

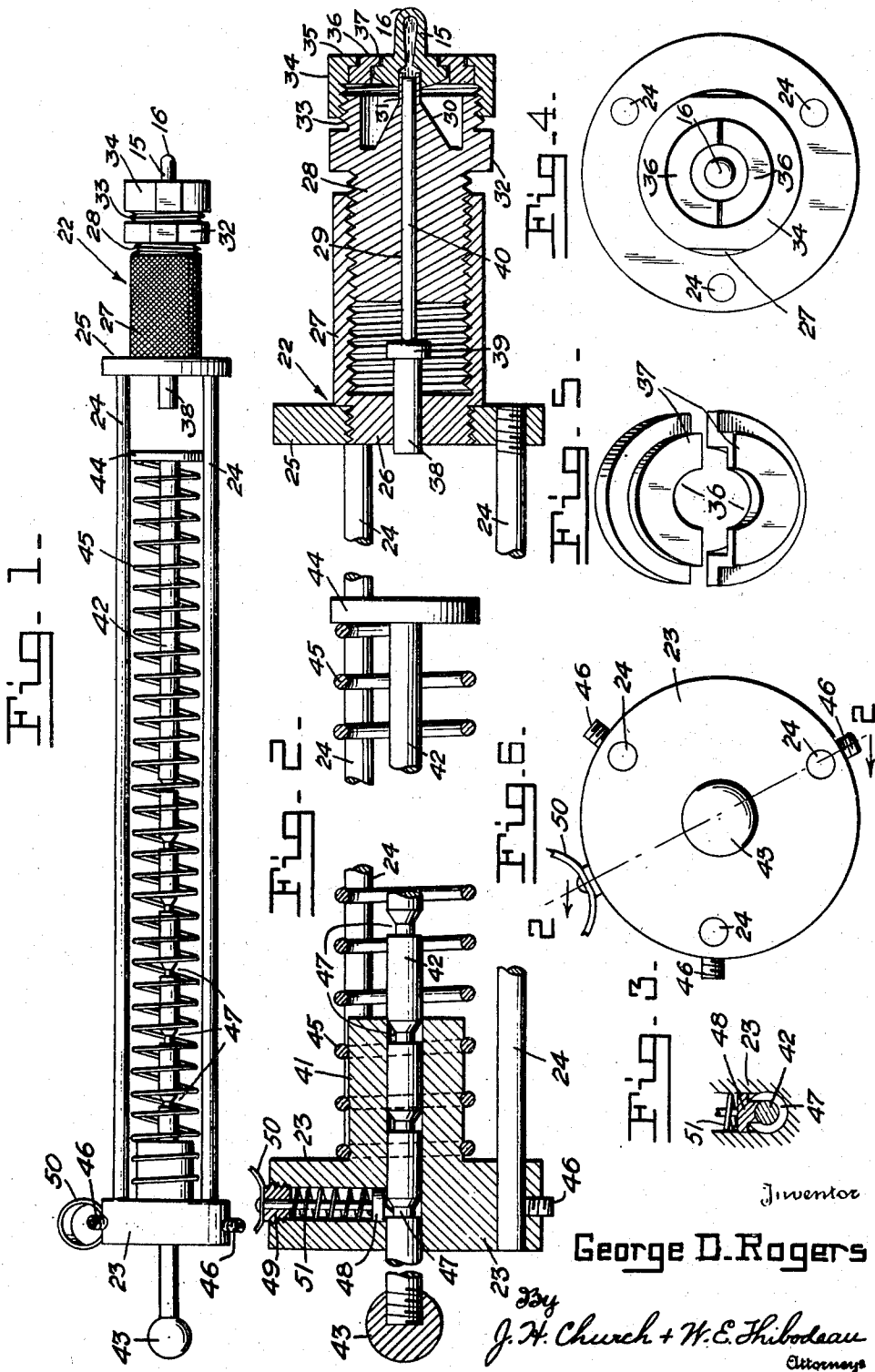
July 27, 1948.

G. D. ROGERS
METHOD OF EXPANDING HYDRAULIC RIVETS BY
INCREMENTS OF INTERNAL PRESSURE

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Filed Oct. 22, 1945

2 Sheets-Sheet 1



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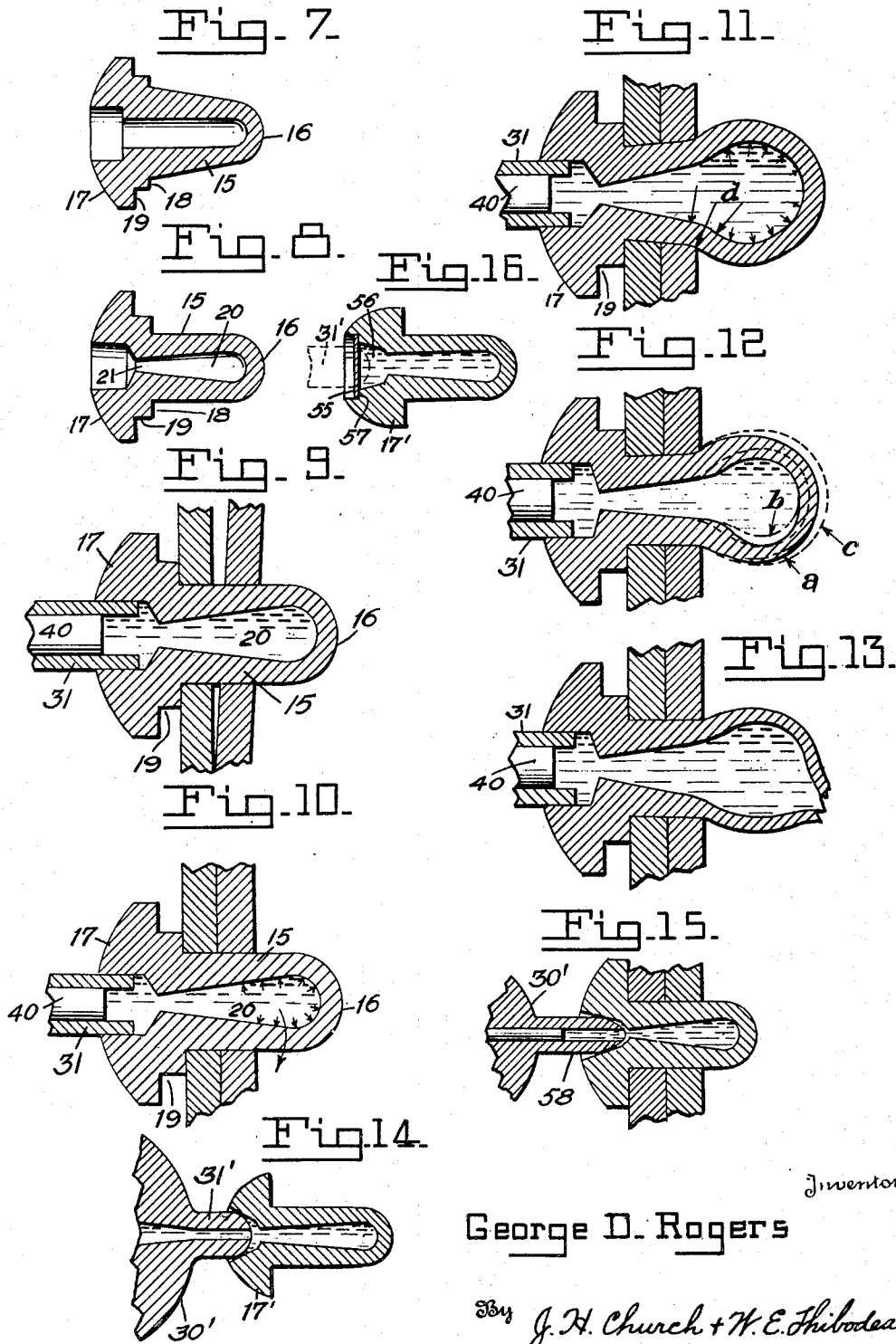
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UNITED STATES PATENT OFFICE

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METHOD OF EXPANDING HYDRAULIC RIVETS BY INCREMENTS OF INTERNAL PRESSURE

George D. Rogers, Buffalo, Mo.

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9 Claims. (Cl. 218—29)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

The invention relates to improvements in method for utilizing hydraulic rivets, and particularly to methods involving coordination of rivet structure and the procedure in causing the rivet to function in a required way by the application of a high pressure liquid.

It is particularly an aim to present steps of procedure by which irregularity of response of metals in course of attenuation may be overcome or compensated for. While the invention has been directed to the perfection of utilization of aluminum rivets (which are perhaps the most difficult to use in attaining the ideal forms hereinafter pointed out), it is also capable of application to rivets of other metals and alloys with improvement of the work output, in ways which will be enumerated.

The invention is in one aspect inspired by a desire to enable the utilization of conventionally produced aluminum and other plastic metals, in a simple rivet form, so that special research need not be conducted to discover improved metal composition or conditions in which objectionable performance can be remedied. Likewise a similar motive is involved in relation to metals plastic at atmospheric temperatures, or in heated condition, so that simple metal specifications of economical production may be utilized in effecting the fastening together of structural members, skin sheets, and other parts, carried out by hydraulically expanding a rivet extremity and/or shank to form an enlargement and/or binding part by which two or more parts through which the rivet is inserted may be secured together.

It is also an aim to avoid faulty performance of the rivet by slight deviations from standard wall thicknesses and proportions in the rivet, or slight imperfections in surface contours, such as are likely to occur in quantity production and by abrasions of the finished article in handling or shipment. This will result in more liberal tolerances in inspection requirements, and effect a marked economy in production costs.

It is an important aim to enable the attainment of full benefits from leverage and compression functions inherent in my rivet elsewhere claimed at the same time that objections heretofore found in the art involving the liability to corrosion when explosives are used, and production of rough and/or jagged fractures or edges, are overcome.

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A highly important aim of the invention is to enable the utilization of a property of metals peculiarly significant in the "bulbing" of the end of a hollow rivet.

In the production of hollow rivets and the distending thereof by hydraulic pressure, using substantially incompressible fluids, slight irregularities in molecular structure of rivets, or slight irregularities in wall thickness, or of surface finish, or other causes have heretofore led to the strain of limited parts more than others, and particularly so with aluminum. In consequence, where a continued extrusion, expansion or bulbing of a hollow rivet is carried out hydraulically, by continuous plastic deformation under constant pressure until the predetermined full riveting action is accomplished, many rivets will fail at those points of local excessive strain, by progressive attenuation or "necking" at a greater rate than the remainder of the wall or walls being distended, and a rough jagged outturned spout or other fracture is produced through which the hydraulic fluid escapes terminating the riveting, often before a sufficient upsetting of the remainder of the bulb end has been accomplished to effect a secure fastening, and at least producing an objectionable finish of the work.

The same difficulty is encountered when a constant volume of liquid is delivered to the rivet. It is known to metallurgists that when a metal is strained to a critical point slightly beyond its limit of elasticity, and then relieved of stress and permitted to recover, it recovers partially from the strain and thereby becomes modified and strengthened in the strained part, so that it is thereafter able to sustain stresses beyond that to which it was subjected in effecting the strain.

Experiments conducted by Dr. Clarke, of California Institute of Technology (Berkeley, California), prove that the yield point in steel tensile specimens elongated under increasing rates of load application, increases in direct proportion to the rate of loading. Hence a rivet expanded by repeated high velocity application of loading should expand to a greater diameter with less liability of failure than is the case under slower rates of loading.

It is therefore an object of my invention to overcome the tendency of rivet walls to fail at limited local parts, by effecting a work-hardening of the parts which tend to fail, so that they may resist the hydraulic pressures applied while other parts of the rivet become shaped as required, and so that a uniform deformation of a

hollow closed rivet may be effected to an extent approximating closely the ideal form sought.

In the present instance for the purpose of practical example the invention is applied to a headed rivet of my invention in which the rivet shank has an extremity which is semispherical, is formed with a chamber therewithin conforming closely to the shape of the rounded extremity of the shank, and has a reduced entrance passage through the head of the rivet. The invention has similar utility in many respects similar to those of other hollow closed-end rivets, however, as will be readily understood.

In carrying out the steps necessary I may use apparatus of various forms but have presented herein a novel device effective for the invention, as more particularly described hereinafter.

Using the rivet as hereinafter described, in a typical instance, after inserting the rivet through the work so that the head is against one side while the closed extremity of the hollow shank is extended somewhat beyond the opposite face of the work (the rivet being "primed" by being filled with a suitable liquid), I force into the entrance opening additional liquid in sufficient quantity and at a pressure and velocity adequate to expand the rivet slightly beyond its elastic limit, and then I relieve the pressure sufficiently or entirely and for a time which permits the strained material to partially recover. I repeat the injection of the liquid and relief of its pressure at short intervals, which may be a fraction of a second, or longer as required by the nature of the work and material in the rivet until the rivet has assumed the desired form and set in the work. Each of these increments of liquid is only a fraction of the total cubic quantity required in order to alter the form of the rivet to the final size and shape.

I have discovered that by imparting high velocity to the introduced small increments, the tendency of the strain of the rivet wall to localize at a weak part or a part weakened during the application of hydraulic pressure, is greatly reduced, and this is distinct from a mere rapid projection of the liquid necessary to effect the expansion of the rivet to the desired maximum cubic dimension in a single charge. In the latter case, when the momentum of the whole injected charge is sufficient to be material in contributing to the deformation of the metal of the rivet, the component of momentum and direction which coincides with the longitudinal axis of the rivet, is such that translation of the content of the rivet longitudinally is manifest so that a predominant action against the extremity of the rivet wall in a longitudinal direction becomes effective, and tendency to break-through is increased. In addition, the tendency toward the progressive localized strain is not counteracted by the work hardening which is accomplished by the intermittent operation, and ruptures occur which would not happen by my method. Also, the elongation of the hollow part of the rivet produced by high velocity of the whole charge prevents radial expansion of the rivet effectively, and a secure setting of the rivet in the work is not attained. The delivery of the increments with the imparting of high velocity to the increments as introduced, together contribute to minimizing the number of stages of expansion required, by effecting strain of the metal by a force component of simple hydrostatic pressure, and a component of impact force by which the plastic deformation of the rivet

metal is effected so rapidly that the inertia of the outwardly acting liquid, and a certain inertia of motion setup in the metal itself, contribute to the end in view; tending to produce a movement of the metal in a direction normal to the surface exposed to impact, regardless of the cohesive strength of local parts of the metal.

Quantities of additional liquid introduced into a rivet corresponding to the one here shown, which are large in proportion to the liquid contained in the cavity, tend to have a "ram" action in which energy of translation of the incoming liquid is transmitted to the liquid initially in the cavity; whereas, the energy of translation for quantities of additional liquid which are small in proportion to the initial liquid is absorbed by the greater quantity of initial liquid and converted into radial energy.

In the utilization of my rivet here illustrated, the aim is to effect the "bulbing" of the extremity of the rivet shank and also to work the shank in such manner that the work is pressed toward the head of the rivet, the shank is expanded in the work, and the extremity of the shank forms a smooth ball-like end sufficiently larger in diameter than the opening through the work to prevent any possibility of longitudinal movement of the work along the shank away from the rivet head. In this "bulbing" of the end of the shank, a compression member of dome-shape is constituted which braces the walls of the tubular shank in such manner that its resistance to shear stresses is greatly enhanced and its liability to collapse by unequal pressures counteracted. In addition, the exposed end of the shank forms a smooth rounded surface which is liable in a minimum degree to corrosion, and avoids abrasion of objects rubbing thereagainst or snagging in fabrics and packages of various kinds such as may be shipped in airplanes, where my rivet has important utility.

Objects, advantages and features of invention in addition to those specifically named herein, reside in the steps of procedure hereinafter enumerated, their order or sequence, as well as their specific nature, and in the construction, arrangement and combination of parts involved in the embodiment of means to effect the application or carrying out of the invention, all as will be apparent, or understood from the accompanying description and drawings, wherein

Figure 1 is an elevation of a tool for communicating hydraulic pressure to rivets in accordance with the invention, one half full size;

Figure 2 is a longitudinal section of the tool enlarged;

Figure 3 is a fragmentary cross section of the trigger head;

Figure 4 is a right hand end view of Figure 1;

Figure 5 is a perspective of the rivet-holding split collar;

Figure 6 is a left end view of Figure 1;

Figure 7 is a longitudinal section of the rivet blank in one stage of manufacture;

Figure 8 is a similar view of the completed rivet;

Figure 9 is an enlarged view of the rivet initially positioned in the work, the ram nozzle shown, but the chuck parts omitted;

Figure 10 is a similar view after correction of loose fit of the work parts and beginning of expanding pressure in the cavity;

Figure 11 is a similar view showing a further stage of expansion of the rivet;

Figure 12 is a similar view illustrating the func-

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tion of the invention in attaining ultimate symmetrical expansion despite initial local fault in the rivet;

Figure 13 is a similar view showing the functioning of a similarly faulty rivet by prior practice;

Figure 14 is a longitudinal section of a simplified rivet and tool nozzle;

Figure 15 is a similar view of a modification of the form of the nozzle;

Figure 16 is a similar view of a primed and sealed rivet.

The rivet, as shown in Figures 7 and 8 is initially formed as a solid blank member having a frustoconical shank 15, on an extremity of which a spherical end 16 is formed; and at its opposite end a spherical mushroom head 17. At the base of the shank an annular shoulder 18 is formed around the shank on the head 17, its diameter being less than the major diameter of the head, so that a rabbet 19 is provided for a purpose which will appear. The conic angle of the shank is of low degree which permits the subsequent chamfering and swaging to final form.

The solid blank is engaged by a stud punch die to form a cylindrical passage and cavity through the head and in the shank, with a spherical termination which is parallel to the spherical external surface of the shank extremity. This forms a continuous wall on the sides and end of the shank. The orifice at the entrance to the cavity in the stud may be flared, or in other forms to accommodate tools or couplings as required. The hollow blank is now subjected to a constricting swaging operation by which the head and adjacent portions of the shank are reduced in diameter until the shank assumes an approximately cylindrical form exteriorly. In this operation the passage through the shank is greatly reduced in diameter and owing to the initial tapered form of the shank a substantially pear-shaped chamber 20 results, extending from the outer end of the shank with a reduced passage 21 through the base of the shank communicating therewith.

As an example of the manner and means of carrying out the steps of my method effectively, I have shown in Figures 1 to 5, a tool which is manually operated, although power operated devices for the same use, of any suitable construction to attain the operations described, may be used. The tool in the present instance comprises a chuck head 22 for engaging and holding the rivet for placement, and a trigger block 23 connected to the chuck head by three rectilinear rods 24 fixed in the head and the block. The chuck head comprises a body portion 25 in which the rods 24 are threadedly engaged, the chuck head having an internally threaded opening into which a corresponding boss 26 of an internally threaded sleeve 27 is engaged, the sleeve being of slightly greater diameter than the boss so as to afford a shoulder screwed tight against the body portion 25. In the outer end of the sleeve 27 a pump body 28 is engaged, this having an elongated portion externally threaded to screw into the sleeve 27, and having therethrough a cylinder bore 29. The extremity of the pump body within the sleeve 27 is formed with a plane surface normal to the bore 29, while at its outer end the body terminates in a conical concentric part 30 having at its apex a slightly tapered nozzle extension 31. The pump body is formed with a hexagon enlargement 32 functioning as a nut member to be turned by a wrench as required, and an externally threaded wall 33 is formed thereon around the

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cone 30 and stopping in a plane with the apex of the cone 30 and base of the nozzle 31. Screwed on this wall there is a collar 34 having an inner flange 35 having an opening which is substantially larger than the head of the rivet. Set in this opening there is a split collar 36 adapted to sit on the flange 35 and extended to fit separably in the opening within the latter flange. The collar has an inner flange portion 37 of a thickness slightly less than the longitudinal measurement of shoulder 18 of the rivet and adapted to fit loosely around that shoulder. The space within the collar 36 is sufficient to accommodate the head of the rivet, and the orifice in the head of the rivet is so shaped that with a rivet engaged as shown in Figure 2, the rivet may be drawn into a tight fit with the nozzle 31 by screwing the collar 34 on to the wall 33 of the pump body.

The tool and rivet are thus fixed in rigid relation so that the tool serves as a carrier for the rivet and the latter may be inserted in drilled openings in work for riveting.

The boss 26 is axially and smoothly bored to a diameter larger than the cylinder bore 29 in the present instance, and receives slidably therethrough a piston bar 38 which is formed with an enlarged shoulder 39 adapted to limit outward movement of the bar part 38 through the boss 26. From the bar 38 a reduced piston 40 is axially extended, fitting snugly and reciprocably in the cylinder bore 29 as shown.

The trigger block 23 is a circular body having a reduced inner concentric guide extension 41 and is axially bored to receive slidably therethrough a plunger 42, the length of which is sufficient to reach from closely adjacent or against the body 25 of the chuck head to a distance outwardly of the trigger block, where it is provided with a manipulating knob 43. At its inner extremity the rod has fixed thereon a circular hammer head 44, a driving spring 45 being confined between this head and the trigger block, fitting around the extension 41 at its outer end. In its unloaded condition this spring extends from the trigger block to or nearly to the chuck head 22, or it may be prestressed in the assembly so as to extend entirely to the head if the function of the tool so requires.

In the present instance the rods 24 are shown as threaded and screwed into the body 25 of the chuck head, and at their outer ends engaged slidably through proper bores in the trigger block, being secured therein by set screws 46. By this means the block 43 may be adjusted relatively to the chuck head if found desirable to increase or decrease initial operating tension of the spring 45, as will be understood. The plunger 42 is formed with a multiplicity of longitudinally spaced encircling grooves or notches 47, having bevelled inner sides (toward the head 44) and outer sides at right angles to the axis of the plunger. The block 23 is bored radially at one point and receives slidably therein a trigger or latch 48 having a bill portion shaped to engage in any aligned notch 47 of the plunger to hold the plunger against inward movement by the thus compressed spring 45. The latch has a stem portion extended outward slidably through a retaining bushing 49 screwed into the outer end of the radial bore in the block 23. The outer end of the latch stem has fixed thereon a trigger ring 50 by which the plunger may be withdrawn to clear plunger 42 and permit its being driven by the spring 45. A small helical spring 51 is engaged around the stem of the latch, confined

between the latch and the bushing 49 so as to press the latch inward against the plunger yieldable to finger pull on the ring 50.

In practicing the invention, the rivet being primed with oil of low viscosity, and the piston 40 being withdrawn to its full limit with the shoulder 39 against the boss 26, and the end of the cylinder bore 29 being also filled with a like oil, the rivet is emplaced in the device by setting it in the split collar 37 while the latter is in place in the collar 34, and the latter is then screwed upon the wall 33 until the rivet fits snugly or wedgingly upon the nozzle 31. Sleeve 27 is screwed along pump body 28 until piston 40 has consolidated any included air bubbles and has made the fluid incompressible for practical purposes. The rivet shank being inserted through the work, and a particular notch of the plunger being predetermined to develop a proper force in the plunger under operation of spring 45, the rod is pulled back to such notch by the knob 43 until the latch 48 engages in the selected notch. The chuck head is then pressed to the work while the trigger is released and a first blow delivered by the hammer. In case the work involves plates which are not in snug engagement, the operator will discern by the sound of the blow delivered that a translation of the outer plate or plates, the rivet and the chuck head has occurred thereby expending a part of the energy of the blow to movement of these parts in such manner that the full hydraulic expansion effect of the operation is not attained in this first blow. Perhaps another one or two blows may be needed before the work parts and rivet are snugged together, and the operator will then recognize a difference in the sound emitted which will show an effective junction of the work parts and injection of liquid begun. Thereupon, a predetermined number of blows are delivered by pulling the knob back to the predetermined notch, and releasing the trigger on each operation. The number of such blows is determined experimentally before hand for the particular rivet in use, so that a sufficient number of blows is imparted, expanding the rivet end generally as shown in Figures 10 or 11, within the limits of expansion of which the rivet is capable. The number of blows will depend upon the nature of the material in the rivet principally, although other factors may be considered, and the force of each blow, as caused by the number of the notch to which the plunger is withdrawn for engagement by the latch 48, may also be proportioned to the nature of the rivet material. I have found in some cases with aluminum rivets that in the neighborhood of seven blows is adequate to effect the full operation with satisfactory results. In the event that some elasticity of materials, or slight leakage around the piston occurs, or as a simple precautionary measure after each blow of the hammer, the pump body 28 is screwed slightly further into the sleeve 27 so as to bring the collar 39 against the boss 26, to compensate for enlarged cavity and to reconsolidate air inclusions thereby insuring maximum compression of the liquid in the rivet and cylinder before each blow of the hammer is delivered. The nozzle and cylinder can accommodate sufficient liquid for the complete expansion of a rivet without refilling between blows, but if desired or expedient an automatic oil supply may be used.

If desired, the holding means for the rivet, including the collars 34 and 36 may be omitted, and the riveting tool may be simply manually in-

serted into the orifice of the rivet after the latter has been manually or otherwise placed in the work, constant manual pressure being maintained on the tool to hold it properly engaged with the rivet during the several operations described. Also, the nozzle 31 and the orifice of the rivet may be modified, as shown in Figures 14 and 15, wherein the orifice is conical and the nozzle spherically shaped on the end to permit its ready insertion in the orifice and to enable the maintenance of a good annular line contact between the nozzle and the rivet throughout the expansion setting of the rivet without requiring strict coaxial alignment of the tool and rivet, and without requiring objectionable effort on the part of the workman to maintain a seal at the junction of the rivet and nozzle.

In the carrying out of my method it is highly important that a liquid of low viscosity be used; because in the event that a heavy liquid is used, with the velocity imparted to the injected liquid, a greater longitudinal translative force is imparted to the content of the rivet tending to longitudinal extension of the rivet above referred to, with the objectionable results there pointed out. While it may be practicable to use water or an aqueous solution, or other liquids, I have found that a light oil performs satisfactorily and has advantages in improving lubrication of the pump piston. Lubricating oils such as Numbers 10, 20 and 30 have been used, the Number 10 oil being thought best of these three. Kerosene and gasoline are believed to be practicable for use as the pressure liquid.

In the functioning of the rivet under impact of the successive injections described, after the rivet and work have been snugged together, there is a concurrent radial expansion of the dome-like head of the rivet extremity and a radial expansion of the rivet shank. In consequence, a very tight binding or compression of the work between the rivet head and the bulbed extremity of the shank is effected in the practice of my invention in which the continuity of the spherical end of the rivet is preserved. If the work is of a soft nature or if the opening in the work is conical the result is that the portion of the shank within the work farthest from the head is enlarged radially and also the pressure becomes effective upon the outer plate of the work acting toward the head of the rivet as indicated by the arrows *d* in Figure 11. When aluminum and other malleable metals or materials constitute the material in the plates of the work, there will be a moderate upsetting of the work radially which will enlarge the hole in the work around the outer part of the shank and add to the security of the fastening, as indicated in Figures 10 and 11. As indicated by the curved arrow in Figure 10 that portion of the shank which extends beyond the work is expanded, assuming a bulbous or spherical shape, the inner portions next to the work will move radially beyond the opening in the work and will become inclined in relation thereto so that the hydrostatic pressure acting normally to the surfaces of such inclined parts will produce an inward pressure upon the work acting toward the head of the rivet. Where methods are used which cause rupturing of the expanded end of the shank, the binding or compression function of my rivet referred to above is not achieved, although the rivet may have been expanded sufficiently to become tightened in the work in some measure. The attainment of the greater se-

curity and the certainty of uniform performance are important attainments making my riveting method available in undertakings of more substantial nature and value where the prior practice would not satisfy the requirements.

In the practice of my invention, in case a rivet is encountered which under prior practice might fail in the manner shown in Figure 13, on the delivery of the first one or more increments of liquid the defective part will be expanded unsymmetrically, as indicated at *a* in Figure 12 (the ideal and symmetrical expansion of the rivet being indicated by dot and dash at *b*), but the relaxation intervals will result in a work hardening of this distorted part proportionate to its greater displacement, and on subsequent expansion steps the part *a* will resist expansion by reason of its greater tensile strength acquired by its greater working, which more than compensates for loss of total strength due to reduction of section, while the other parts of the cavity wall will be expanded in greater degree. The resultant form of the finished work will in consequence more closely approximate the ideal desired symmetrical shape indicated by dotted line *c* of Figure 12, for the purpose of illustration, although some other symmetrical form may be chosen as the ideal.

As my rivet has been work-hardened in part due to its manner of production, this hardening being progressively greater from the extremity of the shank toward its base, and as work-hardening occurs in the shank and tip which hardening is progressively greater toward the tip, the whole rivet acquires a final hardness throughout the finished work which approximates uniformity.

It will be appreciated that due to the benefits of my invention as herein disclosed, slight variations from symmetry in the rivet form and wall thickness are not fatal to successful utilization of the rivet, and there may be fewer rejections of rivets for such faults, with consequent economy.

In order to provide previously primed rivets, the cavities of the rivets may be filled with the desired liquid, and then the orifice closed by a diaphragm 55 of relatively soft metal either of the same material as the rivet, or other metal, such as lead, one manner of effecting the placement of such seal being indicated in Figure 16. In this case the rivet is formed by steps corresponding to those already described, so as to provide a substantially semi-spherical head 17', the shank and cavity being otherwise the same as before. The head is formed with a flared conical injection orifice 56, around the edge of which an outer rabbet 57 is formed affording a planiform shoulder. The sealing diaphragm 55, is set on this shoulder. The diaphragm may be secured by upsetting the peripherally adjacent part of the rivet head, or otherwise, including use of conventional practices for holding discs and the like in encircling mounts. In the use of a nozzle having a spherical end, the latter will be so proportioned as to enter the conical orifice 56 sufficiently far to break the diaphragm before operation of the expansion tool, and to avoid impeding entrance of liquid from the tool. In such case the diaphragm will break at its middle and bend inward around the nozzle, serving as a soft gasket to assure a good tight joint.

The rounded end of the manually held nozzle may be hemispherical in longitudinal section, as dotted at 3' in Figure 16 and shown solid in Fig-

ure 14, but it may also be of parabolic form in such section, as indicated at 58 in Figure 15, or in any other suitable form which will allow for slight angular deviations from true co-axial alignment while still providing an adequate fluid seal in a plane nearly normal to the center line of the rivet cavity when the nozzle is engaged in the orifice of the rivet.

This form would be of advantage in use with the diaphragm-sealed primed rivet of Figure 16. It still preserves the benefit of a universal pivot engagement of the nozzle in the orifice of the rivet, with adequate accommodation of lateral inclination of the tool in relation to the rivet axis. In each of these cases the rivet head may have the shoulder and rabbet 18 and 19 omitted.

Prefilled or primed rivets also may be used in which liquid is retained only through capillary action or surface tension across the diameter of the reduced passage 21 into the rivet cavity, or in which liquid is retained by a wax seal or thin wafer of any suitable material adhering to the rivet head, with or without the use of the counter formed rabbet 57.

Additional proof that the application of loading at high velocities raises the yield point in metals above the values reached when loading is applied at slower velocities is shown by X-ray photographs of explosions of artillery shell. The instantaneous or impact loading incident to the explosion raises the yield point to a degree which permits radial expansion before rupture to diameters far in excess of the diameters reached where the shells are carried to failure by a relatively slow application of hydrostatic pressures.

The delivery of the small increments and the imparting of high velocity to each increment as introduced, together accomplish a two-fold result:

(1) The small increments of fluid, which approximate the minimum necessary to produce plastic flow in the metal, are followed by a higher yield point after each increment is administered, the plastic flow and rising yield point being enhanced in each instance by the high velocity with which the increment enters the fluid contained in the rivet cavity.

(2) The mass of the incoming increment being small in comparison to the mass of the static fluid already in the rivet cavity, little or no longitudinal acceleration is imparted to the latter and no appreciable longitudinal energy is developed therefrom tending to elongate the rivet instead of expanding it radially. The high velocity with which the increment enters enhances the inertia effect of the static mass of fluid in the cavity and contributes to the conversion of the energy of the incoming increment into simple but instantaneous hydrostatic pressure within the rivet cavity.

The result of the two-fold action is a succession of small permanent enlargements of the rivet, each enlargement being accompanied by a higher yield point in the metal. A rivet so expanded to the point of failure theoretically should develop a yield point approximately equal to the fracture strength of the material. Also, theoretically, with the volume of increments adjusted to the point that each will produce infinitesimal plastic flow, the number of increment applications would be infinite. However, it was discovered by me that where administered with the riveting device shown herein, adjustment of the impact weight and length of stroke, gave practical working increments which expanded the rivets in succes-

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sive stages far more successfully than was possible through the use of either constant pressure or measured volume methods controlled by testing laboratory procedures.

While I have described my invention specifically in the best embodiment at present known to me, it will nevertheless be understood that this is purely exemplary, and that variations in construction and arrangement, substitution of material and equivalents, mechanical or otherwise, as well as discretionary variations of sequence and nature of the steps of procedure set forth including additions and subtractions, may be made without departing from the spirit of the invention set forth in the appended claims.

I claim:

1. The method of expanding a hollow rivet of the character described by internal hydrostatic pressure set up therewithin, comprising subjecting the rivet to an internal hydrostatic pressure sufficient only to strain the walls of the rivet beyond their elastic limit to a degree which is a small part of the total permanent deformation desired, relieving the rivet of such pressure whereby straining of the rivet wall is discontinued and partial recovering permitted, and then repeating the application of internal hydrostatic pressure and the relief of pressure as before, whereby successive further stages of strain are produced with intervals of relaxation, until a predetermined total permanent deformation of the rivet is effected.

2. The method of setting hollow rivets of the character described comprising forming a hollow rivet shank with a closed end portion of uniform circumferential wall thickness in its side walls, at least in that part which is exposed beyond the work, and having a reduced passage communicating with the cavity opening through the base of the shank of the rivet, positioning the rivet through the work with said closed end exposed a distance, filling the rivet with an incompressible liquid, forcing successive small increments of liquid into the open end of the rivet at a pressure sufficient to strain the rivet wall beyond its elastic limit with intervals of relief of pressure on said liquid, until the said closed end of the rivet is expanded to predetermined lateral dimensions.

3. The method of setting hollow rivets of the character described comprising forming a hollow rivet shank with a closed end portion of uniform circumferential wall thickness in its side walls, at least in that part which is exposed beyond the work, and having a reduced passage communicating with the cavity opening through the base of the shank of the rivet, positioning the rivet through the work with said closed end exposed a distance, filling the rivet with an incompressible liquid, maintaining said liquid at an initial pressure sufficient to render the content incompressible and with casual gas inclusions consolidated, forcing successive small increments of liquid into

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the open end of the rivet at a pressure sufficient to strain the rivet wall beyond its elastic limit with intervals of relief of pressure on said liquid, until the said closed end of the rivet is expanded to predetermined lateral dimensions.

4. The method of claim 2 wherein said increments are each a small part of the total cubic volume required to expand the rivet to the predetermined degree.

5. The method of claim 2 wherein said increments are each a small part of the total cubic volume of liquid required to expand the rivet to a predetermined degree, and are projected into the rivet at high velocity.

6. The method of claim 2 wherein the intervals of relief of pressure are sufficient for the elastic recovery of the material of the rivet.

7. The method of claim 2 wherein the injected liquid is projected at a velocity sufficient to impart to the initial content of the cavity a velocity in directions normal to the confining surfaces sufficient to supply a component of impact upon the walls of the cavity which is a substantial one in the resultant expanding force effective upon the rivet.

8. The method of setting chambered rivets of the character described comprising initially filling the rivet with an incompressible liquid, repeatedly introducing into the liquid initially contained in the rivet cavity the smallest quantity of an additional liquid which will expand the rivet beyond its elastic limit sufficiently to assume a new permanent set at a desired larger diameter less than the full expanded diameter desired, until the rivet attains a predetermined size and shape.

9. The method of claim 8 including the steps of repeatedly introducing into the rivet an additional quantity of liquid as referred to in claim 8 at the greatest velocity which can be absorbed by the said liquid initially contained without transmitting to the latter sufficient energy of translation longitudinally of the rivet to materially limit radial expansion of the liquid and rivet.

GEORGE D. ROGERS.

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| 2,381,690 | Schultze ----- | Aug. 7, 1945 |
| 2,387,692 | Sundstrom ----- | Oct. 23, 1945 |