June 5, 1956 F. C. DRAPER ET AL 2,748,455

METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

Filed Jan. 2, 1952 7 Sheets-Sheet 1

Fig.1.

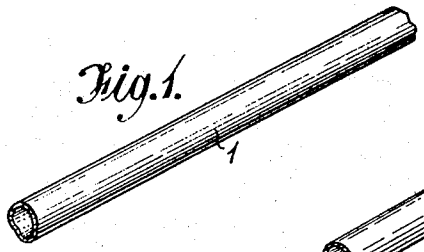


Fig.2.

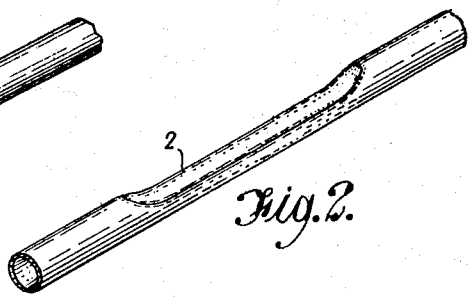


Fig.3.

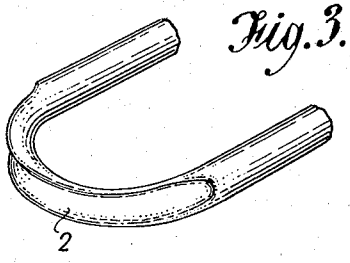


Fig.4.

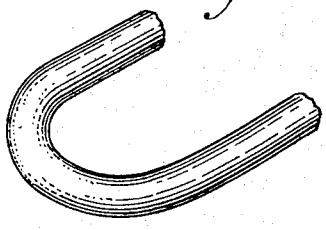


Fig.5.

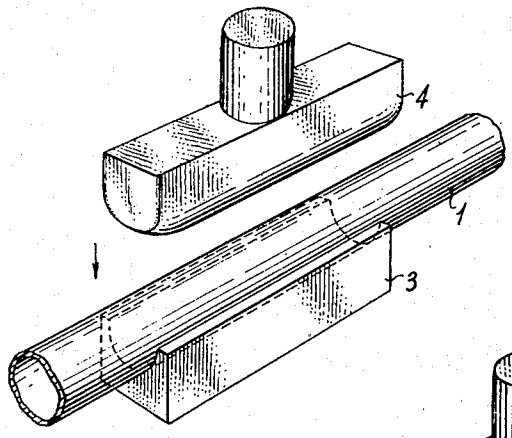
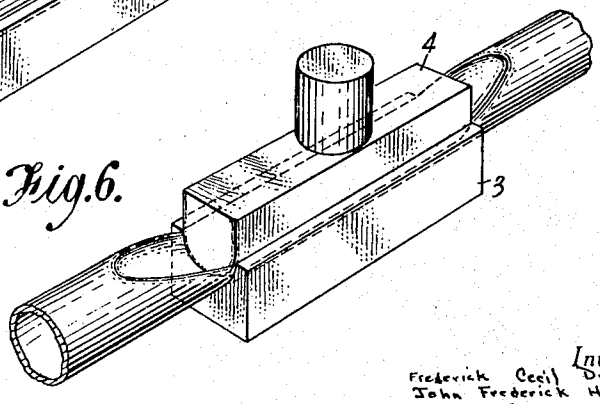


Fig.6.



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METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

Filed Jan. 2, 1952 7 Sheets-Sheet 2

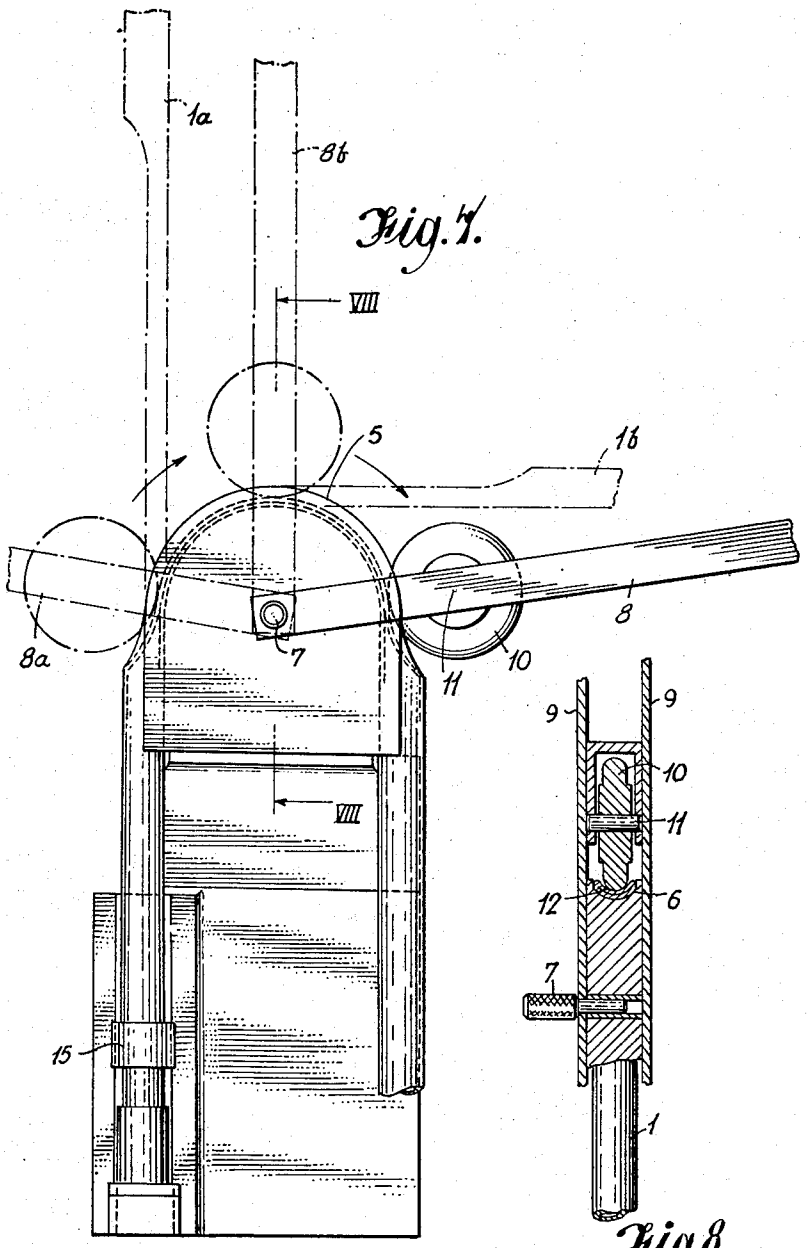

Fig. 7.

Fig. 8.

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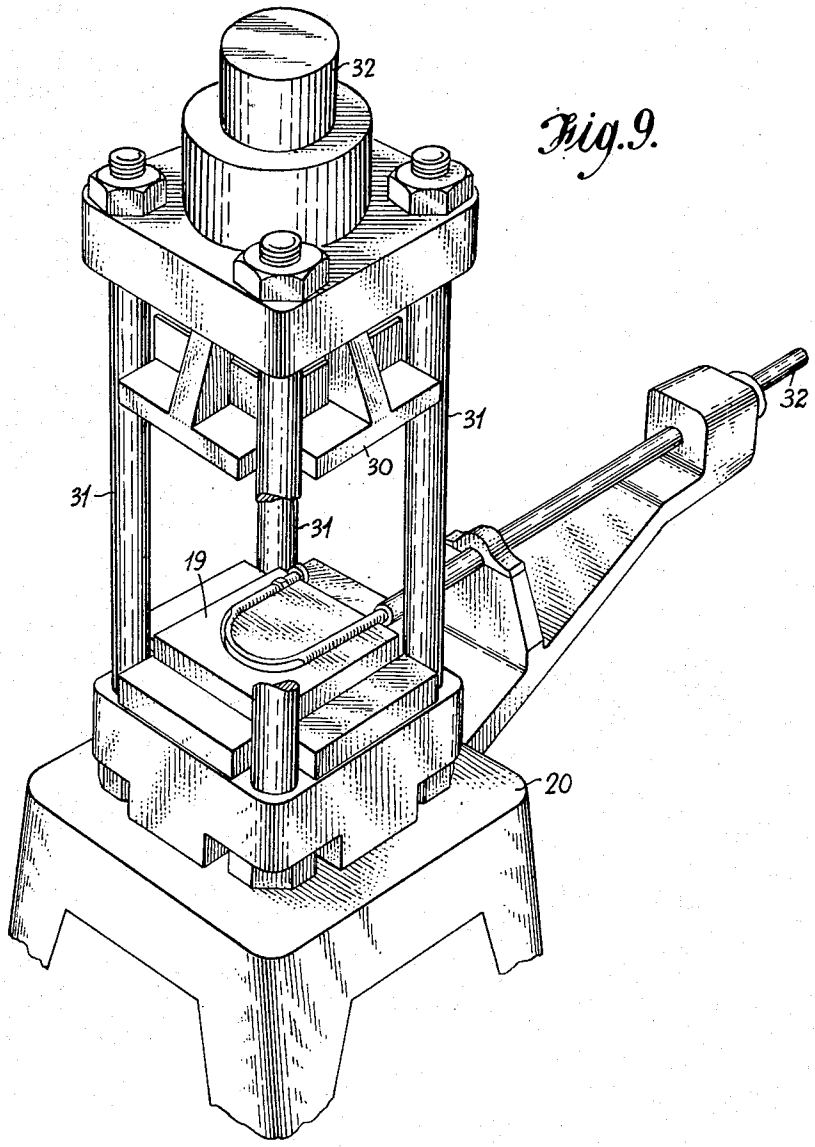
METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

Filed Jan. 2, 1952 7 Sheets-Sheet 3

Fig. 9.



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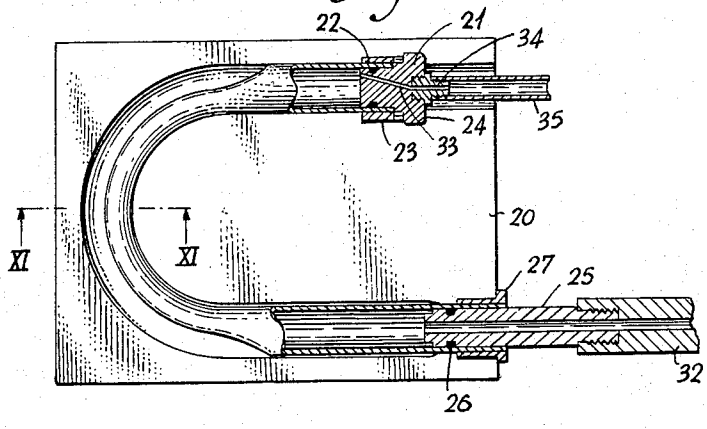
METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

Filed Jan. 2, 1952 7 Sheets-Sheet 4

Fig. 10.



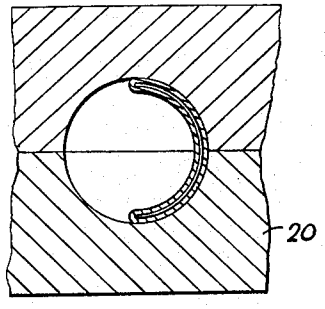


Fig. 11.

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June 5, 1956 F. C. DRAPER ET AL 2,748,455

METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

Filed Jan. 2, 1952 7 Sheets-Sheet 5

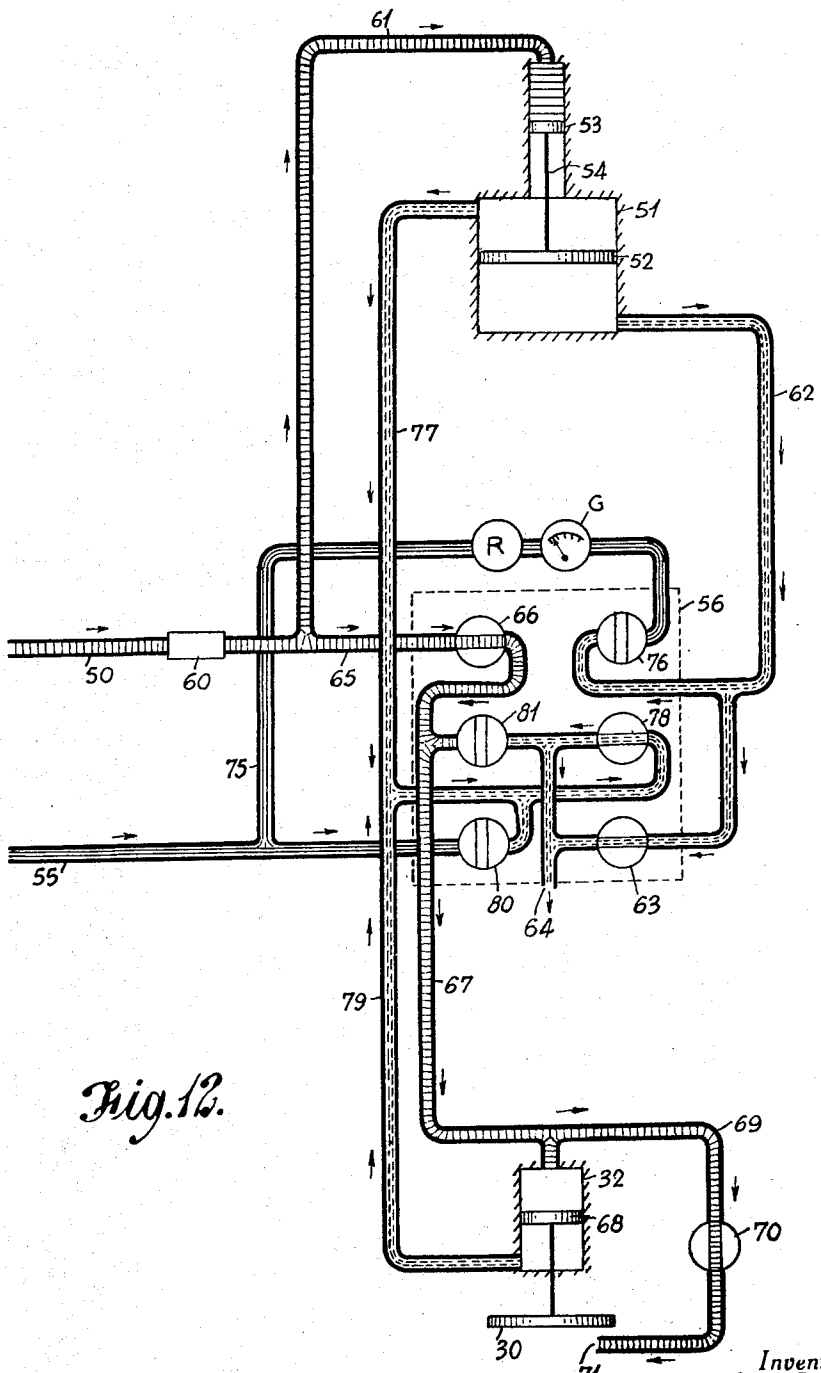

Fig. 12.

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June 5, 1956 F. C. DRAPER ET AL 2,748,455

METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

Filed Jan. 2, 1952 7 Sheets-Sheet 6

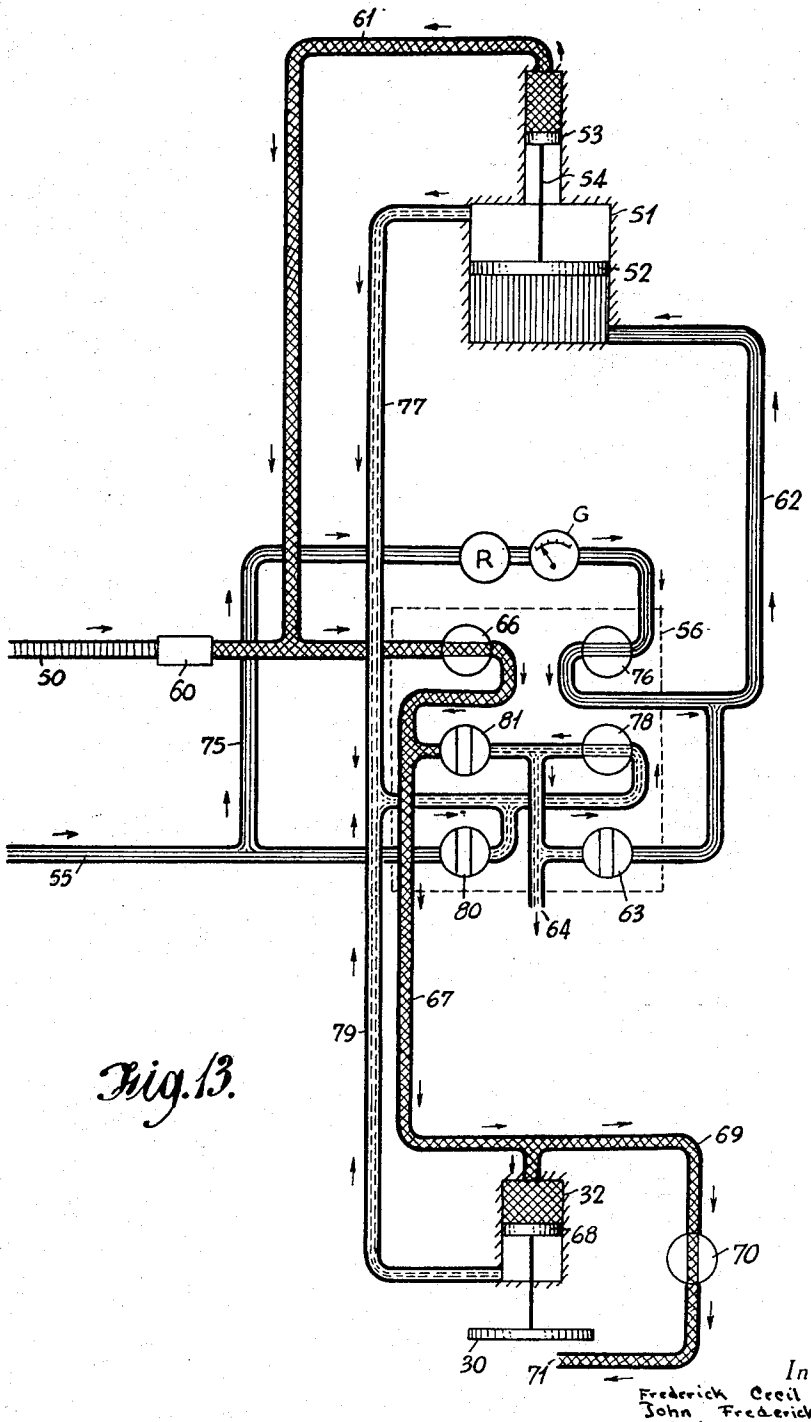

Fig. 13.

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METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

Filed Jan. 2, 1952 7 Sheets-Sheet 7

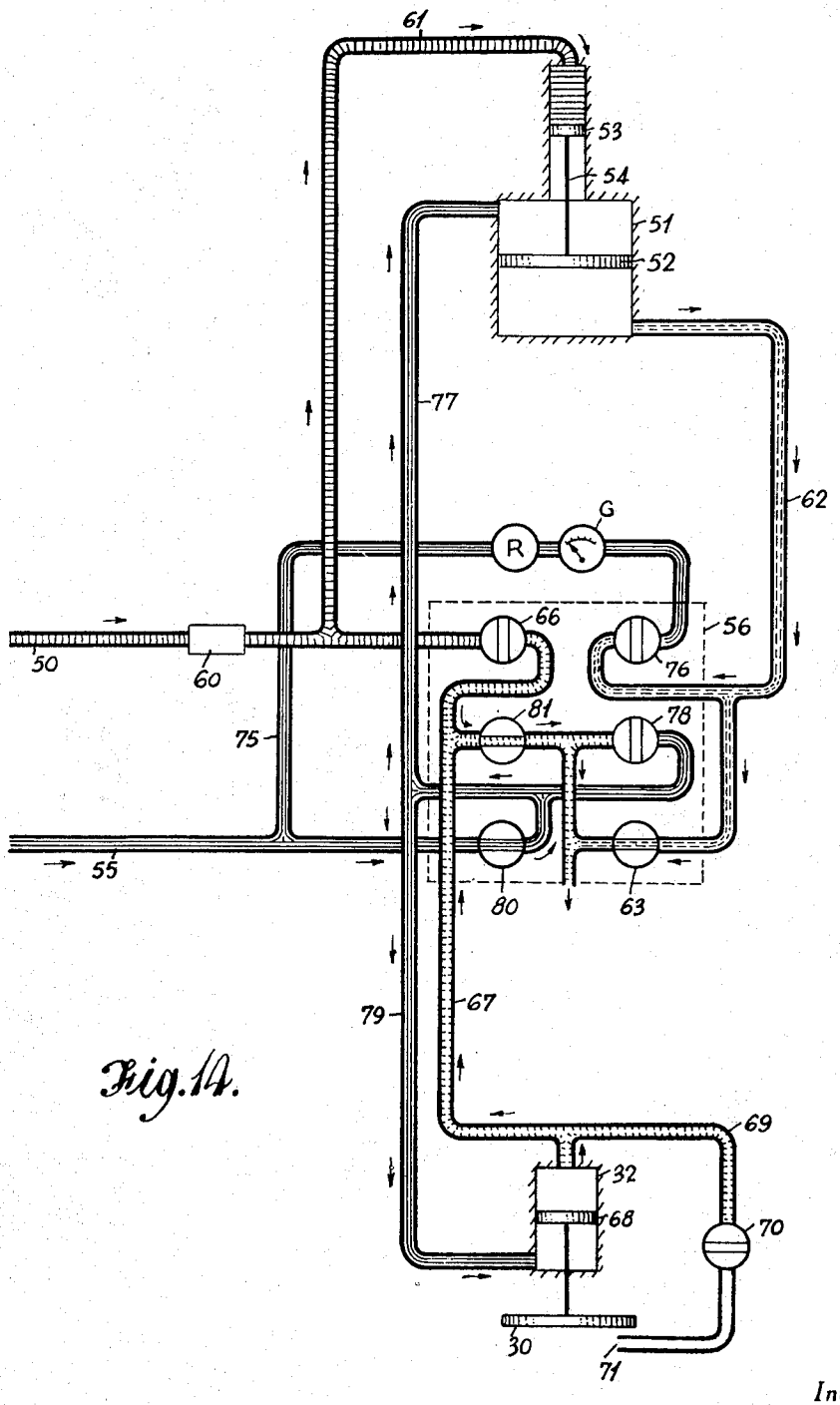

Fig. 14.

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Patented June 5, 1956

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METHOD OF FORMING A BEND IN DUCTILE METAL TUBING

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Application January 2, 1952, Serial No. 264,418

Claims priority, application Great Britain January 5, 1951

6 Claims. (Cl. 29—157.6)

This invention relates to the formation of bends in tubing made of ductile metal and is particularly concerned with the treatment of such tubing in which the diameter is large in relation to the wall thickness. The invention thus has particular application in connection with the production of musical wind instruments, the main body of which consists of a metal tube having one or more bends in it. The customary way of producing the necessary shape in a tube for a wind instrument of this kind is to start with a sheet metal blank from which the tube is shaped and then to bend the tube manually in a large number of small stages.

When bending a tube in this way, a bending moment is applied to the tube, usually in the form of opposing forces acting on the external walls, so that as the tube bends, a neutral axis is established passing approximately through the centre of gravity of the tube. Thus all the parts of the wall of the tube lying on one side of this neutral axis are subject to tension, while parts on the other side are subject to compression. Now although the material of the tube merely elongates under the action of tension, the effect of the compression is to cause the thin wall to buckle and collapse. The amount of compression which can be sustained by the thin wall of the tube which thus acts as a strut is very small, and the result is that as soon as a bending moment is applied to the tube, small wrinkles appear on the inside of the bend where the compression is exerted.

In the ordinary procedure, therefore, these wrinkles or "cockles" have to be beaten out by hand, after which the tube is annealed and then bent a further stage. In order to obtain the final desired degree of bending, a large number of steps of alternate bending and beating together with intermediate annealing are required, and the process as such is very lengthy.

One manner in which such cockling of the wall of the tube which lies on the inside of the bend can be avoided, is to apply a bending moment to the tube while not setting up any appreciable compressive stresses in the wall. Various proposals have been made in order to achieve these conditions and, although in practice some of them have been successful with relatively small diameter piping, considerable difficulty is experienced in dealing with large diameter tubing with thin walls where the ratio of the diameter to the wall thickness is greater than about thirty five to one.

Tubing of this general class has a variety of uses in industry such as large bore short elbows for petrol and oil tanks in aircraft, ducts, particularly for aircraft and power-boats, and also as fuel and secondary air distributing rings on gas turbines and a satisfactory process for bending tubing of this kind has long been required.

According to the present invention, a length of tubing which is to be bent is first compressed laterally so as to cause the parts of the wall which are to constitute the inner and outer surfaces of the bend respectively to approach one another to give a shape of tube which when seen in cross-section is concave towards the side which

is to constitute the outside of the bend; after which the tube is pressed into contact with a former to give it the desired curvature in an axial direction, preferably by means of a roller turning in an arm pivoted at the centre of curvature. The effect of this operation is to cause the compressed tube to behave in a manner similar to a thin strip, the two opposing walls which have been brought close to one another by the compression being pressed into contact with one another by the roller and bending together to conform to the shape of the former. Thus the wall which is to constitute the inside of the bend and which would normally cockle owing to the setting up of compressive stresses is bent smoothly by a bending moment which sets up a neutral axis passing through the material of the wall itself, thus reducing compression to a negligible amount. The bent, compressed tube is finally enclosed within a die having an interior shape corresponding to the required external contour of the tube and fluid pressure is applied to force the wall outwardly so as to expand the tube to the desired final shape.

The tube should be anchored within the die so that the inner radius of the bend fits snugly to the wall of the die and in a manner which prevents the tube from moving forward under the applied fluid pressure. The application of fluid pressure to the inside of the tube stretches the material uniformly under the predominantly tensile radial stresses and provided the inner radius of the tube is properly fitted to the die and securely held, there is no tendency for compressive stresses to develop on the inner radius of the bend and the danger of cockling is therefore eliminated.

In order to allow for the ready insertion of the tube in the die, a split die consisting of two halves may be used, and in order that the bent tube shall fit snugly in the lower half of the die before the die is closed, it is preferred that the tubing should be compressed to an approximately semi-circular or U-shaped configuration when seen in cross-section. In other words, the portion of the wall of the tube which is to constitute the inside of the bend is allowed to retain its original curvature, while the other portion of the wall of the tube is compressed inwardly into contact with the first portion so that the final shape of the compressed tube is that of an elongated trough.

The application of fluid pressure in the die has little effect on the portion of the wall which is to form the inside of the bend since this is closely supported by the wall of the die. The principal effect of the application of pressure is firstly to reverse the curvature of the remaining portion of the wall and then to stretch it and force it into contact with the further wall of the die. This stretching process involves a high degree of cold-working of the metal of the tube and it is preferable to carry it out in two stages. In the first stage just sufficient pressure is applied to reverse the curvature of the concave portion of the wall and to carry out a small initial degree of stretching. After this the tube is removed from the die and annealed, and then the final stretching operation is completed. The other steps in the process, namely, the initial compression, followed by the bending, also involve a high degree of cold-working, and these steps also, therefore, must usually be followed by an annealing treatment.

A process for bending a tube in accordance with the invention will now be described in more detail by way of example with reference to the accompanying drawings, in which:

Figures 1 to 4 show successive stages in the treatment of the tube;

Figures 5 and 6 illustrate diagrammatically the initial step of compression of the tube;

Figure 7 is a plan view of a former, illustrating the method of bending the compressed tube;

Figure 8 is a cross-section on the line VIII—VIII in Figure 7;

Figure 9 is a perspective view of a split die in the open position with a bent tube in position in the lower half;

Figure 10 is a plan view of the lower half of the die shown in Figure 9 with part of the tube in cross-section;

Figure 11 is a part-sectional view on the line XI—XI in Figure 10 showing the cross-section of the compressed tube in the die; and

Figures 12, 13 and 14 are diagrams of the hydraulic circuit used in conjunction with the die.

The principle employed in accordance with the invention is best appreciated from Figures 1 to 4, which show the successive stages in the shape of a tube or pipe under treatment. A plain length of pipe or tubing **1**, as seen in Figure 1, is first compressed to the shape shown in Figure 2 so as to cause the walls of the tube, which are to constitute the inside and outside portion of the bend respectively, to approach one another over a length **2**, which is to constitute the bent portion. The compressed portion of the tube is approximately semi-circular or U-shaped in cross-section as may be seen in Figure 2 and also more clearly in Figure 11. The compressed tube is then bent axially to the desired curvature, and Figure 3 shows the tubing of Figure 2 bent through a curve of 180 degrees. Finally, the bent, compressed tubing of Figure 3 is expanded by hydraulic pressure in a die to the final shape shown in Figure 4.

The initial operation of compression is carried out in a mechanical press, the tubing **1** being placed in the female member **3** of the press, shown diagrammatically in Figure 5, where it is compressed by the male member **4** in the manner shown in Figure 6.

After annealing, the compressed tubing, in the shape shown in Figure 2, is then treated on the former shown in Figure 7. This former is made of hard metal and has a contour **5** corresponding to the desired shape of the bend, in this case a semi-circle. In addition, the forming edge has a concave profile **6**, as seen in Figure 8, for the reception of the convex face of the compressed tube. Pivoted at the centre of curvature of the semi-circular contour **5** by means of a removable pin **7** is an operating lever **8** comprising spaced side members **9** between which is mounted a pressing roller **10** turning in a spindle **11**. This roller has a convex profile **12** for co-operation with the concave profile **6** of the forming edge **5**.

One end of the compressed tubing is gripped in a chuck **15** so that the tubing extends along one side of the former in the position shown as **1***a*, with the end of the compression portion **2** coinciding approximately with the beginning of the semi-circular contour **5**. The operating lever **8** is next placed in the position shown as **8***a* with its side members **9** straddling the tubing, and the pin **7** is inserted. The roller **10** thus engages the end of the compressed portion **2**. The operator then swings the lever **8** about the pivot pin **7** and the tubing **1** is bent to the desired shape. An intermediate position of the lever **8** is shown at **8***b*, in which the tubing has been bent to the shape **1***b*. When the operation is complete, a semi-circular bend has been formed in the tube. As will be best appreciated from Figure 8, the cooperation between the profile **12** of the roller and the profile **6** of the former is such as to set up a bending moment with a neutral axis passing through the material of the wall of the tube. Thus compressive stresses are reduced to a very small value, and in addition the rolling action prevents the formation of any cockles, so that the tube behaves virtually as a thin strip.

The bent tubing is then annealed and is inserted in the lower half **19** of a split die made of white brass, and supported on a pedestal **20** as seen in Figures 9 and 10. One end of the tubing is plugged by means of a plug **21** provided with a sealing ring **22**. The outer wall of the

tube is gripped by a split bush **23**, which serves to lock the plug **21** in position. The plug **21** is formed with an enlarged head **24** which fits into a corresponding recess in the die **20** and serves to lock this end of the tube firmly in position. At the other end of the tube, a hydraulic fluid inlet valve **25** provided with a sealing ring **26** is inserted and locked in position by a split bush **27**, which serves to anchor this end of the tubing also. With both ends anchored in this manner, the inner face of the tubing is held snugly against the corresponding face of the die, and all tendency to cockle is avoided. The cross-section of the tube in the die is shown in Figure 11, from which the close fit and the nature of the deformation of the outer wall necessary to force it into the position shown by the dotted line is clearly seen.

When the tube is in position in the lower half of the die **20**, the upper half **30** is lowered into position, moving on guides **31** under the action of hydraulic pressure applied by a cylinder **32**. To start the operation necessary to expand the tube, hydraulic fluid under low pressure is first introduced by way of a connecting pipe **32** connected to the inlet valve **25**. In order to bleed off the air contained in the tube, the plug **21** is formed with a narrow passage **33** provided with a petcock **34**, fitted with a length of rubber tubing **35** which serves to drain off any fluid which may be expelled during the bleeding process.

As soon as the bleeding is complete, the cock is closed and the pressure of the hydraulic fluid is increased to a value such as to bring about the initial expansion of the tube. After this the pressure is removed, the tube removed from the die and annealed. It is then returned to the die for the final operation of expansion. One end is plugged and gripped by the plug **21** and the split bush **23** as before, but the other end, in which the pressure valve **25** is inserted, remains free to slide in the die, by replacing the split bush **27** with a round bush which is a sliding fit. The full hydraulic pressure is then applied to the inside of the tube and serves to expand the wall on the outside of the bend into contact with the wall of the die. This expansion may require a short extra length of the tube to be drawn into the die and it is for this reason that one end is left free. When the tubing has been finally expanded, it is removed from the die and once again annealed. The ends of the tubing which have been gripped in the die are cut off and then after a final surface treatment, such as buffing, the tubing is ready for use.

The method of obtaining the necessary hydraulic pressure both for expanding the tube and for operating the top half **30** of the die, which acts as a vice to grip the tube, is illustrated diagrammatically in Figures 12, 13 and 14.

In practice, the hydraulic fluid used is water having dissolved in it a small quantity of soluble oil sufficient to prevent corrosion of the working parts. This is supplied at a relatively low pressure in the region of 100 lbs. per square inch at **50**, and this low pressure is employed for opening and closing the vice. The high pressure required for expanding the tubing is obtained by the use of an intensifier **51** comprising pistons **52** and **53** connected together by a rod **54** and acting in opposition to one another. The piston **52**, which may have an area ranging between about thirty and a hundred and twenty times that of the piston **53**, is acted on by compressed air also at a pressure in the region of 100 lbs. per square inch, which is admitted to the system by way of a pipe **55**. The pressure exerted by the piston **53** on the water in contact with it is therefore greater than that of the compressed air in the ratio of the areas of the pistons **52** and **53**, and for the ratios given above will range between about one and a half and five tons per square inch according to the work to be carried out. The operation of the system is controlled by means of a valve box indicated generally at **56** and comprising six positively seating poppet valves, which are cam-operated and which give

the three changes of circuit required by rotating a handle controlling the cam in steps of 120 degrees.

In the position of the valves shown in Figure 12, the tubing has just been inserted in the lower half **20** of the die and the vice is in the process of being closed. The low pressure water entering the system at **50** (indicated by transverse shading) passes first through a non-return valve **60**. Passing by way of a pipe **63**, low pressure water is in contact with the upper surface of the piston **53**, which is in its lowest position. The low pressure water also passes by way of a pipe **65** through another of the poppet valves **66** and thence via a pipe **67** to act on the upper surface of a piston **68** working in the cylinder **32** and controlling the closing of the vice. In addition, the low pressure water passes by way of a pipe **69** and an isolating valve **70** to fill a length of tubing under treatment at **71**.

As soon as the vice is completely closed and all air has been bled from the tubing, the valves are moved into the position shown in Figure 13. In this position, compressed air entering the system at **55** (indicated by longitudinal shading) passes by way of a pipe **75**, a pressure-reducing valve R and a pressure gauge G, through a further poppet valve **76** and thence via the pipe **62** to the underside of the piston **52**. The upper side of the piston **52** is connected by way of a pipe **77** through one of the valves **78** to exhaust at **64** (indicated by broken longitudinal shading), and in the same manner the underside of the piston **68** is also connected to exhaust by way of the pipe **79**.

The action of the compressed air pressure on the underside of the piston **52** applies high pressure to the water in contact with the upper side of the piston **53** (indicated by crisscross shading). This high pressure is transmitted along the pipe **61** and thence via the valve **66** and the pipe **67** to the vice and also to the tubing at **71**, being prevented from passing back to the supply by the presence of the non-return valve **60**. This high pressure firmly clamps the vice and at the same time expands the tubing in the die.

When the expansion is complete, the valves are moved to the position shown in Figure 14, relieving the pressure on the tubing, and at the same time opening the vice. In this position, the compressed air is cut off from the lower side of the piston **52**, which is then connected to exhaust via the valve **53**. Movement of another of the valves **80** applies the compressed air to the upper side of the piston **52**, returning it to the bottom of its stroke, and also by way of the pipe **79** applies pressure to the underside of the piston **58**, thus opening the vice. At the same time, movement of a valve **81** connects the water acting on the top of the cylinder **68** and on the tubing at **71** to exhaust (as indicated by the broken transverse shading). This removal of the pressure from the top of the piston **68** allows this to move upwardly under the action of the compressed air acting on its underside, so as to open the vice. Similarly, the removal of the pressure from the tubing allows this to be disconnected with safety. It can then be further isolated from the source of pressure by means of the valve **70**.

The actual pressure of the high pressure water is governed by that of the compressed air in the intensifier and hence by the setting of the reducing valve R. Thus for the first stage of this expansion, the reducing valve R is set to give a value of the pressure just sufficient for reversing the curvature of the wall of the tubing which is to form the outside of the bend, and the cycle of operations just described is then carried out. After the tubing has been annealed, it is reinserted in the die, the valve R is adjusted to give full pressure and the cycle of operations is repeated to complete the expansion of the tubing.

In the manufacture of musical instruments, the tubing which is to be bent is seldom of uniform bore and usually tapers from one end to the other. The introduction of a taper into the tubing has further complicated matters when producing the tubing by hand as previously described. When using the method in accordance with the invention, however, ordinary parallel tubing may be used as the starting material and the necessary taper may then be introduced in the die. The split die is formed with the desired taper and the final expansion stage then expands the tubing to give it a corresponding taper.

Moreover the bend in the tubing need not necessarily be in the shape of a circular arc. The forming edge **5** may have any desired shape, for example parabolic or hyperbolic. In such cases, of course, the operating lever **8** cannot be simply pivoted but must serve to move the roller round a correspondingly shaped guide track. The split die must naturally also conform to the curve in question.

As already mentioned, the method just described is particularly useful in the manufacture of musical instruments. The results obtained in this way are far superior and more uniform than those obtained by means of the previous methods of hand bending and, by this method, for the first time it has proved possible to manufacture the large bore branches and bends of sousaphones, basses, tubas, euphoniums and similar bass instruments from ordinary seamless brass tubing.

Although the problem has been dealt with primarily in its application to the manufacture of a musical instrument, similar problems arise in other branches of industry in which pipes having a large diameter in comparison with their wall thickness are required to be bent. This method is particularly useful in bending such pipes made of brass or other ductile metals such as any of the well-known light alloys.

We claim:

1. A method of forming a bend in a length of tubing of ductible metal comprising the steps of supporting one side of said tubing and compressing its opposite side laterally so as to cause the parts of the wall of said tubing which are to constitute the inner and outer surfaces of the bend respectively to approach one another toward the inner side of said tubing, whereby the cross-section thereof becomes concave towards the side which is to constitute the outside of the bend, bending said tubing progressively along its axis around a concave former to the desired curvature, said bending being carried out by rolling pressure on said concave outer side so as to minimize causing compressive stresses in the metal of said tubing, and expanding the concave side of said tubing outwardly to the desired final shape.

2. A method of forming a bend in a length of tubing, as claimed in claim 1, in which the cross-section of said compressed concave length of tubing is approximately semi-circular.

3. A method of forming a bend in a length of tubing of ductile metal, comprising the steps of compressing said tubing laterally to give a U-shaped cross-section, rolling said compressed tubing into contact with a concave former of the desired curvature, the convex surface of the bottom of the U during the rolling step being in contact with the former so as to constitute the inside of the bend, and applying fluid pressure to the interior of said tubing, said tubing during said final step being enclosed in a die corresponding to the desired final shape of said tubing.

4. A method of forming a bend in a length of tubing of ductible metal, comprising the steps of compressing said tubing laterally to collapse one side and form a substantially semi-circular concavo-convex cross-section, annealing said tubing, rolling said tubing longitudinally of said collapsed side to force its convex side into contact with a former of the desired curvature, again annealing said tubing, enclosing said tubing in a die corresponding to the desired final shape of said tubing, applying relatively low hydraulic pressure to said tubing while enclosed in said die, again annealing said tubing, applying greater hydraulic pressure to the interior of said tubing while enclosed in said die sufficient to force the

walls of said tubing into contact with the walls of said die, and finally annealing said tubing.

5. A method of forming a long bend in a length of thin-walled tubing of ductile metal comprising the steps of laterally compressing and inwardly deforming a side thereof adjacent to the opposite side to collapse said tube into concave approximately semicylindrical shape for a substantial portion of its length sufficient to form the desired bend, rolling said deformed tubing along its axis around a peripherally grooved former while maintaining its convex side in stationary contact with the groove in said former to stretch its outer edges and prevent forming cockles in its convex side, and applying fluid pressure to the interior of said deformed bent length of tubing to expand and stretch the same to smooth tubular bent form.

6. A method of forming a tapering bend in a length

of cylindrical tubing as set forth in claim 5 wherein the deformed portion is annealed prior to the bending and the expanding steps, and the final expanding step is performed under high pressure in a hollow axially tapered die to shape the tube to conform to the die.

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