May 27, 1941. W. DUBILIER 2,243,814

ELECTROLYTIC CONDENSER

Filed Nov. 5, 1937 2 Sheets-Sheet 1

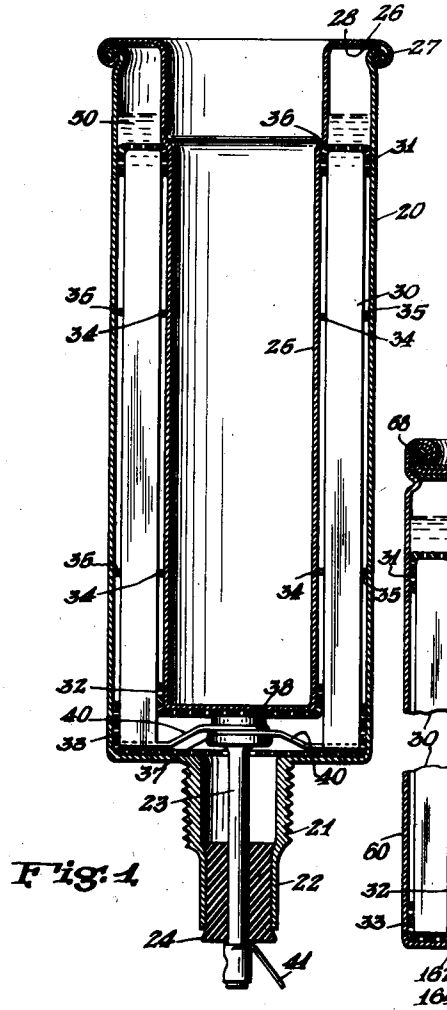


Fig: 1

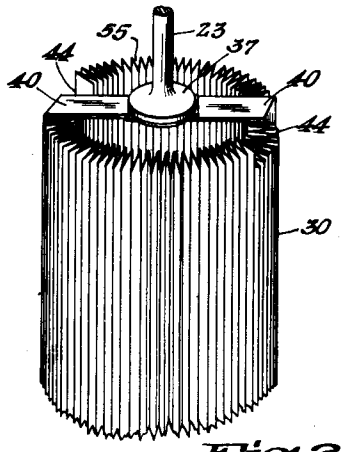


Fig: 2

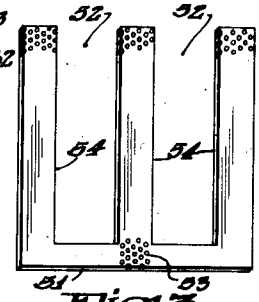


Fig: 3

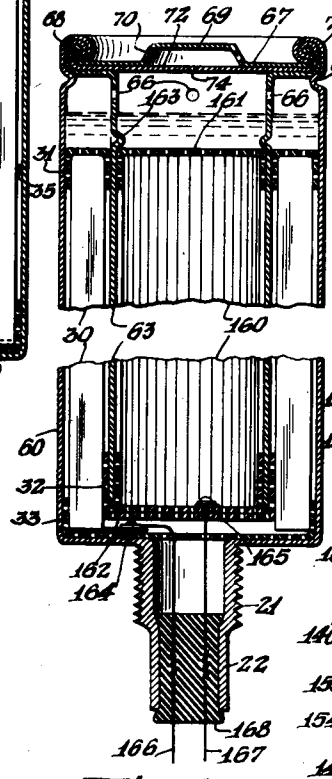


Fig: 13

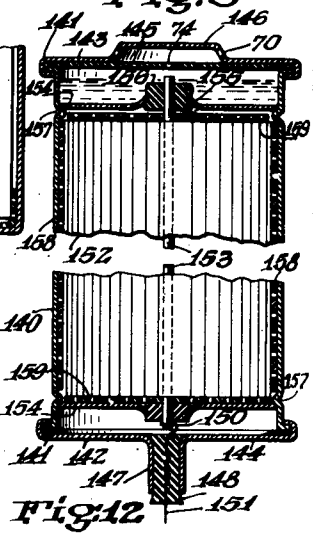


Fig: 12

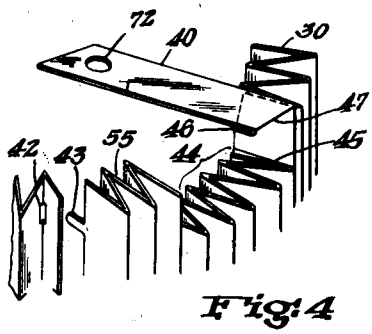


Fig: 4

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ELECTROLYTIC CONDENSER

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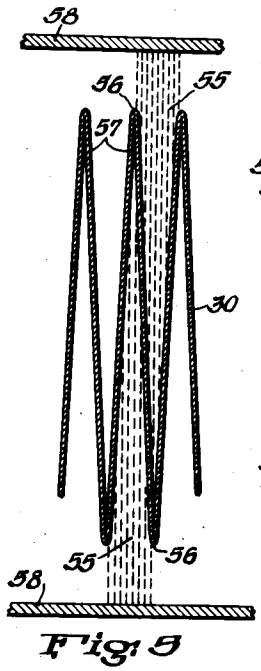


Fig: 5

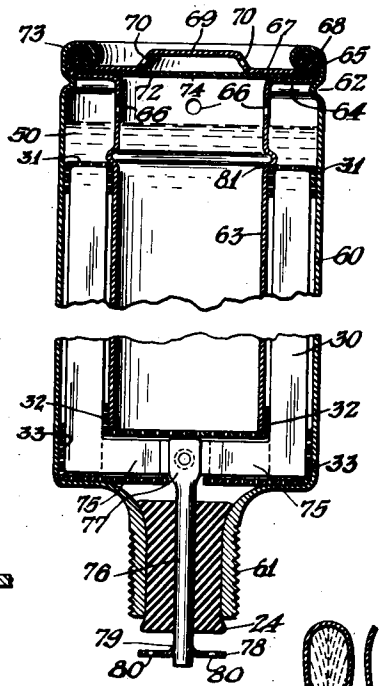


Fig: 8

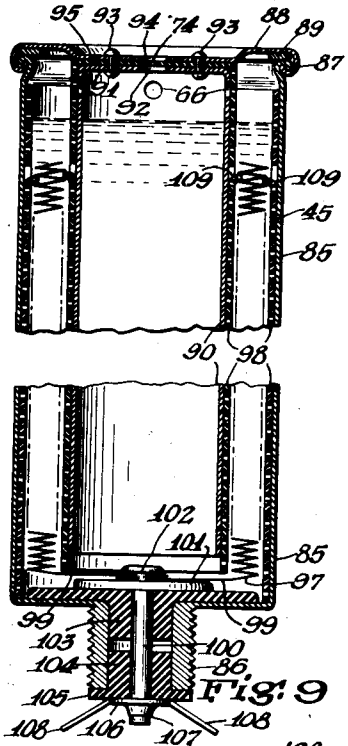


Fig: 9

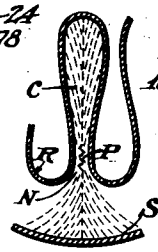


Fig: 6

Fig: 7

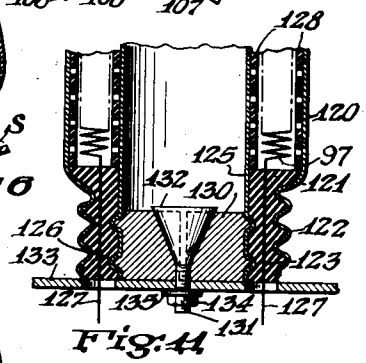


Fig: 11

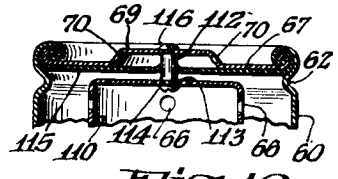


Fig: 10

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UNITED STATES PATENT OFFICE

2,243,814

ELECTROLYTIC CONDENSER

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Application November 5, 1937, Serial No. 173,025

6 Claims. (Cl. 175—315)

This invention relates to electrolytic condensers of the type having a large area of anode surface in a small space, and more particularly but not exclusively to such condensers having a tubular metal container the walls of which serve as a cathode.

Heretofore it has been proposed to fold, corrugate or crimp strip-like or tubular anodes and also to provide rod-like anodes with projecting fins or geometric designs in order to increase the anode area in a given space. It has further been proposed to etch, emboss, or roughen the anode, thus increasing the effective area and thereby obtain more capacity in a given container or can. Prior anode structures having corrugations or the like, can be divided into two classes. In the first class the corrugations are open and their depth is comparable with the spaces between adjacent corrugations. This results in only a moderate increase in anode area and capacity. In the second class the corrugations are close, that is, the spaces therebetween are small relative to the depth of the corrugations.

While anodes of the second class may provide several times the area of anodes of the first class, I have found that the close or deep corrugations proposed heretofore have the serious defect of increasing the equivalent series resistance of the condenser and thereby increasing its electrical losses. A cause for such defect is that, in practice, the sides of a deep corrugation tend to bow away from each other near the apex of the fold and to close up the open space opposite the apex of the fold, thereby forming a bottle neck. The relatively small, narrow cross-section of electrolyte in such bottle neck offers a high resistance to the condenser current and inasmuch as electrolyte resistance is an important factor in the equivalent series resistance of a condenser, such resistance is unduly increased.

The equivalent series resistance or power factor of an electrolytic condenser is made up of three factors, namely, the resistance or losses within the dielectric film, the contact resistance of the electrolyte to the cathode, and the electrical resistance of the electrolyte. The dielectric film is composed of a thin layer of anhydrous and hydrated metal salts in intimate surface contact with the anode. It has been found that the resistance or dielectric losses within this metal salt layer are very small and the phase angle difference of the condenser due to such dielectric losses is only a small fraction of a degree (about two or three minutes). The second factor, or cathode-to-electrolyte contact resistance or loss, has been found to be reasonably small and the phase angle difference of the condenser due thereto may be of the order of one degree or less, and can be reduced materially by using suitable cathode metals, such as copper, nickel, chromium or other non-filming metal. The third factor, or electrical resistance of the electrolyte, gives rise to much greater phase angle differences than the first two factors combined, such differences being about five to nine degrees for electrolytes adapted for operation at several hundred volts. Hence the electrolyte resistance is the determining factor and a low resistance path through the electrolyte will result in a low phase angle difference and correspondingly low equivalent series resistance in the condenser. This becomes increasingly important in condensers for higher operating voltages because such condensers require electrolytes of relatively high resistivity. For instance, the electrolyte for a 450-volt condenser may have a resistivity of about 550 ohms per cm. cube; for a 475-volt condenser the resistivity may be about 700 ohms per cm. cube; and for a 500-volt condenser it may be about 950 ohms per cm. cube; all said resistivities being measured under the same conditions. It can be seen from such examples that the resistivity of the electrolyte is increased in greater proportion than the voltage and that the detrimental effect of bottle necks or other restrictions in current paths through the electrolyte is of special importance in high voltage condensers.

It is an object of the present invention to provide maximum of an electrode, in particular of e. g. the anode area in a given space without materially increasing the equivalent series resistance or power factor over that of a condenser having an uncorrugated anode or an anode with open corrugations.

This object is accomplished according to one feature of the invention by pleating the anode so that the folds forming the pleats are as sharp as possible and so that the sides of the pleats form small acute angles with each other. I have found that such pleating keeps the sides substantially straight and prevents the bowing and bottle necks above mentioned. Preferably the acute angle is not less than five degrees; or, in other words, the triangular open spaces between pleats preferably should have a base of at least about one-tenth the altitude or depth of pleat.

Another feature of the invention that contributes to realization of the above object relates particularly to pleated anodes for insertion in the usual round type of condenser cans of given

diameter. According to such feature, the depth of pleat is so related to the given outside diameter of the anode that maximum capacity is obtained consistent with maintaining a given angle or triangular space between pleats.

Another object of the invention is to reduce the equivalent series resistance of condensers, e. g., of the types above mentioned. This is accomplished by giving the anode a ring or annular shape and providing a, preferably, cylindrical cathode surface both inside and outside thereof, also by insulating the electrodes so as not to obstruct the current paths.

Another object is to dispose a plurality of anodes in low resistance relation to a cathode surface.

Another and related object of the invention is to improve the mounting of anodes in condenser cans, such mountings being mechanically independent of the anode lead or terminal.

A further object is to improve anode terminal connections.

Another related object is to improve the operating characteristics of electrolytic condensers known as the voltage-regulating type.

Other objects and advantages of the invention will be apparent from the following detailed description of certain embodiments thereof, in connection with the accompanying drawings in which, by way of examples,

Fig. 1 is a cross-section of an assembled condenser embodying the invention.

Fig. 2 is a perspective view of a preferred form of pleated anode with a terminal connected thereto.

Fig. 3 is a perspective view of an insulator for use between anode and cathode.

Fig. 4 is a detail perspective view showing a method of forming a tab connection.

Fig. 5 shows the preferred shape of anode pleats, greatly magnified.

Fig. 6 is a diagrammatic showing of the resistance paths between the anode and cathode in a condenser having a bottle-necked corrugation as above mentioned.

Fig. 7 is a graph showing the total length of anode foil for various depths of pleat of given included angle that can be disposed in a given diameter circle or container.

Figs. 8 and 9 are cross-sections of other assembled condensers embodying the invention.

Fig. 10 is a partial section of a cathode support and valve for relieving pressure from a condenser.

Fig. 11 is a partial section of an assembled condenser embodying the invention and illustrates means for mounting the same.

Fig. 12 is a cross-sectional view of a modified form of anode mounting.

Fig. 13 is a cross-sectional view of an assembled condenser having a plurality of anodes according to the invention.

Similar reference numerals indicate similar parts throughout all the figures of the drawings.

Referring particularly to Fig. 1, the container 20 which also may be a cathode, comprises an integral mounting type can having an extruded threaded portion 21 and a deformable neck 22 for hermetically sealing an anode rod 23 with a soft resilient bushing 24. The bushing may be a rubber stopper having a hole therethrough and is positioned on the anode rod within the deformable neck 22, which is then indented or pressed inwardly such as by rolling, spinning, staking or the like, producing a liquid tight seal. An inner container or cathode 25 which may be a pressed aluminum can, extends inside the can 20 and has an outwardly flanged top 26 which serves as a cover extending over a flange 27 on can 20 and is roll-seamed or pressed therewith. The joint of the two cans may be made self-venting by the inclusion of a plastic filled gasket 28 such as plasticized or wax impregnated paper or gauze. An annular pleated anode 30 is disposed in the annular space between cans 20 and 25 and is insulated therefrom by a top washer 31 of U-shaped cross-section. The anode is further insulated at its opposite end by a cup-shaped washer 32 which surrounds the bottom of inner cathode 25, and by a third cup-shaped washer 33 disposed in the bottom of outer cathode 20. A hole for lead 23 is provided in washer 33 in alignment with the extruded neck 22 and with the insulating bushing 24. The washers may be made of any suitable insulating material such as perforated hard rubber, Celluloid or the like which may be pressed to shape. Alternatively, two or more elastic bands 34 may be placed around the inner can 25 and similar bands 35 placed around the outside of the anode 30. In such case flat insulating washers may be used instead of the cup-shaped washers of Fig. 1. The inner container 25 may be provided with projections or a rolled-out step 36 which engages washer 31 and further secures the anode in position. The anode terminal or lead 23 may be upset or provided with a boss as shown at 37 and riveted over anode tabs 40 as indicated at 38. For circuit connections, a solderable lug 41 is secured to the outer end of the anode lead 23 such as by staking.

A structure of anode 30 is more clearly exemplified in Figs. 2 and 4 in an inverted position. It is made of thin sheet metal of a width equal to the height of the anode. To form the anode a metal sheet or strip is bent backwards and forwards upon itself or is passed through a pair of toothed rollers or gears. The pleats thus formed may be made with a large angle and then pressed together to the desired angle, or pressed to make the folds as sharp as possible and to make the pleats flat. Then the pleated strip may be stretched out sufficiently to give the desired triangular space between the pleats and the desired angle at the fold or apex as more fully described below.

For the annular form of anode illustrated in Fig. 2, a pleated strip is bent into the form of a ring with its meeting edges joined together. The joining may be done by meshing the end pleats but if a more secure arrangement is desired, one meeting edge may be provided with slots 42 in the end fold, which slots are adapted to be engaged by tongues 43 in the other meeting edge as shown in Fig. 4. Bending the tongues backward upon themselves then locks the meeting edges together.

A strip or tab 40, as more clearly shown in Fig. 4, is cut from the pleated anode leaving a space 44. The tab is twisted or bent into a horizontal position as indicated at 45, 46, and 47, thus placing the tab in a horizontal radial position extending to the center of the anode. If desired, a second strip or tab 40 is formed diametrically opposite the first tab as shown in Fig. 2. The tabs may be joined together and secured to the terminal 23 such as by riveting or welding. A suitable film-forming and film-maintaining electrolyte is indicated at 50 in Fig. 1 as substantially filling the space between cans 20, 25 and covering the top of anode 30. Such an electrolyte may comprise a solution or ester of a weak acid or weak acid salt as is well known.

Instead of using insulating washer or elastic bands as shown in Fig. 1 or perforated tubular insulation as described below, insulating pieces such as shown in Fig. 3 may be inserted between the anode and the cans. This insulating piece 51 is cut in the form of an E with spaces left at 52 to provide substantially unobstructed current paths to the cathode. The material is preferably very thin sheet rubber or Celluloid and is provided throughout with small perforations such as shown at 53. Such E-shaped piece may be bent into a circular arc and thus provide three upstanding or circular strips 54 spaced about the container or anode for maintaining the anode and cathode surfaces in insulated, closely spaced relation.

Fig. 5 shows, on enlarged scale, the preferred shape of anode pleats forming spaces 55 each of which is an isosceles triangle, the base being at least about one-tenth the altitude and the peak or apex 56 being preferably as sharp as possible. If the pleats are ½ inch deep, for instance, the minimum opening at the base of the triangular space 55 should be about .05 inch, for the said ratio of depth to base. The same shape and proportions may be used for other depths of pleat. The sides 57 of each pleat taper uniformly from the base toward the apex and the included angle between the sides may be about five or six degrees, which is the desired minimum. For angles of less than five degrees or for less space across the base, the condenser resistance or phase angle difference will increase unduly because in such case the width of the current path will be insufficient to carry all the current for the electrode area formed by the sides of the pleat, which current must pass through the base of the triangular body of electrolyte. I have found that the above minimum proportions prevent the creation of too high resistance in such triangular body. Also the straight uniformly converging sides maintain the proportion up to the apex of the angle.

The dotted lines in Fig. 5 indicate how such a triangular pleat according to the present invention provides straight, direct, uncongested paths from every part of the anode surfaces to the adjacent cathode surfaces 58, all said current paths being in parallel both physically and electrically, and having sufficiently large cross-section so as to offer low resistances. The provision of cathode surfaces on both sides of the pleated anode make such paths available to pleats opening in opposite directions as indicated in Fig. 5. The result is a very low resistance through the electrolyte between the entire anode and cathode surfaces.

In contrast, Fig. 6 illustrates what happens in practice when corrugations are formed with a relatively large radius of fold R or when attempting to make the sides of the corrugations parallel. The resilience of the metal in adjacent folds closes the opening of the corrugation therebetween, at least partially, thus forming a bottle neck N of small cross-section and relatively high resistance. The individual current paths C from the anode surface within the corrugation converge at the bottle neck N so that the high resistance path P therethrough is effectively in series with the paths C. After passing through the bottle neck the individual current paths spread out toward the cathode S. Hence there are two factors by which such bottle necks unduly increase the equivalent series resistance and losses of a condenser, first the high series resistance common to all the individual current paths, and second, the lenghtening of such paths by forcing them to converge and then diverge. Both of these factors are avoided in pleated anodes according to the present invention as illustrated in Fig. 5.

When such a pleated anode 30 is to be bent into a ring of given outside diameter as shown in Fig. 2, the depth of the pleats is not fixed and they can be deep or shallow as desired. However, I have found that for a given outside diameter of anode, foil thickness, and minimum included angle of pleat, there is an optimum depth of pleat which will give a maximum total length of anode foil within a given outside diameter, and therefore will give maximum capacity in the given space. If the depth is greater than such optimum the inside circumference of the anode ring will be smaller and the bases of the triangular spaces will be larger, hence the number of pleats in the anode ring will be decreased by both said factors. On the other hand, for less than optimum depths of pleat, the loss of depth overcomes the advantage of increased number of pleats that can be placed in the anode ring.

Two examples of the length of anode foil for various depths of pleat are shown graphically in Fig. 7 and illustrate the optimum depth of pleat for each example. Curve A is for a 1⅜ inch diameter container in which ⅛ inch is allowed for anode insulation and clearance, thereby making the given outside diameter of the anode 1¼ inches. Curve B is for a one inch diameter container having a ⅞ inch diameter anode. In both cases the anode foil is .005 inch thick and the pleats which open inward have the minimum triangular space proportioned as shown in Fig. 5. From the curves, it is apparent that thirty inches of anode foil can be disposed within a 1¼ inch diameter circle if the depth of pleat is between .160 and .230 inch. Similarly, from curve B it is apparent that eighteen inches of foil can be disposed in a ⅞ inch diameter circle if the pleats are about .140 inch deep.

By sacrificing an inch or so of foil length a wider range of depth of pleat is made available, but even so the anode surface will be large relative to the space occupied and the condenser resistance will be kept low. Obviously, if a certain depth of pleat is desired to be made standard for simplicity of manufacture, an average depth of pleat may be chosen which will be approximately the optimum for containers of several different diameters. Also, the advantages of the present invention may be substantially realized even if larger pleat angles than five or six degrees are employed. For example, it may be desired to obtain minimum resistance and power factor with less than the maximum obtainable capacity in a given container. In such case a larger pleat angle can be chosen so that the capacity will be maximum for that angle.

Fig. 8 shows a container 60 with a threaded mounting extrusion 61 at the bottom thereof and a bead or shoulder 62 near the top. An inner tubular cathode 63 having an outwardly flanged portion 64 and an upwardly flanged portion 65 rests upon shoulder 62. The inner tube is supplied with holes 66 to allow for equalization of the pressure inside and outside thereof. A cover 67 having an upwardly turned edge 68 and an extended portion 69 with vent holes 70, is roll-seamed with the top edge of container 60. A diaphragm gasket 72 such as rubber, extends across the top of container 60 and makes

a liquid tight seal 73 as a result of the roll-seaming operation. The diaphragm is supplied with a pin hole 74 to allow the escape of gas. An anode 30 such as shown in Fig. 1 is supplied with tabs 75 which extend radially to the center and are secured, such as by riveting, to a riser bar 76 having a flattened portion 77. The anode is insulated from the container 60 by insulating cups 31, 32 and 33, such as were described in connection with Fig. 1. A tapered rubber bushing 24 having a hole therethrough for the riser bar 76 is forced into position in the neck of the container, for instance, by pulling the bushing through from the outside. A solderable terminal 78 in the form of a washer having an extruded neck is secured to the riser bar 76 as by staking at 79. Terminal 78 is supplied with holes 80 for engaging wire terminals. The inner tube 63 may have an outwardly flared bead 81 resting against the insulation 31 for securing the anode in position. This bead may be replaced by outward indentations of the inner tube.

Fig. 9 shows a container 85 with an extruded threaded neck 86 and an outwardly flanged top portion 87 which is roll-seamed to the edge of a cover 88. A sealing gasket 89, such as rubber, is inserted between the cover and the container flange 87. An inner cathode 90 having an inwardly flanged top 91 and a hole 92 is secured to the cover such as by rivets 93. A corresponding hole 94 in the cover is in alignment with hole 92. A diaphragm gasket 95, such as rubber, is placed between flange 91 and cover 88, and is supplied with a pin hole 74 for relieving pressure within the container. Holes 66 equalize the pressure within the container. The cover 88 is indented to sink the rivets 93 below the end of the unit. In the Fig. 9 construction, an anode 97 has circular pleats in a horizontal position. The spacing between the pleats is preferably at least about one-tenth the depth of the pleat for reasons explained above. These pleats may be obtained by rolling a metal tube, such as aluminum. Anode 97 is insulated from the inner and outer cathode surfaces by insulating sheets 98 which may be perforated hard rubber or Celluloid bent into tubular form. The anode is supplied with tabs 99 which are bent inwardly to engage the riser rod 100 between the boss 101 and the riveted-over portion 102. A rubber disc and bushing 103 insulates the boss on the riser rod from the container. An insulating plug 104, having a shoulder 105, is fitted within the neck 86 of the container. The riser rod 100 extends through centrally located holes in bushing 103 and plug 104 and is secured in liquid tight seal by pressure exerted between boss 101 and the outer end of neck 86, by forcing a terminal 106 onto the riser bar 100. An extruded portion 107 of the terminal is so shaped as to bite into the riser bar. Terminal 106 is supplied with solderable lug extensions 108 for electrical connection. The inner insulating tube 98 extends from the cover 88 substantially to the tabs 99 thereby insulating the tabs from the inner container 90 and securing the anode in position. Projecting insulating tabs 109 are cut from the insulating tubes 98 and engage the pleats of the anode for positioning the same.

Fig. 10 shows the upper end of a container 60 having a bead shoulder 62 and a cooperating cover 67 which is roll-seamed to the container, as in Fig. 8. The cover also has an outwardly extending portion 69 with holes 70. An inner container 110 is secured to cover 67 by a rod 112. This rod has a shoulder 113 against which the inner container is secured, such as by riveting at 114. The rod extends through a hole in a rubber diaphragm 115, the hole being slightly smaller than the diameter of the rod 112 thus causing the rubber to extend upward. The rod is secured to the cover such as by riveting at 116. Gas pressure which might generate within the container pushes the diaphragm surrounding rod 112 upward and the gas escapes to the atmosphere through the holes 70. Holes 66 equalize the pressure inside and outside of the inner container 110.

Fig. 11 shows the lower part of an assembled condenser having an outer tube 120 which is provided with a shoulder 121 and a roll-threaded portion 122 which seals a ring-type bushing 123 to an inner tube 125 which is supplied with beads 126. If desired a shoulder, such as 121, but extending outward, may be provided on the inner tube 125 and then outer tube 120 may be straight except for beads similar to 126. An anode 97 such as described in connection with Fig. 9 has leads or tabs 127 extending through the ring bushing. Two tabs are shown to indicate that the anode may be divided within the container thus making a plural anode, common cathode condenser. Insulation 128 such as shown in detail in Fig. 3 and bent into an arc of a circle, insulates the anode or anodes from the container. Such anodes may be secured in position as described in connection with Fig. 9.

The condenser shown in Fig. 11 may be mounted by screwing it into a socket or opening adapted to engage the thread 122. Alternatively a thread for mounting the condenser may be provided on the inner tube 125. By such mountings the central opening provided by the inner tube assists in keeping the condenser cool by reason of air circulation therethrough, especially when the top of the inner tube is open as in Fig. 1.

Fig. 11 also shows an alternative mounting means in the form of a split or divided plug 130 adapted to engage beads 126 on the inner tube. A bolt 131 having a conical head 132 disposed between the halves of plug 130 passes through a panel or member 133 upon which the condenser is to be mounted. By tightening a nut 134 against a washer 135 and panel 133 the parts of split plug 130 are spread apart so as to engage the inner tube and hold the condenser securely in position.

Fig. 12 shows a container 140 having end flanges 141 for securing covers 142 and 143 such as by turning the periphery of each cover over a corresponding flange. An interposed gasket 144 may be used for sealing cover 142. A gasket for top cover 143 may be self-venting as in Fig. 1 or it may be a rubber diaphragm vent 145 having a pin hole 74 to relieve pressure in the container. In the latter case cooperating vent holes 70 are provided in an extended portion 146 of the top cover. The bottom cover 142 is provided with a deformable neck 147 which is pressed or rolled into liquid tight seal with the rubber bushing 148. An aluminum wire 150 is twisted or secured into connection with a solderable lead-in wire 151 and squeezed into a liquid-tight seal within the bushing 148. An anode 152 is mounted in the container by means of a support member such as an aluminum rod 153 to which the anode is secured by welding, riveting or the like. The supporting rod is held in the container by perforated aluminum discs 154 having deformable necks 155 which are pressed into rubber bushings

156, the rod 153 being a tight fit in the bushings. The discs 154 are positioned in the container by bead indentations or shoulders 157. The aluminum wire 150 is secured to the anode support rod at its lower end, such as by wrapping, welding or the like. Insulation 158 such as is shown in Fig. 3 may be used to insulate the anode from the container wall and insulating washers 159 may be used to insulate the ends of the anode from discs 154.

The condenser shown in Fig. 13 has two separate anodes and therefore is a dual capacity condenser. It comprises an outer-container cathode 60, an inner tubular cathode 63, a vented cover 67, a diaphragm gasket 72, an annular pleated anode 30, and cup-shaped insulating washers 31, 32 and 33, substantially as described in connection with Fig. 8. In addition the modification illustrated in Fig. 13 has a second or inner anode 160 which may be pleated or not as desired. The inner anode is supported in closely spaced, insulated relation to the inner cathode 63, for instance, by two additional cup washers 161 and 162 on opposite ends of anode 160. A bead 163, or indentations in the cathode 63 help to keep anode 160 in position. Each anode is provided with a separate aluminum wire riveted or otherwise secured thereto as at 164 and 165, respectively. These wires are secured in electrical connection with solderable lead-in wires 166 and 167, respectively, such as by welding, twisting, or the like, the connections being sealed within a bushing 168 as described above in connection with Fig. 12. The extruded neck of the container shown in Fig. 13 has a threaded portion 21 for mounting the condenser and a deformable portion 22 for sealing as in Fig. 1. It is apparent in the Fig. 13 construction that the additional support capacity obtained from the inner anode 160 does not interfere with, or detract from, the capacity obtained from the outer anode 30. It is also apparent that both the inner and outer surface of the tubular cathode 63 and substantially all of the space within container 60 are utilized effectively.

In the condenser assemblies described above by way of example the anodes are supported independently of their riser rods or lead-in connections. The flexibility of the anode connecting tubes or wires facilitates assembly and prevents transmission of strains from the terminal to the anodes.

The general characteristics of electrolytic condensers and the materials used therein are so well known that description thereof in connection with the condensers shown in the drawings appears to be unnecessary. It may be mentioned however that if a liquid or wet electrolyte is used it is run into the container to a predetermined level with the anode in position, then the inner cathode is put in place thus forcing the electrolyte up to the desired level over the anode as indicated in Fig. 1, for instance about ¼ inch above the top of the anode. The top of the condenser is then roll-seamed and sealed.

The anode may be made of any film-forming metal but aluminum is generally preferred and used. The container and/or other cathode surfaces are preferably non-film-forming, but instead of using a non-film-forming metal therefor, aluminum may be used and may be plated with chromium on the surfaces which make contact with the electrolyte. The inner cathodes shown in Figs. 8, 9, 10 and 13 need not be mechanically strong, so they may be made of very thin metal and in some cases of foil.

The foil used for the anode 24 preferably has its effective area increased 300 or 400 percent by etching the foil before or after pleating, preferably before. This may be done by chemical, electrolytic, or mechanical processes, or by a combination thereof. For instance, a strip of aluminum foil for the anode may be passed through a solution of a halogen salt and a voltage impressed between the aluminum and another electrode, the solution having sufficient resistance to cause breakdown of the dissolved halogen salt into its component parts wherein the halogen will attack the aluminum forming microscopic peaks and craters, thus increasing the surface area of the foil.

The electrolytic film which acts as the dielectric in the condensers described herein may be formed on the anode by well known methods after it is etched, pleated and assembled. However, I prefer, e. g., the following order of process steps for preparing the anode.

1. Cleaning and etching of a straight aluminum foil in a continuous process.
2. A preliminary film formation on the etched foil, also continuous.
3. Pleating the said foil and cutting it into desired lengths.
4. Fabrication of the pleated foil to the desired anode shape and assembly with a terminal.
5. A second film-forming in an aqueous solution containing approximately 100 grams of boric acid and two grams of borax per liter.
6. Assembly in a container with the operating electrolyte, the latter having a temperature of about 80° C.
7. Immediate ageing of the assembled condenser while hot by applying a D. C. voltage equal to the operating voltage, the anode being positive.

Relative to the second above step, I have found that preforming stiffens the foil so that the sides of the pleats are stiffer but without materially increasing the resilience of the folds. Thus the pleating and fabrication are more easily performed and the anode is less apt to be distorted from the desired shape. The presence of the preformed film reduces the coefficient of friction and thus aids the pleating operation, and in addition reduces the time required to form the final film.

Relative to the fifth above step, the forming voltage for the usual type of condenser is preferably 10% above its given operating voltage. However for the voltage regulating type of condenser the forming voltage should be substantially equal to the given operating voltage. The latter type should have a low leakage current at the operating voltage and a rapidly increasing leakage current above the operating voltage. When such a condenser is used in connection with vacuum tubes supplied by a rectifier (as in the usual radio receiver) the condenser leakage current puts a load on the rectifier and prevents the rectifier voltage from rising to dangerous values while the vacuum tubes are heating up or otherwise not drawing their normal plate current. After normal plate current load is drawn by the vacuum tubes the rectifier voltage becomes normal and the condenser leakage is small. In order to perform satisfactorily such a voltage regulating function, the equivalent series resistance of the condenser must be small because such resistance must be overcome

by the leakage current. A high resistance condenser would have a high internal voltage drop and therefore could not reduce the rectifier voltage. The condensers described herein are especially suitable for voltage regulation because they have very low resistance.

The equivalent series resistance is further decreased by reason of the close spacing of the cathode both inside and outside the pleated anode thereby making the current path through the electrolyte short and of large area, and also of low contact resistance between the cathode and the electrolyte. It is understood of course that the height of the anode and cathode surfaces may be chosen as desired, the capacity of the condenser being substantially directly proportional to the height of the anode, other factors being the same.

It is understood that all features of the invention which were indicated as related ones may be applied and used individually and independently from each other, and that any and all details described hereinbefore may be applied and used with condenser structures other than shown hereinbefore by way of example only.

I claim:

1. A container for an electrolytic condenser comprising two aluminum cans, one of said cans having less diameter and length than the other and coaxially disposed therein, a pleated annular shaped anode disposed between said cans, the volume enclosed by the surfaces circumscribing and inscribing said anode being approximately one to one and a half times the volume enclosed by said inscribing surface, a flange closing the annular space between said cans at one end thereof, and a venting gasket forming part of said closure; said cans being individually closed at the other end thereof.

2. An electrolytic condenser comprising a substantially can-shaped cylindrical container, a pleated anode of substantially annular configuration arranged within and in spaced relation to the cylindrical wall of said container, a substantially cylindrical electrode inside and in spaced relation to said pleated anode, said electrode connected with said container, another pleated anode of substantially annular configuration arranged within and in spaced relation to said cylindrical electrode, and an electrolyte contacting said pleated anodes, said wall and said electrode.

3. An electrolytic condenser comprising a substantially can-shaped cylindrical container, a pleated anode of substantially annular configuration arranged within and in spaced relation to the cylindrical wall of said container, a substantially cylindrical electrode inside and in spaced relation to said pleated anode, said electrode connected with said container, another pleated anode of substantially annular configuration arranged within and in spaced relation to said electrode, and an electrolyte contacting said pleated anodes, said wall and electrode, the volume between two substantially cylindrical surfaces circumscribing and inscribing said first mentioned pleated electrode approximating from one to one and a half times the volume enclosed by said inscribing surface.

4. An electrolytic condenser comprising a substantially cylindrical container, an annular pleated anode arranged within and in spaced relation to said container, the inside apices of the pleats of said anode inscribing a substantially cylindrical volume approximating one-half to three-quarters of the annular volume occupied by said anode, a substantially cylindrical electrode arranged inside and in spaced relation to said pleated anode, said latter electrode connected with said container and provided with communicating passages, another anode arranged within said latter electrode in spaced relation thereto, terminals connected with said anodes and insulatingly extending through said container, and an electrolyte within said container contacting it, said electrode and anodes.

5. An electrolytic condenser comprising a container having inner and outer walls forming an annular space therebetween, an electrolyte substantially filling said space, an annular shaped anode immersed in said electrolyte, rings of insulation around the inner metal wall and other rings of insulation around the outside of said anode, and insulating washers disposed between the ends of said metal walls.

6. An electrolytic condenser comprising a cylindrical cathode container and a further cylindrical cathode of lesser diameter than said container, one end of said cylindrical cathode being supported from one end of said container to form a pair of communicating annular and cylindrical spaces between said container and cathode and inside said cathode, respectively, an annular shaped anode disposed within said annular space in spaced relationship to the walls of said container and cathode to form a first condenser unit, means insulatingly supporting said anode from said container, a further anode disposed in spaced relationship with the inner surface of said cathode to form a second condenser unit therewith, means insulatingly supporting said second anode from said container, and an electrolyte within said annular and cylindrical spaces common to both said condenser units.

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