July 21, 1959 W. P. LANGSFELD 2,895,506

METAL FOIL DIAPHRAGM

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Fig. 1.

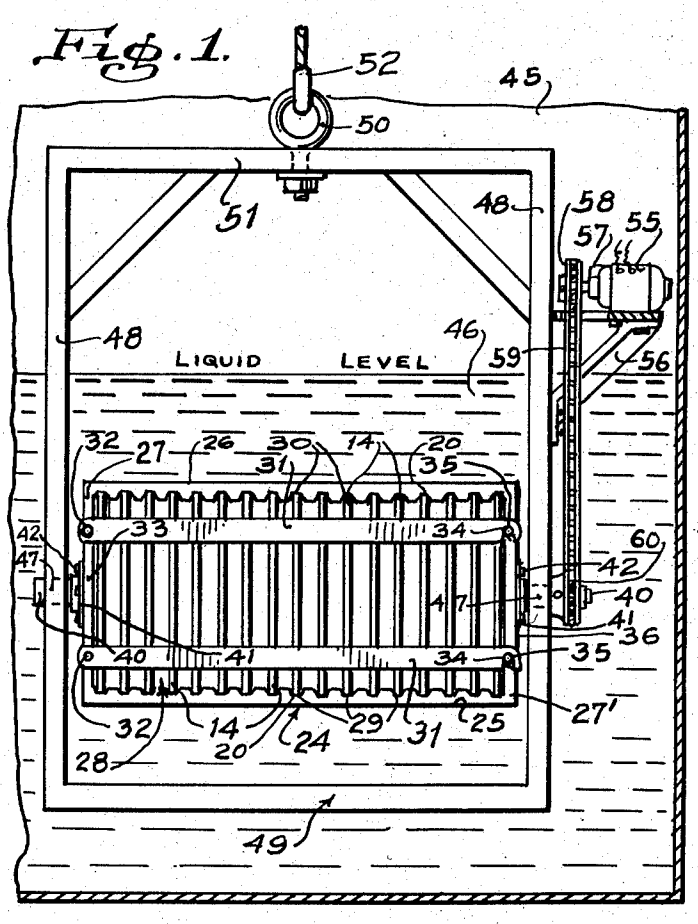


Fig. 2.

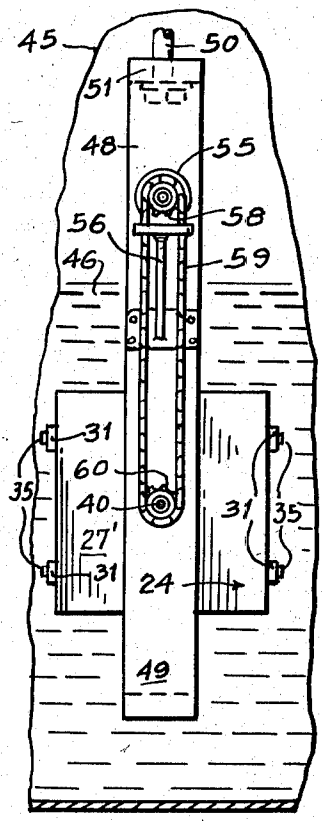
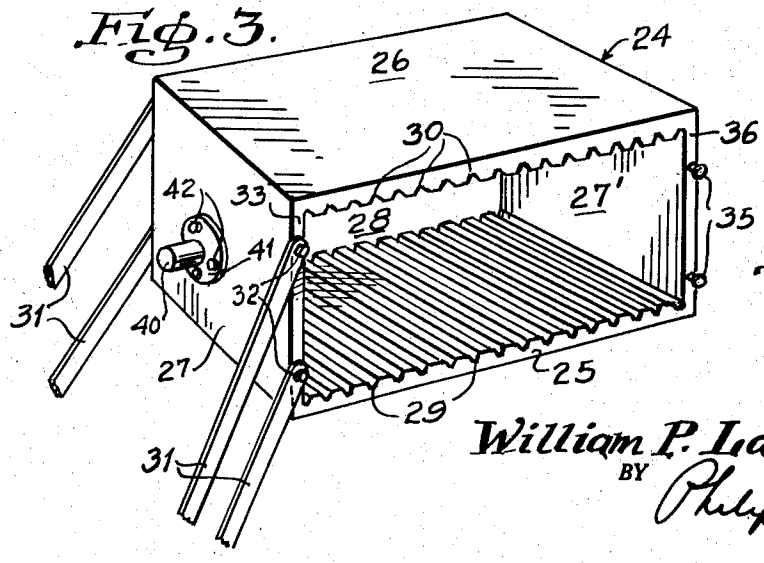


Fig. 3.



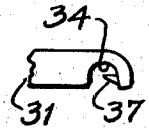


Fig. 3a.

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Fig. 5.

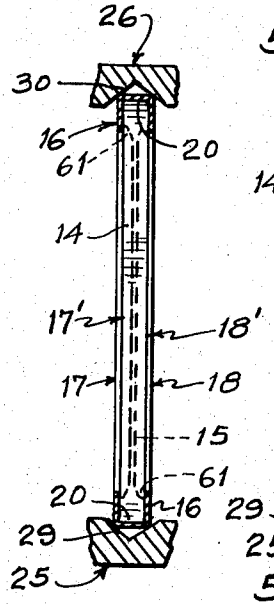


Fig. 4.

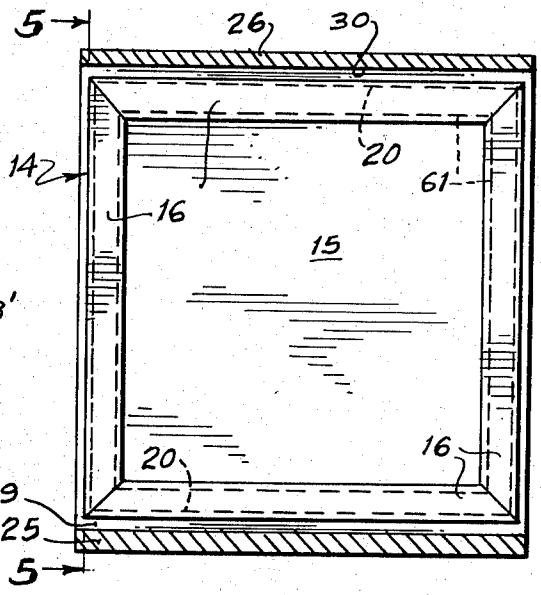


Fig. 7.

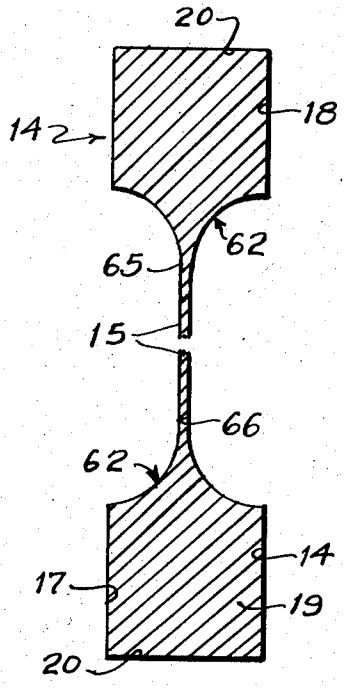
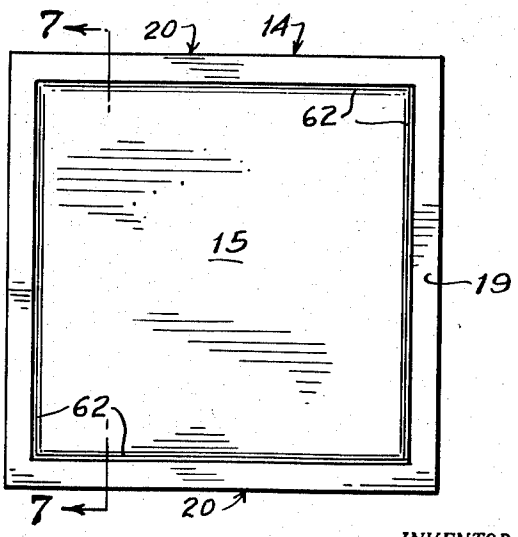


Fig. 6.



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Fig. 9.

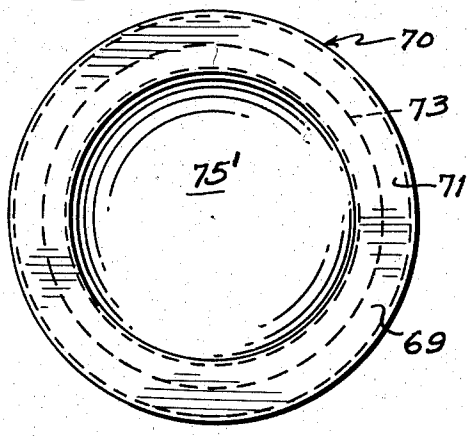


Fig. 12.

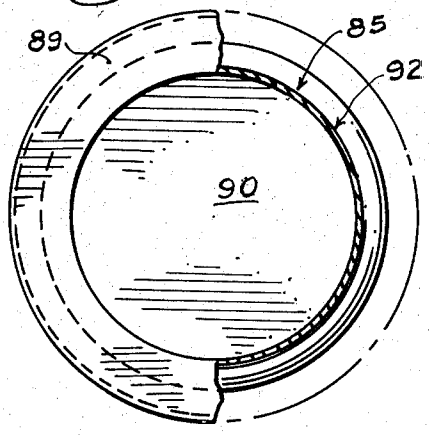


Fig. 8.

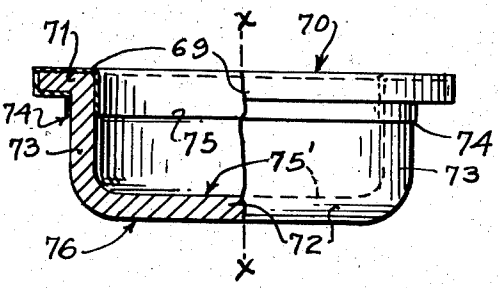


Fig. 11.

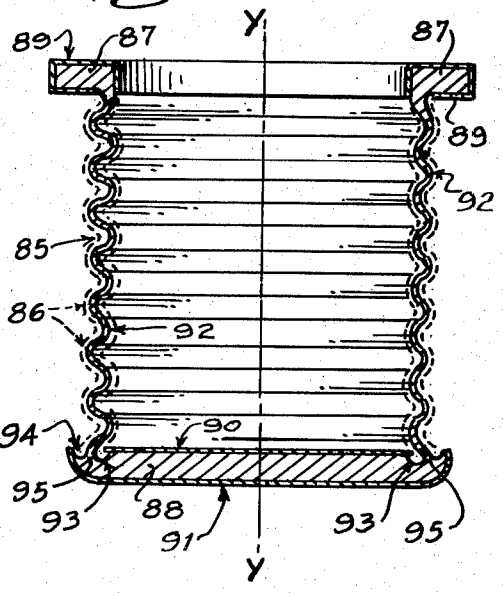
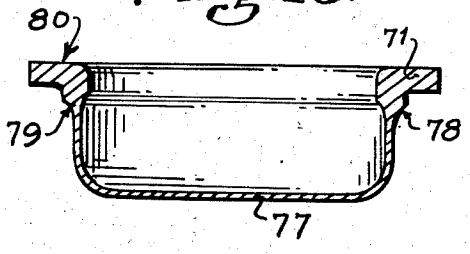


Fig. 10.



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2,895,506

METAL FOIL DIAPHRAGM

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Application October 11, 1954, Serial No. 461,385

1 Claim. (Cl. 137—793)

This invention relates to the production of thin metal diaphragms, and is particularly concerned with a novel metal article having an integrally formed thin or foil diaphragm, and to procedure for the manufacture thereof.

Foil diaphragms, when the foil is of such thickness as to have substantially no stiffness, must be supported by a frame or on flanges for mounting as a closure in devices employing such diaphragms. The frame or flange is then the medium whereby the foil may be mounted in the device. For this purpose the so-called foil diaphragms are mounted on their frames or on such flanges by laminating or welding the frame or flange to the diaphragm. However, the characteristics of the diaphragms so mounted, particularly at their juncture with the frame, are relatively poor, and their bending characteristics at the juncture may not be the same when bending or deflecting in both directions perpendicular to the face of the diaphragm. The major reason for this is that gradual fatigue is introduced into the diaphragm, especially adjacent the outer periphery of the diaphragm close to the frame. This results in decreased operating efficiency of the diaphragm and the necessity for replacing it at relatively frequent intervals in many cases, especially in instruments of high sensitivity.

Further, while it is known to produce diaphragms of a thickness substantially above .005", in certain high precision instruments thinner diaphragms or foils are often required. This has presented the problem of producing foil diaphragms of uniform cross section and having a thickness of about .005" or less, while at the same time possessing satisfactory strength characteristics.

The thickness of metal wall sections or diaphragms heretofore produced in a plate or other work piece functioning as a frame for such wall sections, by mechanical forming processes such as milling, has been limited to a minimum substantially above .005". This is due to the tendency of thin wall sections or diaphragms formed within a thicker plate as the frame, particularly which wall sections are of about .005" thickness or less, to collapse, tear or shear when subjected to such mechanical forming operations. The term "thin diaphragm," "foil" or "foil diaphragm" as employed herein and in the claim is accordingly intended to denote a metallic wall section or diaphragm of a thickness less than can be produced by mechanical forming operations such as milling, such thickness being about .005" or less.

One object of this invention accordingly is the design of a thin diaphragm formed integral with the mounting therefor.

Another object is the provision of an article including a thin or foil diaphragm integral with a frame, the outer periphery of such diaphragm being reinforced at its juncture with the frame.

Yet another object is to provide a foil diaphragm integral with a frame therefor, such diaphragm being

substantially uniform in thickness along the entire surface thereof.

It is a particular object of the invention to produce foil diaphragms of the foregoing type, e.g. composed of metals, including aluminum, iron, titanium, copper, magnesium, zinc or an alloy thereof, and having a thickness less than .005".

Another aim of the invention is to provide novel and simple procedure for the production of the aforementioned diaphragm structures.

Other objects and advantages will become apparent hereinafter.

According to the invention, I am able to produce thin diaphragms having a thickness, for example, as low as .0025", by an etching procedure whereby the diaphragm is formed integral with the frame in which the diaphragm is contained. As the result of the etching treatment, the diaphragm can be provided with a reinforcement at its juncture with the frame, such reinforcement generally having a concave curvature and being in the form of a curved fillet. An outstanding advantage of the thin or foil diaphragm of the invention is that the fatigue ordinarily introduced at the edge of the diaphragm adjacent the frame or flange to which the diaphragm is attached in prior art diaphragm structures, is substantially eliminated. Moreover, the diaphragm of my invention is strengthened at its juncture with the flange or frame by being formed integral therewith and by having a reinforcing member in the form of a fillet interposed at the juncture of the diaphragm with the frame. Another important characteristic of my diaphragm structure is that it is substantially uniform in thickness across or along substantially its entire surface adjacent the aforementioned reinforcing fillet.

In carrying out my procedure, the metal article or plate which is to be provided with a diaphragm according to the invention is coated on selected portions of the surface with a protective masking coating to prevent attack by the etching agent while leaving uncovered that portion of the surface area which is to constitute the diaphragm, and which is available for attack by the etching agent. Such mask may be in the form of a resist or resin which is inert to the etching agent. The work piece or pieces are then exposed to the etching solution, which may be caustic alkali in the case of aluminum or aluminum alloy articles. I prefer to immerse the work pieces and maintain them in a vertical position in the etching tank while being rotated about an axis generally parallel with the horizontal axis of the tank, although non-vertical rotation may be used. While the diaphragms according to the invention may be formed in the etching solution without rotating the work piece, best results are realized by rotation of the part during etching.

As a result of such rotation, the article or plate is uniformly attacked or corroded by the etching solution across or along the surface of the article not covered by the mask, and a fillet or concave reinforcing member is formed at the juncture of the etched surface and the unetched body of metal adjacent the edges of the mask. Rotation of the work piece is continued until a diaphragm of the desired thickness, e.g. less than .005", is produced by the etching action, the resulting diaphragm defined by the corroded or etched surface area of the work piece being integral with its supporting frame.

The invention will be further described below in connection with the accompanying drawings showing various embodiments of the invention and wherein:

Fig. 1 is an elevation of a mechanism for suspending and rotating a plurality of parts in an etching bath to form the diaphragms of the invention;

Fig. 2 is an end view of the device of Fig. 1;

Fig. 3 is a perspective view of the fixture shown in Fig. 1 for supporting the parts in the etching bath;

Fig. 3*a* is a detail of the fixture of Fig. 3;

Fig. 4 is an elevation of a plate in which a diaphragm is to be formed, positioned in the fixture of Fig. 3;

Fig. 5 is a section taken on line 5—5 of Fig. 4;

Fig. 6 is an elevation of the plate of Fig. 4 after formation of a diaphragm therein according to the invention;

Fig. 7 is a section taken on line 7—7 of Fig. 6;

Fig. 8 is an elevation, partly in section, of a dish-shaped part in which a diaphragm is to be formed;

Fig. 9 is a plan view of the part of Fig. 8;

Fig. 10 is a vertical section of the part of Fig. 8 after formation of a diaphragm therein according to the invention;

Fig. 11 is a section of a bellows, the diaphragm of which is reduced in thickness according to the invention; and

Fig. 12 is a plan view, partly in section, of the bellows of Fig. 11.

Referring to Figs. 1 to 7 of the drawing, a plate **14** in which a thin or foil diaphragm **15** is to be formed according to the invention, has a mask **16** coated about the periphery of both of the opposite parallel surfaces **17** and **18** of the plate, the thus coated periphery of plate **14** forming a frame or rim **19** to support such diaphragm as will be described below. The mask also covers the side edges **20** of the plate **14**, and prevents attack by the etching solution of all of the surfaces over which it is applied.

A fixture **24** is provided for supporting a number of plates **14** for rotary motion thereof in the etching tank according to the invention principles. The fixture is in the form of an oblong compartment or container having a bottom **25**, a top **26** and end walls **27** and **27'**. Sides **28** are open for insertion of the plates **14** into the container. Positioned transversely across the inner surface of the bottom **25** of the container is a series of spaced parallel V-shaped grooves **29**, and also extending transversely across the inner surface of the top **26** of the container **24** is a series of similar spaced parallel V-shaped grooves **30** in vertical alignment with the respective grooves **29**. Grooves **29** and **30** extend along the entire length of container **24** from one end wall **27** to the opposite end wall **27'** thereof. The opposite side edges **20** of each plate **14** are slidably received in a pair of opposite grooves **29** and **30** in the bottom and top, respectively, of container **24** to retain the plates in vertical position in the container **24** as seen in Fig. 1.

After the plates have been inserted into the respective grooves through one of the open sides **28** of the container, they are prevented from sliding out by slats **31**, each of which is pivoted at one end on a pin **32** attached to an outer edge **33** of end wall **27**, and has a slot **34** at its other end for engaging a pin **35** connected to the outer edge **36** of the opposite end wall **27'**. The end of each of slats **31** adjacent the slot **34** therein carries a conventional spring biased latching detent **37** to prevent disengagement of the slats from pins **35** during rotation of container **24**. A pair of slats **31** is provided to extend in latched position across each of the open sides **28** to prevent the plates **14** from sliding out of the container **24**. A short shaft **40** is centrally connected to the outer surface of end wall **27** by means of a plate **41** attached to said wall by bolts **42**, and a similar aligned shaft is similarly connected to the outer surface of end wall **27'**.

The fixture **24** containing the plates **14** supported vertically therein is positioned for rotation on a horizontal axis in an etching tank **45** containing a body of etching solution **46**, for example, hot caustic alkali solution where plates **14** are composed of aluminum or an aluminum alloy, the fixture **24** and the plates therein being entirely immersed in the solution. For this purpose shafts **40** at both ends of the container or fixture **24** are journaled

in bearings **47** in the opposite vertical sides **48** of a rectangular frame **49** having a ring **50** centrally connected to a top cross member **51**. Frame **49** is supported in the tank by a crane or other mechanism (not shown) from a hook **52** thereof, such hook being received by the supporting ring **50** of the frame **49**.

A motor **55** is mounted on a bracket **56** connected to frame **49**, and drives shaft **40** for rotation of container **24** and plates **14** therein, through a reducing gear **57**, motor sprocket **58**, chain **59** and sprocket **60** on shaft **40**. The speed of rotation of shaft **40** and the container carrying the plates **14** to be etched, may be varied as desired, and may be, for example, 5 revolutions per minute.

As the plates **14** rotate in the etching bath **46**, all portions of each plate will be in continuous movement in the body of solution, each such portion alternately moving from a lower to a higher position in the bath. In this manner, fresh solution is constantly in contact with the exposed unmasked areas **17'** and **18'** of the opposite surfaces of each plate **14**, and the continuous movement of the etching liquid with respect to the surface of the metal facilitates corrosion thereof by the solution in the selected unmasked portions of the work piece, and also has a scouring effect on such surfaces. Thus, uniform etching takes place across substantially the entire exposed areas **17'** and **18'** of each work piece **14**, and the same depth of etch is formed in each of the exposed surfaces **17'** and **18'**, as indicated in dotted lines in Fig. 5.

Of particular significance, and especially aided by the rotation of plates **14** in the solution, a certain amount of uniform etching takes place under the edges of the mask **16** on the surfaces of each plate **14**, forming a rounded even undercut portion **61** on such surfaces adjacent and beneath the inner edge of the mask about the entire periphery thereof. As the plates rotate in the solution, gas formed by the etching reaction is constantly removed from the undercut portions **61** of each work piece **14**, since all portions of the undercuts **61** are periodically positioned in the solution below as well as above the cavity formed in the exposed surfaces **17'** and **18'** of the work pieces. When such undercuts are in their lower position in the tank, the gas previously trapped therein is permitted to escape upward through the solution.

The solvent solution, after making contact with the rotating work pieces, is conducted away, carrying with it any solids or precipitate, for example, aluminum hydroxide and alumina formed in the etching reaction, and gaseous foam. By rotation of the work piece according to preferred practice of the invention, there will be substantially no accumulation of solids adjacent the mask, since there will be no dead air spaces behind the mask. This also promotes uniform etching and the performance of the etch according to the design requirements.

Rotation of the container **24** and the plates **14** therein is continued until the wall or diaphragm **15** formed between the cavities **65** and **66** eaten into the exposed areas **17'** and **18'**, is of the desired thickness. As a result of the undercutting action of the etchant solution beneath the edges of the mask **16** as described above, a fillet **62** is produced between the outer periphery of diaphragm **15** and the body of the plate **14**, which forms a frame for supporting such diaphragm. Hence, it is seen that by the above described etching procedure, a thin or foil diaphragm of substantially uniform cross section along the surface thereof is provided, such diaphragm being integrally connected through the concave reinforcing member **62** to its supporting frame **19**. By this procedure, for example, a metal plate having a thickness of .108", and composed of an aluminum alloy designated 75S, and containing 90% Al, 1.6% Cu, 2.5% Mn, .3% Cr, and 5.6% Zn, was etched to produce a uniform foil diaphragm of .0025" thickness supported by such frame.

Referring now to Figs. 8, 9 and 10, directed to a modification of the invention, a dish shaped metal, for example, aluminum, article **70** having a flange **71** extending outwardly from the upper periphery of the dish shaped portion **72** of such article has a mask **69** applied over the outer surfaces of the flange and extending downwardly a short distance about the outer surface of the vertical wall **73** of the vessel **70**, to a point **74** on such surface. The mask also extends downwardly along the inner surface of wall **73** from the upper surface of flange **71** to a point **75** in horizontal alignment with point **74**.

One or more of articles **70** may be immersed vertically in an etching bath in a manner similar to plate **14**, so that the axis *x—x* is positioned parallel to the horizontal axis of the etching tank. Members **70** may then be rotated about their axes *x—x*, the etching solution acting on the exposed inner surface **75'** of each vessel **70** and on the exposed outer surface **76** of such vessels in the above described manner, to produce a dish-shaped wall or diaphragm **77** of greatly reduced thickness, according to the invention, as compared to the original thickness of the dish-shaped portion **72**. Diaphragm **77** may be as thin as desired, down to, for example, .0025".

The diaphragm **77** has a uniform cross section along substantially its entire area. As in the case of plates **14**, the etch solution by this method produces concave undercut portions **78** in the metal surfaces adjacent the edge of mask **69**, and such undercut portions result in the formation of a fillet **79** integrally connecting diaphragm **77** with its supporting frame **80** consisting of the upper portion of wall **73** of member **70** which was covered by mask **69**, and flange **71**. Hence, fillet **79**, according to the invention, functions as a reinforcing member for the diaphragm **77**.

Turning now to Figs. 11 and 12, **85** represents a bellows having a corrugated diaphragm **86** composed of a series of circumferential corrugations, the original thickness of which is indicated by dotted lines in Fig. 11. At one end of the bellows **85** is a flange **87** and connected across the other end of the bellows is a plate **88**. A mask **89** is applied over the outer and inner surfaces of flange **87**, a mask **90** is applied over the inner surface of plate **88**, and another mask **91** is coated over the outer surface of plate **88**.

One or more of the bellows **85** are immersed in an etching solution in a manner similar to plates **14** and members **70**, so that the Y—Y axis of each such bellows is positioned parallel to the horizontal axis of the etching tank. The bellows **85** are then rotated about their axes Y—Y, the etching solution acting on the exposed inner and outer surfaces of the corrugated diaphragm **86** to produce a diaphragm **92** of greatly reduced diameter over that of the original diaphragm **86**. It is noted further that the etch solution produces a concave undercut portion **93** on the inner surface of plate **88** adjacent and beneath the periphery of mask **90** and the inner lower end of the diaphragm **92**, and also produces a rounded undercut portion **94** in the outer surface of plate **88** adjacent and beneath the periphery of mask **91** and the outer lower end of the diaphragm **92**. Undercut portions **93** and **94** result in formation of a fillet **95** integrally connecting the bellows diaphragm **92** and its supporting frame or plate **88**, fillet **95** serving as a reinforcing member for the thin diaphragm **92** according to the invention. Accordingly, an article is produced in the form of a bellows having a substantially thinner corrugated diaphragm **92** than the original diaphragm **86**, the corrugations being uniform in section along the entire diaphragm from fillet **95** to flange **87**. Further, the resulting thin bellows diaphragm is connected at one end to a relatively thick and stiff plate **88**, against which the load to which the bellows is to be subjected can be applied readily and safely.

The bellows diaphragm **92**, as well as the diaphragm **15** of Fig. 7 and the dish-shaped diaphragm **77** of Fig. 10, can be produced down to a thickness less than .005" according to the invention. Thicknesses of this low magnitude, especially for production of diaphragms of complicated shape such as the bellows of Fig. 11 or the dished diaphragm of Fig. 10, have been heretofore impossible to produce by any mechanical forming or machining operation known to applicant, since wall thickness is so small that it will not withstand the shearing or tearing action of the mechanical devices. Moreover, the diaphragms of the invention are free of stresses and strains generally present in mechanically formed diaphragms produced by cold forming methods, e.g. cold pressing or rolling of the work piece.

Where the work piece is an acid soluble metal such as titanium, iron, magnesium, zinc or their alloys, the solvent or etching solution can be of suitable acid composition such as aqueous nitric acid, aqueous hydrofluoric acid or mixtures thereof depending on the nature of the metal. According to the preferred embodiment of the invention for etching or removing metal from an aluminum or aluminum alloy material, which is alkali soluble, a hot aqueous solution is employed containing an alkali such as sodium or potassium hydroxide, trisodium phosphate, soda ash or the like, or mixtures thereof. Preferably a sodium hydroxide solution is used. Temperature of the solution in the etching tank is generally maintained in a range say from 100° F. to about boiling during treatment. However, lower temperatures may also be used.

Where an alkali soluble metal, e.g. aluminum is being etched, the alkali concentrations employed in the bath range from 0.1 to 10 normal. Instead of NaOH I may use any of the other equivalent alkalis referred to above adjusting the concentration to give the desired OH ion concentration. If desired, an acid etchant such as hydrochloric acid solution or solutions of salts such as ferric sulfate may be used for aluminum or aluminum alloys instead of alkali solutions.

While the invention procedure is particularly useful in the production of the above described thin or foil diaphragms, which are the novel structures of the invention, the improved method of the invention is also advantageous for producing thicker diaphragms, especially on curved and preformed surfaces. The advantages realized according to the invention are: (1) it permits the production of thin or foil diaphragms, particularly diaphragms less than .005" thick, (2) diaphragms are formed which are re-inforced at their juncture with the supporting frame, (3) minimum of expense in producing the diaphragms, (4) many parts can be processed at the same time, particularly in an emergency, (5) more accurate results are obtainable than by conventional machine milling, and (6) avoidance of the creation of stresses and strains in the parts, usually produced in machine milling processes.

Instead of etching both sides of plate **14**, or both the inner and outer surfaces **75'** and **76** of the dish-shaped article **70**, or both the inner and outer surfaces of bellows diaphragm **86**, to form the diaphragms of the invention, one side or surface of these articles may be coated with a mask and the invention diaphragms produced by etching only the other unprotected side of the article. For example, the inner surface **75'** or the outer surface **76** of member **70** can be completely covered with a mask, and the article immersed in the etching solution which attacks only the uncovered side of the article, the article being treated for a time sufficient to obtain the invention diaphragm of the desired thickness.

While the invention has been described above particularly in connection with placement of the article in which the diaphragm is to be formed vertically in the etching solution, and rotation of the article on a substantially horizontal axis which is the preferred mode of operation, the article or work piece may be suspended

in the solution at an angle other than vertical, e.g. horizontally. Also, the work piece may be rotated other than on its symmetrical axis, e.g. it may be rotated end over end.

Further, although rotation of the work piece during etching is preferred, the diaphragms of the invention may be formed by stationary immersion of the work piece in an etching bath. Thus, for example, article **14** or **70** can be maintained in a stationary position in the etching solution with the outer surface **76** of article **70**, or surface **17** of article **14** uppermost and in a substantially horizontal position or in a vertical position, during the period of etching, the entire inner surface **75'** of article **70** or surface **18** of article **14** being masked. Should objectionable sludge deposits form on the part being etched in this manner, they can be removed by periodic wiping or by agitation of the solution. In these instances, a fillet or reinforcing member will generally also be formed between the diaphragm and its frame, since as described above, undercutting responsible for the formation of such fillet will tend to take place beneath the edges of the mask, e.g. beneath the outer edge **74** of the mask **69**, or the edge of mask **16**, even in the absence of rotation of the part in the solution.

Of course it will be understood that the apparatus described herein for supporting the work pieces in the etching solution for production of the invention diaphragms, should be constructed of materials which are substantially inert to attack by the etchant solutions employed and those skilled in this art will know how to select such materials.

While I have described a particular embodiment of my invention for the purpose of illustration, it should be understood that various modifications and adaptations thereof may be made within the spirit of the invention as set forth in the appended claim.

I claim:

An article comprising an aluminum metal foil diaphragm circumscribed by an integral metal rim, said foil diaphragm having a substantially uniform thickness of less than 0.005 inch, said rim having a thickness of at least 0.1 inch, and a continuous curved fillet along the line of juncture between said diaphragm and rim, said fillet providing a continuously curved contour between the surface of said rim and the surface of said foil diaphragm, said diaphragm, rim, and fillet having been formed from a single piece of aluminum metal.

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