

Jan. 21, 1969

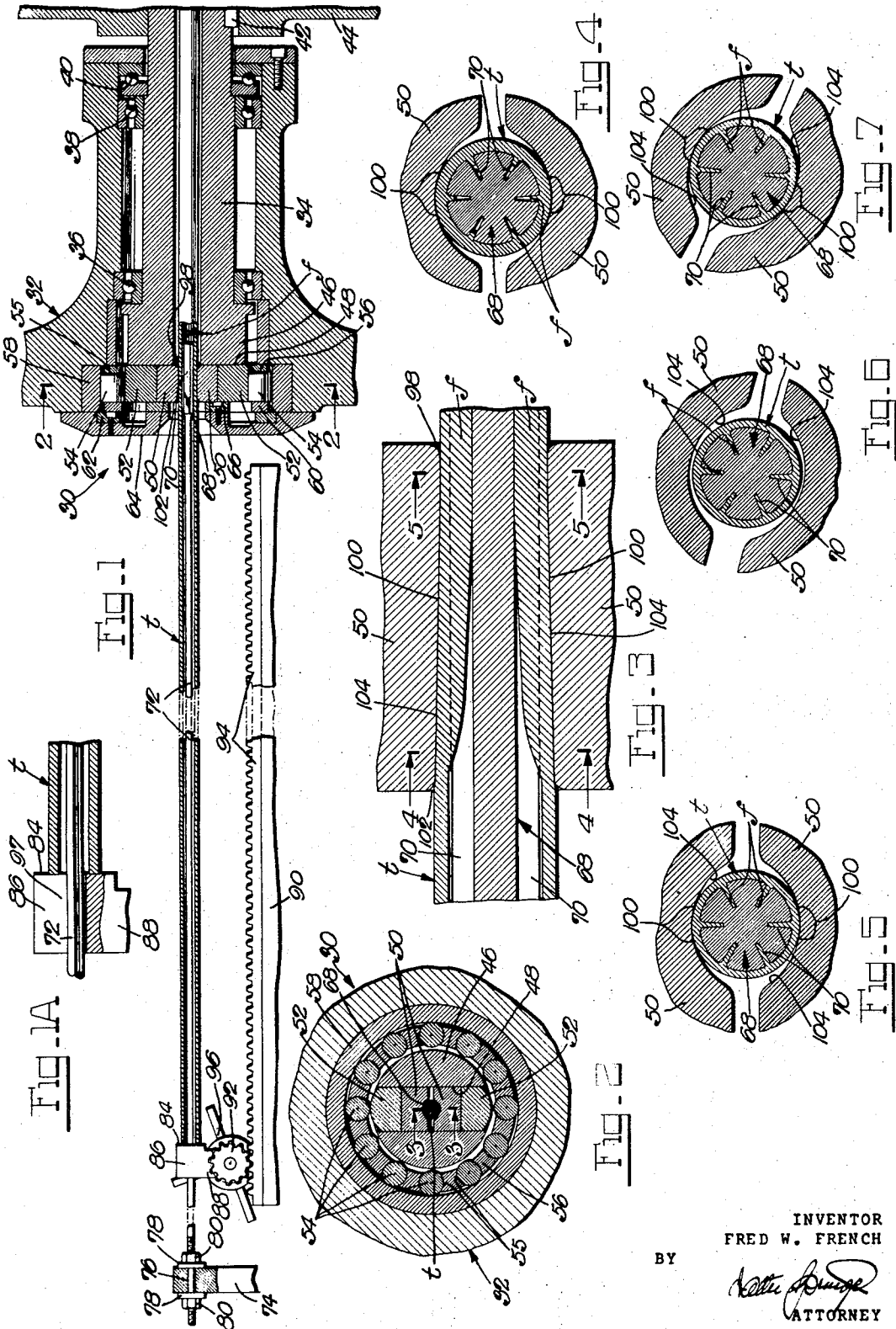
F. W. FRENCH

3,422,518

METHOD OF REFORMING TUBULAR METAL BLANKS INTO INNER-FIN TUBES

Filed Oct. 20, 1967

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Sheet 2 of 2

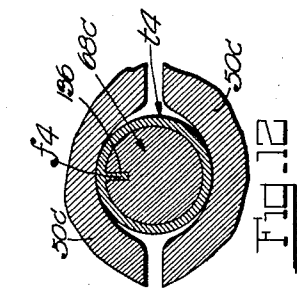


Fig. 12

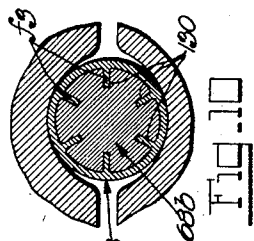


Fig. 10

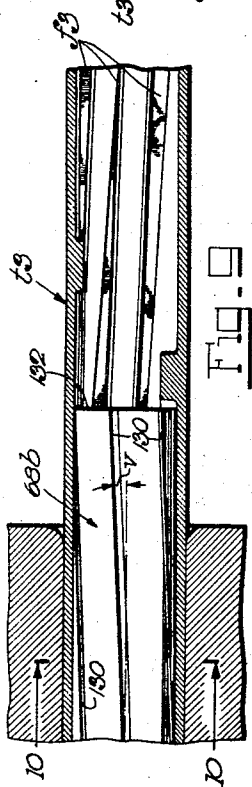


Fig. 9

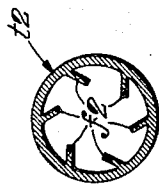


Fig. 8

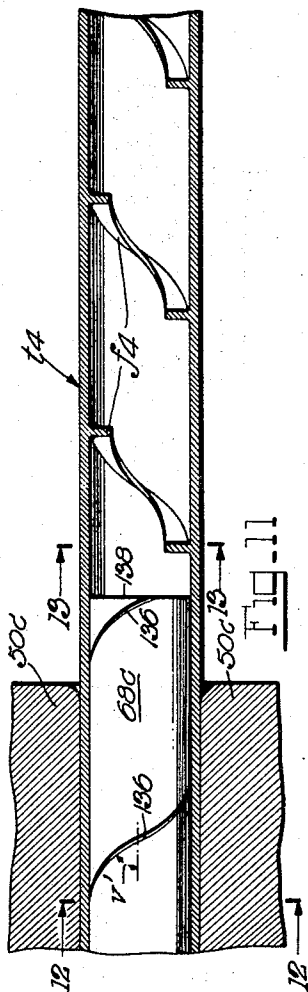


Fig. 11

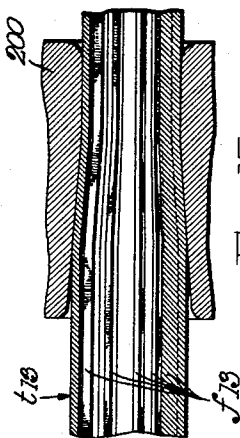


Fig. 16

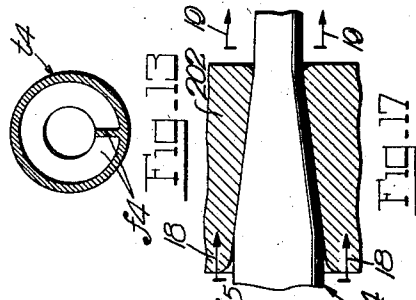


Fig. 13

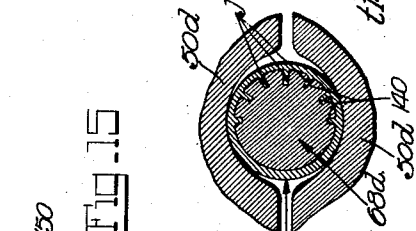


Fig. 17

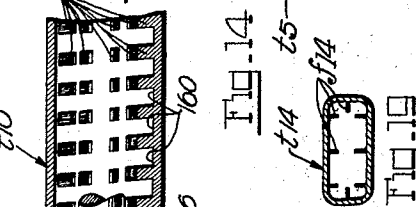


Fig. 14

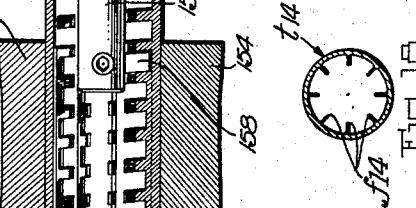


Fig. 15

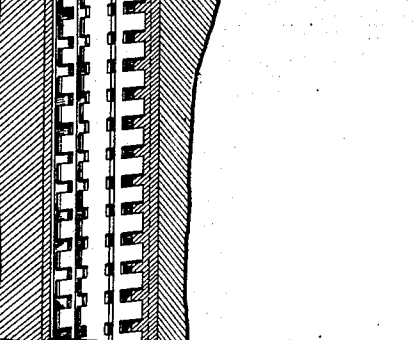


Fig. 18

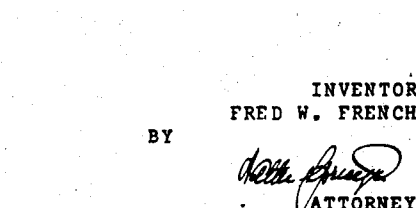


Fig. 19

INVENTOR
FRED W. FRENCH

BY

W. H. French
ATTORNEY

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3,422,518

**METHOD OF REFORMING TUBULAR METAL
BLANKS INTO INNER-FIN TUBES**

Fred W. French, Morris, Conn., assignor, by mesne assignments, to Valley Metallurgical Processing Company, a corporation of Connecticut

Continuation-in-part of application Ser. No. 314,580, Oct. 1, 1963. This application Oct. 20, 1967, Ser. No. 676,961

U.S. Cl. 29—157.3

Int. Cl. B21d 53/06; B23p 15/26; B21c 1/24

9 Claims

ABSTRACT OF THE DISCLOSURE

The disclosure pertains to a method according to which a tubular blank is fed over an axially fixed mandrel having peripheral grooves to the mandrel end from which the passing tube departs, and the blank is on its pass over the mandrel subjected to blows from the hammering dies of a rotary swaging machine, with the dies displacing the blank metal into the mandrel grooves and thereby also reducing the thickness of the peripheral tube wall so that the reformed blank emerging from the mandrel is an inner-fin tube.

This invention relates to fin-equipped tubing in general, and to inner-fin tubing and a method of making it in particular.

This application is a continuation-in-part of my prior application, Ser. No. 314,580, filed Oct. 1, 1963, now abandoned which was a continuation-in-part of my prior application Ser. No. 642,574, filed Feb. 26, 1957, now abandoned.

There is an ever-growing demand for fin-equipped tubing of the more conventional, including the smaller, sizes for use as or inefficient heat-exchangers. To this end, tubing has been equipped with inner fins in an endeavor to attain optimum heat exchange between a tube and a fluid therein. However, while prior inner-fin tubing is satisfactory in some respects, it is deficient in other important respects. Thus, some of this prior tubing is equipped with separate inserted fin formations, with the result that this prior tubing not only lacks high heat-exchange efficiency, but its cost is quite high by reason of its articulated construction, and its practical minimum cross-sectional dimensions are still larger than desired for many practical applications due to the difficulties encountered in joining separate inner fin formations with tubes of the smaller sizes.

It is among the objects of the present invention to produce tubing of most any lengthwise and cross-sectional dimensions and of most any metal, with integral inner-fin formations which have none of the aforementioned shortcomings of prior inner-fin tubing, and which may be of a great variety of patterns differing widely in height, thickness, distribution and direction of the fins, thereby to make available integral inner-fin tubing of a great variety from which to select tubing which is best and most advantageously suited for most any intended, and even special, practical application as or in a heat exchanger.

It is another object of the present invention to devise a method of forming integral inner fins on a tube according to which controlled and safe flow or displacement of tube metal is achieved to the wide extent necessary to obtain the great variety of integral inner-fin tubing in all the aforementioned respects.

It is a further object of the present invention to achieve the formation of integral inner fins on a tube by machine-swaging, i.e., machine-hammering, the tube peripherally and longitudinally against an inserted mandrel with peripheral grooves therein to cause displacement of the tube

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metal peripherally and longitudinally of the tube and radially into the mandrel grooves to form the fins therein, and then separating the mandrel and tube with the inwardly formed fins on the latter remaining intact, thereby to achieve not only controlled flow or displacement of tube metal to the wide extent required to obtain the aforementioned great variety of integral inner-fin tubing in the first place, but also to achieve flow or displacement of the entire tube metal with ensuing heat-transferwise beneficial reduction of the wall thickness of the tube, compacting of the grain structure of the tube and optimum tensile and bursting strength of the same, as well as reformation of its outer wall with sufficient smoothness and regularity to require no subsequent drawing operation in many instances.

Another object of the present invention is to obtain large-capacity production of integral inner-fin tubes of the aforementioned great variety by a continuous method according to which a tube of any length is moved entirely over a longitudinally-fixed mandrel with parallel continuous lengthwise peripheral grooves to at least that end thereof which is trailing with respect to the tube movement, and while so moving the tube subjecting the same peripherally to the typical instantaneous or sharp blows of the hammering dies of a power-operated swaging machine, with the fins formed in the mandrel grooves guiding the tube off the mandrel, thereby not only to obtain integral inner-fin formations on tubes which lengthwise of the latter may extend in many straight or helical patterns in continuous or interrupted fashion or to varying depths, but also to achieve highly economic and efficient formation of integral inner-fin tubing with no problem of separating the tube and mandrel.

A further object of the present invention is to establish a norm which, for successful reformation in an efficient machine-swaging operation of a tubular blank into an inner-fin tube of a given fin pattern and of given cross-sectional dimensions within fair tolerances, immediately furnishes particulars of the blank to be used for the purpose in the important respect of its cross-sectional dimensions. In thus predetermining the correct cross-sectional size of a tube blank for its reformation into an inner-fin tube of a required fin pattern and cross-sectional dimensions within required tolerances, failure of an inner-fin forming operation is averted in any event, and the initial set-up of such an operation is not only greatly facilitated but will bring about an assuredly successful and efficient operation.

Other objects and advantages will appear to those skilled in the art from the following, considered in conjunction with the accompanying drawings.

In the accompanying drawings, in which certain modes of carrying out the present invention are shown for illustrative purposes:

FIG. 1 is a fragmentary longitudinal section through apparatus in which tubing is formed with integral inner fins according to a method embodying the present invention;

FIG. 1A is an enlarged, fragmentary section through certain operating mechanism of the apparatus of FIG. 1; FIG. 2 is a fragmentary section through the apparatus as taken on the line 2—2 of FIG. 1;

FIG. 3 is an enlarged fragmentary longitudinal section through the apparatus as taken on the line 3—3 of FIG. 2, and showing an intermediate stage in the featured method of forming integral inner fins on a tube;

FIGS. 4 and 5 are fragmentary cross-sections taken on the lines 4—4 and 5—5, respectively, of FIG. 3;

FIGS. 6 and 7 are fragmentary cross-sections similar to FIG. 5, but showing further intermediate stages, respectively, in the featured method of forming integral inner fins on a tube;

FIG. 8 is a cross-section through a tube with modified integral inner fins;

FIG. 9 is a fragmentary longitudinal section, partly in elevation, through apparatus and a tube formed thereby, in accordance with the present method, with integral inner fins of another modified arrangement;

FIG. 10 is a fragmentary cross-section taken on the line 10—10 of FIG. 9;

FIG. 11 is a fragmentary longitudinal section, partly in elevation, through apparatus and a tube formed thereby in accordance with the present method, with a single integral inner fin of a further modified arrangement;

FIGS. 12 and 13 are fragmentary cross-sections taken on the lines 12—12 and 13—13, respectively, of FIG. 11;

FIG. 14 is a fragmentary cross-section through apparatus and a tube formed thereby, in accordance with the present method, with integral inner fins of another modified arrangement;

FIG. 15 is a fragmentary longitudinal section through apparatus and a tube formed thereby with further modified integral inner fins;

FIG. 16 is a fragmentary longitudinal section through inner-fin tubing formed in accordance with the present method, and a die in which the inner-fin tubing is reduced;

FIG. 17 is a sectional view similar to FIG. 16, showing inner-fin tubing being drawn through a die for changing the cross-sectional shape of the tube; and

FIGS. 18 and 19 are sections on the lines 18—18 and 19—19, respectively, of FIG. 17.

Referring to the drawings, and more particularly to FIGS. 1 and 2 thereof, the reference numeral 30 designates a conventional rotary swaging machine which forms part of an installation for forming integral inner fins on a tube. The swaging machine 30 has the usual mounted frame 32 in which a hollow spindle 34 is journaled, in this instance through intermediation of antifriction bearings 36 and 38, while operational end thrust of the spindle 34 is taken up by an end bearing 40 next to the journal bearing 38. The spindle 34 extends beyond the rear end of the machine frame 32 and has keyed thereto at 42 a gear or pulley 44 which forms part of a power drive for the spindle that originates at any suitable prime mover, such as an electric motor, for instance.

The spindle 34 has a diametrically enlarged front head 46 provided with a diametrical front groove 48 that serves as a guide for companion dies 50 and associated hammers 52. The hammers 52 in the driven spindle 34 react with rolls 54 so that the latter impart to the hammers 52 and their associated dies 50 rapidly recurring inward blows. To this end, the rolls 54 are arranged in equiangularly spaced fashion in fitting sockets 55 in a cage 56, and ride freely on a highly wear-resistant head ring or race 58 which is pressfitted into the machine frame 32. Forward axial escape of the rolls 54 from their fitting sockets 55 in the cage 56 is prevented by a suitably mounted ring cap 60 on the latter (FIG. 1). The roll-cage assembly 54, 56 and 60 is normally retained in place by a thrust ring 62 on a customarily hinged door 64 on the machine frame 32 which is normally locked in closed position and may be opened for access to the dies and hammers and to the roll-cage assembly. The companion dies 50 and associated hammers 52 are normally retained in proper operative alignment with the rolls 54 by another thrust ring 66 on the door 64 (FIG. 1).

In operation, the companion dies 50 perform a typical swaging operation on stock which is a tube or tubular blank *t* on a mandrel 68. To this end, the dies 50 are rotated, say clockwise in this instance (FIG. 2), by the driven spindle 34, whereby successive rolls 54 impart to the hammers 52 and their associated dies the aforementioned rapidly recurring inward blows. Thus, the dies 50, hammers 52 and rolls 54 are so coordinated that the dies are closed to the desired extent when the hammers pass between diametrically aligned rolls (FIG. 2). The

rotary speed of the spindle 34 is sufficiently high to throw the dies 50 and hammers 52 outwardly by centrifugal force as the latter clear each pair of diametrically aligned rolls 54, thus not only causing sufficient periodic opening of the dies to permit advance of the tubular blank therebetween, but also repositioning the hammers for optimum cooperation with each successive pair of diametrically aligned rolls in imparting hammer blows to the dies. The outer ends of the hammers 52 are customarily rounded for relatively brief cooperation with the rolls 54, resulting in rather quick, i.e. instantaneous, blows by the hammers against the dies. Also, the hammer blows imparted by the hammers 52 to the dies 50 are such that the actual penetration of the dies into the tube periphery at any one place is very small. Hence, in the present machine-type operation it is a large number of hammer blows per time unit against the periphery of the tube which achieves the desired swaging operation thereon. Thus, assuming that the spindle 34 be driven at 325 r.p.m., and with the exemplary arrangement of two dies 50 and twelve rolls 54, the dies would in theory deliver sixty-six simultaneous blows per second against the tubular blank. However, since the roll-cage assembly 54, 56 will inevitably creep in the drive direction of the dies due to planetary action, the actual number of simultaneous blows per second by the dies against the tube is less, and may in the present example be approximately fifty blows per second which are properly referred to as instantaneous blows. This latter exemplary figure will readily indicate the rapidity with which the die blows are struck against the tubular blank. Further, the die blows against the tubular blank are also quite sharp owing to the aforementioned relatively brief cooperation of the outer ends of the hammers 52 with the rolls 54, with these die blows being effective in causing, on and over the small extent of each die penetration into the tube periphery, instantaneous and particularly responsive, including depth-wise, flow of the metal of the tube on the contact of the dies with the latter. It is by virtue of this particular metal flow response to the die blows that the tube metal is forced to the very bottoms of the grooves in the mandrel regardless of the depth of these grooves, with the depth of the grooves in the mandrel being limited only by the requirement that the latter has adequate structural strength for the operation.

The blank *t* is in the instant swaging machine 30 reformed into an inner-fin tube in accordance with a method which forms an important aspect of the present invention. Basically, this method contemplates placing the blank *t* on the exemplary mandrel 68 which is provided with angularly-spaced, parallel longitudinal peripheral grooves that extend at least to one end of the mandrel, swaging the tube peripherally and longitudinally against the mandrel by the hammering dies of a power-operated swaging machine to cause displacement of tube metal peripherally and longitudinally of the tube and into the mandrel grooves depthwise thereof to form the fins therein, and axially separating the mandrel and tube with the fins in the latter remaining intact. To this end, the present mandrel 68 is provided with an exemplary number of six equiangularly spaced, identical peripheral grooves 70 (see also FIGS. 3 to 7) which in this instance extend axially of the mandrel. The mandrel 68, which receives the tube *t* with some slight clearance to assure unimpeded forward feed of the latter over the fixed mandrel between die blows (FIG. 3), may extend throughout the axial extent of the dies 50, and in this instance extends even therebeyond (FIG. 1), and the mandrel is held against axial movement from this position by having a shank 72 thereof releasably anchored to a fixed support 74. To this end, the shank 72 of the mandrel 68 extends, in the present instance, through an aperture 76 in the support 74 and carries washers 78 and nuts 80 which prevent axial movement of the mandrel. However, the nuts 80 are left

so loosely tightened that the shank 72 and, hence, the mandrel 68 have freedom to turn for a reason described hereinafter.

The tubular blank *t* which may be of considerable continuous length, is initially placed over the mandrel shank 72 while the latter is removed from the support 74 and the mandrel removed from or left between the open dies 50. With the tube *t* thus placed over the mandrel shank 72 and on inserting the mandrel 68 between the open dies 50 if it is not already there, the shank 72 is anchored to the support 74 in the explained manner. The tube *t* is thereupon retracted into butting engagement with the front surface 84 of a head 86 of a feed slide 88 (FIG. 1A) which is suitably guided on a fixed support 90 for movement in the direction of the rotary axis of the dies 50 (FIG. 1) and presently carries a rotary pinion 92 in permanent mesh with a rack 94 on the support 90. Turning with the pinion 92 is a handwheel 96. The head 86 of the feed slide 88 is slotted throughout as at 97 for lateral admission therinto and removal therefrom of the mandrel shank 72. The feed slide 88 is at the beginning sufficiently withdrawn from the swaging machine 30 so that the forward end of the tube *t* may rest on the mandrel 68 somewhere within the axial extent of the open dies 50.

The swaging machine 30 may now be set in operation for starting a swaging performance on the tube *t*, the latter being gradually fed by the slide 88 between the rotating dies 50, presently by turning the handwheel 96, as will be readily understood. In thus advancing the tube *t* into the rotating dies 50, the latter will, by numerous hammer blows peripherally and longitudinally against the tube on the mandrel 68, cause gradual displacement of the tube metal peripherally and longitudinally of the tube and into the mandrel grooves 70 (FIGS. 3, 4 and 5), so that tube metal fills the latter throughout and forms integral inner fins *f* on the tube before the latter emerges from the dies 50 at the discharge side 98 thereof, with the fins formed in the mandrel grooves guiding the tube off the mandrel.

The companion dies 50 are over their actual striking areas 100 axially tapered (FIGS. 3 to 5) sufficiently to achieve the aforementioned gradual displacement of tube metal peripherally and longitudinally of the tube *t* and into the mandrel grooves 70, rather than too abrupt displacement of tube metal which would most likely spoil the swaging operation, if not stop the same altogether, due to formation of a metal bulge on the tube at the inlet side 102 of the dies. Also, since the companion dies 50 turn while delivering their blows to the tube periphery, a creeping planetary rotation is imparted by them to the tube *t*, and also to the mandrel 68 by virtue of the interlock of the fins *f* with the mandrel grooves 70. This slight rotational creep of the tube *t* and mandrel 68, in the exemplary clockwise direction of rotation of the dies 50 and between successive die blows, is demonstrated in FIGS. 5 and 7, with the dies shown in FIG. 6 in their momentary open position between their successive blow positions. Of course, the tube *t* has sufficient freedom to turn in this creeping fashion relative to the head 86 of the feed slide 88 which it only butts, while the mandrel has similar freedom to turn, as already mentioned. The confronting surfaces 104 of the companion dies 50 are preferably curved, though on a larger diameter than the outer tube diameter (FIGS. 4 to 7), so that their actual striking areas 100 are of some peripheral extent, which is advantageous in achieving the considerable tube metal displacement required for the formation of the fins *f*, as well as reformation of the outer tube wall in fairly accurate circular form, with a minimum number of die blows against the tube and, hence, at an efficient feed rate of the tube into the dies.

After thus gradually feeding most of the tube *t* into the dies 50 by means of the exemplary feed slide 88 and, in consequence, reforming it into a tube with continuous integral inner fins *f*, the remainder of the tube may be reformed by feeding the trailing end thereof of the blank

into the dies substantially to their discharge side 98. Hence, after the feed slide 88 has reached the end of its forward or feed stroke, recourse may, in this instance, be had to any suitable means at the rear end of the swaging machine, such as a self-gripping tube collet (not shown) operated by a rack and pinion and a hand-wheel the same as the feed slide 88, for example, in order to draw the short trailing end of the tube into the dies 50 and toward, but not to, their discharge side 98. The swaging machine 30 may then be stopped before the reformed tube is entirely retracted from within the axial confines of the dies so as to eliminate any damaging die blows against the mandrel, the tube being thereafter readily withdrawn completely from the mandrel and through the rear end of the swaging machine. Of course, the swaging machine may also perform continuously and uninterruptedly on successive tubes, by bringing a new tube into end-to-end engagement with the presently processed tube *t* before the latter leaves the dies at their discharge side, for the purpose of pushing the nearly finished inner-fin tube beyond the dies by means of the feed slide acting on the new tube. In thus passing the tube *t* completely over the mandrel 68, there is, of course, this advantage that the separation of the reformed tube and mandrel is facilitated. Also, while the feed slide 88 is, in the present example, hand-operated at the wheel 96, the same may, of course, be more advantageously power-operated.

As shown in FIGS. 3, 4 and 5, the gradual peripheral and longitudinal displacement of tube metal in the tube wall and the gradual depthwise displacement of tube metal into the exemplary radial mandrel grooves 70 for the formation of the fins *f* by the swaging operation results in a gradual reduction in the wall thickness of the tube which in the finished inner-fin tube is quite pronounced (FIG. 5) and is highly advantageous from the viewpoint of heat-transfer through the tube. Also, since the finished inner-fin tube is formed throughout of swaged metal of the original tube, it stands to reason that its grain structure is highly compacted, and this is of advantage in that it lends the finished tube not only increased tensile and bursting strength, but, even more important, optimum heat conductivity for its size, including cross-sectional dimensions. Hence, it is obvious that quite important structural and functional advantages of the finished tube spring directly from the explained method of forming integral inner fins thereon by swaging.

It is, of course, obvious that there are practical limits to the depth penetration of the dies into the tube periphery with each blow if the fin formation is to be successful. The exact limits of the permissible depth penetration of the dies with each blow into the tube periphery for a given tube metal have not been determined, nor is it necessary to determine them for it is comparatively easy to stay within these limits. Thus, as long as the rate of feed of the tube into the dies and the depth penetration of the latter with each blow into the tube periphery are coordinated so as to prevent the formation of an increasing metal bulge on the tube at the inlet side of the dies, the reformation of the tube into the inner-fin tube will progress satisfactorily. If, as in the described exemplary fin forming operation, the finished fins *f* are to extend in the mandrel grooves 70 throughout their depths and widths for a clearly defined and regular pattern arrangement of the fins (FIGS. 3 and 5), care will be taken that the dies 50 will near and at their discharge side 98 displace no more metal than is consistent with permissible compacting of the metal in the tube wall and in the fins throughout the depths and widths of the mandrel grooves 70 and permissible lengthwise expansion of the tube, for this metal would otherwise escape lengthwise of the tube and cause bulging thereof as well as destruction of the fins. With this in mind, the dies 50 may readily be made of sufficient axial extent and their striking areas 100 sufficiently tapered to obtain gradual reduction of the wall

thickness of the tube from its original thickness to its final reduced thickness and accurate finish-formation of the fins *f* on feeding the tube into the dies at an efficient optimum or near-optimum coordination rate which naturally depends at least on the metal of the tube, the cross-sectional tube dimensions both original and finished, the number of revolutions of the dies per time unit, the number of companion dies (one or more pairs), and the number of rolls acting on the hammers behind the dies, as will be readily understood. Insofar as longitudinal expansion or elongation of tubes in the course of their reformation into inner-fin tubes is concerned, the expansion is at least 50%, and for most inner-fin tube formations approximately from 100% to 200% depending on the extent of the cross-sectional reformation of a tubular blank into an inner-fin tube.

Given by way of example only, following is a description of an actual early successful fin forming operation on a tube according to the present method and in an installation similar to that of FIG. 1. Thus, an annealed copper tube of original $\frac{3}{8}$ " outside diameter and .065" wall thickness was according to the present method formed with 8 equiangularly spaced identical fins of .194" height and .014" mean thickness, with the final outside diameter of the tube being $\frac{3}{4}$ " and the final wall thickness thereof being .019". The diameter of the mandrel was the same as the reduced inside diameter of the reformed tube, namely .712", whereupon the original blank had .033" (i.e., somewhat over $\frac{1}{32}$ ") lateral play on the mandrel. The swaging machine used in this operation was a conventional rotary swager which had one pair of companion dies, 8 rolls and the die-carrying spindle was driven approximately at 250 r.p.m. The dies were 2" in axial extent and their striking areas tapered approximately 8°, and their confronting striking surfaces were cross-sectionally curved at a larger diameter than the original outside diameter of the tube, and the roll backing surfaces of the hammers were uniformly rounded similarly as shown in FIG. 2. The tube was fed between the operating dies at an approximate rate of one foot per minute.

The above-described actually-made inner-fin tube has cross-sectional fin dimensions which in height and thickness may vary widely therefrom in other inner-fin tubes produced according to the present method. Thus, the fins in tubes produced according to the present method may vary in height from less than the wall thickness of the finished tube (FIG. 14) to most any desired extent toward the center axis of the latter, with the sole limitation in the latter respect being adequate strength of the mandrel left by the depth of the grooves therein so that the mandrel will not break in the course of the swaging of an inner-fin tube. Further, the fins in tubes produced according to the present method may vary thicknesswise from considerably less than the wall thickness of the finished tube, as in FIG. 14 and in the above-described actually-made inner-fin tube, for example, to more than the wall thickness of the finished tube, with the fins in many demanded tubes being in thickness of from less than, to substantially equal to, the wall thickness of the finished tube.

While the fins *f* formed in the tube *t* in the previously described operation extend truly radially of the tube (FIG. 5), it is, of course, fully within the purview of the present invention to form integral inner fins which extend non-radially of a tube, such as the fins *f2* which extend from the inner periphery of a tube *t2* in the oblique fashion shown in FIG. 8, for example.

Also, while the inner fins *f* formed on the tube *t* extend axially of the latter (FIG. 1), it is fully within the purview of the present invention to form inner fins on a tube which extend helically thereof. Thus, FIGS. 9 and 10 show a tube *t3* which has been formed with helically extending inner fins *f3* in an installation which may be like or similar to that of FIG. 1, except that the mandrel 68*b* has angularly-spaced peripheral grooves 130 which

extend helically to the trailing end 132 of the mandrel. Of course, the helical grooves 130 in the mandrel 68*b* must not only extend parallel to each other, but their helix angles ν must be the same throughout, in order that the formed fins *f3* may lead the tube *t3* off the mandrel without stripping the fins from the tube. In the present example, the tube *t3* is formed with six equiangularly spaced helical fins *f3* of quite considerable pitch.

In contrast to the large-pitch helical fins *f3* in the tube *t3* of FIG. 9, FIG. 11 shows a tube *t4* which, in accordance with the present method, is formed with a single steep helical inner fin *f4* (see also FIG. 13). To this end, the mandrel 68*c* is provided with a peripheral groove 136 which extends helically thereof at the same large helix angle ν' throughout to the trailing mandrel end 138, for the exemplary formation of the inner fin *f4* in accordance with the continuous method, and with apparatus similar to that, of FIG. 1, including driven hammering dies 50*c* (see also FIG. 12). Of course, since the helix angle of the peripheral mandrel groove 136 is the same throughout, the finished tube will in a regularly twisting manner be guided off the mandrel 68*c* by the formed fin *f4* in the mandrel groove without stripping the fin from the tube.

The instant method and an installation like or similar to that of FIG. 1 are also suitable for the production of inner-fin tubing with a directional heat-transfer control feature. Thus, FIG. 14 shows a tube *t5* which is substantially over half of its periphery provided with spaced inner fins *f5* which, moreover, vary in height. To this end, the mandrel 68*d*, which is circular in cross-section, is substantially over half of its periphery in this instance provided with exemplary seven equiangularly spaced, parallel peripheral grooves 140 which extend lengthwise of the mandrel to the trailing mandrel end, and are also of different depths, as shown. With the mandrel 68*d* arranged on the front end of a long, somewhat flexible shank which at its rear end is mounted against axial movement, but with freedom to turn, the same as the mandrel shank 72 in FIG. 1, the mandrel 68*d* has freedom to move laterally between the dies 50*d*. Thus, with the original tube being circular in cross-section and of uniform wall thickness throughout, the mandrel 68*d* will, under the numerous blows by the rotating dies 50*d* against the tube periphery, be oriented somewhat off-center with respect to the dies 50*d*, and the wall thickness of the finished tube will vary somewhat, being smaller along the fin formation and larger over the remainder of the tube periphery.

A most important aid in quickly setting up a machine-swaging operation which will produce any specified inner-fin tubing is a norm by which the correct size of a tube blank for its formation into the specified inner-fin tube is easily and immediately predetermined. Thus, it was found that for successful reformation of a tube blank into an inner-fin tube of any specified fin pattern and any specified cross-sectional dimensions within permissible tolerances, the cross-sectional area of the metal of the tube blank must be larger than that of the specified inner-fin tube within a range of from 2 to 1 to 3 to 1. As long as the respective cross-sectional areas of the metal of the tube blank and specified inner-fin tube are within this range, the blank will in a machine-swaging operation over a mandrel be reformed into the specified inner-fin tube in any event, and merely the efficiency of the operation will vary with different selected ratios within this range. For example, the cross-sectional area of the metal of the tube blank from which was produced the earlier described sample inner-fin tubing of 8 inner fins and given outer diameter, wall thickness, and height and thickness of each fin, was about 2.6 times larger than the cross-sectional area of the metal of the produced inner-fin tube, and the elongation of the tube was, therefore, about 2.6 to 1. Accordingly, the cross-sectional area of the tube blank metal for this particular inner-fin tube was selected

at about 2.6 to 1 within the range of from 2 to 1 to 3 to 1, although another ratio within this range, such as 2.45 to 1, for example, might perhaps have resulted in an operation of somewhat greater efficiency in point of blank reformation into the inner tube with the least die blows per time unit and, hence, increased feed rate of the blank and accordingly increased production rate of the inner-fin tube. Once a ratio within the 2 to 1 to 3 to 1 range has been selected for a tube blank and the cross-sectional area of its metal determined, the cross-sectional blank dimensions are as easily and quickly determined, with the inner diameter being equal to the specified outer diameter of the inner-fin tube plus such slight freedom the blank is given for its unimpeded feed over the mandrel, and the outer blank diameter being then calculated. Having thus arrived at the size of a tube blank, an operation is set up with the proper mandrel and swaging dies and also customary shimming of the latter for the particular tube blank, whereupon a full-length blank or a shorter sample length thereof may be swaged into the inner-fin tube. Any operator with some experience will immediately know whether or not the operation is then at or near optimum efficiency. If the efficiency of the operation is found to be somewhat on the low side, a slightly differently sized blank may be used in the operation, with the operator knowing from experience whether the different blank should be of greater or smaller size than the first blank. Thus, in two, and at the most three, short trial operations the blank is found which affords optimum or near optimum efficiency of the operation.

Within the 2 to 1 to 3 to 1 range of cross-sectional areas of the metal of blanks it was found that in general the ratio for inner-fin tubes with axially extending fins is somewhat higher than for inner-fin tubes with helically extending fins, for best operational efficiency. It was also found that for inner-fin tubes of a great variety of inner-fin patterns and cross-sectional dimensions operations of satisfactory efficiency were achieved when the cross-sectional blank area ratio was selected from the more confined range of 2.3 plus or minus 2 tenths to 1, with the best ratio being often within the plus tolerance of this more confined range for inner-fin tubes with axially extending fins, and within the minus tolerance of this range for inner-fin tubes with helically extending fins.

Reference is now had to FIG. 15 which shows the formation of integral finger-like inward projections 150 on a tube 110 which are spaced from each other longitudinally as well as peripherally of the tube. To this end, a tube formed in accordance with the present method with continuous inner fins, is clamped between jaws 152 and 154 of a power-driven chuck, whereupon a bar 156 with a cutting tool 158 may be advanced into and through the tube at an appropriate rate to cut a helical path through the continuous fins in the tube. The cutting tool 158 is adjustable inwardly and outwardly on the bar 156 so that the helical path through the continuous fins in the tube may on successive passages of the cutting tool through the tube be gradually cut deeper until on the last passage of the cutting tool through the tube the helical path through the inner fins extends depthwise to the inner periphery of the tube as indicated at 160 for the finish-formation of the fingerlike inward projections 150 on the tube. Of course, numerous variations in the dimensions of these inward projections lengthwise of the tube and in their longitudinal spacing may be achieved with a cutting tool 158 of different dimensions and with a different, and even varying, rate of advance of the bar 156 into the tube.

While any of the inner-fin tubes shown and described herein may subsequently be drawn to improve upon the smoothness and finished appearance of the outer periphery of the tube, this is for many practical applications entirely unnecessary. Thus, tubing formed with integral inner fins in accordance with the present method will have a fairly smooth and uniform outer periphery.

It follows from the preceding that the instant method

makes possible for the first time the formation of inner-fin tubing of a great variety, not only insofar as fin arrangements are concerned, but even insofar as tube metals are concerned. Thus, any tube metal which may be swaged or forged under blows may in accordance with the present method be formed with integral inner fins. Also, there are no upper limits to the cross-sectional dimensions of tubing formed with inner fins in accordance with the present method. As to the lower limits of the cross-sectional dimensions of inner-fin tubing formed in accordance with the present method, these have not as yet been determined, but no difficulty is expected in forming inner-fin tubing, in accordance with the present method, of quite considerably smaller finished outside diameters than the hereinbefore mentioned finished outside tube diameter of $\frac{3}{4}$ ".

Actual operations have shown that it is also entirely practical to form inner-fin tubing, in accordance with the present method, of larger outside diameter than desired, and subsequently to reduce the inner-fin tubing to the desired outside diameter in a drawing operation, without distorting the sharply defined inner-fins or distributing their accurate relative location and coordination. Thus, FIG. 16 shows a drawing operation on a tube 113 which may have been formed, in accordance with the present method, with inner fins 113. To this end, the inner-fin tube 113 is drawn through a reducing die 200 for the diametric reduction of the former to the exemplary extent indicated. Of course, this reduction of the tube 113 by drawing will have the effect of a slight increase in the wall thickness of the tube, and also of a slight orderly inward shift of the fins 113 therein without, however, distorting the latter in any way or disturbing their accurate relative location and coordination. Subsequent reduction by drawing of inner-fin tubing formed in accordance with the present method may be resorted to whenever desired, but it has especial advantage in reducing inner-fin tubing to especially small desired outside diameters. Also, subsequent drawing of cross-sectionally circular inner-fin tubing of this kind may advantageously be resorted to for changing the cross-sectional shape of the inner fin tubing to an oval or some other cross-sectional shape. In this connection, reference is had to FIG. 17 which shows a die 202 through which is drawn an inner-fin tube 114 of the circular periphery shown in FIG. 18 for its reformation into the exemplary rectangular shape shown in FIG. 19. In thus reforming the tube 114 into the exemplary rectangular shape, the fins 114 therein along the opposite longer sides of the tube are brought closer to each other without, however, appreciably if at all, changing the internal cross-sectional flow area in the tube, with the result that the fins reach deeper into fluid flowing through the tube for increased heat-exchange between the fluid and fins. Of course, while cross-sectional reformation of an inner-fin tube is accomplished by exemplary drawing of the tube through a die, such as the die 202, the same cross-sectional reformation of an inner-fin tube may obviously be accomplished between companion squeezing rolls (not shown).

The great advantages of forming inner-fin tubing in accordance with the present method have already been stressed hereinbefore. These advantages are also reflected in large part in the inner-fin tubing itself. Thus, aside from the highly important advantages that inner-fin tubing of this type may be of most any metal and formed in most any cross-sectional fin pattern, including quite considerable and heat-transferwise beneficial reduction of the wall thickness of the tube, simple tests will readily indicate the considerably increased tensile and bursting strength of this inner-fin tubing by virtue of its formation throughout of swaged tube metal in its finished form. The formation throughout of inner-fin tubing, made in accordance with the present method, of swaged tube metal is as readily and unmistakably indicated by conventional metallurgical tests.

The invention may be carried out in other specific ways

than those herein set forth without departing from the spirit and essential characteristics of the invention, and the present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

What is claimed is:

1. Method of forming a metal inner-fin heat-exchange tube of specified cross-sectional shape and size, which comprises choosing tubular blank stock of a cross-sectional area occupied by its metal which in comparison to that of the specified inner-fin tube is at a ratio anywhere within a range of 2-to-1 to 3-to-1; substantially continuously longitudinally moving a blank of the chosen tubular stock relative to a shorter mandrel therein having lengthwise grooving to an end thereof, with each groove being of the width and depth of the finished thickness and height of the fin to be formed, said blank movement continuing beyond said grooved mandrel end; and while so relatively moving the blank and mandrel in a single pass, striking with power-rotated swaging dies of a swaging machine against the outer peripheral surface of the blank over the mandrel peripherally throughout instantaneous hammer blows to reduce the thickness of the blank wall peripherally throughout and form from the metal of said wall inwardly extending fins of finished thickness, and continuing said die blows against the blank over the mandrel during said continuous relative longitudinal movement until the fins are in substantial form-fit with said mandrel grooves prior to their separation therefrom and the elongation of the tube is substantially at the chosen ratio within said range.

2. The method of claim 1, wherein said range is 2.3 plus or minus two tenths to 1.

3. The method of claim 1, in which the fins extend longitudinally axially of the tube.

4. The method of claim 1, in which the fins extend longitudinally helically in the tube at the same helix angle.

5. Method of producing from a tubular metal blank an inner-fin heat exchange tube, which comprises substantially continuously longitudinally moving a tubular blank of any length relative to a shorter mandrel therein having lengthwise grooving to an end thereof, said movement continuing beyond said grooved end; while so relatively moving the blank and mandrel, hammering against the outer peripheral surface of the tube solely by relatively rotating the blank and the swaging dies of a power-operated swaging machine, said hammering being with sufficient force to induce multitudinous flow surges of the blank metal longitudinally, peripherally, and radially inwardly of the blank to form an inner-fin tube, and continuing said hammering and coordinating said longitudinal movement thereto so that the radial extent of the fin formation is from equal to, to many times, the wall thickness of the inner-fin tube and with the latter being in form-fit with the grooved mandrel; and drawing the inner-fin tube through a reducing die.

6. Method of producing from a tubular metal blank an inner-fin heat exchange tube, which comprises substantially continuously longitudinally moving a tubular blank of any length relative to a shorter mandrel therein having lengthwise grooving to an end thereof, said movement continuing beyond said grooved end; while so relatively moving the blank and mandrel, hammering against the outer peripheral surface of the tube solely by relatively rotating the blank and swaging dies of a power-operated swaging machine, said hammering being with sufficient force to induce multitudinous flow surges of the blank metal longitudinally, peripherally, and radially inwardly of the blank to form an inner-fin tube, and continuing said hammering

and coordinating said longitudinal movement thereto so that the radial extent of the fin formation is from equal to, to many times, the wall thickness of the inner-fin tube and with the latter being in form-fit with the grooved mandrel; and externally compressing the inner-fin tube into a different cross-sectional shape.

7. The method of claim 6, in which the inner-fin tube is compressed by drawing the same through a shape-changing die.

8. Method of producing from a tubular metal blank an inner-fin heat exchange tube, which comprises substantially continuously longitudinally moving a tubular blank of any length relative to a shorter mandrel therein having lengthwise grooving to an end thereof, said movement continuing beyond said grooved end; while so relatively moving the blank and mandrel, hammering against the outer peripheral surface of the tube solely by relatively rotating the blank and the swaging dies of a power-operated swaging machine, said hammering being with sufficient force to induce multitudinous flow surges of the blank metal longitudinally, peripherally, and radially inwardly of the blank to form an inner-fin tube, and continuing said hammering and coordinating said longitudinal movement thereto so that the radial extent of the fin formation is from equal to, to many times, the wall thickness of the inner-fin tube and with the latter being in form-fit with the grooved mandrel; and cutting away recurring lengths of the fins in the tube to leave fingers therein.

9. Method of producing from a tubular metal blank an inner-fin heat-exchange tube, which comprises providing a mandrel having lengthwise uniform-depth grooving to an end thereof, with each groove being of a width of the finished thickness of the fin to be formed and the periphery of the mandrel between all grooves therein being at least equal to the combined width of the grooves; providing a blank the metal of which is of sufficiently large cross-sectional area to substantially fill the mandrel grooves and to provide a body of metal for an elongation of at least 50% of the blank; longitudinally moving the blank over the mandrel therein and beyond said mandrel end; while so moving the blank in a single pass, swaging against the outer peripheral surface of the blank over the mandrel therein to reduce the wall thickness of the blank and form from the metal of the wall inwardly extending fins of finished thickness; and continuing said swaging for continued reduction of the wall thickness of the blank until the fins are in substantial form-fit with said mandrel grooves and the inward extent of the fins is at least equal to the reduced peripheral wall thickness of the blank, and all blank metal in excess of that of the reduced wall thickness and fins going into elongation of the tube.

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65 JOHN F. CAMPBELL, *Primary Examiner*.
P. M. COHEN, *Assistant Examiner*.

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