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Winter et al.

[11] **3,891,952**

[45] **June 24, 1975**

[54] **ELECTROMAGNETIC ASSEMBLY RESISTING AXIAL ARMATURE MOVEMENT FOR WORKING OR FINNING TUBING**

[75] Inventors: **Richard M. Winter**, Mentor; **William F. Aylard**, Northfield, both of Ohio

[73] Assignee: **Non-Ferrous International Corporation**, New York, N.Y.

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Related U.S. Application Data

[62] Division of Ser. No. 141,249, May 7, 1971.

[52] **U.S. Cl.** **335/258;** 335/279; 335/281

[51] **Int. Cl.** **H01f 7/08**

[58] **Field of Search** 335/256, 258, 259, 261, 335/264, 266, 268, 279, 281

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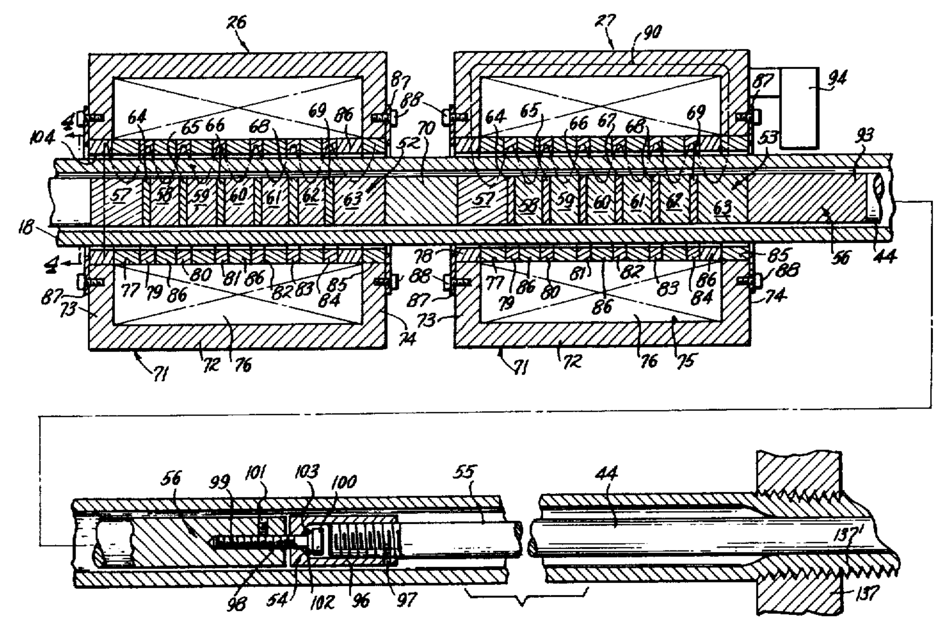
Primary Examiner—G. Harris
Attorney, Agent, or Firm—Walter Kruger

[57] **ABSTRACT**

Fins or threads are formed on the exterior surface of infinite length tubing restrained against rotation and continuously fed longitudinally to a rotating fin forming head. A mandrel initially positioned within the tubing presents a backup tool in the region of the fin forming head, the mandrel being formed from alternate sections of magnetic and non-magnetic material and being held against axial movement by magnets surrounding the tubing and presenting alternate sections of magnetic and non-magnetic material so located that magnetic flux enters and leaves the mandrel at a plurality of locations along the length of each magnet. The fin forming head is free to move axially to avoid stressing the fin forming elements which engage and form helical threads or fins on the exterior surface of the tubing. Initially, the speed of rotation of the fin forming head is adjusted so the rate of formation of fins on the tubing equals the linear speed at which the tubing is fed through the apparatus. If the speed at which the tubing is fed changes, the finning head is free to move axially and actuates a control to either increase or decrease the speed of rotation of the head so fin forming proceeds at the new rate at which the tubing is fed. Emergency shut off means are provided to shut off critical portions of the apparatus in the event of a malfunction such as axial movement of the backup mandrel or axial movement of the rotating finning head beyond certain positions.

7 Claims, 9 Drawing Figures



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SHEET 1

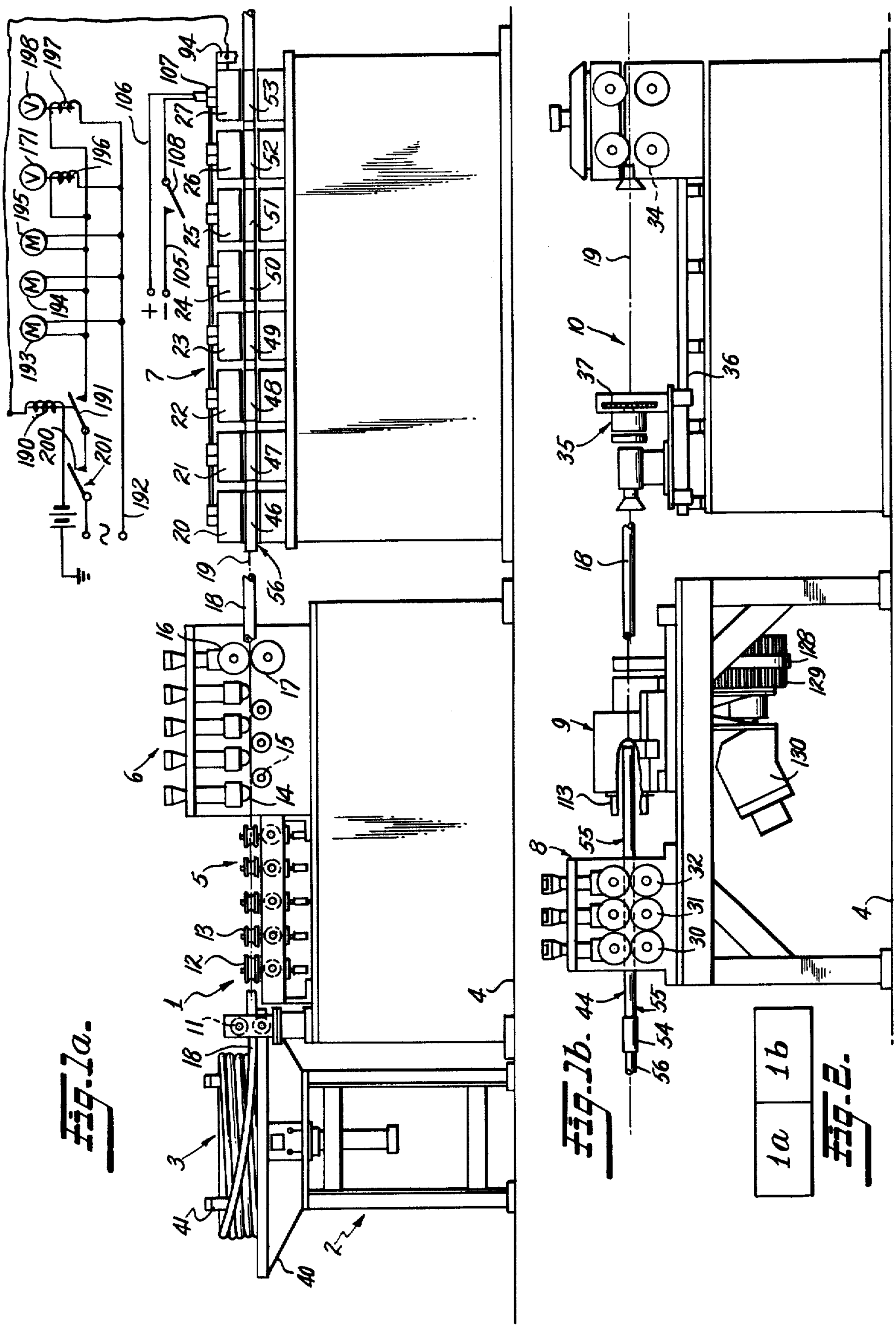

Fig. 1a.

Fig. 1b.

Fig. 2.

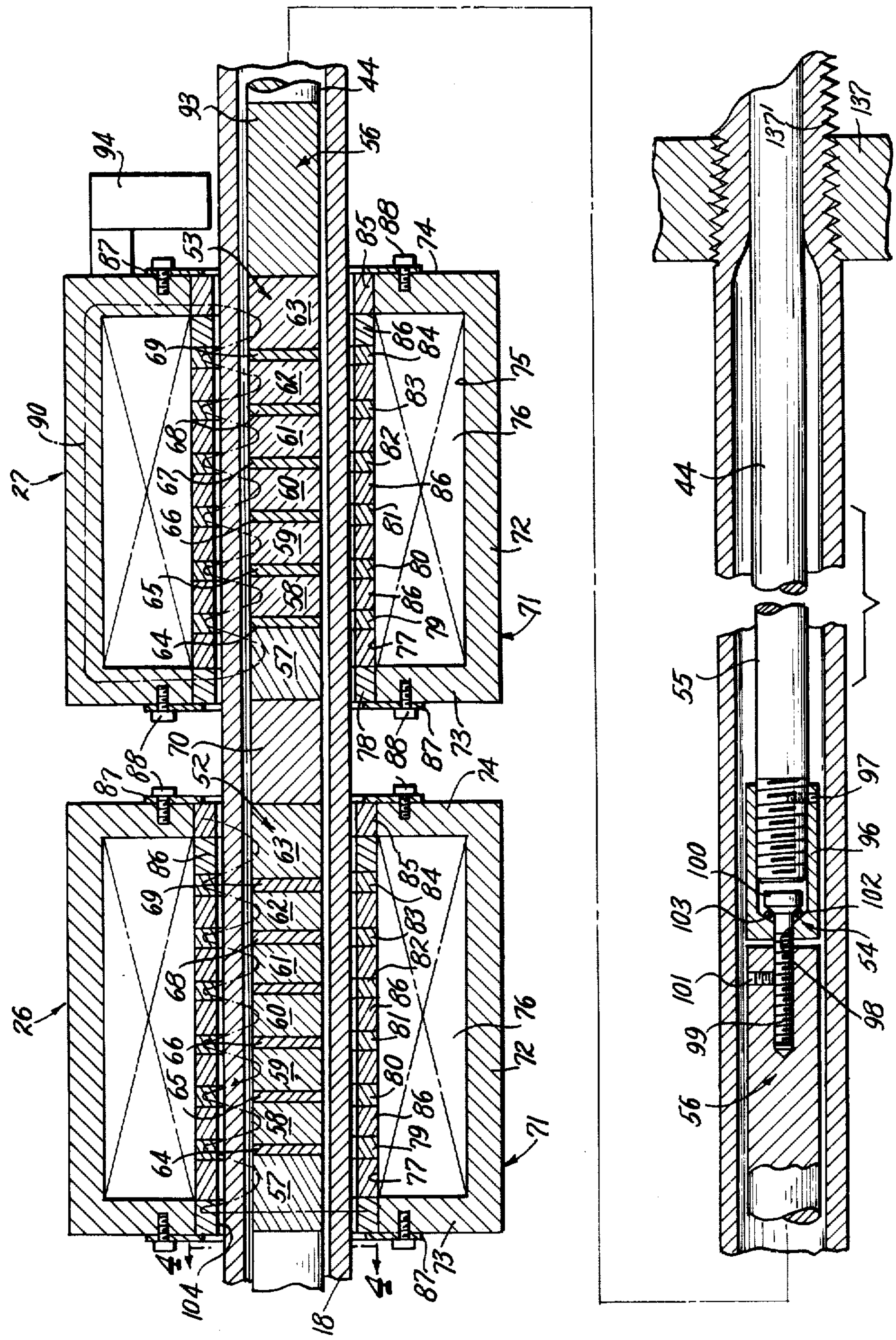
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Fig. 3.

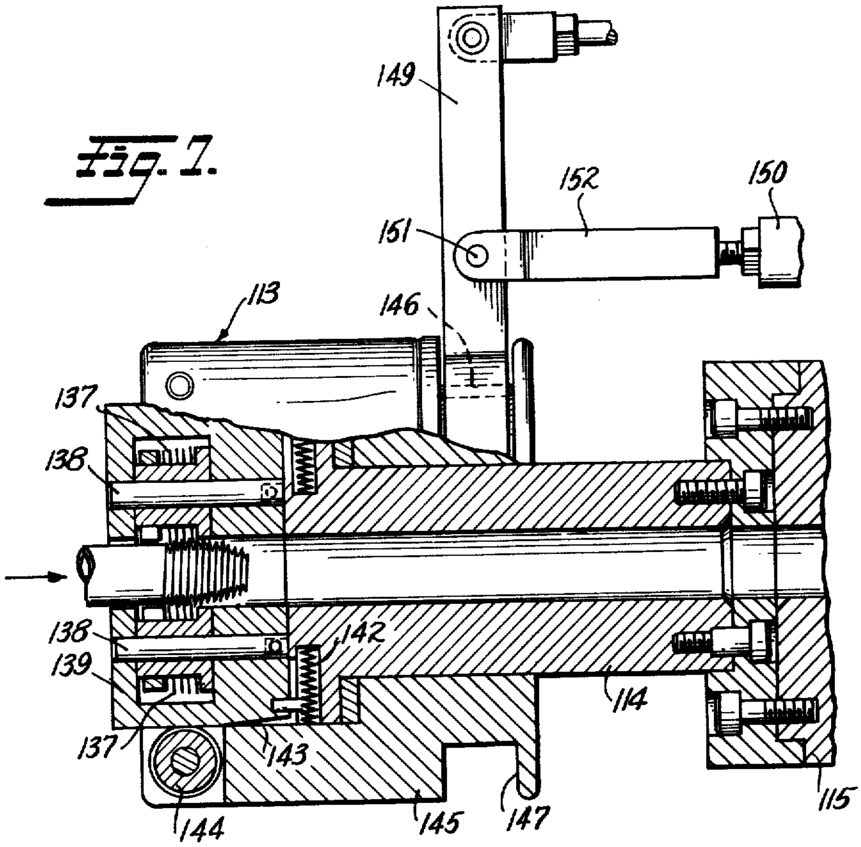

FIG. 7.

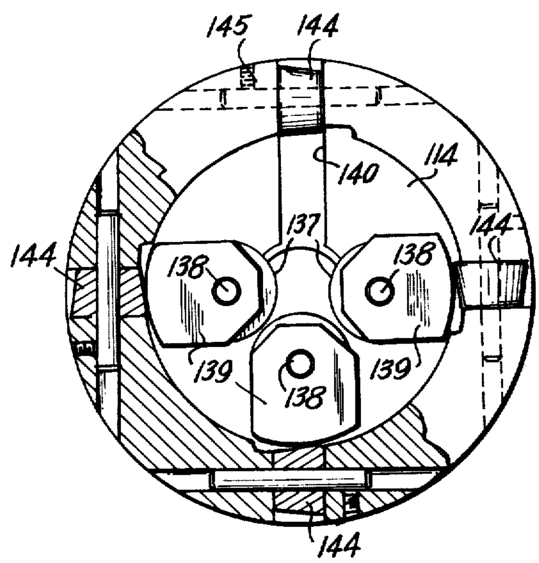

FIG. 8.

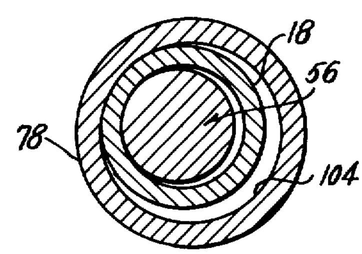

FIG. 4.

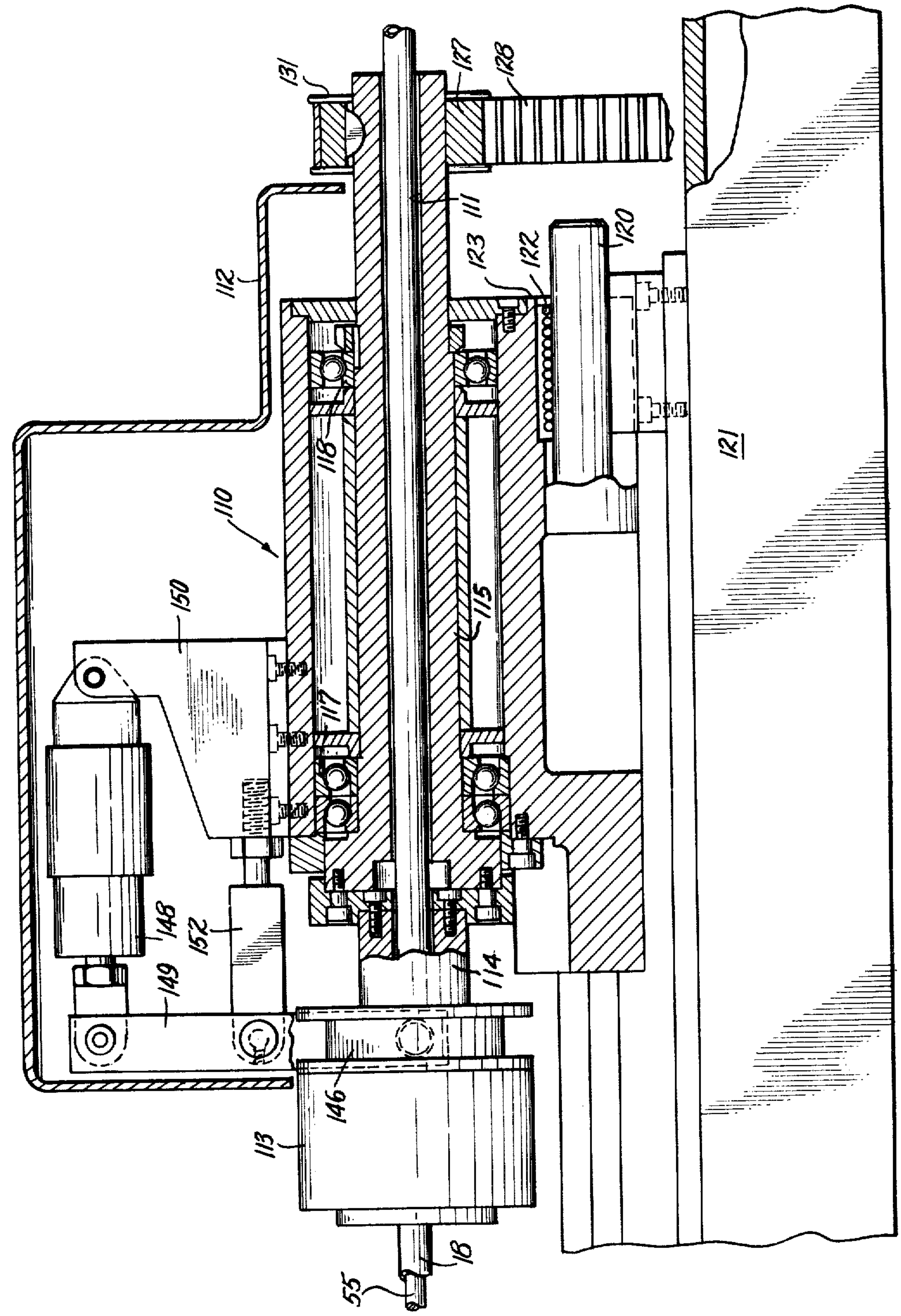
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FIG. 5.

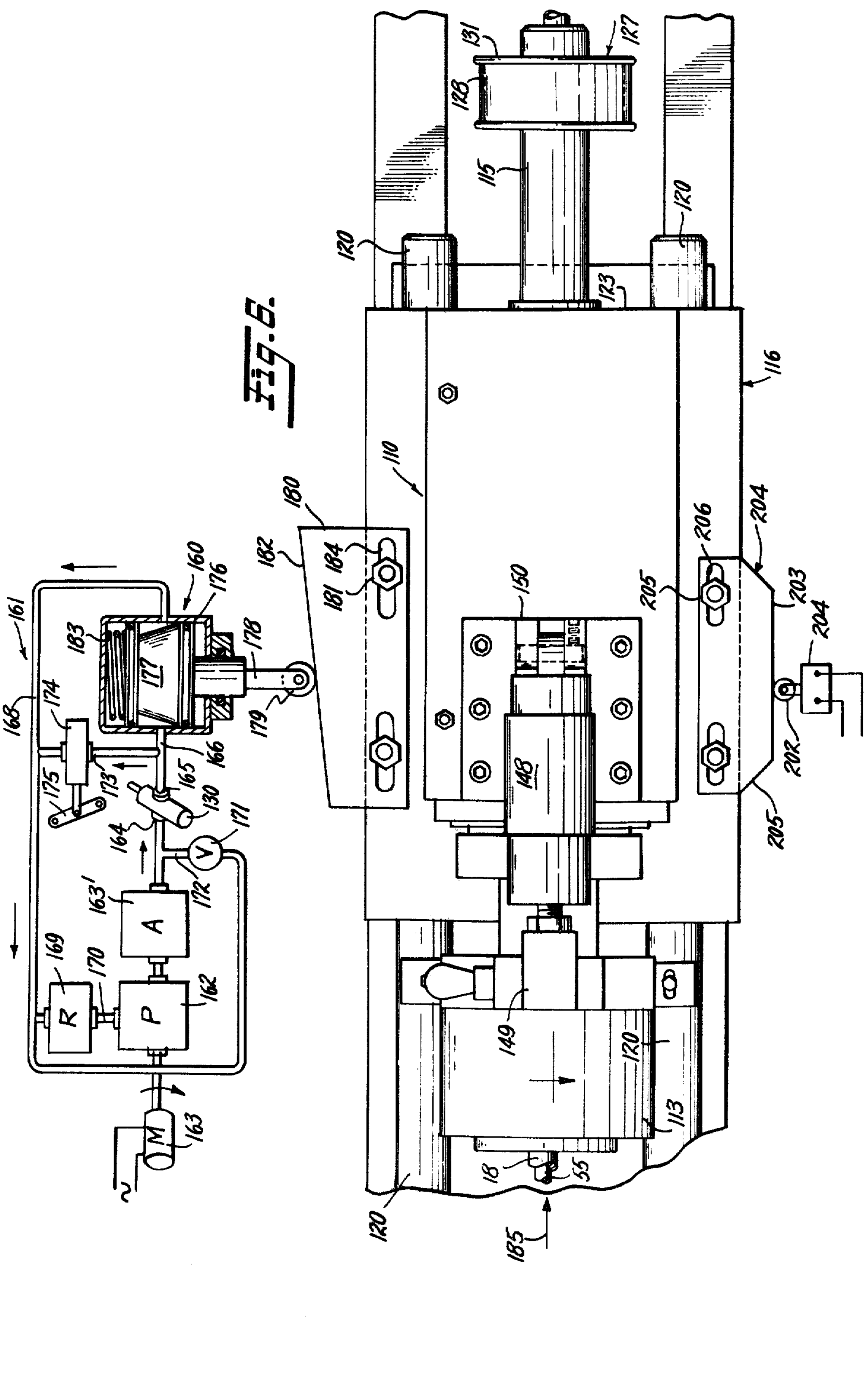

Fig. 6.

ELECTROMAGNETIC ASSEMBLY RESISTING AXIAL ARMATURE MOVEMENT FOR WORKING OR FINNING TUBING

This is a division of application Ser. No. 141,249, filed May 7, 1971.

This invention relates to a method and apparatus for performing a work operation on an indefinite length of non-magnetic material tubing. More particularly, the invention relates to a method and apparatus for forming fins on the exterior surface of an indefinite length of small diameter tubing wherein a backup tool within the tubing is connected to a floating mandrel held against axial movement by magnetic forces.

In addition, the invention relates to an improved magnet arrangement for holding a floating mandrel disposed within non-magnetic or slightly magnetic material tubing against axial movement while moving the tubing axially and performing a work operation on the exterior of the tube with collapse of the tube resisted by a backup tool held by the mandrel. In the preferred embodiment, the mandrel is formed from alternate magnetic and non-magnetic material sections, is held against axial movement by a plurality of electromagnets each including plural pole pieces surrounding the tubing and mandrel, and the mandrel holds a backup tool or anvil within the tubing which prevents crushing or other undesirable deformation of the tubing at a location where a tube finning head, which rotates about the tube, engages the tube to roll a form such as a deep thread or an annular or helical fin on the exterior of the tube. However, instead of forming fins or threads, the apparatus can be used to form any type of enhanced surface on a tube.

Further, the invention relates to a method and apparatus for rolling helical fins on the exterior surface of a tube, or otherwise enhancing the surface of the tube, wherein the tube is advanced at a predetermined constant rate, the forming rolls are mounted on a forming head which rotates about the tube with the forming rolls in engagement with the tube, the forming head is on a floating support which permits axial movement of the head relative to a normal position, and control means responsive to movement of the head from the normal position either increases or decreases the speed of rotation of the head so the rate at which fins are formed on the tubing corresponds to the feed of the tubing.

BACKGROUND OF THE INVENTION

It is well known that fins or other surface deformations which increase the surface area of the outside of tubing improves the heat transfer characteristics of the tubing, and hence, tubing with fins formed thereon is extensively used in heat exchangers. In the past, it has been possible to form fins only on relatively short finite lengths of tubing. The usual arrangement is to provide an elongated mandrel which is fixed at one end, position the tube to be finned on the mandrel and then, form fins on the tube as the tube is moved axially relative to the tube-forming head and mandrel. Such prior apparatus does of course require that the mandrel have a length at least as long as the length of the tube on which the fins are formed. The operation of such prior art apparatus is of course discontinuous in that it is necessary to start the finning operation at one end of the tube and stop the operation at the other end when the length of tubing is finned. Then, it is necessary to load another length of tubing into the apparatus and proceed in the same manner. Because of the necessity of the start-stop operation, finned tubing is quite expensive to produce. In addition, the discs of the fin forming head frequently break as they are initially forced against the tubing. It is also known that the finning head, when it is initially moved into engagement with the tube, does not form a fin of proper depth at the end of the tube. Hence, in many instances, at least several inches of each length of tubing finned by the prior art methods and apparatus must be cut off and discarded.

In addition, some heat exchangers require substantially more tubing than the length that can be finned in accordance with the known methods and apparatus. Hence, it is frequently necessary to connect several lengths of existing finned tubing together when the heat exchanger is assembled. Such connections are of course undesirable since most failures occur at a joint or coupling, and the cost of the heat exchanger is materially increased because of the expense of forming the joints and couplings.

These prior art problems are completely eliminated by applicant's apparatus which provides for forming fins on an indefinite length of tubing continuously. The only restriction on the length of tubing that can be finned is the length that is available for processing in accordance with this method and apparatus. It is contemplated, however, that the tube finning apparatus of this invention could be used in conjunction with a seamless tube-forming mill where the tubing from the mill is fed directly to the fin forming apparatus. In this instance, there is no limit to the length of the tubing which can be finned, and so long as the mill produces tubing, fins can be formed on the tubing continuously.

In addition, where fins are formed on existing tubing, tubing in coils of 500 feet and longer may be used to maintain the number of start-stop operations at a minimum.

SUMMARY OF THE INVENTION

In accordance with the method and apparatus of this invention, small diameter (⅝–1" inside diameter non-magnetic material tubing is continuously fed from a coil or other supply to a finning head and fins are formed on the exterior surface of the tubing in a continuous operation. In the preferred embodiment the tubing is fed from a coil containing perhaps 500 feet of the tubing. The tubing is uncoiled, straightened, fed to the finning head, and after the finning operation is completed, is either recoiled or the straight sections leaving the finning head, are cut to a desired length. When tubing from a coil is exhausted, it is of course necessary to feed the forward end of another coil of tubing through the appaatus. Where the method and apparatus of this invention is used in conjunction with a tube forming mill, the tubing is of course fed continuously to the tube finning apparatus.

The fin forming head is of the type which engages the outside of the tubing and rotates around the tube at a location where the anvil or backup tool connected to the mandrel is located within the tube. The fin forming head includes several grooved or threaded opposed rollers which are forced into the outside surface of the tube to extrude or roll helical fins of the desired height on the tube. During this rolling process the tube is compressed radially against the backup tool connected to the mandrel. Simultaneously, the tube is moved axially relative to the head so a continuous helical fin is fomed on the outside of the tube. As a result of compression of the tube and the axial movement of the tube substantial axial forces are exerted on the backup tool and tend to pull the tool axially with the tubing. Such displacement of the tool is prevented by the mandrel to which the tool is connected and which is held against axial movement by electromagnets encircling the tubing and mandrel at a location upstream from the fin forming head. A mandrel and electromagnets of unique construction which hold the mandrel against endwise movement form a significant feature of this invention.

During the initial operation of starting the fin forming apparatus, it is of course necessary to initially insert the mandrel into the tube. The mandrel and backup tool are then properly positioned within the tube with the mandrel magnetically aligned with plural magnets that hold the mandrel against endwise movement and with the backup tool correspondingly in transverse alignment with the forming rolls of the finning head. When the mandrel and backup tool are inserted in the tube a lubricant is also forced into the interior of the tube so friction between the backup tool and the tubing at the finning head is maintained relatively low. In some instances, a swivel joint may be provided between the magnetically hold portion of the mandrel and the backup tool. This swivel joint allows the backup tool to rotate in response to the progressive helical deformation of the tube against the backup tool as the finning head rotates and forms fins on the tube, without rotating the mandrel.

In the preferred embodiment, the finning head is driven by a hydraulic motor the rotational speed of which is controlled in response to the position of the floating finning head relative to its normal axial position. When the head is moved from its normal position in the direction of travel of the tubing, a sensing device operates to increase the flow of fluid to and correspondingly to increase the speed of rotation of the hydraulic motor which rotates the head. If the head is rotating too fast and tends to climb along the tube so it moves in a direction opposite to the direction of travel of the tube, the sensing device operates to decrease the speed of rotation of the head. While a hydraulic motor is used to control the speed of the head, other variable speed motors such as electric motors can also be used. By virtue of this arrangement, it is assured that the linear speed at which the tube is fed is always approximately the same as the axial rate at which fins or threads are formed on the tube and by virtue of the axially movable forming head, there are no appreciable axial stresses between the tube and the threads or teeth of the forming rollers.

OBJECTS OF THE INVENTION

In view of the above, an object of this invention is a method and apparatus for forming a helical fin on tubing in a continuous manner by engaging the exterior surface of the tubing with a fin forming tool and wherein a backup tool initially placed within the tube is magnetically held against axial displacement by plural electromagnets which extend around the outside of the tube.

Another object is a method and apparatus for continually forming helical fins on the exterior surface of a tube of non-magnetic material of indefinite length

wherein a backup tool is disposed within the tube in opposed relation to a rotating finning head including rollers which are pressed against the outside of the tube, and the backup tool is held against axial movement by plural magnets.

Another object is a unique mandrel and magnet arrangement wherein the mandrel is comprised of plural sections of magnetic and non-magnetic material secured together in end to end relation and in which the magnet has hollow alternate rings of magnetic and non-magnetic material providing axially spaced pole pieces, which rings and alternate sections co-operate to provide a substantial magnetic force resisting axial movement of the mandrel during a continuous work operation on an axially moving indefinite length of non-magnetic material tubing.

A further object is a unique electromagnet and mandrel construction wherein each of a plurality of electromagnets has plural pole pieces energized by a single coil, the mandrel is within tubing of non-magnetic material and is comprised of alternate sections of magnetic and non-magnetic material so spaced apart that plural magnetic forces are exerted by each electromagnet to resist axial movement of the mandrel with the tube, and the plural pole pieces and mandrel sections co-operate to provide a relatively axially short magnet and mandrel assembly.

A further object is a rotating thread or fin forming head which is freely axially movable within predetermined limits, with the tubing on which the helical fins are formed, and in which control means rotate the head at a rate related to the pitch of the threads formed on the tube and the speed of advance of the tube, such that the position of the head does not deviate significantly from a normal centered axial position, while axial stresses between the tube and the head are substantially eliminated.

A further object is a method and apparatus for continuously forming fins or threads on the exterior surface of an indefinite length of non-magnetic material tubing wherein a finning head is free floating axailly, the tubing is fed to the finning head at a constant rate and is restrained against rotation, the finning head is rotated at a speed related to the pitch of the thread formed on the tubing and the speed of travel of the tubing to maintain the fining head in a normally centered position on its floating support, and the speed of rotation of the head is automatically increased or decreased in response to movement of the head axailly from its normal position so the rate at which fins are formed is adjusted to correspond to the speed at which the tubing is fed.

Numerous other objects, features and advantages of the method and apparatus of this invention will become apparent with reference to the accompanying drawings which form a part of this specification, and in which:

FIGS. **1***a* and **1***b* show the tube working apparatus of this invention diagrammatically in front elevation with portions thereof cut away for purposes of explanation;

FIG. **2** shows the manner in which FIGS. **1***a* and **1***b* are related to each other;

FIG. **3** is an enlarged view in vertical section with portions broken away showing the electromagnets, mandrel swivel and a fin forming element;

FIG. **4** is a partial view in section taken along line **4—4** of FIG. **3**

FIG. **5** is an enlarged front elevational view in partial section and with portions thereof removed, of the floating finning head assembly according to this invention;

FIG. **6** is a top plan view of the finning head with the dust cover removed, showing the control for regulating its speed of rotation, and the automatic shut off for stopping the apparatus in the event that the finning heads moves too far axially;

FIG. **7** is a front elevational view in partial section showing additional details of the finning head;

FIG. **8** is an end elevational view of the finning head with portions thereof in section and portions removed for purposes of explanation.

Referring now to the drawings in detail and in particular to FIGS. **1***a* and **1***b*, there is shown the apparatus, in accordance with this invention, for continuously forming a helical fin on the exterior surface of indefinite length tubing. At one end of apparatus **1** is a coil support and pay-off **2** adapted to receive a coil **3** of tubing to be finned by the apparatus, and from which the tubing is fed to the apparatus.

As shown at FIGS. **1***a* and **1***b*, the various components of the apparatus are mounted on suitable supports in the form of frames or tables which rest on the floor **4** of the building where the apparatus is installed. Apparatus **1** includes first and second feed roller and straightening sections **5** and **6**, a magnet section **7**, a third roller section **8**, a fin forming station **9**, and a cutoff and discharge station **10**.

First feed roller and straightening section **5** is located adjacent coil payoff **2**. Roller section **5** includes a pair of guide rollers **11** mounted for rotation about horizontal axes, a pair of pinch rollers **12** which perform a driving function and which are mounted for rotation on vertical axes, and a plurality of staggered straightening rollers **13** mounted for rotation on vertical axes and which function to straighten the tubing **18** in a vertical plane. It will be observed with reference to rollers **12**, for example, that the periphery of each roller is concave so a substantial area of the exterior of the tubing is engaged by each roller.

From roller section **5**, the tubing **18** passes to roller section **6** which includes a plurality on upper rollers **14** and lower rollers **15**. There are also pinch rollers **16** and **17**. Rollers **14** are staggered relative to rollers **15** and these rollers are all mounted for rotation about horizontal axes. The rollers **14** and **15** co-operate to straighten the tubing in a horizontal plane, whereas rollers **16** and **17** are drive rollers to propel the tubing. The drive rollers **12**, and the drive rollers **16** and **17** are each driven at a constant speed so tubing passing through the nips of these rollers are driven longitudinally through the apparatus at a predetermined speed. Guide rollers **11**, straightening rollers **13**, and straightening rollers **14** and **15**, can also be driven, if necessary, to propel the tubing. Each of the rollers **11–17** is adjustably mounted to permit precise adjustment of the location of the roller and the size of the nip between the drive rollers. Correspondingly, the pressure exerted on the exterior of the tubing by the several rollers **11–17** can be accurately adjusted. An additional advantage of the adjustable rollers is that these rollers can be adjusted to accomodate several different sizes of tubing on which fins are to be formed, for example, in the range of ⅝–1". Tubing fed through the apparatus travels along the path indicated by the center line **19**, and the various portions of the apparatus are aligned relative to this centerline.

Magnet section **7** is comprised of eight identical electromagnets **20–27**, each of which is generally cylindrical and has a centrally located opening therethrough. Magnets **20–27** are mounted with the axes of their openings aligned with the nips of the roller pairs **11–17**. With the electromagnets in aligned end-to-end relation, a passage is defined through which tubing **18** moves axially during the operation of the apparatus. Electromagnets **20–27** will subsequently be described in detail.

From magnet section **7** tubing **18** passes through the nips of third roller section **8** which includes roller pairs **30–32**. These roller pairs are pinch rollers identical to those previously described in section **6**. Each roller of the roller pairs **30–32** is driven, and these rollers function to maintain the portion of the tubing within magnet assembly **7** substantially straight as well as to prevent any rotation of the tubing about its axis as a result of the rotating fin forming rollers at fin forming station **9**.

From roller section **8**, the tubing travels to fin forming station **9** where helical fins are formed on the exterior surface of the tubing. From fin forming station **9** the tubing travels to cutoff and discharge station **10** where outfeed pinch rollers **34** are provided to convey the tubing away from apparatus **1**. At outfeed station **10**, a motor driven cutoff saw assembly **35** is provided. Cutoff assembly **35** is mounted on a support **36** for axial movement with the tubing at the same rate as the linear speed that the tubing travels through the apparatus. Cutoff assembly **35**, when actuated, moves cutoff saw **37** into engagement with the tubing and simultaneously, the cutoff assembly **35** is moved axially so the tubing is cut while it is moving.

In instances where it is desired to make coils or finned tubing of an indefinite length, cutoff assembly **35** is not used but instead, suitable apparatus (not shown) for coiling the tubing after it is finned, is substituted for the cutoff assembly.

Coil support and payoff **2** provides for feeding tubing **18** continuously to the apparatus from the coil **3**. Coil payoff **2** includes a support or table **40** having upstanding rollers **41** to feed tubing from the coil. Advantageously, table **40** is provided with roller bearings (not shown) so the coil is free to rotate to feed tubing to roller section **5** at the inlet end of the apparatus.

As shown at FIG. **1***a* and **1***b*, an elongated mandrel **44** extends from a location beyond fin forming station **9** through magnet assembly **7**. As shown at FIG. **3**, mandrel **44** is within tubing **18** and is restrained against axial movement with the tubing by magnet assembly **7**.

With reference to FIGS. **1***a* and **1***b*, it will be seen that mandrel **44** is cylindrical and is comprised of an armature portion **56** including eight armature sections **46–53** which are located respectively within magnets **20–27**. Connected to the armature portion **56** is an anvil or tool portion **55**. Slightly to the left of section **53** (FIG. **1***b*) is a swivel connection **54** which can be used to join anvil portion **55** of the mandrel with armature portion **56**. The anvil portion **55** can also be directly connected to armature portion **56** in which case the swivel connection **54** is not used and the armature is rigid.

FIG. **3** shows the mandrel in greater detail, and also shows the details of the electromagnets **26** and **27**. With reference to FIG. **3**, it is apparent that mandrel **44** is located within tube **18** and that the sections **52** and **53** of the mandrel extend through the electromagnets **26** and **27** respectively. Armature sections **46–53** of the mandrel are identical and each includes seven pieces of magnetic material **57–63** separated from each other by non-magnetic material spacers **64–69.** The end pieces **57** and **63** are longer axially than the intermediate sections **58–62.** The several sections **46–53** are separated from each other respectively by non-magnetic material separators **70** which are substantially longer than the spacers **64–69** and are essentially equal in length to the spacing between adjacent ones of the electromagnets, for example, the electromagnets **26** and **27** shown at FIG. **3.**

As shown at FIG. **3,** for magnets **26** and **27,** each of the magnets **20–27** are identical. Magnet **27** includes a cylindrical body **71** with a side wall **72** which has inwardly extending integral end flanges **73** and **74** respectively, which provide an annular space **75** for an electromagnetic coil **76.** The inside of the coil and the openings through end flanges **73, 74** provide a smooth bore **77** to receive eight magnetic material pole piece sleeves **78–85** separated respectively by non-magnetic material spacer sleeves **86.** End pole piece sleeves **78** and **85** are longer axially than the intermediate pole piece sleeves **79–84.** The several magnetic and non-magnetic material sleeves are retained in the bore **77** against axial movement by annular clamp rings **87** at the opposite ends of the magnet and which are secured to the ends of the magnet with bolts **88** to maintain the sleeves in tight abutting relation to each other and against axial movement within bore **77.**

With reference to FIG. **3,** it will be seen that in the working position of magnet **27** and mandrel **44,** magnetic material piece **57** of the mandrel is in opposed relation to end pole piece **78** of the magnet and that the right hand end of piece **57** extends axially through the first spacer sleeve **86** to a position where it slightly overlaps magnetic material sleeve **79.** Similarly, magnetic material section **63** of the mandrel is in opposed relation to end pole piece **85** of the magnet and the left hand end of section **63** extends axially through a space sleeve **86** and to a position so it slightly overlaps pole piece sleeve **84.** It will also be seen that each of spacers **64–69** of the mandrel has a width slightly less than the width of pole piece sleeves **79–84** and that in the working position of the magnet and mandrel, these spacers and pole pieces are aligned with each other in a plane perpendicular to the axis of the mandrel. Magnetic material pieces **58–62** are each of the same width, which is slightly greater than the width of spacer sleeves **86** and, with the magnet and mandrel in the working position of FIG. **3,** the several magnetic material sections **58–62** are transversely aligned with spacers **86.**

By virtue of the construction of magnet **27,** wherein pole pieces **78–85** are spaced apart from each other, and magnetic material sections **57–63** of mandrel **44** are spaced from each other and have their several magnetic material sections positioned substantially between the several pole piece sleeves, magnetic flux **90** generated by energizing the coil **76,** (the coil energizes magnet **27** in an axial direction) enters and leaves each of the magnetic material sections **57–63** of the mandrel. In the arrangement shown where magnet **20** has eight pole piece sleeves and mandrel section **53** has seven magnetic material pieces, flux **90** enters and leaves the magnet at seven axially spaced locations to enhance the resistance of the mandrel to axial displacement from the aligned FIG. **3** position within the magnet. It has been found that this arrangement using eight pole piece sleeves in the magnet and seven magnetic material sections on the portion of the mandrel within the magnet provides five times more resistance to axial displacement of the mandrel than where the mandrel section **46** is a continuous length of magnetic material and the magnet has only two pole piece elements.

Each of magnets **20–27** is identical to the magnet **27.** In addition, each of sections **46–53** of the mandrel is identical to the section **53.** There is a separator **70** between each of the sections **46–53.** In the preferred embodiment, pole piece sleeves **78–85** of the magnet are formed from iron or steel with good magnetically conducting properties, whereas spacers **86** are formed from non-magnetic materials, such as copper or brass. As previously explained, pole piece sleeves **78–85** are held in abutting relation to spacers **86.** With regard to mandrel **44,** each of magnetic material sections **57–63** is formed from iron or steel with good magnetically conducting characteristics, whereas spacers **64–69** and separators **70** are formed from copper or brass. The several magnetic material sections, spacers, and separators are secured together, for example, by brazing, so that armature section **56** of the mandrel is rigid.

Secured to the right hand end of magnetic material section **63** of the mandrel is a brass spacer **93** which extends to the right of magnet **27.** Adjacent the outside of tube **18** in transverse alignment with non-magnetic material spacer **93** is a magnetic material proximity sensing device **94.** In the event that mandrel **44** moves axially to the right as a result of a malfunction in the apparatus, magnetic material piece **63** also moves to the right and sensing device **94** senses the presence of the magnetic material. The output from sensing device **94** can be used to sound an alarm or alternatively, can be used to operate a master circuit breaker or control to shut down the apparatus.

As previously explained, armature section **56** of the mandrel can be connected to tool section **44** of the mandrel by a swivel joint **54.** Advantageously, swivel joint **54** is located downstream from magnet assembly **27,** yet is a substantial distance upstream from fin forming station **9.** So locating the swivel joint provides sufficient time to shut down the apparatus before the slightly larger diameter swivel joint **54** reach the fin forming apparatus where it could cause damage, should the mandrel **44** move axially. As shown at FIG. **3,** the swivel joint includes a threaded sleeve **96** into which one end of the tool portion **55** of the mandrel is threaded and is secured against unthreading by a set screw **97.** The other end of the sleeve **96** has a smaller diameter opening **98** through which a threaded stud **99,** having an enlarged head **100** extends. Armature portion **56** of the mandrel is threadedly connected to stud **99** and is secured to the stud against relative rotation by a set screw **101.** Ball bearings **102,** between the tapered axially facing surface **103** of sleeve **96** and the opposing surface of head **100** provide a low friction bearing connection which permits tool portion **55** of the mandrel to rotate freely relative to armature portion **56,** but joins the portions against axial separation. Opening **98** is made sufficiently large that armature portion **56** of the mandrel can also tilt slightly relative to tool portion **55.**

As shown at FIG. 4, armature portion 56 of the mandrel has a diameter which is only slightly less than the inside diameter of tube 18. Similarly, the outside diameter of tube 18 is only slightly smaller than the inside diameter of the opening 105 of the several pole piece and spacer sleeves of each magnet. By virtue of this arrangement, the air gap between the several pole piece sleeves of the magnet and the magnetic sections of the mandrel is maintained at a minimum to assure sufficient attraction between the mandrel and magnet that axial displacement of the mandrel is effectively prevented. There is, however, sufficient clearance between the mandrel and the inside of the tube, and opening 104 through the magnets and the outside of the tube, that the tube moves through the magnets and over the mandrel with very little frictional resistance.

As shown at FIG. 1*a*, the coils of the magnets 20–26 are energized with direct current conducted by wires 105 and 106 connected to a suitable direct current power supply. The coils of the several magnets are connected across wires 105 and 106 so the coils are in parallel. The wires are connected to the coils at junction boxes 107 adjacent each magnet. A switch 108 in wire 106 is provided to control energization of the coils.

THE FIN FORMING STATION

As shown at FIGS. 1*b*, 5 and 6, fin forming station 9 includes a fin forming mechanism 110 having a bore 111 therethrough and into which the tool end of tool portion 55 of the mandrel extends. A dust cover 112 extends over the mechanism 110.

FIGS. 5 and 6 show the details of fin forming mechanism 110. With reference to FIGS. 5 and 6, it will be seen that fin forming head 113 is at the left hand end of the assembly and is secured to a hollow drive sleeve 114. Sleeve 114 is secured to a thick walled hollow drive shaft 115 mounted for rotation on a support pedestal 116 by bearings 117 and 118. As is apparent with reference to FIG. 5, sleeve 114 and drive shaft 115 mount head 113 in overhanging cantilever fashion for rotation with the sleeve and shaft and against axial movement relative to the support pedestal 116.

Pedestal 116 is mounted for horizontal movement on a pair of spaced apart cylindrical slide bars 120 secured to base 121 against endwise movement. There are two bars 120 which are parallel to each other and are equally spaced on each side of a vertical plane passing through the center line of the fin forming assembly. Suitable bearings 122 are provided between pedestal 116 and slide bars 120 to maintain friction at a minimum and provide for free floating axial movement of finning head 113 with pedestal 116, relative to base 121.

Sleeve 115 is elongated and extends beyond end 123 of pedestal 116. Keyed to the end of hollow drive shaft 115 is a sprocket pulley 127 which is driven by a toothed timing belt 128 that connects the pulley 127 to a toothed drive pulley or drum 129 (FIG. 1*b*) on a variable speed hydraulic motor 130 located below the fin forming apparatus. Sprocket pulley 127 has side flanges 131 which prevent timing belt 128 from moving axially relative to this pulley. Drive pulley 129 is elongated axially and timing belt 128 moves axially along the drive pulley when the finning head moves axially so the head is continuously driven.

By virtue of this arrangement, pedestal 116 and fin forming head 113 can freely move as a unit along slide bars 120 in an axial direction relative to a tube fed through the apparatus while head 113 is driven by hydraulic motor 130.

FIGS. 5–8 show the details of fin forming head 113. With reference to FIGS. 7 and 8, fin forming head 113 includes four fin forming rollers 137 (only two of which are shown at FIG. 7) in equally spaced circumferential relation on the head. Each roller 137 is mounted for rotation on a shaft 138 supported by a support block 139. The axis of shaft 138 is tilted slightly relative to a plane including the axis of tube 18 so rotation of head 113 while rollers 137 are in engagement with the exterior surface of the axially moving tube causes helical fins to be formed on the outside of the tube. Support blocks 139 are mounted for limited radial movement in slots 140 of head support sleeve 114. Each block 139 is normally urged outwardly away from tubing 18 by a spring 142. Cam faces 143, at the outer surface of block 139, are provided to move the block inwardly so fin forming rollers 137 are forced into the outside surface of tube 118.

Blocks 139 are moved inwardly by a plurality of cam rollers 144 mounted on an actuating ring 145 arranged to move axially relative to support sleeve 114. Actuating ring 145 is moved axially while it is rotating with the head by a yoke 146 which engages in a peripheral groove 147 of ring 145. As shown at FIG. 7, ring 145 is in its forward position where rollers 144 cam support blocks 139 inwardly to force rollers 137 into engagement with the exterior surface of the tube for form a deep thread of helical fin on the surface of the tube. In a retracted position (not shown) of ring 145 rollers 144 and the ring are moved axially so rollers 144 engage the inner cam faces 143 to allow support blocks 139 to move outwardly away from the surface of the tube under the action of the springs 142.

With reference to FIGS. 5 and 7, yoke 146 is moved to correspondingly move actuating ring 145 by the action of a hydraulic cylinder 148 having its piston rod pivotally connected to the upper end of yoke arm 149. The outer end of cylinder 148 secured to a bracket 150 fixed to pedestal 116 so the cylinder and bracket move with the pedestal when head 113 moves axially. An intermediate portion of yoke arm 149 is pinned as at 151 to an arm 152 adjustably secured to bracket 150. By virtue of this arrangement, it will be apparent that when cylinder 148 is elongated, actuating ring 145 is retracted and fin forming rollers 137 are away from the surface of tube 18. When cylinder 148 is contracted to the position shown at FIGS. 5 and 7, actuating ring 145 moves forward and rollers 144 cam fin forming rollers 137 against the outside surface of the tube with sufficient force to form helical fins or threads on the surface of the tube.

HEAD SPEED CONTROL

As previously explained, the rollers of roller sections 5, 6 and 8 feed tubing 18 through the apparatus at a constant speed, i.e., the drive rollers of each of these roller sections is driven at a constant speed. As a result of unexpected variables, however, for example, unexpected slippage, it has been found that the tubing is really not fed at a constant speed even though the drive rollers rotate at a constant speed. As a result of the freely axially movable floating pedestal 116 on which finning head 113 is mounted, slight changes in the speed at which tubing is fed through the apparatus cause the head **113** to move axially with pedestal **116** so no appreciable axial forces are exerted on the deep fin forming threads of the fin forming rollers. Since the extent of permissible axial movement of the pedestal **116** and head **113** is limited by the length of the bearing bars **120**, the speed of rotation of finning head **113** is adjusted to maintain the head and pedestal between the front and rear limits of travel of the pedestal. This speed control is accomplished by changing the speed of rotation of the hydraulic motor **130** which rotates the finning head, and the speed of the motor is advantageously controlled in response to movement of the pedestal toward its front and rear limits of travel.

During normal operation of the apparatus, finning head **113** is rotated at a speed such that the rate at which threads are formed along the length of the tube equals the linear speed at which the tube if fed through the apparatus (thread forming rate equals thread pitch times speed of rotation of head **113**). If the tube is fed at a linear speed greater than the rate at which the threads or fins are formed on the tube **18**, finning head **113** will move pedestal **116** axially on the slide bars **120** in the direction of travel of the tube. Then, it is necessary to increase the speed of rotation of head **113** so the fins are formed at a faster rate on the tube. Conversely, if head **113** is rotating too rapidly, the head will tend to climb along the tube and move in a direction toward roller section **8** of the apparatus. It is then necessary to decrease the speed of rotation of the head so the rate of formation of fins on the tube precisely equals the linear speed of the tube.

Such regulation of the speed of motor **130** and correspondingly, the speed of head **113**, can be accomplished manually, or automatically.

Automatic control of the speed of rotation of the finning head is accomplished by automatically adjusting flow control valve **160** in response to the axial position of finning head **113** and pedestal **116** on the slide bars **120**. As shown at FIG. **6**, flow control valve **160** is connected in the hydraulic system **161**. Hydraulic system **161** includes a pump **162** driven by a motor **163**. Motor **163** can be of the variable speed type or alternatively, a variable speed drive can be used to couple the motor to the pump so the pressure and flow of hydraulic fluid from the pump can be regulated. pressurized fluid from pump **162** flows to accumulator **163** and then to the inlet **164** of hydraulic motor **130** which rotates finning head **113**. Then the hydraulic fluid flows through the outlet **165** of motor **130** to inlet **166** of valve **160**. Hydraulic fluid passes through valve **160** to the valve discharge **167** and thence through the return flow line **168** to resevoir **169** which is connected to the inlet **170** of pump **162**. There is also a safety valve **171** in a return flow line **172** which connects between accumulator **163** and inlet **164** of motor **130**. In the event of a malfunction where it is desired to stop motor **130**, valve **171** is opened thereby bypassing hydraulic fluid from the accumulator directly back to the resevoir **169**. In addition, there is a hydraulic circuit **173** connected in parallel across valve **160** and which includes a manually operable flow control valve **174** which is manually operable by manipulation of lever **175** to control the speed of motor **130** by regulating the flow of hydraulic fluid from the discharge **165** of the motor.

Flow control valve **160** is of the type shown schematically at FIG. **6** wherein the flow of hydraulic fluid through the valve is directly proportional to the position of the valve within its housing. As shown at FIG. **6**, valve **160** includes a housing **176** and a flow control element **177** in the form of a spool. Connected to flow control element **177** is an operating rod **178** provided with a cam roller **179** at its outer end. Roller **179** engages a tapered plate type cam **180** secured to pedestal **116** by studs or bolts **181**. Cam plate **180** has a tapered or slanted cam face **182** engaged by roller **179** and which face resists movement of the spool toward the cam under the action of spring **183**. Plate cam **180** is provided with elongated slots **184** which facilitate positioning the cam in a desired position axially along pedestal **116**.

The action of valve **160** under the control of cam **180** is such that when tubing **18**, which travels in the direction of arrow **185**, is travelling faster than the rate at which fins are formed on the tubing by the rotating head **113**, head **113** and pedestal **116** move in the direction of arrow **185**. As a result, cam **180** moves in the same direction thereby allowing spring **183** to further open the valve by maintaining cam roller **179** in engagement with face **182**. As a result, hydraulic fluid can flow faster from outlet **165** of motor **130**, and correspondingly, the speed of motor **130** and head **113** driven thereby increases. Such increase in the speed of rotation of the head causes fins to be formed at the same rate as the tubing is fed through the apparatus, and correspondingly, no further axial movement of the head occurs.

To initially adjust the position of pedestal **116** relative to valve **160**, manual control valve **174** can be regulated by manipulating the lever **175**. Under some circumstances it may be desirable to control the speed of motor **130** wholly manually. Where complete manual control is desired, valve **160** is disabled so all the hydraulic fluid flowing through the motor discharges through the manual control valve **174**. Under these conditions complete manual control of the speed of rotation of motor **130** is obtained.

As shown at FIG. **3**, the fins or teeth **170** of fin forming rollers **137** form a deep thread or helical fin on the exterior surface of tube **18**. The action of the fin forming rollers **137** is to compress the tube radially into engagement with tool portion **55** of the mandrel, thereby simultaneously roll forming or extruding fins on the exterior surface of the tube and reducing the inside diameter of the tube. As a result of compressing the tube radially while the rollers **137** rotate around the outside surface of the tube, the tube itself has a tendency to rotate, but such rotation is prevented by the roller pairs **30–32** of roller section **8** which grip and feed the tube at a location ahead of the finning head. However, as a result of the compression of the tube against the mandrel while the fin forming rollers rotate around the tube, tool portion **55** also rotates, but without any detrimental effects. Where the swivel **54** is used to join tool portion **55** of the mandrel with armature portion **56** of the mandrel, the tool portion **55** can freely rotate without rotating the armature portion of the tool. This arrangement, including the swivel, can be used when necessary to reduce wear on the armature portion of the mandrel since this armature portion is not truly floating centrally of the magnets, but is usually drawn off center toward one side as shown at FIG. **4**.

OPERATION

Non-magnetic material tubing **18**, for example, copper or brass tubing is obtained in coils containing in excess of 500 feet of the tubing. The coil 3 of tubing is placed on the coil payoff 2 and is fed through the apparatus so its free end is beyond fin forming head 113. Advantageously, a lubricant is forced into the free end of the tube and next, mandrel 44 is inserted in the tube so the several sections 46–53 of the armature are aligned respectively with the magnets 20–27. In this position the non-magnetic material portion 93 is opposite magnetic material proximity sensor 94 and tool portion 55 extends through head 113. Then, switch 108 is closed to energize the coils of magnets 20–27. Then, the rollers of roller sections 5, 6 and 8 are started to drive the tube axially through the apparatus. With head 113 rotating at approximately the required speed, cylinder 148 is actuated to move fin forming rollers 137 into engagement with the outside of the tube. Initially, the rollers will only cut a shallow thread in the surface of the tube, but will subsequently be fully cammed against the tube to form threads or fins at the full desired depth. Axial forces tending to displace tool portion 55 of the mandrel as a result of compressing the tube radially against the mandrel while moving the tube longitudinally, are resisted by the magnets 20–27. If the speed of rotation of head 113 is either slower or faster than the speed required to form threads on the tube at the rate of travel of the tube, the head will float axially so axial stresses in the fin forming elements are avoided, and there is no tendency for the elements to break. If the speed of rotation of head 113 is too great and the head tends to climb along the tube, cam 180 will move spool 177 to decrease the flow of fluid through valve 160, thereby reducing the speed of rotation of the hydraulic motor 130 which drives the head. If the speed of rotation of head 113 is too low, the head will travel with the tube, allowing spring 183 to further open the valve 160, thereby increasing the flow of hydraulic fluid from motor 130 and correspondingly, increasing the speed of rotation of the finning head. Alternatively, the speed of rotation of head 113 can be manually regulated by manipulating lever 175 to adjust valve 174 to maintain the head 113 rotating at a speed to form fins at the rate of travel of the tubing.

Should the apparatus malfunction during a tube finning operation so mandrel 44 jams and moves with the tubing, or should mandrel 44 be displaced axially from the normal position shown at FIGS. 1*a* and 1*b* without the magnets 20–27, the presence of magnetic material section 63 of the mandrel will be sensed by proximity sensor 94, and the apparatus will shut down.

As shown at FIG. 1, proximity sensor 94 controls a relay 190 with contacts 191 in the power supply lines 192 for the portions of the apparatus. As shown, motors 193, 194 and 195 are connected across the power lines. Motor 193 drives the rollers of straightening roller sections 5 and 6, motor 194 drives the rollers of feed roller section 8, and motor 195 drives outfeed or pullout rollers 34. Solenoids 196 and 197 are also connected across the lines. Solenoid 196 maintains valve 171, which is an exhaust valve in return pipe line 172 (FIG. 5), closed so long as solenoid 196 is engergized. Solenoid 197 operates an override valve 198 so connected to hydraulic cylinder 148 that the cylinder operates in its normal manner, as previously explained, so long as solenoid 197 is energized, but is extended to move fin forming rollers away from the tube 18 as soon as solenoid 197 is de-energized. Relay 190 operates to maintain contacts 191 closed so long as proximitiy sensor 94 senses the non-magnetic material of section 93 of the mandrel. If the mandrel moves so magnetic material section 93 is sensed, contacts 191 open, motors 193, 194 and 195 are de-energized, valve 171 is opened to stop motor 130, and override valve 198 is reversed to extend cylinder 148 and move the fin forming rollers 137 away from the surface of tube 18.

In series with contacts 191 of relay 190 are contacts 200 of a microswitch 201. Microswitch 201 provides for shutting down the apparatus in the event that finning head 113 and pedestal 116 move too far axially from a predetermined central position. With reference to FIG. 6, microswitch 201 is positioned at one side of pedestal 116 and includes a roller follower 202 which engages a face 203 of a control plate 204 secured by bolts 205 to pedestal 116 for movement therewith. Plate 204 has slots 206 to provide for axial adjustment of the plate on the pedestal within predetermined limits. Face 203 is parallel with the axial direction of travel of pedestal 116. With pedestal 116 in the position shown at FIG. 6 with roller 202 engaging face 203, contacts 200 of microswitch 201 are closed and the fin forming apparatus will then operate. However, should pedestal 116 move too far in either direction relative to its position at FIG. 6, roller 202 will ride down onto the sloping end faces 205 of control plate 204 with the result that contacts 200 of the microswitch will open. When contacts 200 open, the circuit shown at FIG. 1 *a* is interrupted and the apparatus is shut down in the same manner previously explained when contacts 191 of relay 190 open. By virtue of this arrangement, damage to the apparatus is prevented should mandrel 55 be displaced axially or should head 113 and pedestal 116 move too far axially. Of course, the motor for cut-off assembly 35 can also be controlled by the relay 190 and the microswitch 201.

The apparatus of this invention is capable of forming fins on relatively smaller diameter tubing, for example, ⅝ inch tubing, butt can also be used to form fins on tubing up to one inch in diameter. To form fins on tubing of different diameter it is of course necessary to change portions of the apparatus. However, this changeover can be quite quickly accomplished since it is only necessary to substitute a mandrel 44 of the proper diameter, substitute pole piece sleeves and spacers having a diameter only slightly greater than the outside diameter of the tube in the magnets, change forming head 113, and adjust the nips of the rollers in roller sections 5, 6 and 8. Since the speed of rotation of finning head 113 can be varied by adjusting variable speed motor 130, the new head can be rotated at the proper speed for forming fins on the tubing, even though the thread or fin pitch is different, while maintaining the tubing feed at the previous linear speed.

While a preferred embodiment of the tube working apparatus of this invention has been shown and described in detail, and while the preferred method of practicing the invention has also been described, it is to be understood that numerous changes can be made in the preferred method and apparatus without departing from the itended scope of this invention set forth herein and defined in the appended claims.

What is claimed is:

1. Magnetic apparatus for resisting axial movement of an armature within a non-magnetic tube extending through the magnet comprising, in combination:

an annular magnet assembly having a generally centrally located opening extending through the assembly;

the tube extending through the opening and beyond ends of the magnet assembly;

an armature of a diameter smaller than and within the tube;

flux producing means to create magnetic flux in said magnet; and

cooperating pole piece means on said magnet assembly and magnetic material means on said armature for causing magnetic flux to enter and leave said armature at multiple locations along the armature, so that axial displacement of the armature with respect to the magnet assembly is effectively resisted.

2. Magnetic apparatus according to claim 1 wherein, said magnet assembly includes

a magnetic material casing,

a coil within said casing, and

a plurality of annular pole pieces of magnetic material axially spaced apart from each other and within said coil and casing;

said coil having an opening therethrough of a diameter only slightly greater than the diameter of said pole pieces so that the pole pieces are directly adjacent the coil to enhance the magnetic force of the magnet on the armature.

3. Magnetic apparatus according to claim 2 wherein, said casing and coil each have openings of a diameter to receive said pole pieces therein;

said pole pieces extend through said coil and casing; and

means on said casing for removably securing said pole pieces within said coil so that pole pieces of a different inside diameter can be substituted to facilitate adapting the magnet assembly for use with different size tube.

4. Magnetic apparatus according to claim 1 wherein said magnetic material means on said armature includes

a plurality of axially spaced apart sections of magnetic material.

5. Magnetic apparatus according to claim 4 wherein said pole piece means on said magnet includes

a plurality of annular pole pieces of magnetic material axially spaced apart from each other; and

means maintaining said armature in spaced relation to said pole pieces.

6. Magnetic apparatus according to claim 5 wherein said plurality of annular pole pieces are spaced apart by annular spacers of non-magnetic material; and

said plurality of axially spaced apart magnetic material armature sections are spaced apart by non-magnetic material spacers securing said magnetic material sections together.

7. Magnetic apparatus according to claim 1 wherein said magnet is an electromagnet having a cylindrical body;

said flux producing means is a coil within the body; and

said pole piece means comprise

a plurality of sleeves extending through said body and coil in end to end abutting relation to each other,

alternate ones of said sleeves having magnetic material characteristics,

the remainder of said sleeves having non-magnetic material characteristics; and

means connecting said sleeves to said body against axial movement.

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