series of coupled resonant cavities.

Traveling wave tubes are useful for amplifying high frequency electromagnetic waves, or microwaves, with reasonably high efficiency and stability over a wide frequency band. Such amplification is achieved by propagating the microwaves along a slow-wave structure in approximate synchronism with an electron beam. Under proper conditions, the microwaves will abstract energy from the beam in accordance with known principles of electron beam interaction and become amplified.

One type of slow-wave structure comprises a series of coupled resonators defined by a succession of conductive disks enclosed by a conductive envelope. A central aperture in the disks permits passage of the electron beam, while kidney-shaped coupling slots located successively above and below the beam direct the microwaves along the structure in synchronism with the beam. For normal requirements, these structures are fairly large and can be fabricated by a number of known techniques; for example, a plurality of cylindrical sections each containing one disk can be brazed together to form the desired structure. However, as the microwave frequencies become higher, the size of the structure that is required becomes smaller. The structures that would be desired for some extremely high frequency purposes are so small, and the alignment and spacing tolerances so rigorous, that they cannot be fabricated by any conventional techniques.

Accordingly, it is an object of this invention to fabricate within close tolerances exceedingly small slow-wave structures of the coupled resonator type.

This and other objects of our invention are attained by a method of fabrication comprising the steps of alternately threading copper disks and iron spacers on a wire such as molybdenum. The wire is suspended freely from one end and is attached to a heavy plumb-bob at the other end which stretches the wire and stabilizes it. Relatively long steel sleeves are located on the wire between the disk and spacer assembly and the plumb-bob, and between the assembly and its point of suspension. The assembly is hung vertically with a relatively heavy weight bearing on the uppermost sleeve to force the disks to parallel alignment. Next, the assembly is lowered through a radio-frequency coil which welds the pieces together by induction heating. A copper shell is then electroformed over the welded disks. Finally, the center wire is removed and the iron spacers are dissolved in acid, thereby leaving the desired structure.

As will be fully appreciated later, the weight bearing down on the assembly forces the spacers and disks into parallel alignment while the relatively long sleeves on opposite sides of the assembly insure that the disks and spacers will be perpendicular to the central axis defined by the wire. It should be pointed out that this parallel alignment is possible only because the disks are suspended on the wire; if they were mounted on a jig, even slight pressures would make them bow. The use of the radio-frequency induction coil for welding the assembly is particularly advantageous because the heating is localized, thereby limiting the molten area of the array to minimize possibilities of misalignment. Further, as the array is lowered through the field, the disks are successively

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seated in planes parallel with the upper surface of the plumb-bob. After the envelope has been electroformed over the assembly, the iron spacers are easily dissolved by injecting hydrochloric acid into the central aperture of the assembly.

These and other advantages and features of the invention will be more clearly understood from a consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a perspective view of a portion of a completed coupled resonator slow-wave structure;

FIG. 2 is a perspective view of apparatus for fabricating the slow-wave structure of FIG. 1; and

FIG. 3 is a perspective view of the disk and spacer assembly of FIG. 2.

Referring now to FIG. 1, there is shown a coupled resonator type slow-wave structure 10 for use in a traveling wave tube, which comprises an envelope 11 and a succession of resonant cavities defined by an array of disks 12. When the structure is used in a traveling wave tube, an electron beam is projected through central apertures 13. The resonators are then excited by electromagnetic wave energy which meanders along the structure by way of kidney-shaped coupling slots 14. As the electromagnetic wave energy travels along the structure, it abstracts energy from the beam and becomes amplified according to known principles of traveling wave interaction. The resonant frequency of the coupled resonators must correspond to that of the microwave frequency of the electromagnetic wave. Hence, as the frequency of operation increases, the size of the structure must be reduced.

The apparatus shown in FIG. 2 was designed for fabrication of slow-wave structures such as that shown in FIG. 1 having disks which are only .004 inch thick and .17 inch in diameter. The apparatus of FIG. 2 is completely suspended by a central wire 16, to which a heavy plumb-bob 17 is attached at one end.

As best seen in FIG. 3, the disks 12 are separated by iron spacers 18 having a thickness which corresponds to the width of the resonant cavities between adjacent disks in the structure of FIG. 1. A lower steel sleeve 20 which has the same outer diameter as the disk and spacer assembly is threaded onto the wire between the disk and spacer assembly and the plumb-bob. A similar upper sleeve 21 is located above the disk and spacer assembly. Bearing down on the upper sleeve 21 is a relatively heavy weight 22. The force of this weight on the disks and spacers forces them together so that they are parallel to each other. The relatively long sleeves 20 and 21 are fairly tightly threaded on to the wire, and, because of their relatively long length, they force the aligned disk and spacer assembly to be perpendicular with the central wire 16. The wire, of course, is maintained taut and vertical by the heavy plumb-bob weight 17.

Surrounding the assembly is an envelope 24 of heat resistant material such as quartz for maintaining the disk and spacer assembly in a desired atmosphere. After the disks 12 and spacers 18 are properly aligned, they are welded together. In order to prevent undesired oxidation during the welding, any oxygen in the quartz envelope 24 is first flushed out with nitrogen. An appropriate reducing atmosphere such as hydrogen is then injected through the input of the envelope as shown by the arrow. The disks and spacers are then welded together by lowering them through the middle of a radio-frequency coil 25 by any convenient apparatus designated generally by a pulley 26. An appropriate oscillator connected to coil 25 heats the assembly to approximately 800° C. by the known principles of induction heating. This type of welding has several advantages: the welding takes place in an appropriate atmosphere; the heating is localized thereby limiting the



molten area of the array to minimize possibilities of misalignment; as the array is lowered through the field the disks are successively seated in planes parallel with the upper surface of the plumb-bob; the welding operation is relatively simple.

After welding, the structure is completed by electroforming a conductive shell over the disk and spacer assembly to form the envelope 11 shown in FIG. 1. The iron spacers are then removed by injecting an appropriate etchant such as hydrochloric acid into the central aperture 13 of the structure which selectively dissolves the iron spacers. It is normally convenient to use copper disks 12 and a copper envelope 11 because these materials are appropriate for most slow-wave structures, and also because the hydrochloric acid selectively dissolves out the iron spacers while leaving the copper intact.

The structures which have been made by this process are approximately one-half inch long and comprise twenty .004 inch thick copper disks. The upper and lower sleeves that were used were both three inches long while the weight of the plumb-bob and upper weight were both approximately 1.07 pounds. This weight can conveniently be supported by a molybdenum center wire of approximately .012 inch in diameter which corresponds to the diameter of the central aperture 13. It is sometimes difficult to remove the molybdenum center wire after the welding operation, in which case hot dilute hydrochloric acid can be used to dissolve out the molybdenum wire.

As can be seen in FIG. 3, the copper disks 12 each overlap their corresponding iron spacers by about .004 inch. This is advantageous for two reasons. First, it insures that the entire periphery of each disk will be diffused into the outer envelope shell during the electroforming process. Second, it permits the accurate forming of the kidney-shaped coupling slots 14. As seen in FIG. 1 the coupling apertures in the final structure are partly defined by the electroformed envelope 11. The thin overlap which surrounds each slot before electroforming diffuses into the envelope shell, but it also prevents electroforming material from collecting on the interior of the slot. Various known methods can be used for electroforming the copper shell of the desired thickness onto the cylinder composed of the disk and spacer assembly.

In summary, slow-wave structures can be fabricated by a method comprising the steps of attaching a plumb-bob 17 to a wire 16, successively threading onto the wire a lower sleeve 20, a plurality of metallic disks 12 each separated by a metallic spacer 18, an upper sleeve 21, and a weight 22, suspending the wire to hang freely, lowering the disk and spacer assembly in a reducing atmosphere through a radio-frequency field of sufficient intensity to weld the disks and spacers together, electroforming a metallic envelope 11 over the disks and spacers, and dissolving selectively the spacers in an appropriate solution without affecting the disks and envelope.

With this method it is possible to manufacture structures comprising extremely thin, delicate disks which are equispaced, parallel to each other, and perpendicular to a central axis. The disclosed method and apparatus, however, are merely illustrative of the application of the principles of our invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention. In particular, materials other than copper and iron can be used provided the disk and envelope materials are chosen to resist the etchant used to dissolve the spacer material.

What is claimed is:

1. Apparatus for manufacturing slow-wave structures comprising, means for positioning and spacing the conductive disks comprising a plurality of metal spacers each

interposed between successive conductive disks thereby forming a disk and spacer assembly, means for joining together the disks and spacers of the assembly, and means for selectively dissolving the spacers, wherein the improvement comprises:

means for vertically suspending the assembly comprising a wire extending through apertures in the disks and spacers and attached at a free end to a plumb-bob having a horizontal planar top surface upon which the assembly is supported;

an annular radio-frequency induction coil arranged coaxially with the disk and spacer assembly, and having a much smaller axial length than the axial length of the disk and spacer assembly;

means for vertically lowering the assembly through the coil;

and means for exciting the coil with sufficient radio-frequency power to melt and weld only that portion of the assembly immediately adjacent the coil, whereby successive spacers and conductive disks are welded together and seated in planes parallel with the upper surface of the plumb-bob through the application of localized heat to the assembly.

2. The apparatus of claim 1 further comprising:

uppermost and lowermost cylindrical sleeves slideably mounted on the wire on opposite ends of the assembly, each having an axial length that is considerably longer than its diameter to aid in the horizontal alignment of the disks;

and a weight slideably mounted on the wire and supported by the uppermost sleeve.

3. The method of making slow-wave structures comprising the steps of alternately threading each of a plurality of conductive disks and metal spacers onto a central wire, joining together the disks and spacers, and selectively dissolving the spacers, wherein the improvement comprises:

vertically suspending the wire from one end;

applying a downward force on the wire comprising the step of including a plumb-bob on the lowermost end of the wire;

applying a downward force on the assembly comprising the step of threading a weight onto the wire that bears upon the assembly;

lowering the assembly through a localized radio-frequency electric field of sufficient power to melt and weld that portion of the assembly exposed thereto, whereby successive spacers and conductive disks are welded together and seated in planes parallel with the upper surface of the plumb-bob through the application of localized heat to the assembly;

and electroforming a conductive envelope about the disk and spacer assembly prior to dissolving the spacers.

#### References Cited

##### UNITED STATES PATENTS

|           |         |                 |          |
|-----------|---------|-----------------|----------|
| 2,290,338 | 7/1942  | Koehring        | 219—9.5  |
| 2,618,234 | 11/1952 | Armacost        | 29—494   |
| 2,652,623 | 9/1953  | Marden          | 29—500 X |
| 2,747,066 | 5/1956  | Brace           | 29—494 X |
| 2,761,828 | 9/1956  | Eldredge et al. | 204—52 X |
| 2,846,379 | 8/1958  | Chambers et al. | 264—52 X |
| 3,083,444 | 4/1963  | Mitchell et al. | 29—155.5 |
| 3,105,285 | 11/1963 | Favre           | 29—155.5 |
| 3,188,724 | 6/1965  | Bates et al.    | 29—418   |

JOHN F. CAMPBELL, *Primary Examiner*.

J. W. BOCK, L. J. WESTFALL, *Assistant Examiners*.