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2,761,828

METHOD OF FORMING INTERNALLY FLANGED STRUCTURES

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FIG. 1

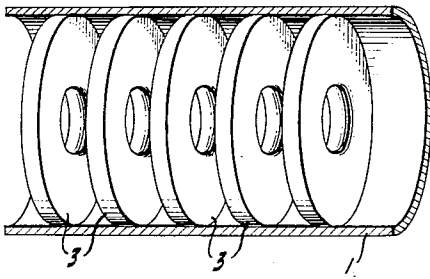


FIG. 2

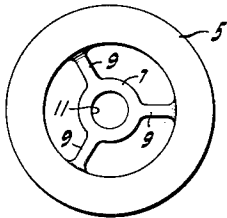
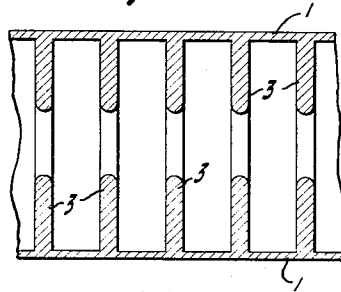


FIG. 3

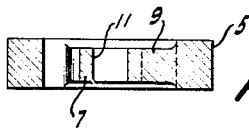


FIG. 4

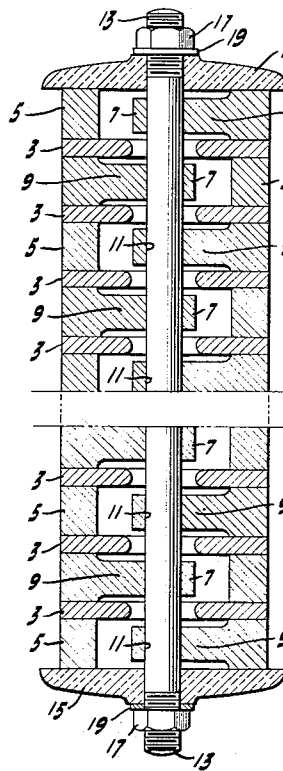


FIG. 5

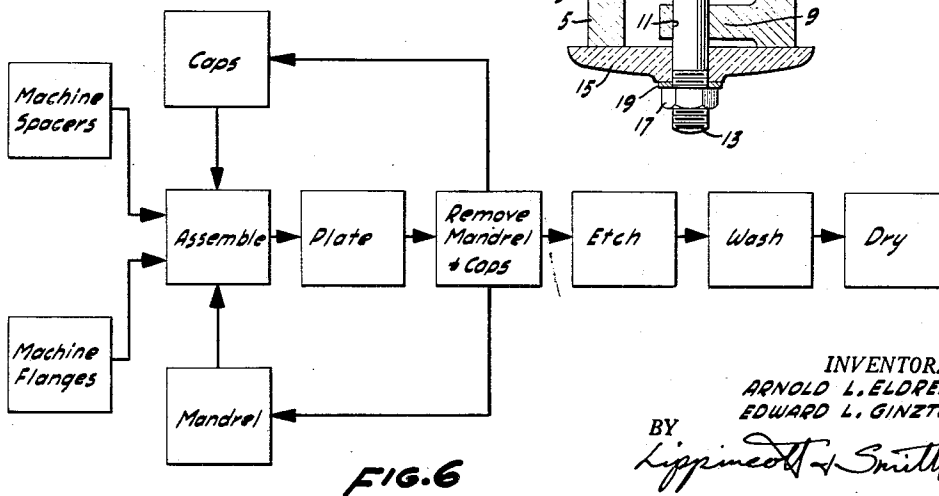


FIG. 6

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METHOD OF FORMING INTERNALLY FLANGED STRUCTURES

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6 Claims. (Cl. 204—9)

This invention relates to methods for making highly conductive internally flanged metallic structures to exact dimensions, within extremely fine limits or tolerances. The invention is adapted to the construction of cavity resonators in general and, in particular, to the construction of disc-loaded wave guides of the type employed in linear electron accelerators, which, it will be recognized by those skilled in the art, can be considered as being comprised of a long series of coupled cavity resonators.

A linear electron accelerator of the disc-loaded type comprises a tubular body which has, spaced along its length, a plurality of internally projecting flanges or "discs" of annular form, which divide the accelerator into a plurality of coupled, resonant cavities. The body as a whole comprises a wave guide, which is excited, from one end, by a suitable source of microwave power. Electrons are injected at the input end of the device, and if the dimensions are proper and the electrons are injected in the proper phase of the traveling waves existing in the wave guide, these electrons travel constantly in a field which tends to accelerate them and add to their energy. Under proper conditions the electrons can be brought up to within a few percent of the speed of light in the first few inches of their passage through the accelerator structure.

It is well known that in a wave guide the phase velocity of the waves carried thereby is, in general, greater than the speed of light while the group velocity or energy velocity is less than the speed of light, so that in effect it takes a measurable interval after the application of power to fill the accelerator with energy. The rate of expenditure of energy during the period when electrons are being accelerated is very high. Therefore, in order to operate the device with driving equipment of reasonably low power, a preferred mode of operation is to provide the energy in pulses, so that although the instantaneous expenditure is high the average power required is moderate. The purpose of disc-loading accelerator-guide is to slow both the phase and the energy velocity. The device is so designed as to reduce the phase velocity to the speed of light. The energy or group velocity is reduced to perhaps $\frac{1}{100}$ of this value. The pulses are so timed that the entire guide will be filled with energy, and hence able to accelerate the electrons within it, during the desired pulse periods, but it is unnecessary to keep it excited during the intervals between pulses. At the same time the phase velocity is such that the electrons, traveling with nearly the speed of light during most of their journey, "ride the crests" of the waves traveling down the wave guide accelerator and gain energy during their entire passage.

In order to secure this effect and operate the accelerator at a high efficiency it is necessary that the characteristic impedance of the loaded guide be extremely uniform throughout its length. The spacing of the loading discs should be not greater than a free-space quarter wavelength of the exciting wave and the dimensions of the cavities formed by the loading discs must be uniform to an extremely high degree of accuracy. How great the

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accuracy required must be may be illustrated by an example: in an accelerator designed for operation at a free-space wavelength of 10.55 centimeters the internal diameter of the guide, between loading discs, is 3.247 inches plus-or-minus 0.0002 inch. The distance between loading discs, center to center, is 1.028 inches plus-or-minus 0.001 inch. The thickness of the loading discs is 0.231 inch plus-or-minus 0.0002 inch and the internal diameter of the central opening through each disc is 0.731 inch plus-or-minus 0.0005 inch. The length of the entire structure is six feet.

The electrical conductivity at the junctions between the loading discs and the body of the guide must be as high as possible. Any lumps of solder which might be used in connecting the discs to the guide would cause irregularity, which would set up standing waves; i. e., reflected waves traveling in the opposite direction from the main flow of energy, which would tend to decelerate the electrons of the beam and cause a material drop in over-all efficiency.

If the errors in construction are random and are held within the tolerances as listed above, the reduction in electron energy due to construction errors will be only about 0.5 percent, but if the tolerances are relaxed, the energy lost rises very rapidly. Doubling the tolerances increases the energy loss eight-fold, and further relaxation of the tolerances cause an even greater rise in the losses.

Electron accelerators have been constructed to within the recited tolerances by forming the loading discs to the required degree of accuracy, mounting them upon a mandrel between spacers which can later be retracted, and shrinking the outer guide upon the discs. Accelerators of this type, however, have to be constantly pumped to maintain the required degree of vacuum within them, since raising the structure to the temperature necessary to drive out adsorbed or occluded gases would necessitate heating the outer tube to beyond its annealing temperature, so that it would no longer hold the loading discs tightly enough to maintain the desired electrical contact and low resistance. Brazing or sweating the discs in place, using either hard or soft solder, has resulted in solder accumulations at the joints, setting up impedance irregularities and resulting in standing waves, and moreover, it has been found difficult if not impossible to maintain the accuracy of spacing desired during the operation. No other conventional method of construction has proved satisfactory for giving the desired degree of mechanical accuracy in a device which could be de-gassed, completely evacuated, and sealed off.

From the foregoing it should be apparent that the principal objects of the present invention are to provide a method of constructing internally flanged structures to a high degree of dimensional precision, to provide a method of fabricating such structures so that they are metallically continuous and of low electrical resistance; to provide a method of constructing objects of the class mentioned, the walls of which are sufficiently homogeneous and non-porous to form the envelopes of evacuated apparatus; to provide a method of constructing tubular loaded wave guides which are substantially free of impedance irregularities and which may be sealed, evacuated, and out-gassed without disturbing their structural precision; and to provide a method of building such structures which does not require the use of unusual tools or techniques, as far as the individual steps in the methods are concerned.

Considered broadly, the method of the present invention comprises the steps of forming individually the inwardly projecting flanges of the metal which is to comprise the completed structure, e. g., copper, silver, or gold, to exact dimension as regards their internal di-

ameter, thickness, and contour, forming spacers of a different metal, as far as possible removed from the flange material in the potential series and preferably an amphoteric metal such as aluminum or zinc, to the exact dimensions as regards outer diameter, thickness and contour, of the finished internal diameter of the wave guide, the interspace between the flanges, and the contour of the flanges respectively, the spacers preferably comprising a relatively heavy rim of the required inter-flange spacing and a lighter web, of somewhat shorter axial length than the rim, which is apertured longitudinally. Spacers and flanges are then assembled, alternately, into a stack of the length of the completed guide, the assembly preferably being accomplished under water. The ends of the assembly are capped, preferably by closures of insulating material, the assembly is immersed in a plating bath, and a coating of the required thickness to form the wall of the guide is electro-deposited upon flanges and spacers alike. The resultant structure is then taken from the plating bath, the caps are removed, and the assembly is placed in an etchant which will attack the spacers but not the material of the guide itself; while there are numerous materials which will do this, the particular one chosen depends in part upon the material of the spacers and in part upon convenience; if aluminum spacers are used the choice is usually a strong solution of a caustic alkali, preferably sodium hydroxide. When dissolution of the material of the spacers is complete, the assembly, now a unitary structure, is removed from the etching bath, washed, dried, and is then ready for assembly into a complete device, which may be out-gassed and exhausted in a conventional manner, the electro-deposited structure forming the envelope of the accelerator or other structure for which the device is designed.

The invention will be more clearly understood from a detailed description of the method which follows, taken in conjunction with the accompanying drawings wherein:

Fig. 1 is an isometric drawing of a portion of a loaded wave guide as constructed in accordance with the method of the instant invention, the nearer wall of the guide being broken away more clearly to illustrate the construction;

Fig. 2 is a fragmentary cross-section of a completed wave guide of the type illustrated in Fig. 1;

Fig. 3 is a plan view of a spacer for use in the use in the construction of a wave guide in accordance with the present invention;

Fig. 4 is an axial cross-section of the spacer illustrated in Fig. 3, the plane of section being indicated by the line 4-4 of Fig. 3;

Fig. 5 is a cross-sectional showing, on a smaller scale, of an assembly of loading discs and spacers, ready for the electro-deposition operation; and

Fig. 6 is a flow sheet indicating the steps of the method.

The method of the present invention will be described as it is applied to the construction of the accelerator wave guide, the dimensions of which, together with the tolerances in those dimensions, were cited above in the general discussion of the background of the invention. It will at once be recognized, however, that the same method can be employed in the manufacture of nearly any hollow body which requires extreme dimensional accuracy. In the particular example chosen for illustrative purposes the cavities must be uniform in size. For other applications cavities of different or graduated dimensions may be required, and, in fact, the uniform structure which will be described has been combined with other sections including non-uniform cavities for certain specific purposes.

The cut-away isometric drawing of Fig. 1 illustrates a short section of uniform, disc-loaded wave guide, comprising a tubular sheath or wave guide proper 1, along which, at precise intervals, are disposed loading-disc 3. Fig. 2 shows a cross-section of the same structure. The section-lining in Fig. 2 is intended to illustrate the uniform, homogeneous character of the discs and the shell of

the wave guide. There is no brazed or soldered connection to break the conductive continuity between the loading discs and the shell, nor is a mere pressure contact relied upon to form the electrical connection, but the entire structure is a unitary homogeneous mass. The extreme accuracy required in the various dimensions has already been emphasized, as has the fact that it is this requirement for accuracy which renders conventional methods of manufacture completely unsuited for the purpose.

In the manufacture of the wave guide thus illustrated the first steps are the manufacture of the loading discs 3, and the spacers which separate them. The loading discs are not separately illustrated, since their form is believed to be completely apparent from the showings in Figs. 1 and 2. In the manufacture of the discs the critical dimensions are the thickness and the diameter of the central opening. The outside diameter is relatively unimportant, since the outer periphery will merge with the shell in any event. If desired the outer periphery may be knurled or otherwise roughened to give a greater area of contact with the shell which is later to be electro-deposited thereon, but experience has shown that such roughening is unnecessary to the formation of a homogeneous union between the discs and the shell. Making the external diameter of the loading discs equal to the internal diameter of the shell is of assistance in the ultimate alignment of the discs and spacers and is therefore preferred. The preferred material of the discs is oxygen-free copper, but other materials may, of course, be used.

In order to obtain the exact dimensioning of the discs as to thickness, the final dimensioning may be achieved by either a turning or a lapping process. The internal diameter is obtained, preferably, by turning, since usually the internal edge is rounded, as shown in Fig. 2. Because of the relatively high coefficient of thermal expansion of copper, it is particularly important, if the tolerances are to be maintained, to prevent any material heating of the parts during the latter stages of machining. To this end, not only are the finishing cuts very light, as must always be the case with extremely fine work, but large amounts of coolant are used to flood the cutting tool and the coolant used is taken from a thermostatically controlled bath which is maintained at constant temperature, preferably differing by only a few degrees from the normal ambient, above or below, so that very slight heating or refrigeration, as the case may be, will maintain constancy.

One suitable form of spacer is illustrated in Figs. 3 and 4. The spacer shown comprises a relatively heavy rim 5, joined to a central hub 7 by an apertured web, the latter in this case, comprising spokes 9. The hub is pierced by an aperture 11, by means of which the spacers may be aligned on a mandrel. The spacers are formed of a metal well separated from that of which the discs are formed in the electro-potential series, and preferably of one of the amphoteric metals, such as aluminum or zinc, which can comprise the acid radical in the formation of salts and hence be strongly attacked by an alkaline etchant.

The spacers are machined to size, using the same precautions as those already specified in connection with the machining of the loading discs. In the case of the spacers, however, the two dimensions which are important are the outside diameter and the axial width of the rim, with the added factor that the rim should be conformed exactly to the surfaces of the loading disc against which it is to abut. In the present instance this means, of course, that the top and bottom surfaces of the rim must be plane and parallel. The radial thickness of the rim 5 is not important, as long as it is thick enough and strong enough to support itself, and the loading discs against which it abuts, under a moderate degree of axial compression, sufficient to insure a substantially water-tight joint when the discs and spacers are assembled. In order that the pressure may be concentrated at the rim, the web and

hub are preferably relieved as shown, and this means that there is less material to be etched away.

It is desirable that after manufacture both the loading discs and the spacers be stored at a substantially constant temperature until they are ready to be assembled, so that there will be no material temperature differences (and therefore dimensional differences) in the parts when they are assembled.

When ready for assembly the spacers and loading discs are stacked alternately, as illustrated in Fig. 5, and clamped together so as to form a rigid structure. For a wave guide the easiest method of assembling and clamping is to string the parts on a mandrel 13, passed through the bore 11 in the hubs of each of the spacers. Caps 15, preferably of insulating material, are provided at the top and bottom of the resultant stack, and the whole assemblage is clamped together by nuts 17 bearing against washers 19 which, in turn, bear against the caps. In the particular device here described, where the internal dimensions of the cavities forming the guide are of extreme importance, there is no such critical relationship with respect to their alignment, and therefore, in this instance, no particular precautions are taken to insure that the various cavities are strictly coaxial. A deviation of a few thousandths is here of no importance, and some rough computations show that even if the discs and spacers were mutually displaced, laterally, by as much as $\frac{1}{16}$ inch there would probably be no measurable effect on the efficiency of the accelerator; the crudest methods are ample to secure better alinement than this. In the event that exact alinement is desired, the outer diameters of the loading discs and spacers can be machined to the same diameters and tolerances, and the assembly made by alinement in an accurate V-block. For the present purpose, however, this is unnecessary.

Preferably the assembly is made under water, in a bath of the same temperature as that within which the plating is later to be done. When thus assembled the inside of the stack of discs and spacers is, of course, filled with water. Accordingly when the assemblage is removed from the assembly tank and immersed in a plating bath there is no differential pressure established between the cavity within the assembly and the liquid without. There is therefore no tendency for the electrolyte which is used in the plating to enter the junctions between the spacers and the caps and, perhaps, deposit metal on some undesired portion of the discs or flanges, within the tube or form a fin at the ends of the terminal spacers. The cavity within the assembly could, of course, be filled with water after assembly, but such a procedure would be inconvenient and might result in incomplete filling and a resulting pressure differential.

The completed assembly is immersed in a conventional plating bath and treated in customary fashion to obtain a deposit of copper (in the present case), of the desired thickness. Preferably the assembly is mounted vertically in the bath and is moved either in a pendulum fashion or merely oscillated forward and backward during the entire coating operation to insure that the plating process is uniform, free of flaw holes. To insure complete uniformity of plating, it is found convenient to rotate the cylindrical structure at intervals by about 90° . The mechanism of oscillation of the mandrel of the assembly in the bath is of a conventional type, and equipment for its accomplishment is not, therefore, illustrated.

When the plating is complete the assembly is removed from the bath, washed, and the caps and mandrels removed.

The assembly is then placed in a suitable etching solution, which will attack the spacers but not the copper. In practice the cheapest and most satisfactory etchant for use with aluminum spacers is a strong solution of sodium hydroxide—caustic soda. This same material is also an effective etchant where zinc spacers are employed. It leaves the copper surfaces clean and bright, without

any adherent metal, and with cavities whose dimensions are determined solely by the sizes of the spacers used. No treatment which might affect the dimensions of the parts is required, mere washing being sufficient. If the electro-deposition of the shell has been accomplished in accordance with known and conventional plating technique, and the parts are chemically clean and free from oil at the time that the plating is done, the junction between the discs and the shell of the loaded guide are electrically perfect. The deposit of copper, or other material chosen for the shell, is homogeneous and of high conductivity. Test samples, cut apart and polished, show no line of demarcation between the loading discs and the shell, although by etching and microscopic analysis differences in crystallization can be detected. Most important, no stresses are set up in this structure which would tend to cause deformation when the device is baked in order to outgas it.

Under ordinary conditions it is not necessary to use thermostatic control to maintain substantially constant temperature for either the assembly bath or the plating bath, since these are usually of sufficient volume and thermal capacity so that their temperature will remain substantially constant and uniform throughout. During the initial stages of the plating, however, the temperature of the plating bath should be kept constant to within about 1°C .; if because of large changes in ambient temperatures, small volume of the baths, or material resistive heating thereof, the temperature changes would exceed this value, thermostatic control should be provided during at least the deposit of the first $\frac{1}{10}$ to $\frac{1}{8}$ inch of the coating.

The various steps in the method are illustrated in the flow-sheet of Fig. 6. In general this flow sheet needs no explanation beyond that given above. It will be clear that if the structure built is designed uniquely for a specific duty the mandrel and caps will usually have to be made especially for the purpose. If the structures are to be sections of a longer accelerator the mandrel and caps can be used, repeatedly, and the same holds true if more than one device of a kind is to be constructed.

In connection with the assembly of sections, made in accordance with the method described herein, into longer assemblies, it is of interest that the clean ends of the sections permit their union by the diffusion process, wherein the ends of two sections are abutted with a sheet of gold-leaf between them, clamped in position and raised to a temperature less than the melting point of either the copper or the gold. The diffusion of the gold molecules results in an alloy which forms a secure, gas tight joint, without appreciable dimensions, even as compared to tolerances such as have been specified.

Neither heating such as is used in this process, nor the higher temperatures used in outgassing, affect the dimensional stability of devices constructed as herein described. The electro-deposited shell is unstressed in its formation, and therefore heating causes no warping due to release of stresses.

Having thus described the invention, what is claimed is as follows:

1. The method of forming a disc-loaded homogeneous, internally flanged cavitied structure of exact internal volume which comprises the steps of shaping flanges of the metal to comprise said structure to the exact internal and thickness dimensions of the completed structure, shaping centrally apertured spacers of the exact thickness of the desired separation between said flanges and outer dimensions of the desired cavities and of a different metal from that of said flanges, assembling said flanges and spacers alternately to form a stack, capping the ends of said stack to prevent the entry of liquid therein, clamping the capped stack together to present a continuous outer surface, plating a continuous layer of the metal to comprise said structure on said outer surface,

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removing the capping from said structure, and etching the metal of said spacers from the interior of the structure.

2. The method as defined in claim 1 which includes the additional steps of maintaining said flanges and said spacers at a substantially constant temperature throughout said shaping and assembling operations.

3. The method of forming internally flanged tubular metallic structures to exact dimensions which comprises machining a plurality of discs of the metal to be used to the form of the flanges and to the required tolerances, maintaining a body of coolant at a substantially uniform temperature, bathing said discs in the said coolant during the machining operation, similarly machining a plurality of spacers from a metal spaced from the metal of said discs in the potential series, said spacers including apertured webs extending across the central portions thereof, assembling said discs and spacers alternately into an alined stack, clamping said stack in its alined position, immersing said stack in a plating solution and electro-depositing therefrom a coating of the metal of said discs on said stack, and thereafter dissolving said spacers from the interior of the resultant structure.

4. The method of forming homogeneous internally-flanged metal tubes of exact dimensions which comprises the steps of shaping a plurality of metal flange discs to the dimensions required of the internal flanges, shaping from a different metal a plurality of centrally apertured spacers having opposite faces conformed to bear against said flange-discs and outer peripheries dimensioned to conform to the internal diameter of the desired tubular structure, stacking said flange discs and spacer discs alternately in alinement and clamping the resultant stack in compression to form a rigid assembly, electro-depositing a continuous coating of the metal of said flange-discs on the peripheries of said flange-discs and spacer discs alike and of sufficient thickness to support said flange discs rigidly, and immersing the resultant structure in an etchant to dissolve said spacer discs from the interior thereof.

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5. The method as defined in claim 4 which includes the steps of filling the assembled spacers and flange discs with liquid and capping the assembly to retain said liquid therein prior to the electro-deposition of the coating thereon.

6. The method of forming unitary, internally flanged tubular metallic structures to exact dimensions which comprises the steps of shaping individual flanges of the metal to be used to the required tolerances, shaping spacers corresponding to the required separation between said flanges to like tolerances, said spacers being formed of a different metal widely spaced in the potential series from said first mentioned metal and provided with apertured webs which extend across the central portion of said spacers and have substantially identical apertures formed therein adapting them to be strung on an alining and clamping mandrel, constructing a mandrel of a length somewhat greater than the tube to be constructed and of a diameter to fit the alining apertures in said webs, assembling said flanges and spacers alternately and in alinement on said mandrel, and clamping the assembly so formed into a rigid bar, electro-depositing a coating of the metal of said flanges on said flanges and spacers alike, and immersing the assembly in an etchant which will attack the metal of said spacers to the exclusion of that of said flanges to dissolve said spacers and leave an internally flanged unitary tube.

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