

Aug. 15, 1967

W. G. NUTT ETAL

3,336,175

METHOD OF CONSTRUCTION OF HELIX WAVE GUIDE

Filed April 9, 1964

2 Sheets-Sheet 1

FIG. 1

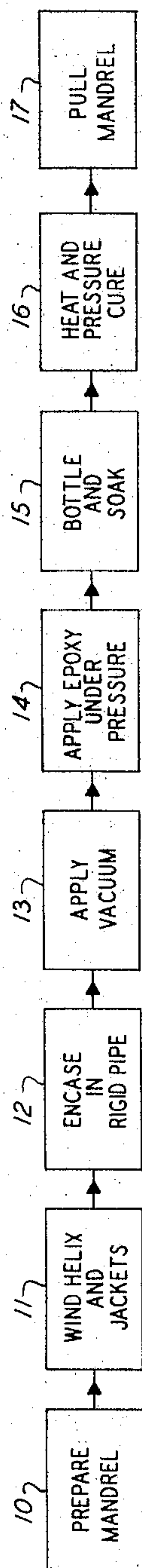
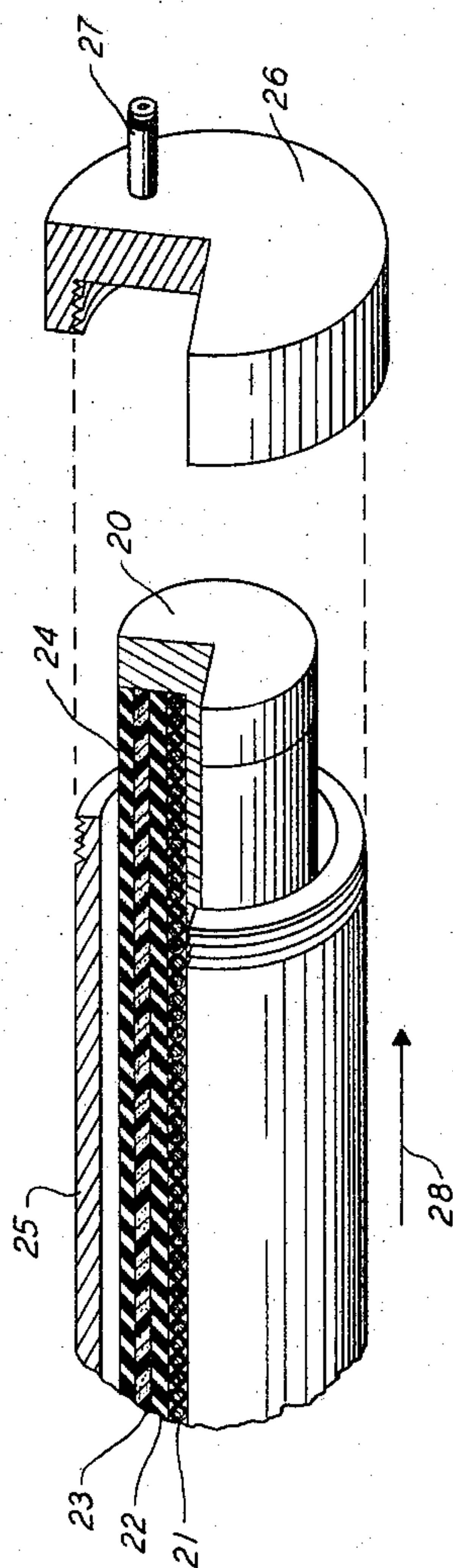


FIG. 2



INVENTORS W. G. NUTT
H. N. PADOWICZ

BY *Kenneth W. Mather*
ATTORNEY

Aug. 15, 1967

W. G. NUTT ET AL

3,336,175

METHOD OF CONSTRUCTION OF HELIX WAVE GUIDE

Filed April 9, 1964

2 Sheets-Sheet 2

FIG. 3

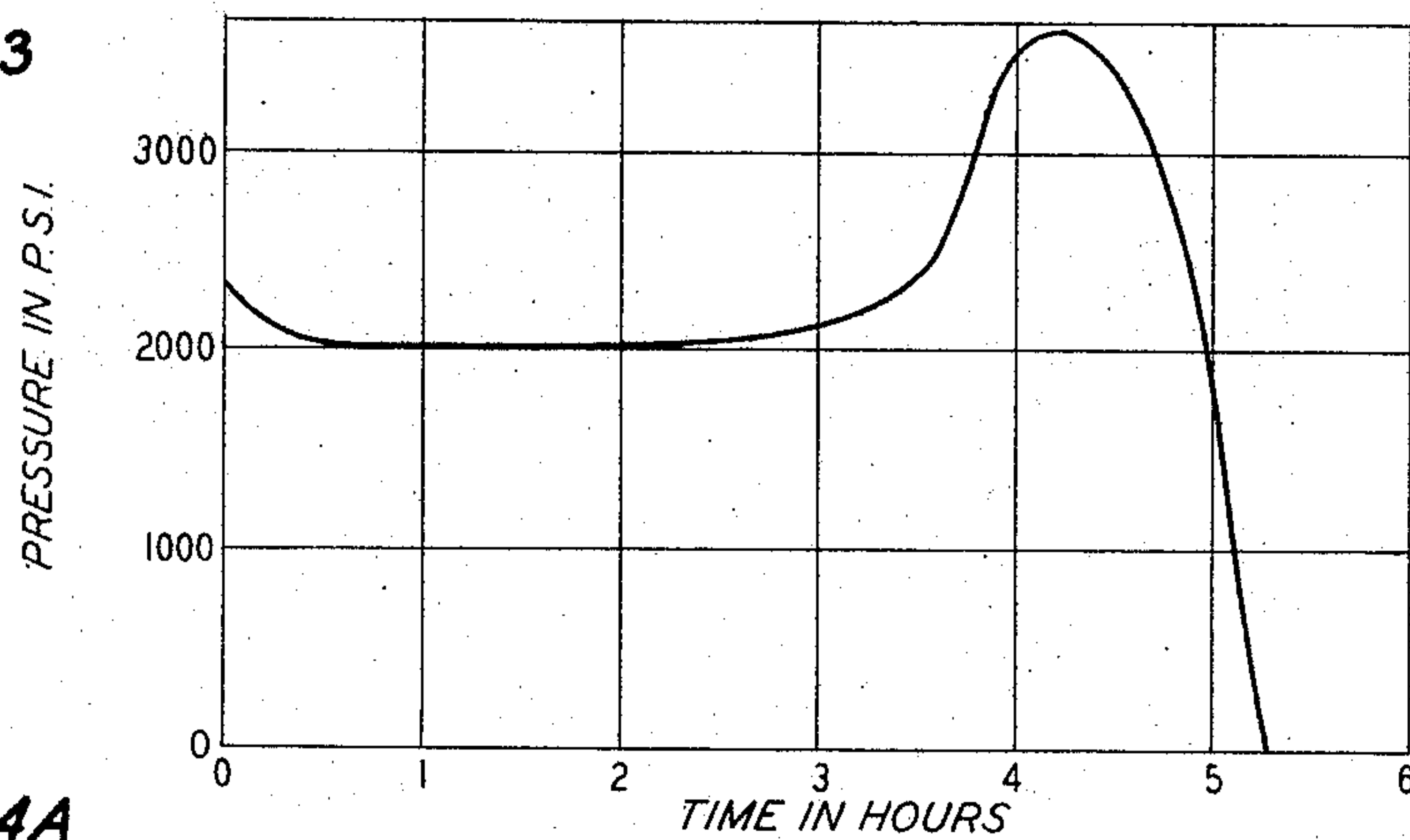


FIG. 4A

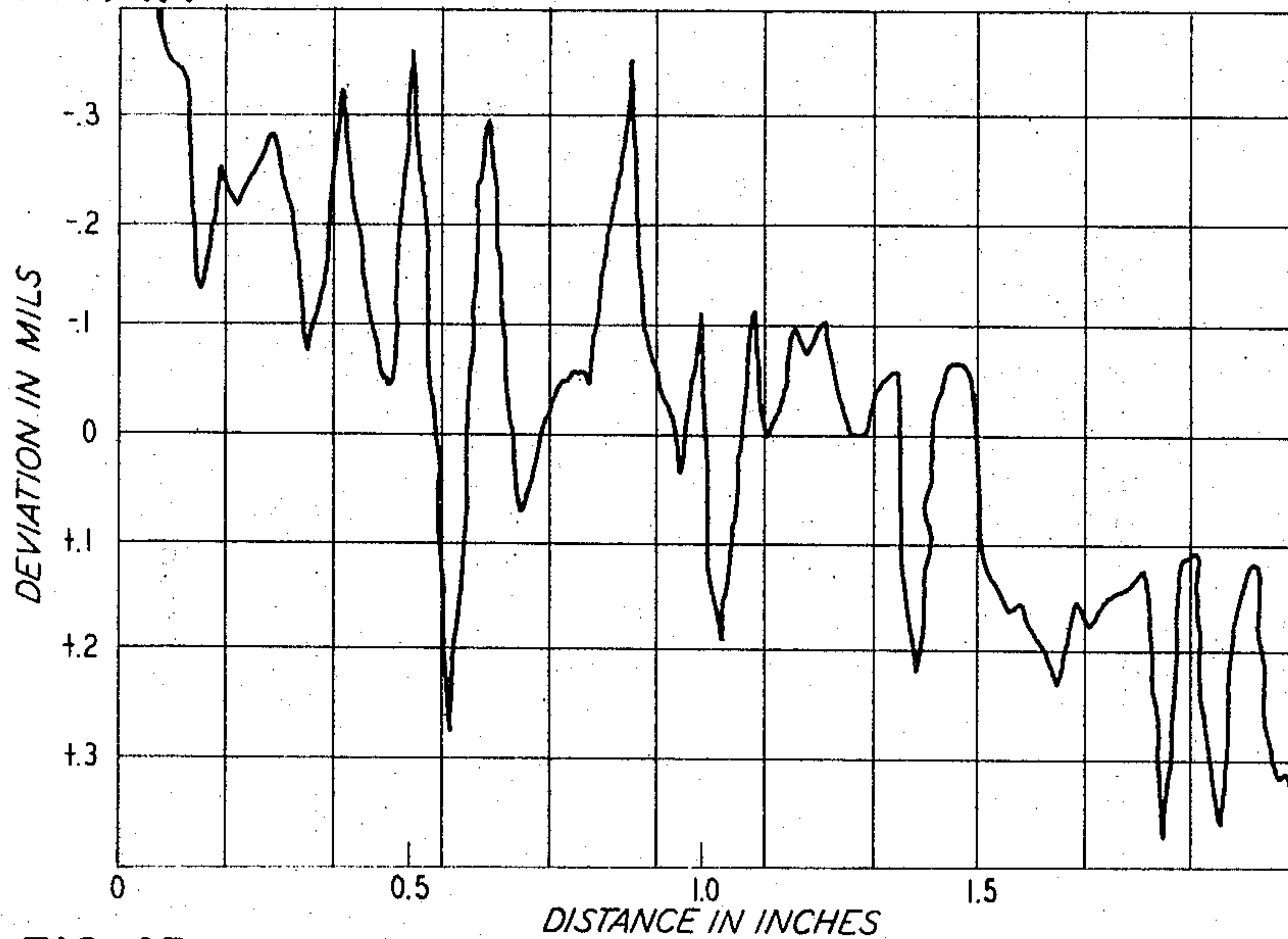
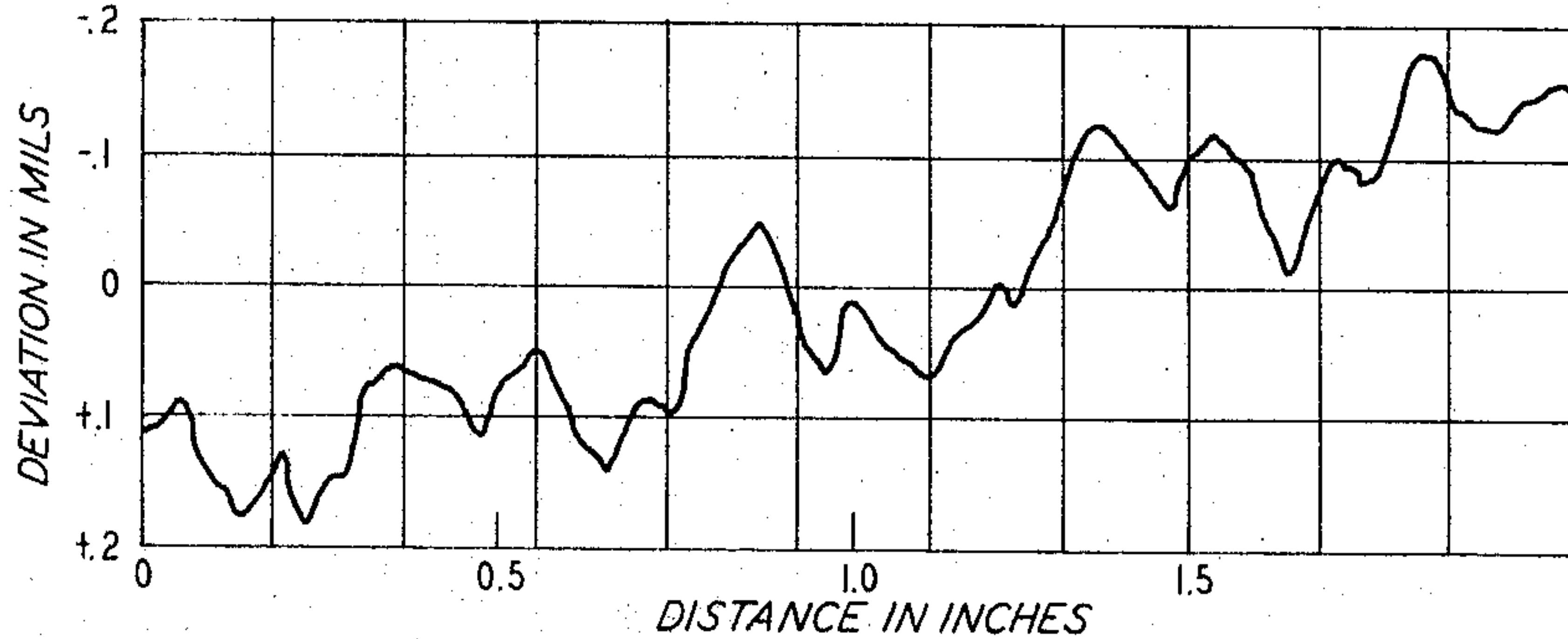


FIG. 4B



3,336,175

METHOD OF CONSTRUCTION OF HELIX WAVE GUIDE

Wendell G. Nutt, Basking Ridge, and Henry N. Padowicz,
Chatham Township, Morris County, N.J., assignors to
Bell Telephone Laboratories, Incorporated, New York,
N.Y., a corporation of New York

Filed Apr. 9, 1964, Ser. No. 358,438

4 Claims. (Cl. 156—173)

ABSTRACT OF THE DISCLOSURE

A fabrication process for helix wave guide in which the assembled structure is impregnated with epoxy resin and allowed to soak for at least one hour at an elevated pressure and at a temperature below the curing temperature. The guide produced by subsequent thermal curing at elevated pressure is substantially free of surface irregularities and internal blisters.

This invention relates to a method of construction of a wave guide, and more particularly, to a method of construction of a helix wave guide having a rigid steel pipe as a protective sheath.

It is known that a closely wound helical conductor of diameter greater than 1.2 free space wavelengths is a transmission medium that is suitable for propagating a properly excited circular electric TE_{01} mode. It has been shown that such a medium greatly minimizes the inherent tendency of this mode to degenerate into spurious modes. The helical conductor typically is surrounded by a plurality of jackets, one of which can be dissipative to introduce a large difference in the attenuation constants presented to the spurious modes and the TE_{01} mode and thereby to reduce mode degeneration still further.

Since this type of wave guide is advantageous because of its low spurious mode transmission levels, an economical method of construction thereof is particularly desirable. To this end, it has been priorly found that a conductive metallic material is attractive for use as a protective sheath. As disclosed in United States Patents 2,845,695 and 2,848,696 issued on Aug. 19, 1958, to J. R. Pierce and to S. E. Miller, respectively, the outside protective sheath can be wound of overlapping, thin metallic strips or it can be made of a woven metallic braid.

Methods of construction have also been disclosed for fabricating helix transmission lines with outer protective sheaths of metallic material which exhibits more rigidity than a wound sheath structure. For example, several methods of using a solid pipe as opposed to braided metal or overlapped, thin strips of metal have been tried. One method involves cutting the length of pipe longitudinally in half, inserting the helical conductor and its associated jackets in one pipe half, and covering it with the other pipe half. This method is cumbersome, expensive and much rigidity is lost because of the cut.

Another method involves providing a single longitudinal seam, springing the pipe open, and then inserting the helical conductor. The pipe then returns nearly to its original shape. Here again there are disadvantages since such a method works well only with relatively short sections, the line produced is not watertight, and some rigidity is lost.

Another possible method involves pushing the helical conductor and its associated jackets into a rigid steel pipe. If the steel pipe is made small enough to give necessary support to the helix, then it is substantially impossible to insert the helix into the steel pipe without destroying the windings. On the other hand, if the steel pipe is made large enough so that the helix and associated jackets will

enter into the steel pipe easily, the void remaining between the pipe and the helix jackets is obviously undesirable for many reasons.

In United States Patent 3,056,710, issued to Charles F. P. Rose on Oct. 2, 1962, a method for constructing a helix guide with rigid steel jacket is disclosed in which both the inside of a pipe of slightly enlarged diameter and the outside of a wound helix and jacket assembly are coated with an uncured thermosetting synthetic resin, such as an epoxy, and the helix is inserted in the pipe with the resin on the two surfaces serving as a lubricant. As a result of this method of assembly, the resin simultaneously serves as a filler and, upon heat curing, as an adhesive which seals the two assembled parts into a unitary wave guiding structure. However, such a method produces a helix guide oftentimes characterized by irregular interior surfaces and blister-like voids within the jacket layers external to the helix winding.

More recent fabrication methods have involved forming the several helix guide layers with wrapping materials either wetted with epoxy or dry, inserting the wrapped assembly into an outer rigid pipe, and then applying epoxy under pressure to fill the voids and to wet the jacket materials completely. When the epoxy reaches the guide end distant from the source of its application, pressure is removed, and the guide unit is moved to an oven for curing, constant rotation of the unit being maintained during the cure. This technique is fully discussed in the article by A. C. Beck and C. F. P. Rose, entitled "Waveguide for Circular Electric Mode Transmission," which appears at pages 159-162 of the September 1959, issue of the Proceedings of the Institution of Electrical Engineers, volume 106, Part B, Supplement No. 13, Part 4. However, problems of surface irregularities and internal blisters remained, and minimum transmission losses achieved at 55 kilomegacycles were 28 percent or more above theoretically predicted levels for helix guide.

It is, therefore, the object of the present invention to construct a helix wave guide of improved transmission characteristics.

In accordance with a preferred embodiment of the invention, a method of fabricating a helix guide comprises the steps of winding a conductive helix and its external lossy and non-lossy jackets upon a mandrel, inserting the wrapped mandrel into a rigid metallic pipe, exhausting the assembly, filling the void between the external pipe and wrapped mandrel with epoxy applied under pressure, soaking the assembly under pressure for a predetermined period at room temperature, curing the assembly by a thermosetting procedure utilizing thermal coefficients of expansion to generate additional impregnating pressure, and removing the mandrel from the cured assembly.

The provision of the pressure soak period permits substantially uniform impregnation of all jacket materials to begin and the enclosure of the assembly within a pressure tight member during the heat cure, permits additional impregnating pressure to be generated during thermal expansion of the epoxy. The inclusion of these two steps in the guide fabrication process has produced a helix guide of improved transmission characteristics.

The above and other objects of the invention, its nature and its various features and advantages will become more apparent upon consideration of the accompanying drawing and the detailed description thereof which follows hereinafter.

In the drawing:

FIG. 1 is a flow chart illustrating in block form the process in accordance with the present invention;

FIG. 2 is a partially broken away perspective view of a helix guide section at one stage in the process of FIG. 1;

FIG. 3 is a graphical representation of a pressure versus time characteristic typical of the present invention; and

FIG. 4A and FIG. 4B are recorded traces of the interior surface smoothness of helix guide sections fabricated, respectively, in accordance with a prior art process, and in accordance with the process according to the present invention.

Referring now to the drawing in detail, FIG. 1 is a flow chart which, when read from left to right, identifies the successive steps of the process of helix guide fabrication in accordance with the invention. FIG. 2, illustrating a partially broken away helix guide section during a particular portion of the fabrication process depicted in FIG. 1, will be referred to as the description of FIG. 1 proceeds.

As indicated by block 10, the first step in the fabrication process of the present invention comprises preparing the mandrel 20 of FIG. 2, which is of suitable length and of exactly the cross section desired for the inner surface of the finished helix line. Mandrel 20, which typically comprises a precision ground straight section of a metal such as steel, is carefully cleaned and coated with a suitable mold release agent to facilitate mandrel removal after fabrication is complete. The mandrel can be a solid shaft or it can be hollow, in which case a typical wall thickness is one quarter inch.

Next, the helix guide is formed upon mandrel 20, as indicated by block 11. First, elongated conductive member 21 is wound on the mandrel, with adjacent turns thereof being insulated from each other, either by an air gap or by the presence of an insulating enamel coating on the conductor itself. One arrangement for winding such a helical conductor is disclosed in United States Patent 3,039,707 issued June 19, 1962, to A. C. Beck and E. L. Chinnock. Multiple lead helices can also be simultaneously wound. The conductive member 21 can be either solid or stranded, and can comprise copper alone, or a base metal such as iron or steel plated with a highly conductive metal such as copper or silver. Number 37 wire is well suited to helix guide fabrication processes. Further dimensions and characteristics of conductor 21 are similar to the specific characteristics and dimensions disclosed in United States Patents 2,848,695 and 2,848,696, referred to above.

In order better to match the wall impedance of the helix to the impedance of the hollow guiding path within the guide, a layer 22 of low loss dielectric material can be wound over the single layer helical conductor 21, as disclosed in detail in United States Patent 3,110,001, issued Nov. 5, 1963 to H. G. Unger. One particularly advantageous material used for forming the transformer layer 22 is Fiberglas roving composed of many threads or continuous filaments of glass that are loosely twisted to form a yarn-like structure. A binder, such as that designated 801 by Owens Corning Fiberglas Corporation, can be utilized to provide coherence to the roving as it is applied. A transformer layer thickness of 6 mils is typical.

Around layer 22 is wound a lossy jacket 23 which can comprise either an electrically lossy medium such as additional Fiberglas roving coated with an 8 percent graphite solution or other similar material, or a magnetically lossy medium such as Ferroxidure, as disclosed in the now abandoned application of A. G. Fox, Ser. No. 137,825, filed Sept. 13, 1961, as assigned to the assignee of this application. Alternate lossy jacket materials include metal or metal oxide coated Fiberglas cloth or carbon loaded paper in string or tape form. The lossy jacket thickness, typically 15 mils, is generally greater than the thickness of transforming layer 22, and can be proportioned in accordance with the disclosure of United States Patent 2,950,454 issued Aug. 23, 1960 to H. G. Unger.

A covering jacket 24, which can comprise ordinary Fiberglas roving, can be applied over the lossy jacket 23

to provide mechanical support to the previously applied layers. A liquid binder, as with transformer layer 22, can be used.

With the helical conductor and associated jackets in place, the next step in the fabrication process, indicated in FIG. 1 as block 12, is to encase the wrapped guide assembly in a rigid pipe 25. Pipe 25, which acts as a shield and which gives mechanical rigidity to the final product, can comprise copper, aluminum, or steel, and has an inside diameter greater than the outside diameter of the wrapped member to be inserted therein. A typical inside diameter of pipe 25 is 2.105 inches for a 2.000 inch inside diameter helix. From the dimensions given hereinabove for the several layers, a clearance of approximately 25 mils will thus be provided between the member to be inserted and the encasing rigid pipe. To facilitate the insertion of the wrapped member into the pipe, the interior of the pipe can be wetted with an epoxy to be more fully described hereinafter. Rigid pipe 35 is longitudinally pushed over the wrapped member, as indicated by arrow 28 in FIG. 2, and end cap 26 is engaged therewith. End cap 26 and pipe 25 can have mating screw threads as illustrated, or each can have engaging or butting flanges which are bolted together to provide a sealing fit. A cap similar to cap 26 is placed on the end of the wrapped mandrel opposite from the end illustrated.

With the end caps thus in place, and as indicated by block 13 in FIG. 1, the space between the outer pipe and the wrapped mandrel is evacuated of water vapor and other volatile substances. A partial vacuum can be provided by attaching a vacuum manifold through tubing not shown in FIG. 2 to connector 27. When the desired partial vacuum is attained, the tubing is sealed. By thus evacuating the assembly of volatile substances, more intimate adherence of the epoxy to the conductive winding and the various jacket surfaces is ensured. Although the provision of a vacuum is advantageous, it is not essential to the realization of a significant improvement in transmission performance in accordance with the invention.

As indicated in FIG. 1, the process continues with filling the space between the outer pipe and the wrapped mandrel, and saturating the wrappings themselves, with a resin or epoxy under pressure. Any plastic material which may be catalytically cured to form a thermosetting polymer can be used as the resin. A suitable catalyst is usually an amide, an amine, or a combination of both. A specific example of an epoxy used in practicing the invention comprises a mixture of Epon Resin No. 815 available from Shell, Incorporated, 1000 parts by weight; Versamid No. 140, available from General Mills, 80 parts by weight; curing agent Z, Shell, 160 parts by weight; and Velveteen R, an amorphous silica, available from Tamms Industries Company, 1000 parts by weight. The silica is utilized as a solid inert filler to reduce shrinkage in the space between surrounding pipe and mandrel. This epoxy is applied under pressure from a charging cylinder attached through tubing to the connector on the end cap not shown in FIG. 2. A typical pressure is 2500 p.s.i., although other pressures can be employed, as determined by the strength of the pipe and the desired speed of impregnation. When the space within the helix guide is filled, and the pressure remains constant, the connecting tubing is sealed and the epoxy source is removed. Thus the pressure within the guide assembly remains at a considerably elevated level.

With the external connecting tubing sealed off at both ends, the helix, its several wound layers, and the epoxy can be said to be "bottled." In this condition, and in accordance with the invention, the mechanically complete helix guide is permitted to soak, under the influence of the elevated pressure and at a temperature below that at which thermal curing begins, for a period sufficient substantially to impregnate the entire assembly with epoxy, typically no less than one hour. Room temperature is generally satisfactory. This procedure comprises the "bot-

tle and soak" step indicated as block 15 in the chart of FIG. 1.

Upon completion of the soak period, the entire bottled assembly, or unit, is placed within a temperature controlled environment, such as an oven, in which the temperature of the epoxy impregnated assembly is raised to effect a thermosetting cure of the resin. This step is indicated as block 16 in FIG. 1 of the drawing. For a unit impregnated with the epoxy specifically referred to earlier, the temperature is raised to 280° F. and held for a period of approximately four hours. Since the pressure within the unit is high and uniform throughout, rotation of the unit as curing proceeds is not ordinarily necessary as was the case in the prior art.

FIG. 3 graphically illustrates as curve 30 the pressure condition obtaining within the guide during the epoxy application, the soak, and the heat curing periods. The impregnating pressure initially is 2,500 p.s.i., indicated on the ordinate. When the epoxy application is complete and the pressure source is disconnected, the monitored pressure typically falls to 2,000 p.s.i. and remains constant during the soak period. When heat is applied, the pressure within the sealed unit initially rises as the epoxy expands. By thus utilizing the thermal coefficient of expansion of the epoxy to generate additional impregnating pressure, the total internal pressure within the sealed unit can be nearly doubled, thereby ensuring more complete epoxy impregnation throughout the assembly. With the pressure thus raised above that initially applied, the thermal curing process begins, the epoxy shrinks and sets, and the pressure is relieved. In the cured state, therefore, the epoxy acts both as a filler or binder for the successive jacket layers and the surrounding pipe and as a homogeneous adhesive layer between the outer jacket winding and the surrounding pipe.

It will be understood that the values of pressure, temperature and time given herein above are interrelated. Thus, if high initial impregnation pressures are used, a shorter soak period will be sufficient. For a given physical structure, therefore, the parameters can be varied somewhat from the specific examples given.

The final step in the guide fabrication process is indicated as block 17 in FIG. 1 and involves removing the mandrel from the helix guide, and preparing the guide extremities for suitable connection to other sections. In order to free the mandrel from the wound conductive helix, a typical procedure is to apply a pulling force to the mandrel, such as provided by a mechanical winch or an hydraulic extractor. For guide lengths of twenty feet, it has been found that pulling forces less than 1500 pounds are sufficient for extracting the mandrel once broken free of the helical winding.

The performance and physical characteristics of helix guide sections fabricated in accordance with the present invention have been compared with guide sections prepared in accordance with prior art techniques. In particular, guides prepared according to processes including and processes omitting the soak and pressure curing periods of the present invention have been tested and the results recorded. FIG. 4A is a record of surface irregularity obtained by sensing the inside surface of a helix guide section of prior art fabrication techniques by drawing a sled-mounted differential transformer therethrough. FIG. 4B is a record of surface irregularity obtained by identical methods in a helix guide section fabricated in accordance with the preferred embodiment of the present invention. From visual inspection of the traces given, it can be seen that the surfaces encountered in prior art helix guides are considerably more irregular than guides in accordance with the present invention. Specifically, the presence of air pockets, or blisters, within the body of the guide jacket was significantly reduced by the introduction of the pressure soaking and thermal pressure curing periods. One contributing factor is believed to be the ab-

sence of any significant pressure gradient along the unit during the curing procedure.

Further tests involving transmission loss measurements at 55 gigacycles on 3000 feet of helix guide made with the soak period showed a loss of 2.1 db per mile, an improvement of 0.2 db over prior art measurements, and only 0.3 db greater than theoretically predicted loss levels. The improvement in transmission characteristics provided by the invention is therefore significant in view of the long lengths of helix guide contemplated for use in a cross country communication system employing the circular electric wave mode or circular wave guides.

In all cases, it is understood that the above described arrangement is only illustrative of the many possible specific embodiments which can represent the application of the principles of the invention. Further applications involve packaging of electrical and mechanical components in which pressure impregnation can be used to eliminate voids and to ensure that the encapsulating resin adheres to all component parts. In such arrangements, the inclusion of a pressure soak period and an increased pressure condition due to thermally induced expansion of the encapsulating resin during cure can contribute significantly to improving the characteristics of the finished products. Each such application will have particular pressures, temperatures, and curing characteristics best determined by individual analytical or experimental evaluation.

What is claimed is:

1. A method of construction of a hollow helical wave guide of circular transverse cross section comprising the steps of

coating a clean straight mandrel with a material having the characteristics of a mold release,

winding an elongated conductive member about said mandrel in substantially helical form with adjacent turns of said member insulated from each other, surrounding said helical member with a plurality of wrapped layers of dielectric material, at least one of said layers presenting loss to energy propagating therewithin,

encasing the wrapped mandrel assembly in a rigid hollow pipe and capping the ends thereof,

creating a vacuum within said pipe,

introducing into the space between said pipe and said assembly an epoxy resin under a substantially elevated pressure condition,

permitting said encased assembly to soak under pressure at room temperature for a period of at least one hour,

raising the temperature of said encased assembly to a temperature sufficient to effect thermosetting of said resin and holding it at such level until thermosetting is complete, and

removing said mandrel from the interior of the helix wave guide produced.

2. A method of construction of helix wave guide comprising the steps of

winding a helical conductive member and a plurality of successive dielectric layers of differing characteristics about a clean straight mandrel of selected circular transverse cross section,

encasing said wound mandrel in a rigid tubular member having vacuum and pressure tight end caps, reducing the pressure within the interior of the encased unit to evacuate volatile substances,

filling under pressure the interior of said unit with an epoxy resin of the type capable of being thermally cured,

sealing said unit in a manner maintaining an internal pressure substantially equal to said filling pressure,

permitting said sealed unit to soak in an elevated pressure condition for a period exceeding one hour, the temperature of said unit during said period remaining below the temperature for which thermal curing begins,

7

raising the temperature of said sealed unit to a temperature sufficient to effect thermal curing of said resin and maintaining said temperature until curing is complete, and
removing said mandrel from the center of the guide 5 produced.

3. In the process of construction of a helix guide having an inner wrapped layer arrangement inserted within an outer rigid jacket, the steps of
filling the void between said jacket and said inserted 10 wrapped arrangement with epoxy resin,
maintaining for a period exceeding one hour the pressure within said jacket at no less than 2000 p.s.i. and the temperature therewithin below the curing temperature,
curing said resin, and
removing said mandrel.

8

4. In a process of fabricating steel jacketed helix wave guide in which epoxy resin is applied under pressure to the interior of said jacket, the step of
soaking the contents of said jacket in said pressurized resin at room temperature for a period exceeding sixty minutes.

References Cited

UNITED STATES PATENTS

2,877,504	3/1959	Fox	264—279	X
3,056,710	10/1962	Rose	156—195	X
3,121,206	2/1964	Mandrel	333—95	
3,222,433	12/1965	Makay	264—279	X

15 EARL M. BERGERT, *Primary Examiner*.
J. P. MELOCHE, *Assistant Examiner*.