Dec. 23, 1958 W. P. LANGSFELD 2,865,125

APPARATUS FOR SELECTIVELY CONTOURING A METAL PART BY ETCHING

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Fig. 1.

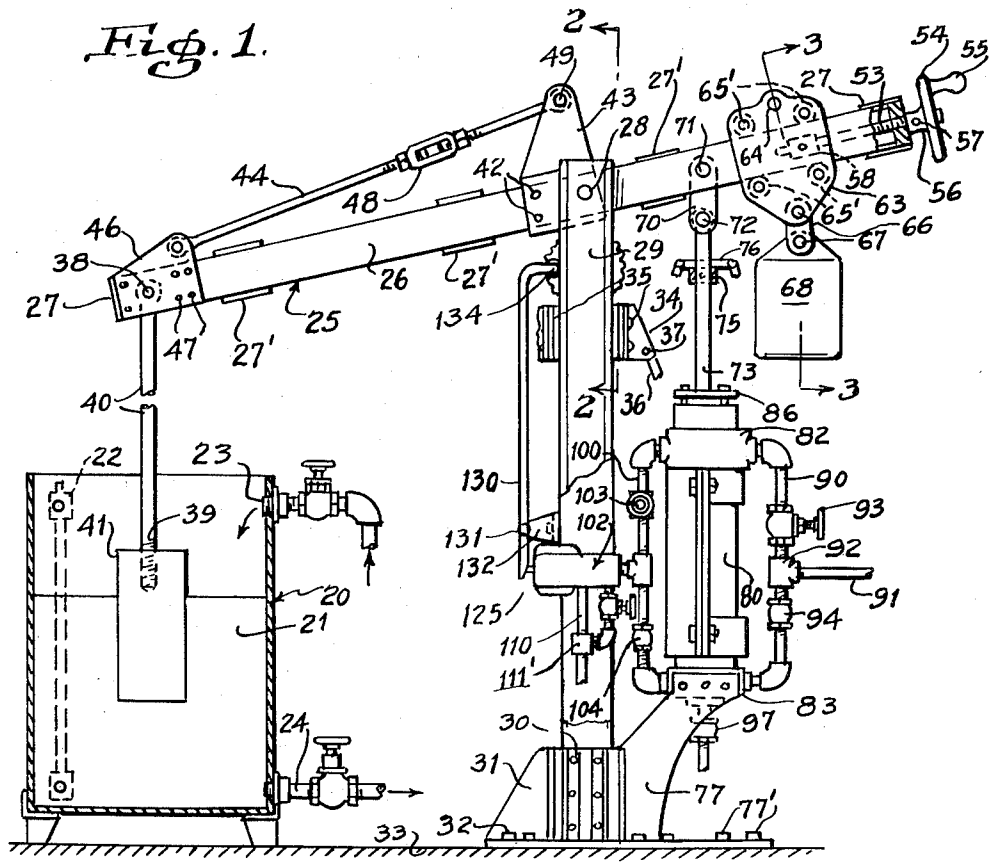



Fig. 2.

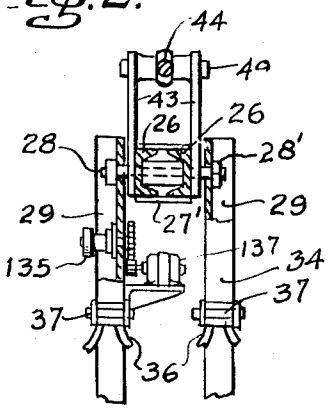



Fig. 3.

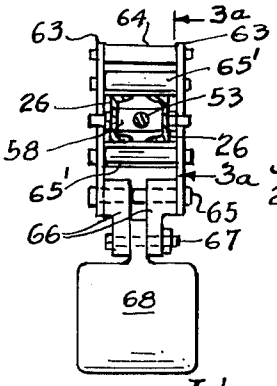



Fig. 3a.

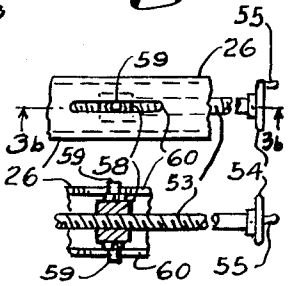



Fig. 3b.

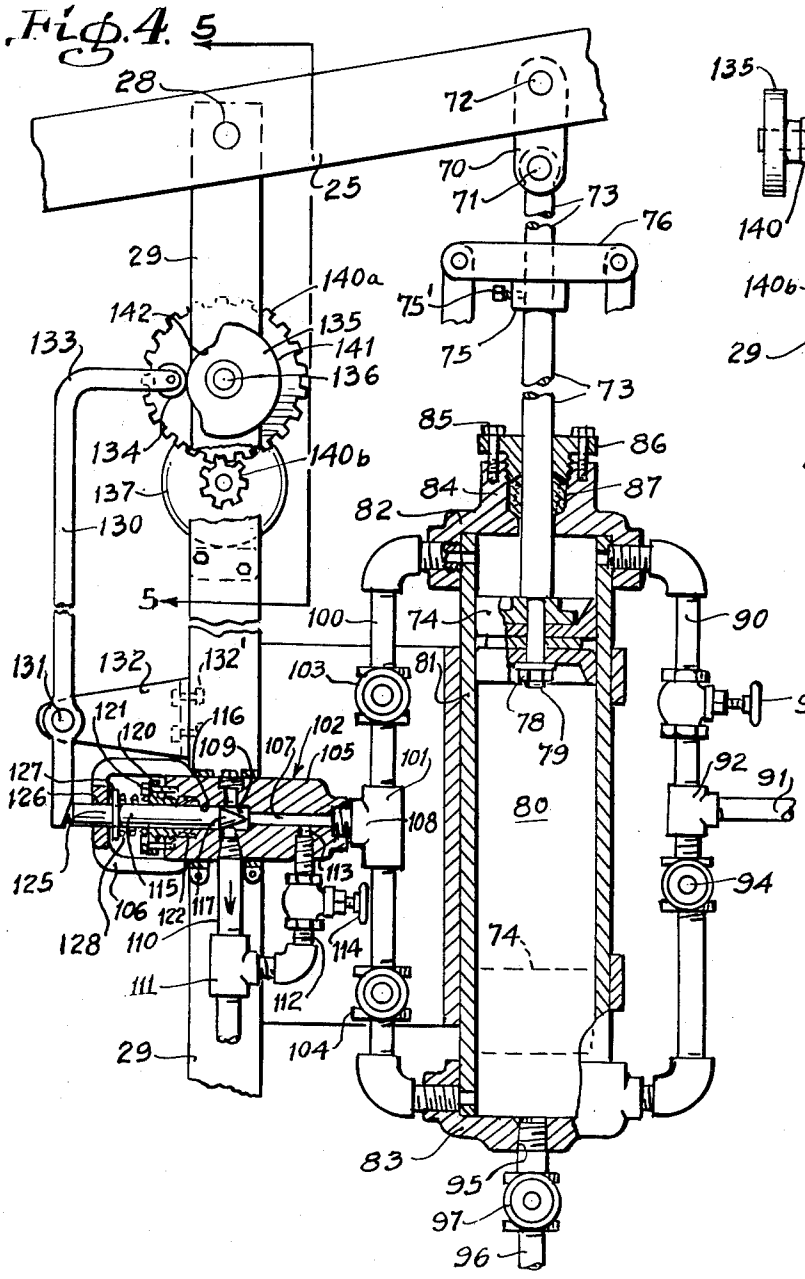
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APPARATUS FOR SELECTIVELY CONTOURING A METAL PART BY ETCHING

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Fig. 4.



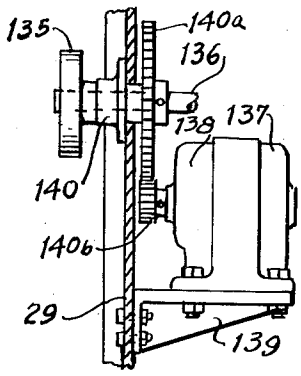




Fig. 5.

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Fig. 6.

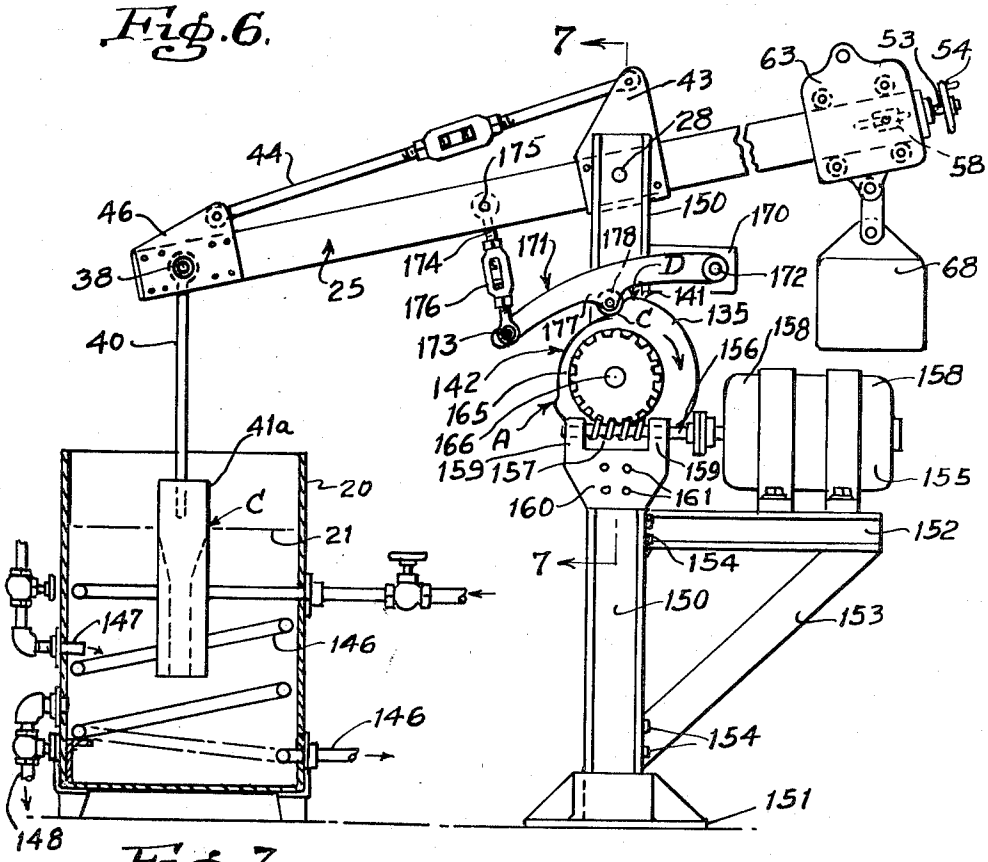
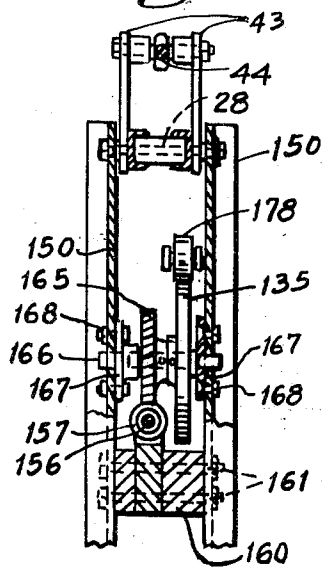



Fig. 7.




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Fig. 8.

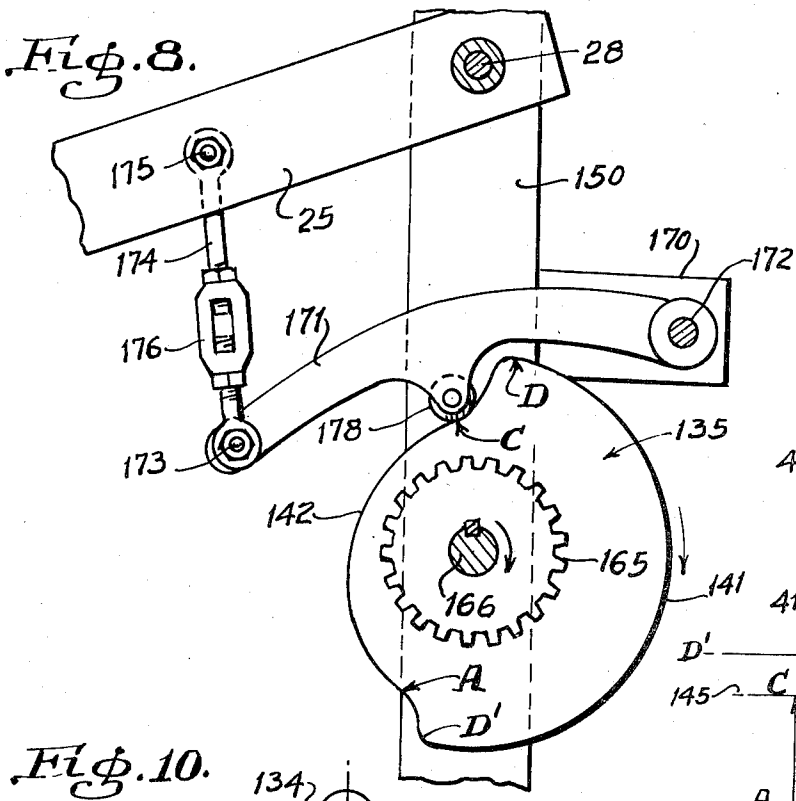



Fig. 9.

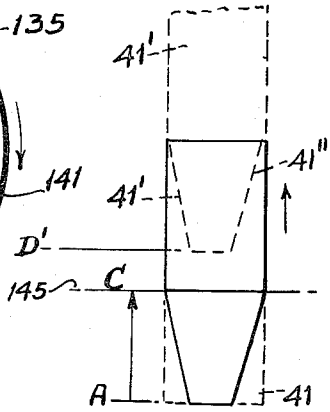



Fig. 10.

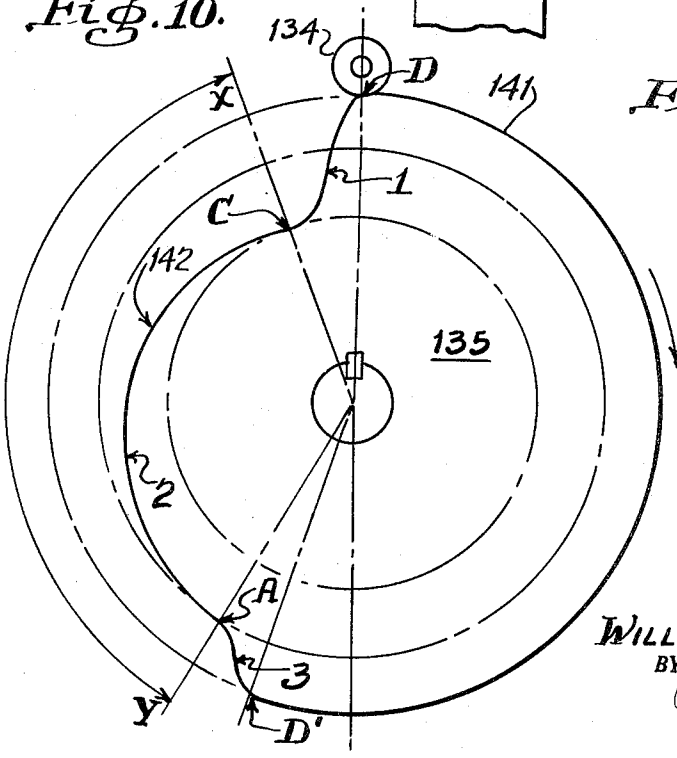
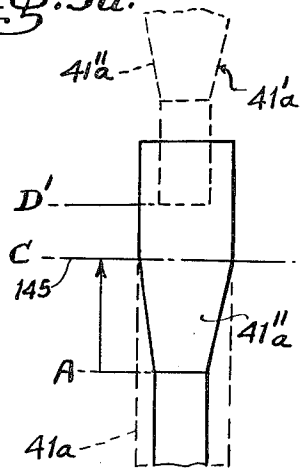



Fig. 9a.




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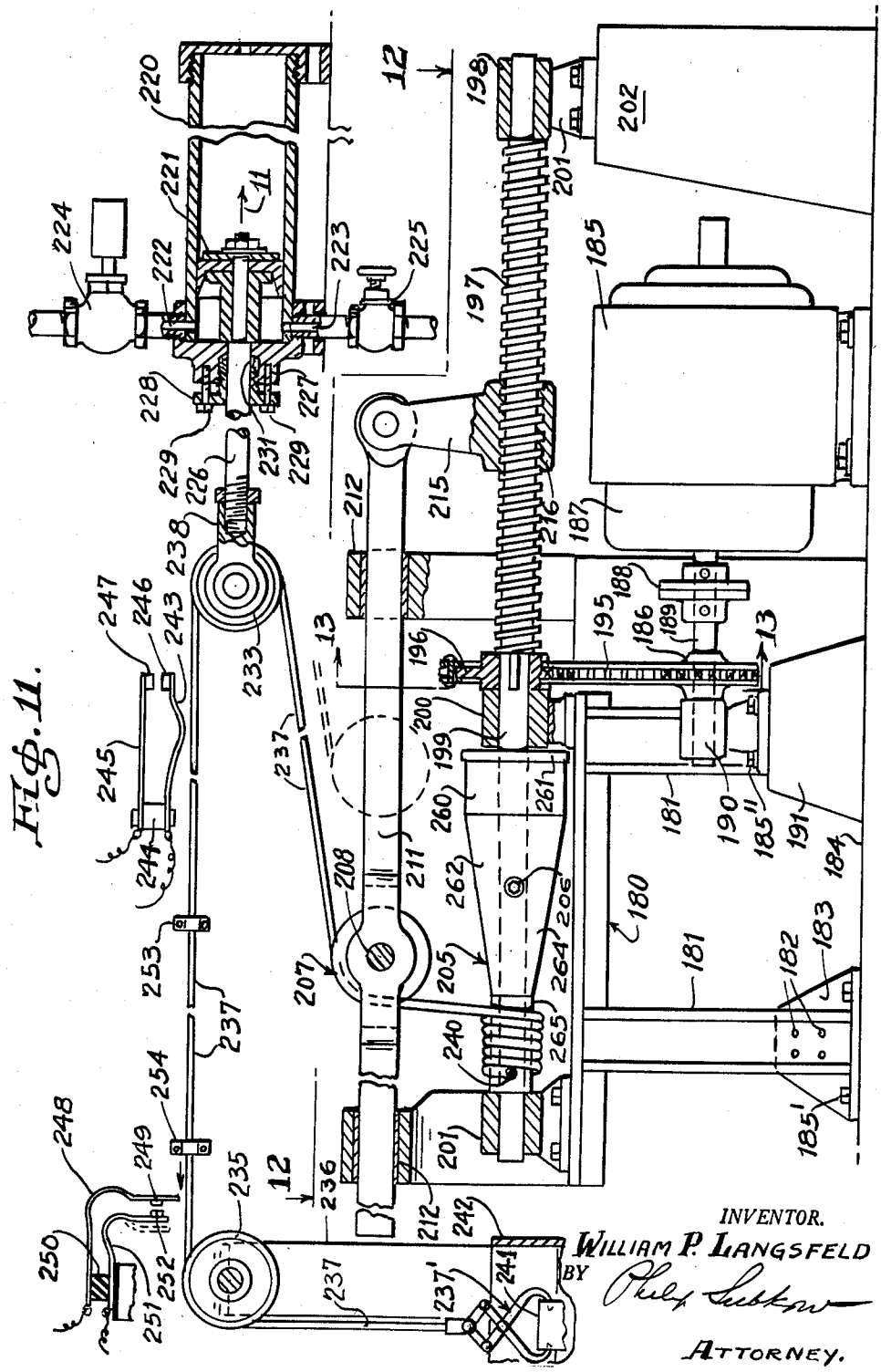


Fig. 11.

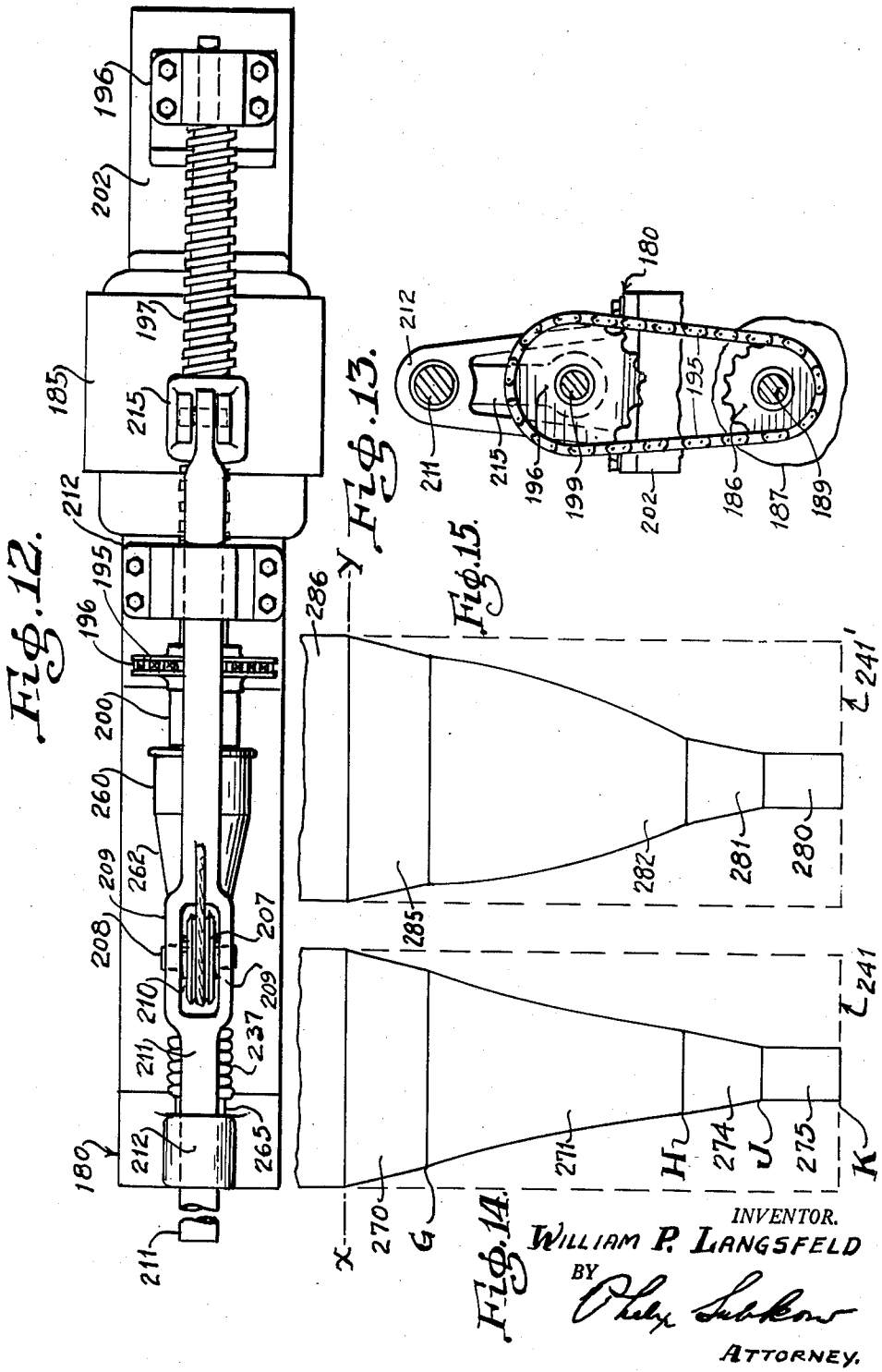
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APPARATUS FOR SELECTIVELY CONTOURING A METAL PART BY ETCHING

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6 Sheets-Sheet 6




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United States Patent Office 2,865,125 Patented Dec. 23, 1958



2,865,125

# APPARATUS FOR SELECTIVELY CONTOURING A METAL PART BY ETCHING

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Application November 22, 1954, Serial No. 470,245

7 Claims. (Cl. 41—9)

This invention is a continuation-in-part of my application, Serial No. 464,301, filed October 25, 1954, now U. S. Patent No. 2,802,726.

This invention relates to the etching or removal of metal from the surface of a metal object or part, for example, one composed of iron, nickel, titanium, magnesium, zinc, aluminum or their alloys. More particularly the invention is concerned with novel procedure and automatic apparatus for the controlled etching of a metal part or work piece to produce a desired contour or etch configuration thereon.

It is known to etch acid soluble metals such as magnesium, zinc and their alloys with an acid solution such as aqueous nitric acid. It is also known to etch alkali soluble metals such as aluminum and its alloys with a solution having a solvent action on the aluminum or alloy surface, such as a hot aqueous alkali solution, for example, one containing sodium hydroxide. One method of carrying out the etching process employing acids is to immerse the metal part to be etched in the etching bath, while another is to splash the solution contained in a bath against the work, the surface of which is to be etched or dissolved away. The prior art method for etching alkali soluble metals such as aluminum or its alloys is by immersion.

One object of this invention is to devise novel apparatus and procedure for readily dissolving or removing metal in a controllable manner from the surface of a metal work piece, for example, composed of iron, nickel, titanium, aluminum, magnesium, zinc, and the like or their alloys, to impart a preselected contour or etch configuration to said work piece.

Another object is to provide apparatus and procedure for the controlled etching of a metal part.

Another object is to design novel apparatus particularly adapted for the uniform or non-uniform controlled etching or removal of metal from the surface of a work piece, particularly one composed of aluminum or its alloys.

A still further object is the provision of novel procedure and automatic apparatus for controllably etching in an efficient manner one or more metal parts or work pieces to produce a preselected etch configuration or contouring thereof.

Yet another object is the provision of metal parts having a novel surface contour produced by etching.

Other objects and advantages will become apparent from the following description of the invention.

The etch rate or amount of etching which takes place on the surface of a metal part in a given time is dependent on the concentration of the etching bath, the temperature thereof, and the time of immersion of the part. The etch rate for a particular bath can thus be predetermined, and by maintaining the temperature and concentration of the etching bath constant, the degree of etching can be varied by controlling the time of immersion of the part. Thus, for example, if it is desired to produce a tapered sheet,



the portion of the sheet to which the taper is to be applied can be immersed in the etching bath, and the sheet withdrawn vertically from the bath at a controlled uniform rate, depending on the etch rate of the sheet in that particular solution and the degree of taper desired; or, the sheet can be immersed in the etch solution at a controlled uniform rate to form the desired taper, followed by rapid removal of the sheet from the solution.

According to one mode of practicing the invention, I submerge one or more work pieces or parts in a bath containing a metal dissolving agent, that is, an etching solution. Means are provided for then withdrawing the work pieces from the bath at a preselected time rate, which may be uniform or non-uniform, to thus controllably vary the time of immersion and amount of attack of the etching bath on different portions of the work pieces placed in the bath. When the work pieces are completely withdrawn from the bath, the work pieces will be etched to a predetermined etch pattern, and all of the work pieces so treated according to the invention will have substantially the same etch pattern, shape or contour as a result of such treatment.

Instead of withdrawing the work pieces at a preselected rate to obtain a predetermined etch pattern, the work pieces may be immersed in the etching solution at a preselected time rate, which may be uniform or non-uniform, to obtain said predetermined etch pattern, and the work pieces then quickly withdrawn from the etching bath after such pattern has been produced, in order to stop the etching action at this point.

In a preferred mode of procedure, a metal part is passed through an etching solution at a time rate with respect to the rate of immersion, which is not a linear function of time, but which is a predetermined non-linear function of the time established by the parameters of the apparatus. By thus passing the metal part into or withdrawing it from the etching solution at a varying velocity, a part may be obtained having a chemically etched contoured surface portion, for example, in the form of a concave or convex curve, all of the tangents to such surface portion taken in the same plane having different slopes. Also, in accordance with the invention, a metal part may be passed through the etching solution at varying velocity based on a predetermined series of functions. Thus, for example, a part may be produced having one or more tapered surface portions and one or more irregular or curved surface portions formed by passage of the part into contact with the etching solution at a non-uniform velocity.

A particular feature of my invention resides in the provision of automatic equipment for automatically controlling the rate of immersion or withdrawal of the work piece to impart a preselected contour or shape thereto. For this purpose the contour of the part to be formed by etching is first determined, and means, for example, in the form of a cam, is designed based on, or corresponding to, this contour for controlling the rate of upward or downward movement of the means supporting the work piece, to thereby control the time of immersion of the various portions thereof in the etching bath so as to produce the preselected contour as a result of the etching reaction.

The metal part or parts to be etched according to the invention may be coated on selected portions of the surface thereof with a protective masking coating to inhibit or prevent attack by the etching agent of the surface so covered, while the adjacent uncoated portions are available for such attack. In those instances where it is desired to permit etching to at least some degree of all surfaces of the work pieces submerged in the solution, a mask need not be used. The etched work piece may be

used in the decorative arts or in structures or machine parts.

One form of apparatus found particularly advantageous for carrying out the above procedure, that is, for controlling the rate of immersion in or withdrawal of a work piece from an etching tank to produce a desired etch pattern, includes a beam or lever pivotally supported on a pivot intermediate its ends. A support for one or more work pieces is suspended from the beam near one end thereof, the support having means at its lower end for securing the work pieces thereto. A cam or other means especially designed in relation to the contour to be imparted to the work piece, as aforementioned, is arranged to control hydraulic or mechanical means for pivotal motion of said beam. Such pivotal motion of the beam produces movement of said support, preferably in a vertical direction, at a corresponding controlled rate, such controlled rate of movement being imparted to the work piece during its immersion into or removal from an etching bath according to the invention.

In another form of the invention a mandrel having an outer contour, based on the shape to be imparted by etching to a work piece, is rotated to wind a cable upon or unwind it from the surface of the mandrel. The cable is supported on a system of pulleys, and one or more work pieces are suspended from the end of the cable. The speed of travel of the cable over the surface of the mandrel during winding or unwinding of the cable, which speed depends on the shape of the outer surface of the mandrel, determines the rate at which the work piece or pieces suspended at the end of the cable will be immersed in or withdrawn from the etching solution. This rate of immersion or withdrawal of the work piece from the etching solution in turn affects the shape of the work piece so that a work piece of a preselected shape can be automatically produced by proper design of the aforementioned mandrel, based on the use of an etching solution having an essentially fixed concentration and temperature.

The invention will be more clearly understood by reference to the following description of certain embodiments of the invention taken in connection with the accompanying drawings, wherein:

Fig. 1 is an elevation of a device according to the invention;

Fig. 2 is a section taken on line **2—2** of Fig. 1;

Fig. 3 is a section taken on line **3—3** of Fig. 1;

Fig. 3*a* is a view taken on line **3*a*—3*a*** of Fig. 3;

Fig. 3*b* is a section taken on line **3*b*—3*b*** of Fig. 3*a*;

Fig. 4 is an enlarged elevational view, partly in section, of certain components of the device shown in Fig. 1;

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

Fig. 6 is an elevation of a modification of the device shown in Fig. 1;

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

Fig. 8 is an enlarged view of certain details of the structure shown in Fig. 6;

Figs. 9, 9*a*, 14 and 15 are each a schematic illustration of a metal part contoured in an etching solution according to the invention;

Fig. 10 is a diagrammatic view of the cam employed in the device of Figs. 1 and 6;

Fig. 11 is an elevational view of another modification of a device according to the invention;

Fig. 12 is a plan view taken on line **12—12** of Fig. 11; and

Fig. 13 is a vertical section on line **13—13** of Fig. 11.

Referring particularly to Figs. 1 to 5, numeral **20** represents a tank in which metal work pieces, parts or sheets are etched or subjected to the solvent action of a body of solution **21** maintained in the tank. Numeral **22** is a glass gage to indicate the level of the solution in the tank, **23** is an inlet pipe for the solution, and **24** represents a drain pipe.

Where the work pieces are composed of an acid soluble metal such as magnesium iron, titanium, zinc or their alloys, the solvent 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. The tank **20** may have a series of coils (not shown) therein for circulation of steam or hot water to maintain the temperature of the solution in the tank.

Where an alkali soluble metal, for example, 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.

A beam **25** in the form of a pair of parallel spaced channel members **26** connected together by cross plates **27** at their ends and **27'** at spaced intervals between such ends, is pivoted intermediate the ends of the beam on a pivot pin **28** supported in the upper ends of a pair of parallel vertical standards or channels **29** secured by means of bolts **30** at their lower ends to a base member **31** in turn bolted as at **32** to a base **33** such as concrete. Pivot pin **28** is adjustable by means of nut **28'**. Side angles **34** are secured by means of bolts **35** to the upper portions of standards **29**, and a number of rods **36** are connected at one end to a fastener **37** on such plates, the other ends of the rods (not shown) being anchored in the concrete base **33** to support the standards **29** in vertical position.

A work support **40** is pivotally suspended from a pivot pin **38** at the forward end of beam **25**, to the lower end of which support is secured by means of fasteners **39** a work piece **41** to be treated in etch solution **21** according to the invention. Connected by bolts or fasteners **42** to each of channels **26** of beam **25** adjacent pivot point **28** thereof, is a vertical plate **43**, forming a pair of parallel supports at the upper end of which is connected by means of pin **49** one end of a beam reenforcing rod **44**, the other end of which is secured in the upwardly extending ends of another pair of vertical plates **46** bolted or riveted as at **47** to the forward end of beam **25** adjacent the pivot pin **38**. A turnbuckle **48** is provided to adjust the tension on rod **44**.

Mounted axially at the rear of beam **25** is a screw **53** (see Figs. 1, 3, 3*a* and 3*b*) operated by a wheel **54** having a handle **55**. One end of screw **53** is received within a bearing **56**, the screw being fixed for rotation with the handwheel by means of set screw **57**. Slidably disposed between channel members **26** of beam **25** and threadably receiving screw **53** centrally therein, is a block **58** adapted to travel axially along beam **25**. A pair of lugs **59** are connected to opposite sides of block **58**, such lugs being received in axial slots **60** disposed in horizontal alignment in opposite channel members **26**. Pins **59** and slots **60** serve as guide means to permit axial movement of block **58** along beam **25** on rotation of screw **53**.

Block **58** is connected through pins **59** to a pair of parallel vertical plates **63** positioned closely adjacent the outer sides of the beam channels **26**. These plates are connected at their upper and lower ends by cross pins **64** and **65**, respectively, and the rolls **65'** which ride on the flanges of channels **26**. A pair of links **66** are pivotally suspended from the lower pin **65**, and to the bottom

of these links is connected by means of pin 67 a counterweight 68. It is seen that by rotation of wheel 54 and screw 53, axial movement of block 58 in response thereto will carry with it counterweight 68 to adjust the position thereof along beam 25.

A pair of links 70 are each pivotally connected at their upper ends to a pivot pin 72 on beam 25, such pivot pin being located intermediate the beam pivot pin 28 and the plates 63 supporting counterweight 68. The lower ends of links 70 are each pivotally connected by means of pivot pin 71 to the upper end of a hydraulic piston rod 73 connected to a hydraulic piston 74 (see Fig. 4) for actuating beam 25 according to the invention. Piston rod 73 has a collar 75 thereon adjustable by means of set screw 75', for engagement with a stop member 76 which slidably receives rod 73 for limiting upward movement of the piston rod and the piston 74 connected thereto.

Piston 74 is connected by means of nut 78 to the lower end 79 of rod 73, and is slidably mounted within a cylinder 80 for vertical movement axially therein. The cylinder 80, which is mounted on the supports 77 in turn bolted as at 77' to the concrete base 33, comprises a body member 81 and upper and lower cylinder heads 82 and 83, respectively. Cylinder head 82 in turn has an upwardly extending member 84 integral therewith, and to the top of member 84 is connected by means of bolts 85 a packing gland 86 for securing packing 87 between member 84 and piston rod 73 to prevent leakage of hydraulic fluid from cylinder 80. A pipe 90 is threadably connected to the lower and upper piston heads 82 and 83, respectively, of cylinder 80, the pipe 90 being in turn connected through a T 92 to another pipe 91, and having valves 93 and 94 therein on opposite sides of the T. The cylinder 80 has a lower outlet 95 to which is threadably connected a pipe 96 having a valve 97 therein.

Another pipe 100 is also threadably connected into the upper and lower cylinder heads 82 and 83 of cylinder 80, on the opposite side of the cylinder from pipe 90. A T 101 connects pipe 100 with a valve 102, pipe 100 having a pair of valves 103 and 104 therein, located on the opposite sides of T 101. Valve 102 is an elongated member having a body portion 105 and a guide 106 connected to said body member. One end of valve body 105 has a central bore 107 therein which communicates at one end with the leg 108 of T 101, the other end of the bore opening into a counterbore or port 109. Connected to port 109 is a pipe 110 in turn connected through a T 111 to a pipe 112 which is threadably secured at its upper end in an inlet 113 in valve body 105, communicating with the bore 107 therein, there being a valve 114 in the pipe 112.

A needle type elongated valve stem 115 is slidably positioned axially in a bore 116 in the other end of valve body 105, the inner end of valve stem 115 having a V-shaped point 117 thereon positioned within port 109 and adapted to engage the adjacent end of bore 107 to close off communication between it and port 109. A packing gland 120 is connected by bolts 121 to the outer end of valve body 105 to maintain packing 122 in position to provide a liquid seal. The outer end 125 of the valve stem is slidably received in an aperture 126 in guide member 106. Adjacent the end 125 of the valve stem is disposed a collar 127, against which is positioned one end of a spring 128, the other end of the spring abutting the packing gland 120. Spring 128 normally urges valve stem 115 outwardly to cause movement of the valve point 117 away from bore 107 so as to open communication between bore 107 and port 109.

Valve stem 115 is urged outwardly through the action of spring 128 but is restrained in such outward movement by contact of the outer end of the valve stem with the lower end of a lever 130 which is pivoted intermediate its ends on a pivot pin 131 mounted on a bracket 132 connected by bolts 132' to standards 29. The upper curved end 133 of lever 130 has a cam roller 134 thereon which engages the surface of a cam 135 mounted for rotation on a shaft 136 (see Fig. 5) in turn mounted in a bearing 140 and driven by the change gears 140a and 140b and a motor 137 through a speed reducer 138, the motor being mounted on a bracket 139 connected to standards 29. It is seen that the cam roll 134 is at all times forced into contact with the peripheral surface of cam 135 since spring 128 always presses the valve stem 115 outwardly against the lower end of the lever 130, causing it to rotate clockwise to urge roller 134 against the cam. When cam roller 134 rides on the high portion 141 of cam 135 (see also Fig. 10), lever 130 forces valve stem 115 inwardly, tending to close valve 102 through engagement of valve point 117 with the end of bore 107. On the other hand, when the cam roller rides onto the low portion 142 of the cam 135, lever 130 pivots clockwise about pin 131, permitting spring 128 to urge valve stem 115 outward to move valve point 117 away from bore 107 to open valve 102.

The valves 93, 94, 97, 103 and 104 (see Fig. 4) can be manipulated so that the piston 74 rises or falls in cylinder 80 when the cam roller 134 rides on the low portion 142 of cam 135. Rise of the piston 74 causes beam 25 to rotate counterclockwise about its pivot 28 and thus lowering support 40 and the work piece 41 suspended thereon into the tank 20 to immerse said work piece into etch solution 21. Descent of the piston 74 causes beam 25 to rotate clockwise about its pivot point to thus raise support 40 and the work piece 41 thereon out of the etch solution in tank 20. As will be described in detail below, the cam 135 is specially designed to bring about a predetermined rate of immersion in or withdrawal from etch bath 21, of the work piece 41, so as to contour the work piece into a preselected shape.

Assume, for example, that it is desired to contour work piece 41 into a piece 41' by means of the device of Fig. 1, part 41' having the shape indicated in Fig. 9, including a tapered portion 41''. To produce such a part by automatically controlling the rate of immersion or withdrawal of the work piece 41 from the solution according to the invention, a cam 135 is designed based on a specific operating concentration and temperature of the etching solution and on the etch rate thereof on the metal or alloy of which part 41 is composed. The cam, in this instance, is to be designed to produce the desired contouring of part 41 by controlled withdrawal of the part from the etching bath.

Cam 135 is accordingly designed so that when cam roller 134 rides on the high portion 141, lever 130 closes valve 102, that is, by seating point 117 of the valve over the end of bore 107. Under these circumstances the work piece 41 is entirely out of the solution 21.

As soon as the work piece 41 is immersed to the desired degree in the solution, at which time piston 74 is at its high point in cylinder 80 (as seen in Fig. 4), the cam roll 134 (assuming clockwise rotation of cam 135) drops from point D on cam 135 to the low point C (see Fig. 10). This opens valve 102 to its fullest to permit fluid to pass into the cylinder 80 above piston 74 and force it downward. Starting at point C on the low portion 142 of cam 135, the contour of the rise from C to A on the cam is developed from the known factors such as the required length of time of immersion, required length of travel of the work piece in the solution, and the speed of lift of the work piece. These factors in turn are dependent on concentration of the solution and temperature thereof. As the cam continues to rotate clockwise, it will cause lever 30 and valve stem 115 to move inward at a predetermined controlled rate until the roll 134 reaches point A at the opposite end of the rise on the low portion 142 of the cam. During the period of travel of cam roller 134 from the lowest point C on the low portion 142 of the cam to the highest point

A at the other end thereof, piston 74 travels downwardly at such a rate as to cause support 40 and work piece 41 thereon, through the intermediary of beam 25, to move upwardly out of the solution at such a controlled uniform rate as to produce the tapered contour 41'' on part 41, as seen in Fig. 14.

It is apparent that a cam can be designed for production of any desired etch configuration by automatically controlling rate of immersion in or withdrawal from the etch solution, of the work piece so as to control rate of attack of the solution in accordance with the contour desired to be imparted to said work piece. Such cam in each instance must be designed for a particular concentration of etch bath and temperature of operation therein. It should be noted that generally the same cam can not be used interchangeably for production of the same part in the same solution, by both timed immersion and withdrawal of the part. Thus, for example, a cam of different shape than that of cam 135 would be required to produce the same part 41' in the same solution, that is, at the same concentration and temperature, but by immersion rather than withdrawal.

In the operation of the embodiment shown in Figs. 1 and 4, assume that the piston 74 is in its lower position shown in dotted lines in Fig. 4. Under these conditions, the end of beam 25, to which the work piece is attached, is raised with the support 40 suspended above the solution. A work piece 41 is then attached to the lower end of the support using clamps, bolts, or any suitable fasteners. During this period, cam roller 134 is positioned on the high portion 141 of cam 135, preferably at the point D (see Fig. 10), and valve 102 is closed, that is, valve stem 115 is in seated position at the end of bore 107. At this point valves 94, 97, and 103 are closed, and valves 93, 104, and 114 are opened to permit oil or other pressure fluid to flow through pipe 110, inlet 113, bore 107, and the lower end of pipe 100 into the cylinder 80 below piston 74, forcing same upwardly in the cylinder while the fluid above the piston is bled downwardly from the upper end of pipe 90 through pipe 91 and back to the pressure source (not shown).

As the piston 74 rises in cylinder 80, beam 25 pivots counterclockwise to lower support 40 and the work piece 41 thereon, and when the piston reaches the top of its stroke governed by the valve 102 and contact of the adjustable collar 75 with stop 76, the lower end of part 41, which is to be etched, is immersed in the etch solution. As seen in Fig. 9, the location of surface 145 of the solution with respect to the part will correspond to the position of roller 134 at point C on the cam. (In the following description, the letters A, C and D' in Figs. 9 and 9*a* represent the positions of part 41 with respect to the surface of the etching solution corresponding to the positions of roller 134 at points A, C and D', respectively, on cam 135 during rotation thereof.) The rise of the piston 74 is comparatively rapid, so that substantially little, if any, etching takes place on part 41 during this period of immersion. As soon as the piston has reached its upward limit of travel and the part 41 has been immersed to the level indicated at C, valves 93, 104 and 114 are closed, and valves 103 and 94 are opened, and the cam actuating motor 137 is turned on to rotate the cam 135 at a constant speed. The cam roller quickly drops from point D to point C on the cam assuming clockwise rotation of the cam due to the action of spring 128, which urges valve stem 115 outward to fully open port 109 to communication with bore 107.

Pressure fluid then passes through pipe 110, port 109, bore 107 and the upper end of pipe 100 into the top of cylinder 80 above piston 74. This commences to force the piston downward with the pressure fluid below the piston being bled upward through the lower end of pipe 90 into pipe 91 for return to the pressure source. At the same time, beam 25 is pivoted clockwise to raise support 40 and the work piece 41. As the cam roller proceeds to follow the contoured portion 142 of cam 135, since the radius of curvature of the contoured portion 142 becomes increasingly larger (as seen in Fig. 10 in proceeding from radius X to radius Y), lever 130 gradually pivots clockwise about pivot point 131, forcing valve stem 115 inwardly against the action of spring 128 and gradually decreasing the area of the passage 143 between the valve head 117 and the inner end of bore 107 until the cam follower reaches point A of the cam. This gradual building up of obstruction to the flow of pressure fluid into the top of cylinder 80 above piston 74 as the cam follower rotates along the contoured portion 142 of the cam 135 permits introduction of only sufficient fluid pressure into cylinder 80 to produce a predetermined substantially uniform rate of downward movement of the piston and hence a predetermined substantially uniform rate of upward movement of support 40 and the work piece 41 thereon, until the piston reaches an intermediate limit of travel near its lowermost position (as shown in dotted lines in Fig. 4), at which time port 107 is still partly open. This results in formation of the taper 41'', because the solution was permitted to attack the various sections of portion 41'' for uniformly different periods of time, with the lower sections of portion 41'' being subjected to the action of the solution longer than the upper sections thereof.

When the piston 74 reaches the above indicated intermediate limit of travel near its lower limit of travel, the cam follower is now at point A on the cam, and the work piece 41' has been withdrawn from the solution down to point A at the lower end of the taper, as seen in Fig. 9, that is, the bottom of the part is at the surface 145 of the solution. The cam follower 134 then quickly moves from point A at the upper end of the contoured portion 142 of the cam to point D' on the upper periphery 141 of the cam. During this movement of the cam follower, sufficient additional pressure fluid enters the cylinder above piston 74 to cause the cylinder to move down to its lowermost limit of travel shown in dotted lines in Fig. 4. This latter movement causes beam 25 to pivot clockwise sufficiently so as to completely withdraw the part 41' from the solution. The part 41' is now removed from the support 40 and a fresh piece of stock 41 secured thereto. The above operation can then be repeated to produce another tapered part like 41'.

As previously pointed out, if the etch configuration of a part 41 is produced by control of the rate of immersion of the part in the etching solution rather than by controlling the rate of withdrawal therefrom, and cam 135 were employed to control such rate of immersion in a manner similar to that described above, a somewhat different etch configuration from the tapered section 41'' would be formed; or, in other words, if it is desired to obtain the same etch configuration as taper 41'' by etching during immersion of the part rather than during withdrawal, a cam of a different design from cam 135 would be required, assuming the same concentration and temperature of etch solution were employed.

In Figs. 6 to 8 of the drawings is shown another modification of the device of the invention for automatically controlling the rate of immersion or withdrawal of a metal part for preselected contouring thereof. The instant modification, as in the case of that described above, comprises a beam 25 formed in the same manner as the beam of Fig. 1, and pivoted intermediate its ends on the pivot pin 28 mounted at the upper ends of a pair of parallel vertical standards 150. The component parts connected to beam 25 are the same as the component parts connected to the beam 25 of Fig. 1, and includes reenforcing rod 44, plates 43 and 46, plates 63 and the suspended counter weight 68, and the mechanism including the screw 53 and handwheel 54 for adjustment of the counterweight.

Tank 20 in Fig. 6 contains a series of coils 146 through which a heating fluid such as steam or hot water may be

passed to regulate the temperature of the etching solution in the tank. Numeral 147 represents a liquid inlet to the tank, and pipe 148 is a liquid outlet or drain.

Standards 150 are supported on a suitable base 151, and mounted on a platform 152 supported on a bracket 153 which is connected by means of bolts 154 to the standards, is a motor 155. The motor shaft 156 rotates a worm 157 through a speed reducing device 158, the worm 157 being supported for rotation in two upwardly extending bearings 159 of a bearing bracket 160 connected by means of bolts 161 to the standards 150. Worm 157 is in meshing engagement with a worm gear 165 fixed on a shaft 166 for rotation therewith, the shaft being journalled in bearing plates 167 connected by means of bolts 168 to the opposite standards 150. A cam such as the cam 135 previously described is also mounted on shaft 166 for rotation therewith in response to the rotation of gear 165.

A bracket 170 is connected to standards 150 at a point above gear 165 and cam 135. An arcuately shaped arm 171 is pivoted at one end thereof on a pivot pin 172 mounted on bracket 170. The other end of arm 171 is pivotally connected by means of pivot pin 173 to one end of an adjustable rod 174 pivoted at its other end on a pin 175 mounted on beam 25 between its main pivot point 28 and the point 38 of pivotal attachment thereto of support 40. Rod 174 has a turnbuckle 176 thereon to adjust the distance between pivot points 173 and 175. Arm 171 has a depending portion 177 intermediate its ends, on which is mounted a cam roll 178 which rides on the outer periphery of cam 135.

In operation of the modification shown in Fig. 6, the cam 135 is rotated to a position where the cam follower 178 is in contact with the high portion 141 of the cam. Under these conditions it will be noted that arm 171 will be pivoted counter-clockwise on its pivot pin 172 to a point where the opposite pivot point 173 will be at its highest position. This will raise the beam 25 to a point above the etching solution 21 in tank 20 so as to permit securing a work piece 41*a* to the lower end of support 40. On clockwise rotation of cam 135 the cam roller 178 will drop from point D on the cam surface to the lowermost point C on the low portion 142 of the cam. During this period of movement of the cam follower, the beam 25 rotates counter-clockwise sufficiently to lower support 40 and the work piece 41*a* thereon to a point where the work piece 41*a* is partly submerged in the solution, that is, with the surface 145 of the solution corresponding to the position of roller 134 at the point C on the cam, as indicated in Fig. 9*a*. As the cam roller proceeds to follow the contoured portion 142 of cam 135, since the radius of curvature of the low portion 142 becomes increasingly larger, as previously pointed out, arm 171 will pivot clockwise at a predetermined uniform rate during movement of the cam roller 178 from the point C to the point A at the upper end of the contoured portion 142 of the cam. This also produces a uniform clockwise pivotal motion of beam 25 of Fig. 6 about its pivot 28, in turn bringing about a predetermined uniform rate of upward movement of support 40 and the work piece 41*a* thereon until the work piece 41*a* has been withdrawn from the solution a distance equal to the length of the tapered portion 41″*a* of the work piece measured along its longitudinal axis. The work piece 41*a* is now submerged in the solution with the surface 145 of the solution at a level with point A at the lower end of the taper as shown in Fig. 9*a*. For the reasons previously noted, this gradual withdrawal of the intermediate portion 41″*a* of the work piece results in the formation of the uniform taper imparted to the intermediate section of the work piece. As the cam continues to rotate clockwise, the cam follower 178 quickly moves from point A to point D′ on the cam, and during this movement of the cam follower, the arm 171 and beam 25 are rotated a sufficiently additional amount in a clockwise direction to completely withdraw the finished tapered work piece 41′*a* from the solution. This period of withdrawal of the lowermost section 41‴ of the work piece takes place sufficiently rapidly so that little, if any, etching of this section takes place during this time.

In Figs. 11 to 13 is shown still another modification of the automatically controlled contouring principles of the invention. Referring particularly to Fig. 11, a frame 180 is mounted on a pair of standards 181, each of which are connected at their lower ends by means of bolts 182 to a base member 183, in turn fixed in a base 184, for example, of concrete, by means of bolts 185′. Bolted to the base 184 is a reversible motor 185 which drives a sprocket 186 through a reducing device 187, coupling 188 and shaft 189. The end of shaft 189 is mounted in a bearing 190 which is bolted to an anchor member 191 by bolts 185″. Sprocket 186 drives a chain 195 which is in meshing engagement with a gear 196 positioned above sprocket 186. Gear 196 is axially connected to one end of a screw 197, the other end of which is journalled in a bearing 198 mounted for support on a buttress 202. Gear 196 is also axially connected to one end of a shaft 199 which is mounted for rotation at one end in a bearing 200 adjacent gear 196, and at the opposite end thereof in a bearing 201. Said bearings 200 and 201 are supported on frame 180, and the shaft 199 is in alignment and rotatable with the screw 197. Mounted on shaft 199 between bearing 201 and the bearing 200 is a mandrel 205 having a set screw 206 therein for fixedly mounting the mandrel on the shaft 199 for rotation therewith.

A sheave pulley 207 is mounted for rotation on a pin 208 positioned at opposite ends in arms 209, forming a slot 210 in an elongated bar 211. Bar 211 is mounted in bearings 212 on frame 180, the bar 211 being axially slidable within said bearings. At the inner end of bar 211 is mounted a depending support member 215 at the lower end of which is integrally formed a sleeve 216 which is internally threaded to receive screw 197. It will be seen that rotation of screw 197 by the drive gear 196 will cause sleeve 216 and the bar 211 connected thereto to move axially in one direction or the other, depending upon the direction of rotation of the gear 196.

Mounted above the frame 180 is a cylinder 220 having a piston 221 positioned for slidable movement in the cylinder in a direction parallel to the linear direction of travel of bar 211 and sleeve 216 along screw 197. The cylinder 220 has a fluid pressure inlet 222 and outlet 223 with valves 224 and 225 connected in the inlet and outlet pipes 222 and 223, respectively. The piston 221 has a rod 226 which extends through the flanged head 227 of the cylinder 220. A packing gland 228 is secured by means of bolts 229 to flange 227 for maintaining packing member 231 in position to provide a liquid pressure seal, the piston rod 226 being slidable within the aperture 231 of cylinder head 227. Mounted on the outer end of piston rod 226 is a yoke 238 having a rotatable pulley 233 positioned at the outer end thereof, and at the top of a vertical support 236 opposite pulley 233 and in axial alignment with piston rod 226 is a rotatable sheave pulley 235. A cable 237 is received over pulleys 235 and 233, the cable then passing over pulley 207 and being connected at 240 to the reduced end of mandrel 205. A metal work piece 241 can be secured by suitable means such as clamp 237′ to the end of cable 237 suspended over pulley 235 for immersion in an etching solution contained in etching tank 242.

Mounted over the cable 237 closely adjacent pulley 233 is a tripper 243 positioned on an insulated support 244, and also connected to support 244 is a contact member 245. When tripper 243 is urged upwardly so as to bring about engagement of the contacts 246 and 247 at the ends of members 243 and 245, this closes a circuit (not shown) connected to the pressure source (not shown) for introducing pressure fluid through inlet 222 and into cylinder 220. Mounted over cable 237 closely adjacent pulley

235 is a tripper 248 having a contact 249 at one end thereof, the tripper being secured at its opposite end to an insulated support 250, to which is also secured a contact member 251 having a contact 252 at its opposite end adjacent contact 249. On cable 237 between trippers 243 and 248 are a pair of spaced adjustable lugs 253 and 254. When tripper 248 is urged toward member 251 to cause engagement of contacts 249 and 252, this also closes a circuit (not shown) to said pressure source for introducing pressure through inlet 222 into cylinder 220.

Lug 253 is so positioned along cable 237 that when the length of cable to be wound about mandrel 205 is actually wound thereon, lug 253 will contact the tripper 243 to operate same and introduce air into the left end of cylinder 220 to raise the work piece at the end of cable 237 out of the solution. Likewise, lug 254 is so positioned along cable 237 that when the cable has been completely unwound from the mandrel 205, and the work piece is inserted in the solution to the desired depth, the lug 254 will contact tripper 248 to cause introduction of air into the left end of cylinder 220 to raise the work piece out of the solution. It is thus seen that the operation of either tripper 243 by lug 253 or tripper 249 by lug 254 permits introduction of air into cylinder 220 to the left of piston 221, urging same to the right as shown by the arrow in Fig. 11. This also carries yoke 238 and pulley 233 to the right which causes movement upwardly of that portion of cable 237 suspended from pulley 235 sufficiently to lift work piece 241 clear of the etching solution in tank 242, whether the cable 237 is completely wound upon, or unwound from, the mandrel 205. The position of lugs 253 and 254 may be adjusted along cable 237 depending on the amount of cable to be wound onto or unwound from mandrel 205.

It is noted that the cable 237 is of a thickness substantially equal to the pitch of the screw 197, so that as the gear 196 simultaneously rotates screw 197 and shaft 199 in a counter-clockwise manner, as viewed from the right end of Fig. 11, to cause a winding of the cable about mandrel 205, the threaded sleeve 216 and bar 211 will move rearwardly an amount equal to the thickness of cable 207 for each turn of screw 197 and shaft 199. In this manner, pulley 207, which feeds the cable to mandrel 205, is always located with respect to the mandrel so that the cable is fed evenly to the mandrel as the cable is wound thereon; that is, the pulley 207 continuously moves rearwardly during such winding operation an amount to permit the cable to wind helically about the mandrel, with each turn of the cable positioned closely adjacent the previous turn, but with no overlapping or piling up of the cable on itself regardless of the shape or contour of the mandrel 205.

Also, when gear 196 drives screw 197 and shaft 199 in a clockwise direction as viewed from the right end of Fig. 11, sleeve 216 and bar 211 carried thereby move forwardly an amount equal to the thickness of cable 237 for each turn of cable unwound from about mandrel 205. Hence, guide pulley 207 moves continuously forward during such unwinding operation an amount equal to the thickness of the cable for each turn of cable unwound, so as to facilitate smooth, uniform removal of the cable from the mandrel.

When the cable 237 is being wound about the mandrel 205, work piece 241 will be thereby lifted upwardly at a rate corresponding to the rate of winding of the cable about the mandrel 205. Since motor 185 rotates gear 196 and hence screw 197 and shaft 199 at a constant speed, this rate of winding in turn will depend upon the diameter of that portion of the mandrel about which the cable is being wound. If the diameter of such portion increases, the rate of upward movement of the work piece increases, as the mandrel will then receive a greater portion of the cable to make one turn thereof about the mandrel. On the other hand, if the diameter of that portion of the mandrel about which the cable is being wound decreases, the rate of upward movement of the work piece supported at the end of the cable also decreases. It is noted that during the period of winding or unwinding of cable 237 from about mandrel 205, pulley 233 remains stationary at the end of piston rod 226, which is urged to its greatest extent of outward movement by the weight of the cable and work piece suspended therefrom, as seen in Fig. 11.

In the embodiment of Fig. 11, the mandrel 205 takes the place of the cam 135 in the embodiments of Figs. 4 and 6. That is, the outer shape or contour of the mandrel 205 controls the rate of immersion or withdrawal of the work piece 241 from the solution in tank 242. In this manner, as previously described, the etch rate of the solution on various portions of metal part 241 will be varied to produce the desired contouring or shape of part 241. As in the case of cam 135, mandrel 205 is designed, based on a specific operating concentration and temperature of the etching solution and on the etch rate thereof on the particular metal or alloy of which part 241 is composed.

As shown in Fig. 11, the mandrel 205 thereof has an outer contour composed of a cylindrical end portion 260 of large diameter having a flange 261 about the outer edge thereof, an adjacent tapered or conical portion 262, and another cylindrical end portion 265 of diameter smaller than the other cylindrical end portion 260.

In operation of the embodiment shown in Figs. 11, 12 and 13, assume that the cable 237 is completely unwound from the mandrel 205, and that piston rod 226 and pulley 233 have been retracted to the right to the full extent permitted by actuation of the piston 221 forward or to the right, indicated by the arrow in Fig. 11, to the far end of cylinder 220. The end of the cable 237 is now clear of the surface of the solution in tank 242, and a cylindrical work piece 241 to be contoured as shown in Fig. 14 is connected by suitable means to the end of the cable. Pressure valve 224 is then closed and vent valve 225 is opened, permitting piston 221 to move backward, that is, to the left in cylinder 220. The piston rod 226 and pulley 233 are urged in this direction by the gravitational pull of part 241 suspended on the end of cable 237. In this manner, the part is quickly submerged in the etch solution until that portion of part 241 below the dotted line X in Fig. 14, representing the surface of the etch solution, is immersed in the solution. This period of immersion is sufficiently rapid so that practically no etching of part 241 takes place during this period. When the part comes to rest in the solution, the piston has reached the end of its stroke to the left.

At this time motor 185 is started to cause rotation of gear 196, screw 197, shaft 199 and mandrel 205 in the counter-clockwise direction as viewed from the right end of Fig. 11, and valve 225 is closed and valve 224 opened. This winds the cable 237 about the reduced cylindrical end portion 265 of the mandrel 205 at a uniform rate, which in turn raises work piece 241 at the other end of the cable at a uniform rate in the etch solution. When the cable has been wound about the entire end portion 265 of mandrel 205, part 241 will have risen in the solution a distance such that the level of the solution is now at point G on the part. The rising of the part 241 in the solution at a uniform rate results in formation of the straight tapered portion 270 of the work piece corresponding to that portion of the part lifted from the solution during this period, since the solution was permitted to attack the various sections of portion 270 for uniformly different times, with the lower sections of portion 270 being subjected to the action of the solution longer than the upper sections thereof.

As the screw 197 and shaft 199 continue to rotate at constant speed the cable 237 proceeds to wind about the intermediate conical portion 262 of the mandrel 205. However, since each turn of the cable on portion 262 has a larger diameter than the previous turn, the rate of

upward movement of the work piece **241** suspended at the end of the cable will constantly increase as the cable winds from the small end of conical portion **262** to the large end of this portion. During this period of winding of the cable entirely about conical portion **262**, the part **241** will rise in the solution from point G a distance such that the level of the solution is now at point H in Fig. 14. The rising of the part **241** in the solution at a constantly increasing rate or velocity during this period thus produces a portion **271**, the surface of which has a concave curvature of increasing slope in a downward direction, instead of a straight line taper as in the case of portion **270**.

As the mandrel **205** continues to rotate at constant speed, cable **237** winds about the enlarged end portion **260** of the mandrel to flange **261** thereon. During this period part **241** is caused to again rise at a uniform rate from the etching solution from point H to point J near the lower end of the part, to form a second straight tapered portion **274** similar to tapered portion **270**.

Just as the cable **237** becomes completely wound about the mandrel and approaches the flange **261**, the motor **185** is shut off, and lug **253** on cable **237** trips the tripper **243** causing flow of pressure fluid from the pressure source through open valve **224** and into the cylinder **220** behind piston **221**. This forces the piston forward in the direction of the arrow in Fig. 11, to the end of its stroke, carrying with it rod **226** and the pulley **233** thereon. This action of piston **221** is relatively rapid, and hence causes a correspondingly rapid complete withdrawal of the part **241** from the solution through movement of the cable as result of the retraction of rod **226** and pulley **233**. Hence, substantially no etching of part **241** takes place from point J to the lower end K of the part, and thus the lowermost portion **275** of the part is of substantially cylindrical shape.

If it is desired to contour a part by automatically controlled immersion employing the mandrel **205**, instead of by automatically controlled withdrawal of the part as described above, the contoured part **241** is removed from the end of cable **237** and another stock cylindrical part **241'** secured to the cable in its place. Pressure valve **224** is then closed and vent valve **225** opened, permitting piston **221** to move backward, that is, to the left in cylinder **220**, carrying rod **226** and pulley **233** in the same direction. This movement of the piston is halted by closing valve **225** when the pulley has moved sufficiently so as to permit the cable to lower only the bottom portion **280** of the part **241'** into the solution, the level of the solution being indicated by the line Y in Fig. 15. This period of immersing the lower end **280** of the part **241'** in the solution is insufficient to cause any significant amount of etching of portion **280** so that it remains substantially cylindrical in shape.

At this point, the motor **185** is turned on in the reverse direction from that noted above, causing the gear **196**, screw **197**, shaft **199** and mandrel **205** to rotate at a uniform speed in a clockwise direction viewed from the right end of Fig. 11, to cause the cable **237** to unwind from mandrel **205**. During the unwinding of the cable **237** from the enlarged cylindrical end portion **260** of the mandrel, the part **241'** at the end of the cable is lowered into the solution at a uniform rate, since the cable is unwound from portion **260** at a uniform rate. This produces a straight downward taper in the portion **281** of the part adjacent the end portion **280**, since the lower section of portion **281** is subjected to a greater etching period than the upper section thereof.

As the mandrel **205** continues to rotate clockwise at constant speed, the cable **237** unwinds from the intermediate conical section **262** of the mandrel. Since each turn of the cable during this period has a smaller diameter than the preceding turn, descent of the work piece **241'** suspended at the end of the cable will proceed at a constantly decreasing rate or velocity as the cable unwinds from the large end of conical section **262** to the small left end there. Since the rate of etch continues to decrease accordingly under these circumstances, a convexly curved portion **282** of increasing slope in an upward direction is produced, which portion increases in section from its lower end upwardly therefrom.

Finally, as the cable unwinds from the small cylindrical end portion **265** of the mandrel, during which period part **241'** descends further into the etching solution at a constant rate, another straight downwardly tapering portion **285** is formed similar to portion **281** of the part. The smaller end of tapered portion **285** is located adjacent the upper end of portion **282**, since such smaller end remains in the etching solution longer than the upper end of portion **285**.

When cable **237** has been substantially unwound from mandrel **205**, the level of the etching solution is at the line Y with respect to the part **241'**, the upper portion **286** thereof being above the surface of the solution. Following the formation of each of the etched portions **281**, **282** and **285** of part **241'**, and while the part is being immersed to form the respective contoured portions following formation of a previous contoured portion, each of the previously etched portions continues to be etched at the same rate since these portions are now entirely immersed during these periods. Thus, for example, following contouring of portion **281** of the part **241'**, this portion continues to be etched at a uniform rate during continuous lowering of the part in the solution to contour portions **282** and **285** of the part as above described, since portion **281** remains completely immersed during such contouring period. Also, portion **282** will be immersed and undergoing constant etching during the period of contouring of the upper portion **285**. Thus, by the time the part is immersed to where the surface of the solution is at line Y above portion **285**, the lowermost portions **280** and **281** will have been undergoing etching for a longer period than any of the other upper portions **282** and **285** of the part, and hence will be etched down to a size having a section smaller than any of said upper portions. Likewise portion **282** will be etched down to a size having a section smaller than the upper portion **285**. In this manner, the portions **280**, **281** and **282** retain their initially formed contour during etching of the respective upper portions of part **241'**, but the diameter of portions **280**, **281** and **282** decreases during etching of such respective upper portions.

Just as the cable **237** becomes unwound from mandrel **205**, lug **254** contacts tripper **248** which operates to force fluid pressure through valve **224**, which had been previously opened, into the cylinder **220**. Vent valve **225** having been previously closed, the pressure forces piston **221** to the right, carrying with it rod **226** and pulley **233**, until the piston reaches its limit of movement in this direction. During this period, the piston movement is sufficiently rapid so that corresponding movement of the pulley **233** and upward movement of the cable **237** below pulley **233** quickly withdraws part **241'** from its position with respect to surface Y of the solution as seen in Fig. 15, to a point above such surface where the part is no longer in contact with the solution.

At this point, the etched part **241'** is removed from cable **237**.

The contour of mandrel **205** in proportion to the contour of the etched parts **241** and **241'** is not necessarily accurate, and is intended only to be a schematic illustration.

It is understood that the controlled immersion or withdrawal of the parts from the etching solution according to the invention is preferably carried out while maintaining concentration and temperature of the solution substantially constant. By thus controlling the etching bath temperature and concentration during the time of

etching, and utilizing the invention principles, parts of substantially any desired shape may be formed, and such parts may be produced within close tolerances.

Means may be provided to remove or wash any residual etching solution from the etched part following removal of the part from the etching solution.

Of course it will be understood that the apparatus described herein 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 purposes 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 claims.

I claim:

1. Apparatus for controlling the rate of movement of an object into and out of an etching solution for contouring a surface portion of said object, which comprises a mandrel having a preselected outer surface contour corresponding to the contour to be formed on said surface portion, a cable connected at one end to said mandrel, a support for said cable permitting movement thereof over said support, an end portion of said cable being vertically suspended from said support for attachment to an object, means for rotating said mandrel on the axis thereof to wind said cable around, and to unwind it from, the outer surface of said mandrel for automatically controlling the rate of movement of said cable and of movement of said object on said cable end portion through said solution to contour said surface portion, and means actuated in response to rotation of said mandrel to permit winding of said cable on said mandrel without causing said cable to wind onto itself, for movement of said object through said solution.

2. Apparatus for controlling the rate of vertical movement of an object into and out of an etching solution for contouring a surface portion of said object, which comprises a mandrel having a preselected outer surface contour corresponding to the contour to be formed on said surface portion, a cable connected at one end to said mandrel, a support for said cable permitting movement thereof over said support, an end portion of said cable being vertically suspended from said support for attachment to an object, means for rotating said mandrel on the axis thereof to wind said cable around, and to unwind it from, the outer surface of said mandrel for automatically controlling the rate of movement of said cable and of vertical movement of said object on said cable end portion through said solution to contour said surface portion, and means actuated in response to rotation of said mandrel to permit winding of said cable on said mandrel without causing said cable to wind onto itself, and means connected to said cable to impart a relatively rapid vertical movement upwardly to said end portion of the cable when a predetermined length of said cable is wound about said mandrel and also when a predetermined length of said cable is unwound from said mandrel.

3. Apparatus for controlling the rate of vertical movement of an object into and out of an etching solution for contouring a surface portion of said object, which comprises a tank, an etching solution in said tank, a mandrel having a preselected outer surface contour corresponding to the contour to be formed on said surface portion, a cable connected at one end to said mandrel, a rotatable support for said cable, an end portion of said cable being vertically suspended from said support for attachment to an object, means for rotating said mandrel on the axis thereof to wind said cable around, and to unwind it from the outer surface of said mandrel for automatically controlling the rate of movement of said cable and of vertical movement of said object on said cable end portion through said solution, in accordance with the contour of said mandrel, and means moving in a direction parallel to the axis of said mandrel in response to rotation thereof to permit winding of said cable on said mandrel without causing said cable to wind onto itself, said last named means including a member to receive said cable and guide it over said mandrel so that each turn of said cable thereon is disposed closely adjacent a preceding turn of the cable.

4. Apparatus for controlling the rate of vertical movement of an object into and out of an etching solution for contouring a surface portion of said object, which comprises a mandrel having a preselected outer surface contour corresponding to the contour to be formed on said surface portion, a cable connected at one end to said mandrel, a rotatable support for said cable, an end portion of said cable being vertically suspended from said support for attachment to an object, means for rotating said mandrel on the axis thereof to wind said cable around, and to unwind it from the outer surface of said mandrel for automatically controlling the rate of movement of said cable and of vertical movement of said object on said cable end portion into said solution in accordance with the contour of said mandrel, a screw mounted coaxially of said mandrel and rotatable therewith, a sleeve mounted on said screw for axial movement thereof on rotation of said screw, a supporting member connected to said sleeve, a cable guide connected to said supporting member for movement in a direction parallel to the axis of said mandrel and said screw on rotation thereof, said cable being received over said cable guide to permit winding of said cable on said mandrel without causing said cable to wind onto itself.

5. Apparatus for controlling the rate of vertical movement of an object into and out of an etching solution for contouring a surface portion of said object, which comprises a tank, an etching solution in said tank, a mandrel having a preselected outer surface contour corresponding to the contour to be formed on said surface portion, a cable connected at one end to said mandrel, a rotatable support for said cable, an end portion of said cable being vertically suspended from said support for attachment to an object, means for rotating said mandrel on the axis thereof to wind said cable around, and to unwind it from the outer surface of said mandrel for automatically controlling the rate of movement of said cable and of vertical movement of said object on said cable end portion into said solution in accordance with the contour of said mandrel, a screw mounted coaxially of said mandrel and rotatable therewith, a sleeve mounted on said screw for axial movement thereof on rotation of said screw, a supporting member connected to said sleeve, a cable guide connected to said supporting member for movement in a direction parallel to the axis of said mandrel and said screw on rotation thereof, said cable being received over said cable guide to permit winding of said cable on said mandrel without causing said cable to wind onto itself, and means connected to said cable to impart a relatively rapid vertical movement upwardly to said end portion of the cable when a predetermined length of said cable is wound about said mandrel and also when a predetermined length of said cable is unwound from said mandrel.

6. Apparatus for controlling the rate of vertical movement of an object into and out of an etching solution for contouring a surface portion of said object, which comprises a mandrel having a preselected outer surface contour corresponding to the contour to be formed on said surface portion, a cable connected at one end to said mandrel, a rotatable support for said cable, an end portion of said cable being vertically suspended from said support for attachment to an object, means for rotating said mandrel on the axis thereof to wind said cable around, and to unwind it from the outer surface of said mandrel for automatically

controlling the rate of movement of said cable and of vertical movement of said object on said cable end portion into said solution in accordance with the contour of said mandrel, a screw mounted coaxially of said mandrel and rotatable therewith, a sleeve mounted on said screw for axial movement thereof on rotation of said screw, a supporting member connected to said sleeve, a cable guide connected to said support for movement in a direction parallel to the axis of said mandrel and said screw on rotation thereof, said cable being received over said cable guide to permit winding of said cable on said mandrel without causing said cable to wind onto itself, a second rotatable support for said cable, said last named support receiving the portion of said cable between said first mentioned rotatable support and said cable guide, means for moving said second rotatable support in a direction away from said first named rotatable support to impart a vertical movement upwardly to said end portion of the cable, and means associated with said cable for actuating said last mentioned means when a predetermined length of said cable is wound about said mandrel and also when a predetermined length of said cable is unwound from said mandrel.

7. Apparatus for controlling the rate of vertical movement of an object into and out of an etching solution for contouring a surface portion of said object, which comprises a tank, an etching solution in said tank, an elongated mandrel having a preselected outer surface contour corresponding to the contour to be formed on said surface portion, a cable connected at one end to said mandrel, a first pulley for receiving said cable, an end portion of said cable being vertically suspended from said pulley for attachment to an object, means for rotating said mandrel on the axis thereof to wind said cable around, and to unwind it from the outer surface of said mandrel for automatically controlling the rate of movement of said cable and of vertical movement of said object on said cable end portion in accordance with the contour of said mandrel, a screw mounted coaxially of said mandrel and rotatable therewith, a sleeve mounted on said screw for axial movement thereof on rotation of said screw, an elongated arm connected to said sleeve, a second pulley connected to said arm for receiving and guiding said cable, said screw having a pitch approximately equal to the width of said cable so that movement of said arm and said second pulley in response to rotation of said screw permits winding of said cable on said mandrel without causing said cable to wind onto itself, and permits unwinding of said cable from said mandrel when said screw is rotated in the opposite direction, a third pulley for said cable, said last named pulley receiving the portion of said cable between said first and second pulleys, means connected to said third pulley for moving same in a direction away from said first pulley to impart a vertical movement upwardly to said end portion of the cable, and means associated with said cable for actuating said last mentioned means when a predetermined length of said cable is wound about said mandrel and also when a predetermined length of said cable is unwound from said mandrel.

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