Oct. 22, 1940. T. H. NELSON 2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 1

FIG. 1.

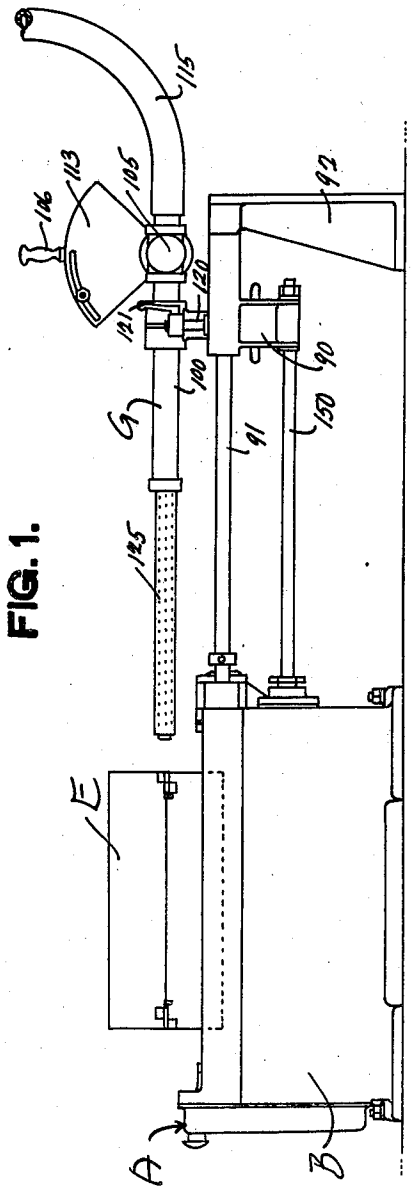
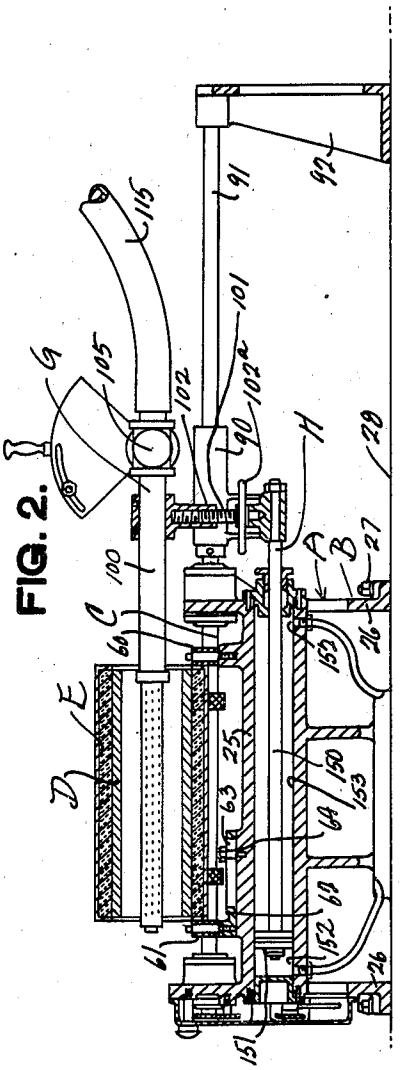


FIG. 2.



INVENTOR
Tom Holland Nelson
BY
Lancaster, Allwine and Rommel
ATTORNEYS

Oct. 22, 1940. T. H. NELSON 2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 2

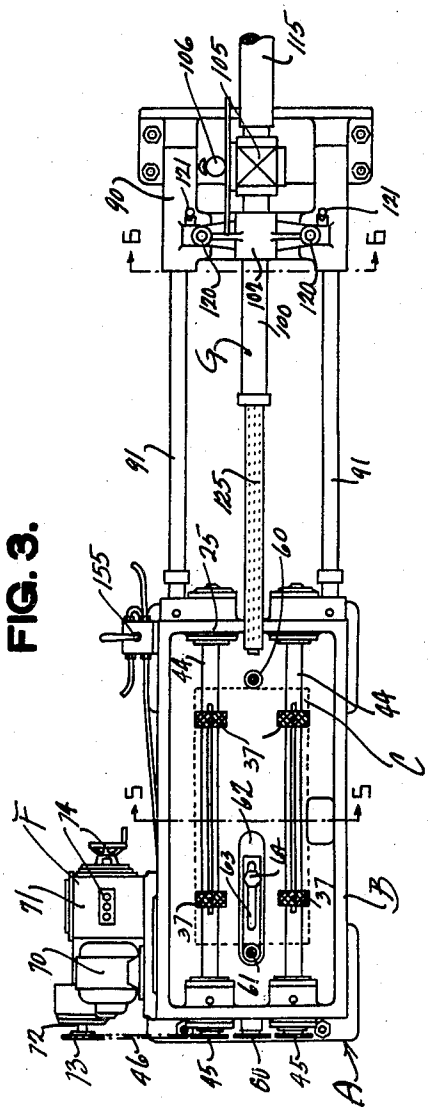


FIG. 3.

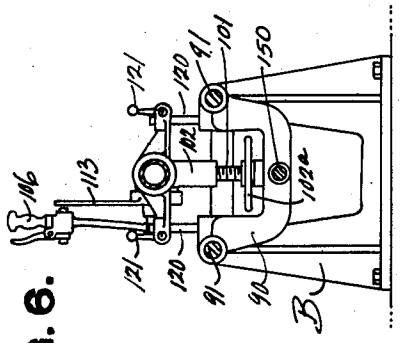


FIG. 6.

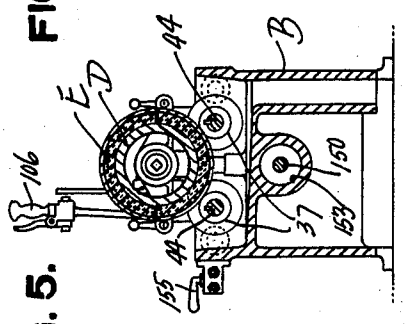


FIG. 5.

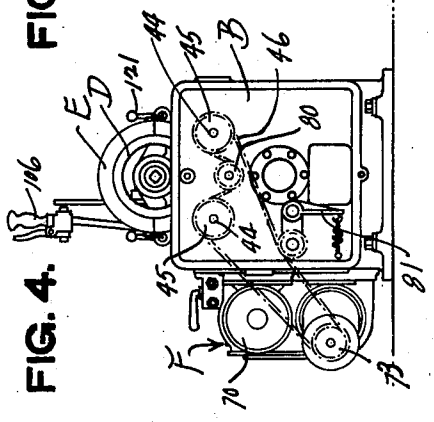


FIG. 4.

INVENTOR
Tom Holland Nelson
BY
Lancaster, Allwine & Rommel
ATTORNEYS

Oct. 22, 1940. T. H. NELSON 2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 3

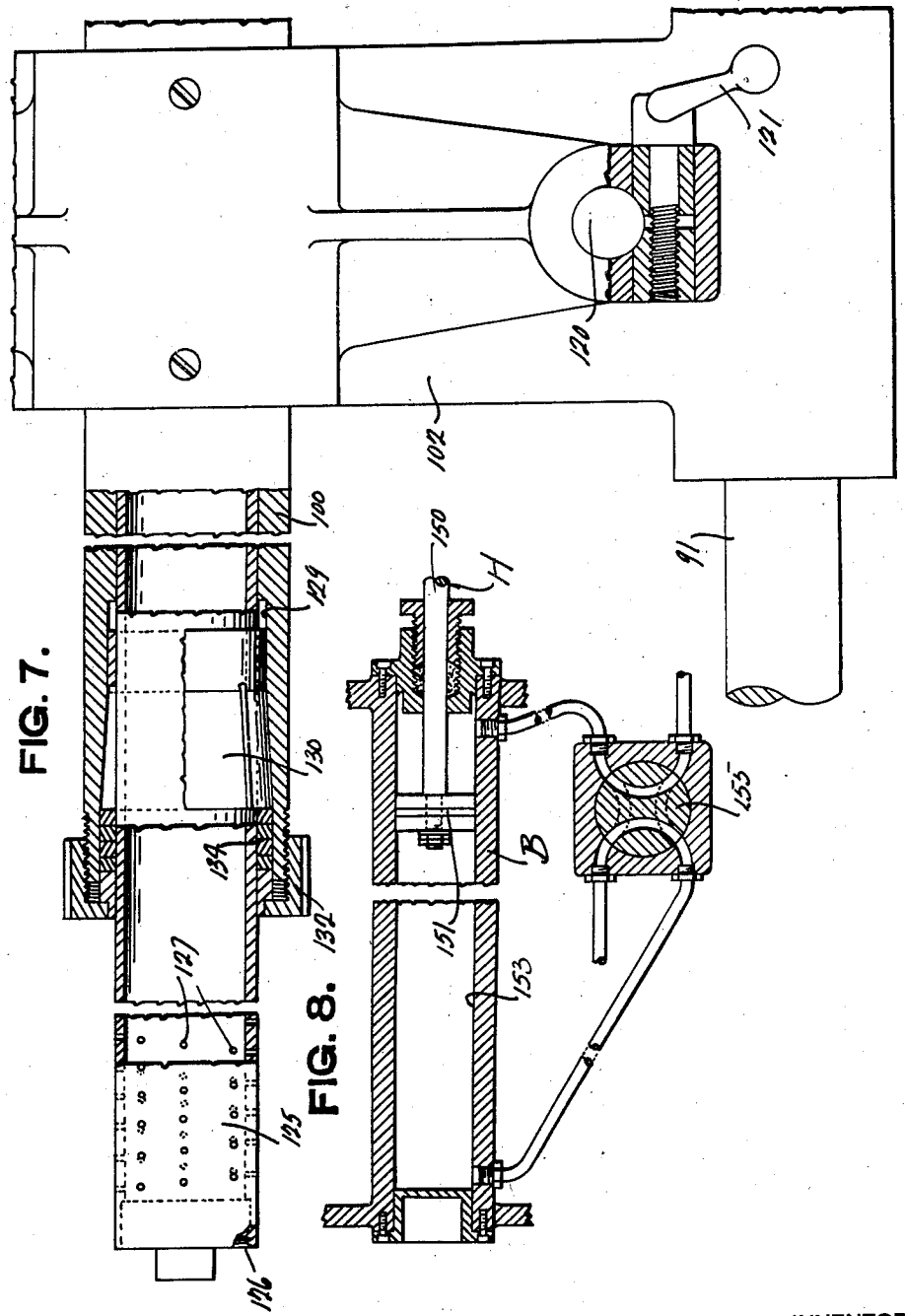


FIG. 7.

FIG. 8.

INVENTOR
Tom Holland Nelson
BY
Lancaster, Allwine & Rommel
ATTORNEYS

Oct. 22, 1940. T. H. NELSON 2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 4

FIG. 10.

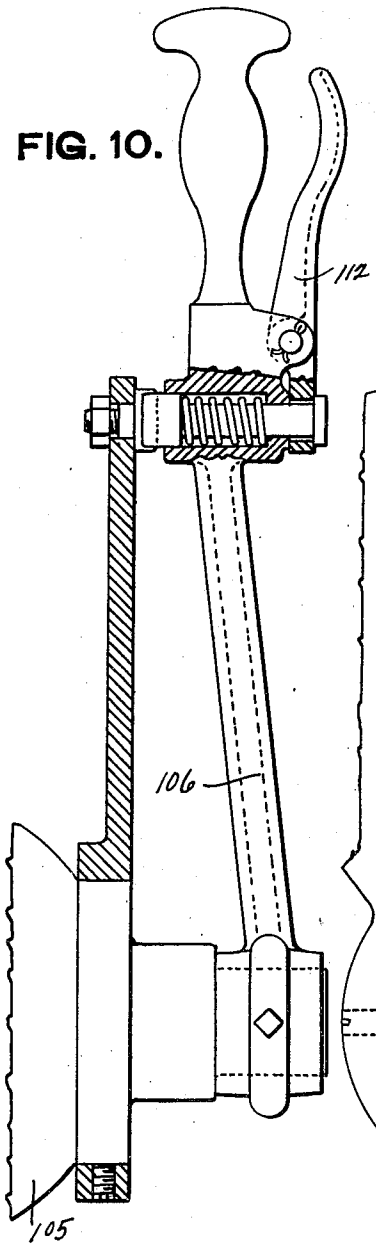
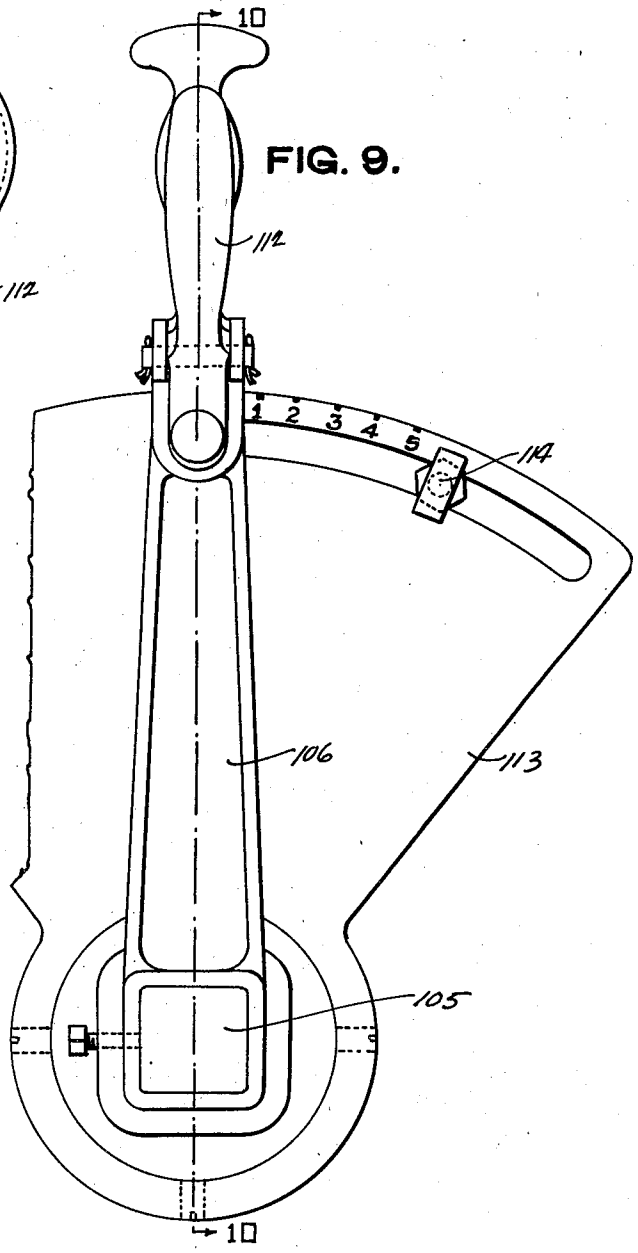


FIG. 9.



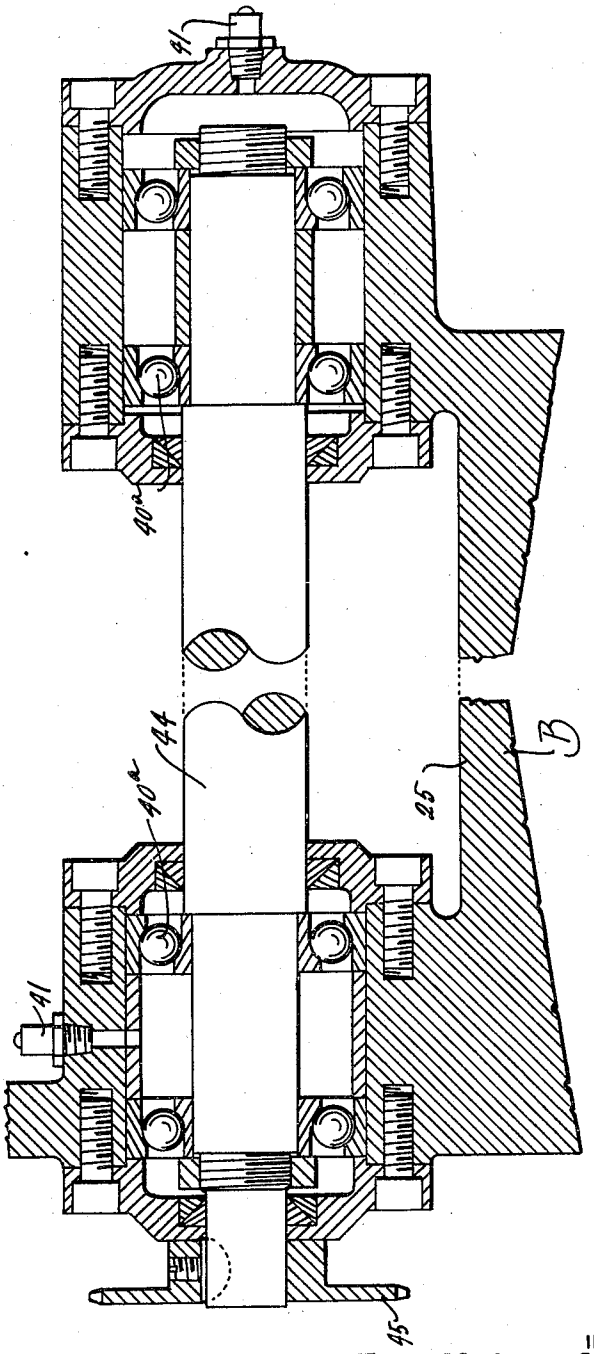
INVENTOR
Tom Holland Nelson
BY
Lancaster, Allwine and Rommel
ATTORNEYS

Oct. 22, 1940. T. H. NELSON 2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 5

FIG. 11.

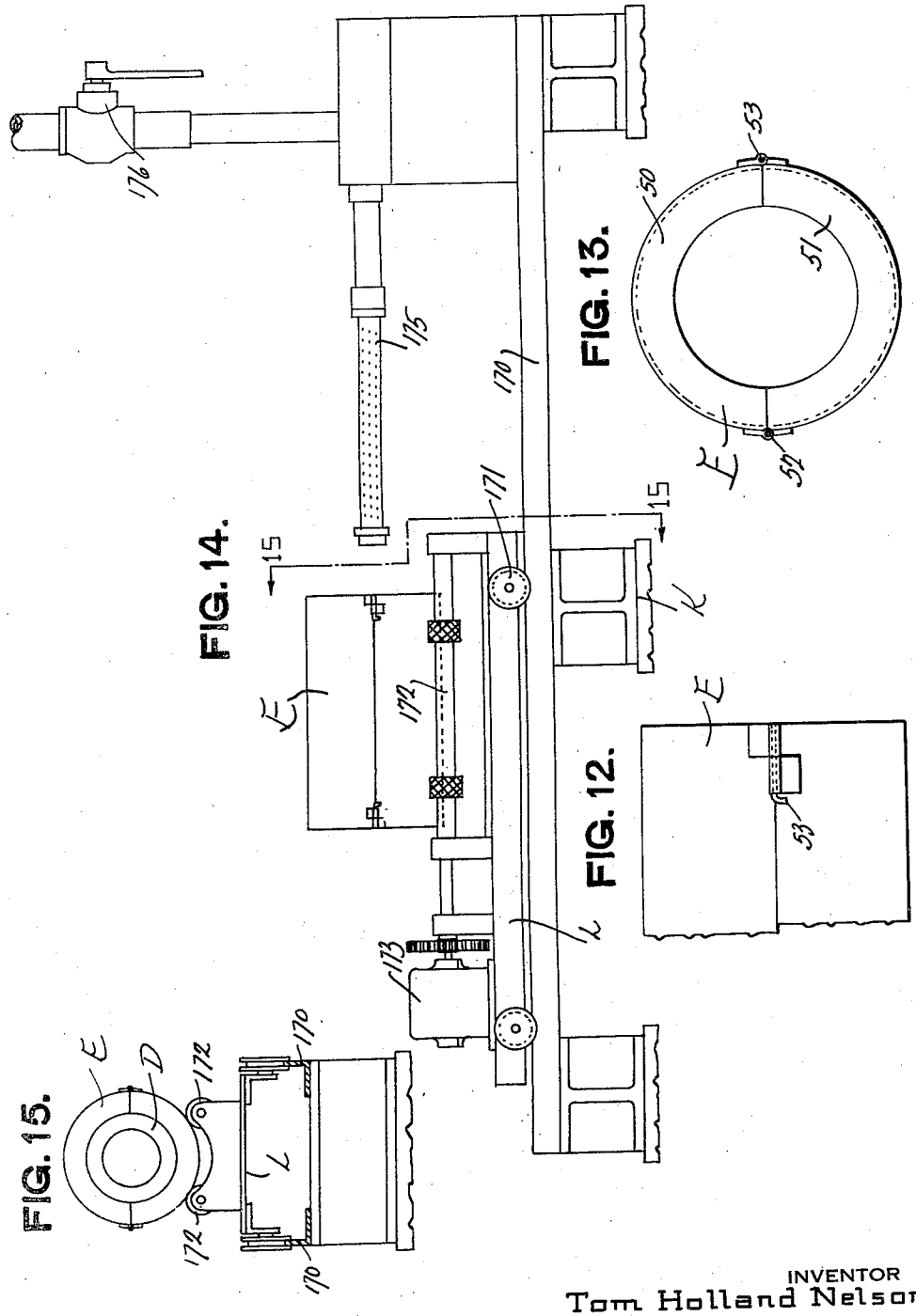


INVENTOR
Tom Holland Nelson
BY
Lancaster, Allwine and Rommel
ATTORNEYS

Oct. 22, 1940. T. H. NELSON 2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 6



INVENTOR
Tom Holland Nelson
BY
Lancaster, Allwine and Rommel
ATTORNEYS

Oct. 22, 1940. T. H. NELSON 2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 7

FIG. 16.

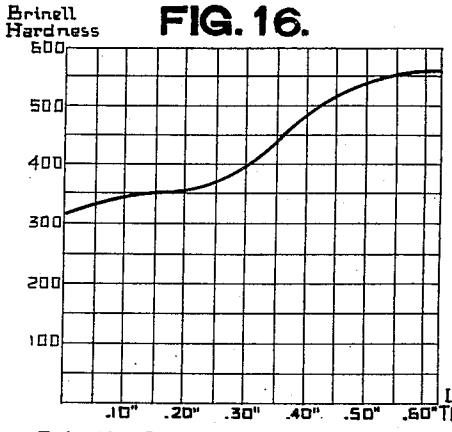


FIG. 17.

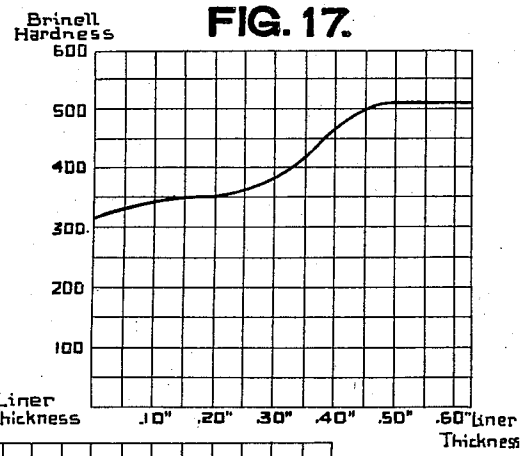


FIG. 18.

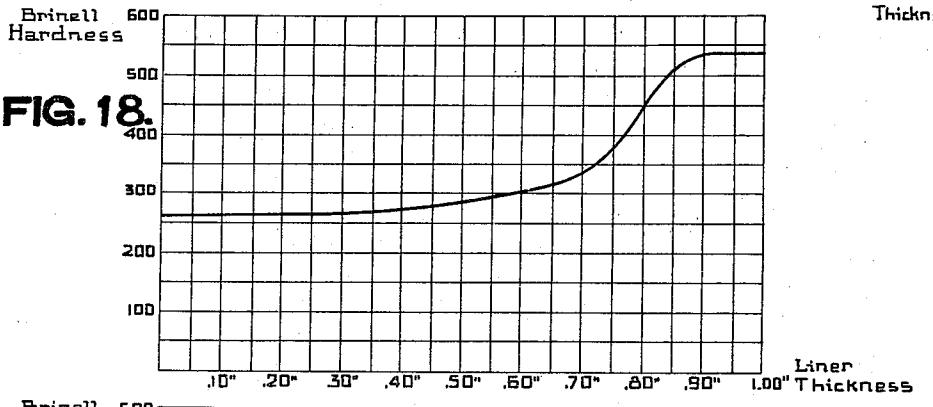
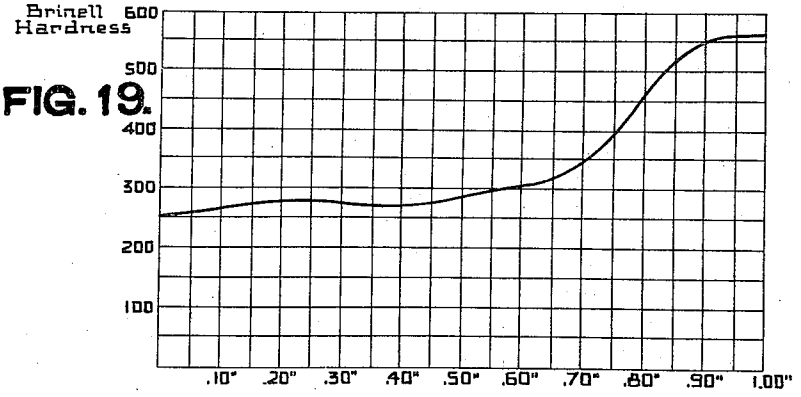


FIG. 19.



INVENTOR
Tom Holland Nelson
BY
Lancaster, Allwine and Rommel
ATTORNEYS

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Original Filed March 3, 1939 8 Sheets-Sheet 8

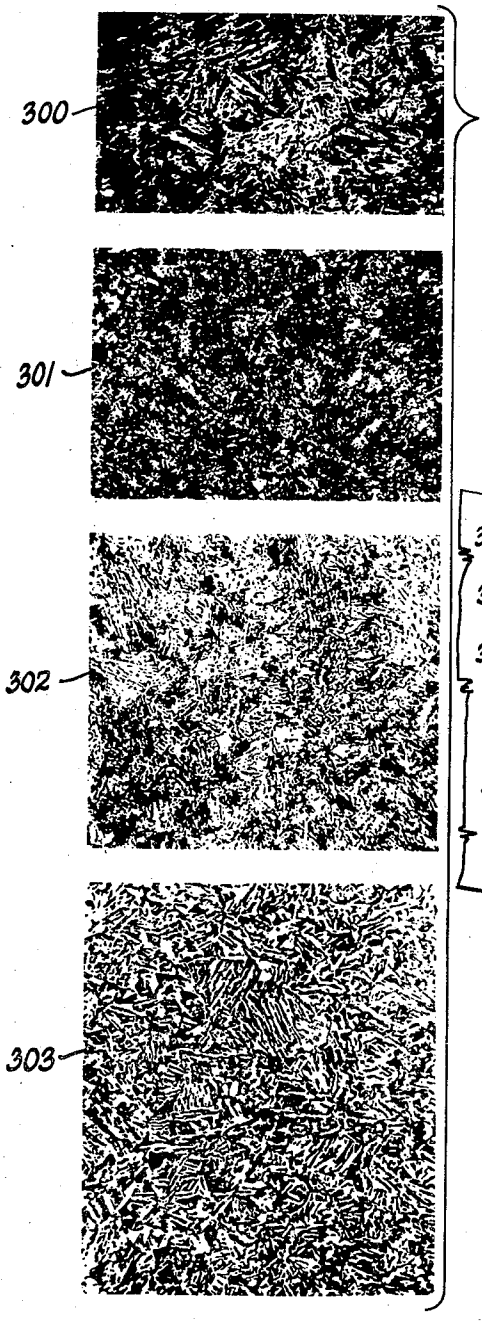
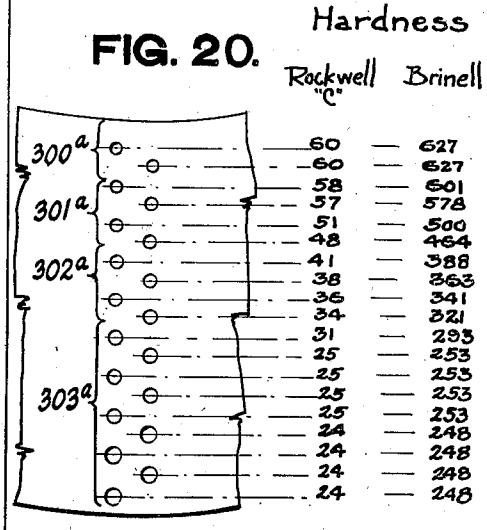


FIG. 21.

FIG. 20.



INVENTOR.
Tom Holland Nelson

BY Lancaster, Allwine and Rommel
ATTORNEYS.

Patented Oct. 22, 1940 2,218,958

UNITED STATES PATENT OFFICE

2,218,958

APPARATUS FOR THE HARDENING OF TUBULAR STEEL ARTICLES

Tom Holland Nelson, Villanova, Pa., assignor to Harrisburg Steel Corporation, Harrisburg, Pa., a corporation

Original application March 3, 1939, Serial No. 259,680. Divided and this application October 25, 1939, Serial No. 301,288

6 Claims. (Cl. 266—6)

The present application relates to a hardened article made of steel or alloy, and is a division out of my co-pending application, Serial No. 259,680, filed March 3, 1939.

Many wrought steel cylinders or tubular articles, such as pump liners, are subjected to wear and abrasion on the internal surface thereof, due to the action of pistons or moving parts, and the abrasive effect of grit. For that reason it is desired to have the internal surface of the cylinder or pump liner of maximum hardness. In order that the pump liner or cylinder may withstand not only the wear but also shocks, etc., as an incident of the particular use to which it is subjected, it is desired to have a gradient hardness thru the thickness of the material thereof; the hardness tapering from the internal surface, in uniform manner, to the outer surface thereof where it is desired to have a tough and machinable surface which is not brittle. To that end the present invention relates to the development of a pump liner or other tubular article the inner surface of which is hardened to the maximum degree for which the steel or alloy is capable of developing, with a normal or soft condition to a desired depth on the outer wall of the liner, and with a rather uniform or gradient hardness on the intermediate portion of the wall. The liner on its inner surface preferably develops a maximum hardness, for example approaching 650 Brinell, is attained; the Brinell hardness rather uniformly decreasing in the direction of the outer surface of the liner or cylinder, where it is desired to have a Brinell hardness of approximately 250.

I am well aware that heretofore various methods for producing surface hardness have been used, such, for instance, as case hardening, nitriding, alloy metal spraying, and inserted liners, but these methods are limited in their application. For instance, case hardening to be commercial has a limited depth and involves considerable length of time at higher temperatures than is desirable for certain steels. Nitriding is very restricted so far as depth is concerned, and the time factor is longer by far than case hardening.

In both case hardening by cementation, or nitriding by the nitriding process, considerable length of time is required and they are restricted by depth of penetration and other commercial factors, and are prone to cracking and spauling under severe load.

I have found the art known as flame hardening to be unsuitable for the internal hardening of tubular articles such as pump liners. Extensive experiments have been conducted to that end, and have resulted in very marked differences when compared to the process which is set forth in my parent application above identified, so far as surface hardening is concerned. In flame hardening heat is applied to merely a portion of the surface of the article from a source so much higher in temperature than the desired ultimate temperature that very definite strains and stresses are set up, remembering of course that other portions of the tubular article are at normal temperatures. Further, with flame hardening additional stresses more severe than with my process are developed during the quenching action in bringing the heated portion down through the critical stage. Thus there are dual risks of setting up stresses and strains by the art of flame hardening, each of which in turn is capable of causing distortion and cracking of the article. The dimensional accuracy, uniformity of surface hardness, and abrasive resistance demanded of a pump liner are well known. These three features I have found unattainable by flame hardening. By my process the entire mass of material is heated to a uniform temperature and the article can be considered almost in a state of rest, free from strain. As an incident of the insulation jacket and the uniform spraying desirable characteristics of my liner as herein outlined are obtained, and they cannot be obtained with any of the other processes of the prior art above mentioned.

With the present method the wrought steel is of the same chemical composition throughout, and no other element is added in the process such as carbon in the case of case-hardening, or nitrogen for the formation of ironnitride in the case of nitriding.

A further object of the present invention is the production of a hardened cylinder, liner, or the like, by means of internally spraying the liner which has been heated to a point above its critical temperature. The inner or outer surface of the cylinder or liner which is not to be hardened is encased, during such spraying, in some refractory material; the volume of quenching medium and time of treatment being carried out under optimum conditions which will insure the most effective results, according to the analysis of the metal used and the thickness and nature of the article to be hardened.

A further object of this invention is the provision of an improved machine for hardening tubular articles.

Other objects and advantages of the invention will be apparent during the course of the following detailed description.

In the accompanying drawings, forming a part of this specification, and wherein similar reference characters designate corresponding parts throughout the several views,

Figure 1 is a side elevation of an improved machine used for the hardening of such tubular and cylindrical articles as pump liners.

Figure 2 is a longitudinal sectional view taken through the improved machine showing a cylinder or pump liner in position on the machine, for hardening.

Figure 3 is a plan view of the machine shown in Figure 1.

Figure 4 is an end view of the machine.

Figures 5 and 6 are cross sectional views taken substantially on their respective lines shown in Figure 3 of the drawings.

Figure 7 is an enlarged fragmentary sectional view taken through the spray nozzle of the improved machine; showing its mounting means.

Figure 8 is a fragmentary longitudinal sectional view taken through a control piston of the machine.

Figure 9 is a side elevation of the quenching medium control handle or lever.

Figure 10 is a longitudinal sectional view taken substantially on the line 10—10 of Figure 9.

Figure 11 is an enlarged fragmentary longitudinal sectional view taken through one of the roller shafts adapted to support the article to be hardened.

Figure 12 is a fragmentary end view of a refractory jacket adapted to receive the article to be hardened.

Figure 13 is an end view of the jacket shown in Figure 12.

Figure 14 is a side elevation of a modified form of the invention.

Figure 15 is an end view of the machine shown in Figure 14.

Figures 16 to 19 inclusive are charts showing curves which designate the degree of hardness through varying thicknesses of liners or cylinders, under different conditions of quenching control.

Figure 20 designates a fragment or wall section of a liner which has been Rockwell tested for hardness; the accompanying figure at the hardened portion of the liner designating the Rockwell "C" hardness and the corresponding Brinell hardness.

Figure 21 designates micro-photographic views of various micro-structures taken at four points in the wall thickness of the liner shown in Figure 20, from the martensitic 60 Rockwell inner hardened surface to the normal, soft or unhardened pearlitic outer surface of the liner having a Rockwell hardness of 24.

In the accompanying drawings, forming a part of this specification, and wherein are shown preferred and modified forms of the invention, the letter A may generally designate the preferred form of cylinder hardening machine, which includes a foundation frame B having means C thereon to rotatably receive a pump liner or cylinder D to be hardened. This liner or cylinder is ordinarily encased in a refractory jacket E of suitable insulating material; the supporting means C being driven by means F. Spray means G is provided for supplying quenching medium; means G being movably located by means H for movement towards or away from the liner or cylinder D.

The supporting frame B is designed primarily to receive a cylinder or liner with its axis in horizontal position. However, it is to be understood that this invention is not to be limited to a method or mechanism for hardening treatment of cylinders or liners while in horizontal position, since it is entirely feasible to have the cylinders or liners vertically positioned or inclined at an angle to the vertical or horizontal. The frame B includes a supporting bed 25 supported by legs 26. The frame B may be of metal or other construction and is preferably anchored at 27 to a concrete foundation 28. The bed 25 includes a piston cylinder 153 adapted to receive the piston of means H which regulates movement of the spray apparatus G.

As is more particularly shown in Figures 2, 3 and 5 of the drawings the means C for supporting the liner and its refractory jacket consists of roller shafts 44 having keyed therewith serrated supporting rollers 37, in any approved number, upon which the liner E and its encased jacket is adapted to rest. The means F is used to drive the rollers 44 in the same direction, that is, either clockwise or counter-clockwise. The manner in which these shafts 44 are supported is detailed in Figure 11 of the drawings where it is shown that the shafts 44 are rotatably supported upon suitable anti-friction bearings 40a located in the end walls of the bed 25; suitable means 41 being provided for feeding grease or other lubricant to the cups or casings wherein the anti-friction bearings are received. Both shafts 44 extend outwardly at their rear ends through the end wall of the supporting bed 25, where they are provided with suitable sprocket wheels 45 to receive a drive chain 46 constituting part of the drive means F.

It is to be understood that other articles than cylinders and pump liners may be hardened according to the method herein described. For the most part the machine is adapted to internally harden pump liners, such as that shown at D in Figure 2 of the drawings. As will be subsequently described, a feature of the method is the encasement of the liner within a cylindrical refractory jacket E, preferably of asbestos. This jacket is shown in Figures 2, 12 and 13 of the drawings and consists of complementary jacket portions 50 and 51, which are hinged at 52 and provided with suitable pin operated latch means 53, shown in Figure 12 of the drawings. These jacket portions 50 and 51 may include a thin walled casing filled with asbestos or other insulating material, or they may be themselves made up of any refractory insulating material desired. The jacket E snugly fits around the external surface of the liner D to be hardened, but it does not obstruct in any degree the openings at the end walls of the liner. It is of course understood that various size refractory jackets will have to be employed; their use depending upon the size of cylinder or pump liner which it is desired to harden.

The lower shafts 44 may be suitably spaced so that the serrated rings or enlargements 37 thereon may take liners and jackets of different diameters. However, liners vary in length; it very often being desirable to use a liner of the same diameter in different lengths. In order to accurately position the liner against longitudinal movement upon its roller supporting means, an end roller 60, shown in Figures 2 and 3 of the drawings is provided, located on center line of the machine. The roller 60 has a vertical axis and it idles on its supporting shaft; the forward end

surface of the liner or insulating jacket being adapted to engage it to limit the longitudinal movement of the liner and its jacket in one direction. A similar roller 61 is provided for abutment against the opposite end of the jacket or liner; this roller 61 being positioned for rotation on a vertical axis but being mounted on a slidable base 62. The base 62 has a slot 63 disposed longitudinally therein along the longitudinal axis of the machine; a set screw 64 being mounted on the bed of the machine to clamp the base 62 in position so as to definitely space the rollers 60 and 61 to accommodate a jacket of determined length.

Referring to the drive means F, shown best in Figures 3 and 4 of the drawings, a motor 70 is provided for driving a change speed gearing 71. The latter has a drive shaft 72 provided with a sprocket wheel 73 upon which the drive chain 46 is trained. Means 74 is provided for changing the speed of rotation of the chain 46. The latter is trained about an idler sprocket 80, in order to insure driving of the roller shafts 44 in the same direction, and a belt tightener 81 may be associated therewith.

Referring to the means G for spraying of the quenching medium in the liner or cylinder, the same includes a movable carriage 90 slidably supported upon parallel bars 91; the bars at one end being connected with the frame B of the machine and at the other end having a supporting standard 92. This carriage 90 is U-shaped, as shown in Figure 6 of the drawings. It is moved along the parallel bars 91 by means to be subsequently described, in order to move it into and out of spraying and quenching relation with a liner supported upon the machine.

The spray means includes a horizontal spray nozzle supporting tube 100, adjustably supported upon the carriage 90 by means of a screw 101; the tube 100 having a yoke and nut 102 attached thereto, and depending normal thereto within which the screw 101 fits. The screw 101 is provided with a handle 102^a for rotating the same; the handle 102^a being freely rotatably supported in the depression of the U-shaped carriage, as shown in Figures 2 and 6 of the drawings. It is readily apparent that upon turning the handle 102^a the nozzle will be vertically adjusted to suit the size of the liner being quenched.

The spray nozzle mounting tube 100 is provided with a valve casing 105 at an end thereof; the valve being operated by means of a lever 106, shown best in Figures 9 and 10 of the drawings; the lever having a spring actuated detent 112 which operates against a quadrant 113 in order that the lever may assume any of several well-defined positions; an adjustable stop 114 being provided in the quadrant to limit the open movement of the valve to any desired maximum. The tube 100 is of course provided with a flexible hose 115, as shown in Figure 1, so that the spray may be connected with any suitable water supply source and still move to permit its entrance and exit with respect to the liner.

Suitable guide rods 120 are provided upon the carriage, as shown in Figure 6, to prevent turning of the spray nozzle; clamping levers 121 being associated with the carriage and engageable against the rods 120 to clamp the yoke 102 at a desired level.

A spray nozzle 125, as shown in Figure 7 of the drawings, is closed at one end by a screw plug 126 and it is provided with radial openings 127 therein arranged in spiral relation around the periphery of the spray nozzle. The latter is inserted into a counterbored tapered opening 129 in the end of the spray nozzle supporting tube 100, as shown in Figure 7 of the drawings; a split tapered clamping sleeve 130 being provided for seating against the tapered counterbore of the tube 100. A clamping nut 132 associated with follower rings 134 is adjustably positioned in threaded relation on the end of the tube 100; and upon turning thereof the followers will urge the split sleeve into the tube 100 and due to its seating relation on the tapered counterbore the spray nozzle will be clamped in position.

The means for advancing and retracting the spray nozzle and its supporting carriage is best illustrated in Figures 2 and 8 of the drawings. This means H includes a rod 150 supported by the carriage, having a piston 151 on the end thereof slidable within the piston chamber 153 of the frame B. Ports 152 are provided at opposite sides of the piston 151 for ingress and egress of fluid so that the piston may be moved back and forth in the chamber 153. The operating medium is preferably air, although steam or any fluid may be used. Control is effected through a two-way valve 155, as shown in Figure 8; the valve 155 being positioned on the frame of the machine as shown in Figure 3.

In a modified form of the invention shown in Figures 14 and 15 of the drawings a supporting frame K is provided, having suitable tracks 170 thereon. A pump liner supporting carriage L has suitable wheels 171 which travel along the tracks 170. The carriage L is provided with suitable rollers 172 actuated by means of a motor 173; the liner and its refractory casing being adapted to rest on the rollers in the same relation as above described for the preferred embodiment of this invention. The spray nozzle 175 is mounted in a stationary position upon the frame K; the quenching medium being controlled by a valve 176. The carriage L may be manually or otherwise moved to advance and retract the pump liner or cylinder to be hardened with respect to the spray nozzle.

It is within the scope of the present invention to rotate the spray nozzle instead of the article to be hardened. In that case the liner or article to be hardened will preferably be vertically positioned to insure an even distribution of water or quenching medium.

It should be noted that the refractory jacket encases and is in contact with the outer surface of the article to be hardened. This not only excludes the quenching medium from contact with the outer surface of the pump liner or article to be hardened, but also excludes air. In order to obtain the best gradient hardness through the wall where special steels may be involved, a jacket could be so constructed that it may be heated to a temperature just below the critical point of the material. This jacket may, or may not be a refractory. It could, for instance, be a double sleeve with any type of heating medium, the object being to slow down the rate of cooling of the exterior wall through the critical range. With quite a number of steels a refractory without preheating is quite capable of doing this, but with certain complicated alloy steels with air-hardening tendencies it is quite conceivable that it might be necessary to actually have a heated jacket on the outside and definitely control the rate of cooling of the outside, while a sufficient flow of water, or other quenching medium is maintained on the inside through the spray to maintain the maximum hardness on

the interior, yet at the same time obtain the maximum degree of softness on the interior.

The speed of rotation of the article is such as to centrifugally distribute the quenching medium around the inner surface of the rotating pump liner; the quenching medium being free to continuously flow out the open ends of the pump liner.

While I do not desire to be restricted to use of any particular composition, the constituents of the steel used in the pump liners hardened in accordance with the curves shown in Figures 16 to 19 inclusive are as follows:

Carbon	.445
Sulphur	.027
Phosphorus	.018
Manganese	.49
Silicon	.26
Chrome	.16
Nickel	.17
Molybdenum	.426

The preferred method of treatment is to adjust the valve lever **106** so that a full or approximately full flow of the quenching medium is initially forced into the pump liner, which has been heated to above the critical temperature. After a predetermined time the quantity of quenching medium fed through the nozzle is lessened by adjustment of the valve and the quenching medium is permitted to spray into the pump liner at a reduced volume and over a predetermined period of time which is preferably longer than the time for initial spray at full volume. This insures proper gradient hardening of the pump liner or cylinder; preventing run-back of the heat into the liner. Thus, the factors of volume and time are co-related. The speed of rotation of the cylinder may also be a factor co-related to controlled volume and time treatment; it being necessary to produce a proper centrifuging of the quenching medium within the liner.

In the charts shown in Figures 16 to 19 inclusive, the horizontal lines designate Brinell hardness, and the vertical lines from left to right designate the liner thickness.

The charts **16** and **17** designate the hardness curve for a liner with a wall of ⅝ inch thickness; the two charts designating different time treatment of liners of ⅝ inch thickness. The curves shown in Figures 18 and 19 designate the hardness curves for liners of 1 inch wall thickness. These curves were plotted from Rockwell hardness tests.

The ⅝ inch wall thickness liner whose hardness curve is illustrated in Figure 16, was heated above the critical temperature to a hardening temperature of 1510° F. The spray medium, with the valve lever at full position (No. 5) shown in Figure 9 of the drawings, was permitted to flow into the pump liner for a period of twenty seconds, during which time 13.40 gallons of water or quenching medium was disposed of. The valve lever was then thrown to the No. 1 position, reducing the volume of flow approximately to ⅕th, and this treatment was carried out over a period of 140 seconds, during which time 13.30 additional gallons of quenching medium was used. At this time the finishing temperature of the liner was 140° F.

For the hardness curve shown in Figure 17, the liner was heated above the critical temperature to a hardening temperature of 1510° F., and with the valve lever in the No. 5 position, full flow of the quenching medium was admitted to the liner over a period of thirty seconds, during which time 20.10 gallons of quenching medium was disposed of. The valve lever was then thrown to the No. 1 position, reducing the volume of flow to ⅕th, and this treatment was extended over a period of 155 seconds, during which 14.73 additional gallons of quenching medium was disposed of. The liner registered "Cold" at the termination of the treatment.

The size of the ⅝ inch wall thickness liner treated according to the hardness curve shown in Figures 16 and 17 was $8\frac{5}{16}$ inches outer diameter by 21⅝ inches in length. It is a noticeable feature of the treatment above referred to that the liner will elongate during hardness. Therefore, to compensate for this characteristic, I may take a liner which is shorter than that required. The degree of elongation appears to be proportionate to the depth and degree of hardness obtained. For instance, the liner whose hardness curve is shown in Figure 17 was noted, for the composition of steel used, to have elongated 3/128th of an inch.

The size of the liner with 1 inch wall thickness, whose curves are plotted in Figures 18 and 19 was $8\frac{5}{16}$th inches outer diameter by 22 inches in length.

The liner whose curve is shown in Figure 18 was heated to a hardness temperature of 1510° F. With the valve in the No. 5 position, full flow of the quenching medium was permitted to enter the cylinder liner over a period of twenty seconds, during which time 13.30 gallons of water was disposed of. The valve lever was then thrown to the No. 1 position, reducing the volume of flow to one-fifth, and the treatment was carried out over a period of 260 seconds, during which 24.70 gallons of quenching medium was used. The finishing temperature of the liner was 160° F. and the elongation of the liner was 3/64th of an inch.

Referring to the chart shown in Figure 19, the liner was heated above the critical temperature to a hardening temperature of 1510° F. and with the valve open at the No. 5 position treatment is carried out over a period of thirty seconds, during which 20.10 gallons of quenching medium entered the liner. The valve lever was then thrown to the No. 1 position, reducing the volume of flow to ⅕th, and the treatment was carried out over a period of 220 seconds, during which additional quenching medium in amount of 20.90 gallons entered the pump liner. The finishing temperature of the article was 140° F. and the elongation of the cylinder was 7/128ths of an inch.

Referring to the micro-phonograph reproduced in Figure 21 of the drawings, the magnification is "× 500". The upper reproduction designated at **300** illustrates the martensitic structure of the hardened inner wall of the liner, this section being taken somewhere in the area of the wall thickness designated at **300a** in Figure 20 of the drawings. The micro-photograph portions **301** and **302** designated in Figure 21 of the drawings designates the Troostitic-Sorbitic transition between the inner and outer wall thicknesses of the liner; the micro-photograph **301** being taken somewhere in the area of the wall thickness designated at **301a** in Figure 20 of the drawings, and the micro-photograph **302** being taken at a section somewhere in the area **302a** shown in Figure 20 of the drawings. The micro-photograph **303** shown in Figure 20 of the drawings illustrates a typical normal pearlite

structure and is taken somewhere in the area designated at 303a in Figure 20 of the drawings. This wall section is comparatively soft and it is distinguished as "normal" from "fully annealed".

From the micro-photographs it will be noted that the martensitic structure 300 is recognizable by reason of its accicular formation, and that the Troostitic-Sorbitic micro-photographs 301 and 302 are recognizable by reason of their finely divided structures which have little if any definite outline. The white areas of ferrite in the micro-photograph 303 and the darker areas which designate carbide of iron in this micro-photograph 303 of course identify the structure as normal, or unhardened and machinable pearlitic.

It is not believed necessary to designate a curve for the hardness of the section of liner shown in Figure 20. This liner is of one inch thickness. The liner was of course heated to a hardening temperature of 1510° F. With the valve in No. 5 position, full flow of the quenching medium was permitted to enter the cylinder liner over a period of 45 seconds, during which time 30.15 gallons of water was disposed of. The valve lever was then thrown to the No. 1 position, reducing the volume of flow to 1/5th, and the treatment was carried out over a period of 105 seconds, during which 9.98 gallons of quenching medium was used. The fluishing temperature of this liner was "cold," and the elongation of the liner was 3/32nd of an inch. This liner of course was treated according to the above outlined process, and initially the liner was of a length so that the elongation would compensate and bring the total over-all length to that desired of the liner.

It is readily apparent from the foregoing that a homogeneous steel pump liner is provided, so far as chemical analysis is concerned, the hardness of which gradually tapers from the inner to the outer surface where maximum toughness and ductility is obtainable. In other words the line of demarcation between the hardened part and the softer part of the metal is eliminated, and this is the undesirable characteristic of hardening processes heretofore used. The initial full volume flow of quenching medium, according to the tests above enumerated, cools the pump liner to the desired depth, and the subsequent slowing up of the volume quenching medium is just sufficient to maintain the interior of the liner cold, or substantially below the critical at which desired hardness is to be maintained; the cooling of the outer shell of the cylinder being slowed up so that it will fall below the critical hardening point slowly and be free of the quenching hardening effect. It will be understood by those skilled in the art that the outer shell having once dropped below the critical point will not harden.

While the above hardness curves are plotted according to Rockwell hardness tests, I have provided a destructive test, as follows: A piece of the liner after heat treatment is broken off the liner; the fracture representing a complete cross-section of the wall thickness. It is then tempered for the purpose of coloring to any of the well known tempered colors. The result is somewhat surprising, since instead of the metal thru the thickness thereof having a uniform color; such, for instance, as straw, brown, purple, or blue, the wall thickness will develop very definitely in two colors; the one color definitely representing the depth of hardness which it is desired to obtain in the pump liner or other article which has been hardened according to the above method, and the other color definitely representing the unhardened or softer portion. This method does not, as yet, establish the degree of hardness, but it very definitely establishes the depth of hardness. This is very important, since in combination with a hardness testing machine it is possible to obtain the maximum hardness obtained on the face of the liner and by the color tempered process above outlined it is possible to obtain the depth of hardness. It is within the scope of this invention to harden a tubular liner on the outer surface and provide inner machinable ductile surface, by practicing the above process in reverse.

An optimum condition is a liner hardened on its inner surface to between 500 and 650 Brinell, graded to the outer surface which has a hardness of 200 to 350 Brinell.

It is of course understood that various tubular articles, and indeed other articles may be treated according to the method herein outlined, and that the size of the liner is immaterial.

I claim:

1. In a machine for the hardening of steel cylinders the combination of an insulating cylindrical shaped jacket, means for rotatably supporting the jacket with the cylinder fixed therein on a horizontal axis, means for rotating the jacket and its cylinder, means for spray quenching the interior of the cylinder while it is being rotated, and means for variably controlling speed of rotation of the cylinder and volume feed of the quenching medium whereby they may be synchronized to most effectively harden the cylinder to the maximum hardening at the quench location that the material of which the cylinder is made is capable of developing.

2. In means for the hardening of tubular steel articles such as cylinders the combination of an insulating jacket for receiving the steel article to be hardened, means for rotating said insulating jacket and the steel article therein, and spray means for quenching portions of the cylinder not covered by said insulating jacket.

3. In a machine for the hardening of tubular articles the combination of means for circumferentially encasing the tubular article in an insulation jacket, means for rotating the article and its encasing jacket during the hardening operation, and means for spray quenching the interior of the article while it is being rotated.

4. In a machine for the hardening of tubular articles one circumferential surface of which is to be soft and the other circumferential surface of which is to be hard the combination of a refractory jacket for contacting and encasing that circumferential surface which is to be soft, means for rotatably supporting the tubular article and the jacket during the hardening operation, and means for uniformly spray quenching the circumferential surface of the article which is to be hardened while the article is being rotated.

5. In a machine for the internal hardening of tubular articles the combination of a roller bed, an insulation jacket provided with means to laterally open and close the same throughout the length thereof, said jacket adapted to receive the tubular article to be hardened, and said jacket being rotatably supported upon said roller bed, and spray quenching means operatively related to the roller bed and said jacket so that the spray may be disposed within the jacket and

the tubular article therein for quenching the latter.

6. Apparatus for the hardening of tubular steel articles comprising an insulation jacket provided with means to open and close the same for attaching itself upon and enclosing a circumferential surface of a tubular steel article for protecting that circumferential surface against being hardened during a quenching operation, means for rotating said steel article and the insulating jacket therewith, and spray means for simultaneously enveloping the other circumferential surface of the tubular steel article in a quenching bath for hardening of the latter circumferential surface.

TOM HOLLAND NELSON.