April 22, 1958 R. S. GORMAN 2,831,789

HARDENING AND TEMPERING TUBULAR STEEL ARTICLES

Filed April 19, 1954 2 Sheets-Sheet 1

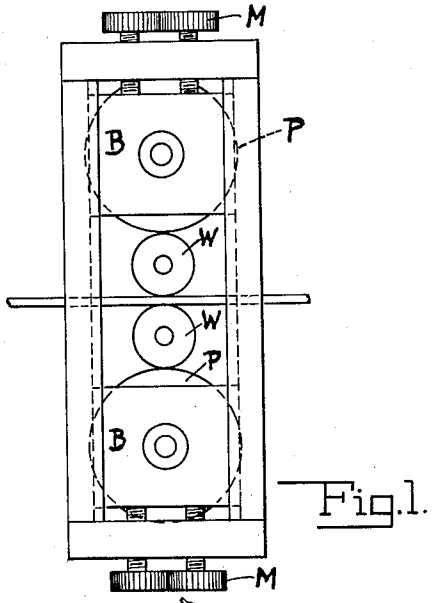


Fig. 1.

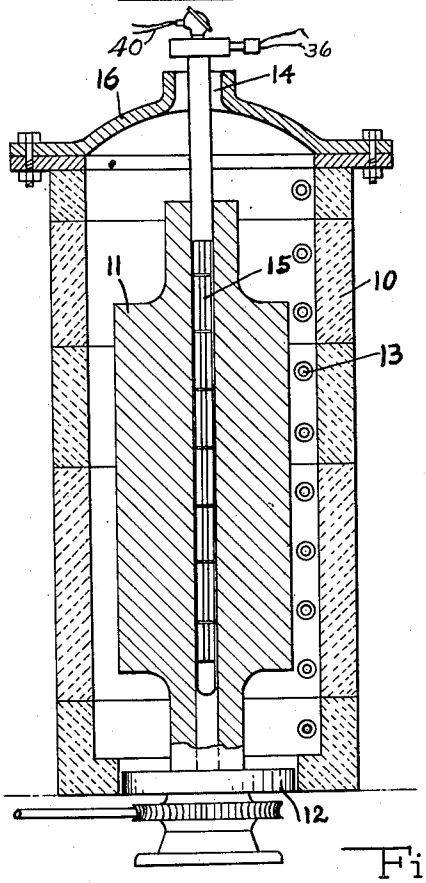


Fig. 3.

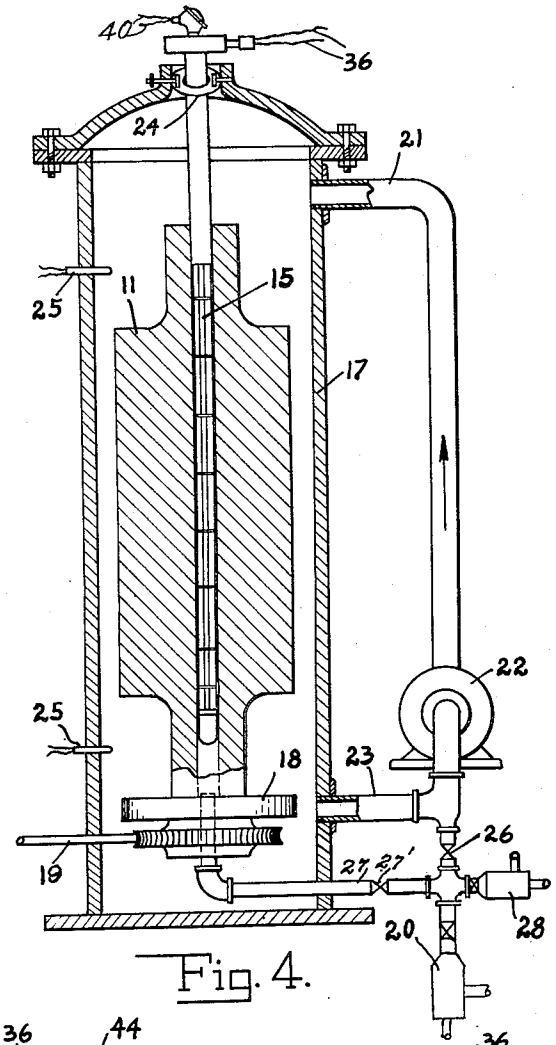


Fig. 4.

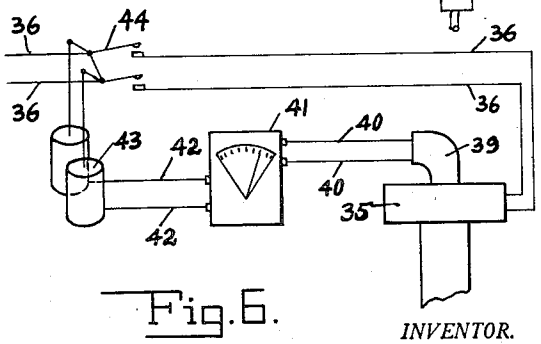


Fig. 6.

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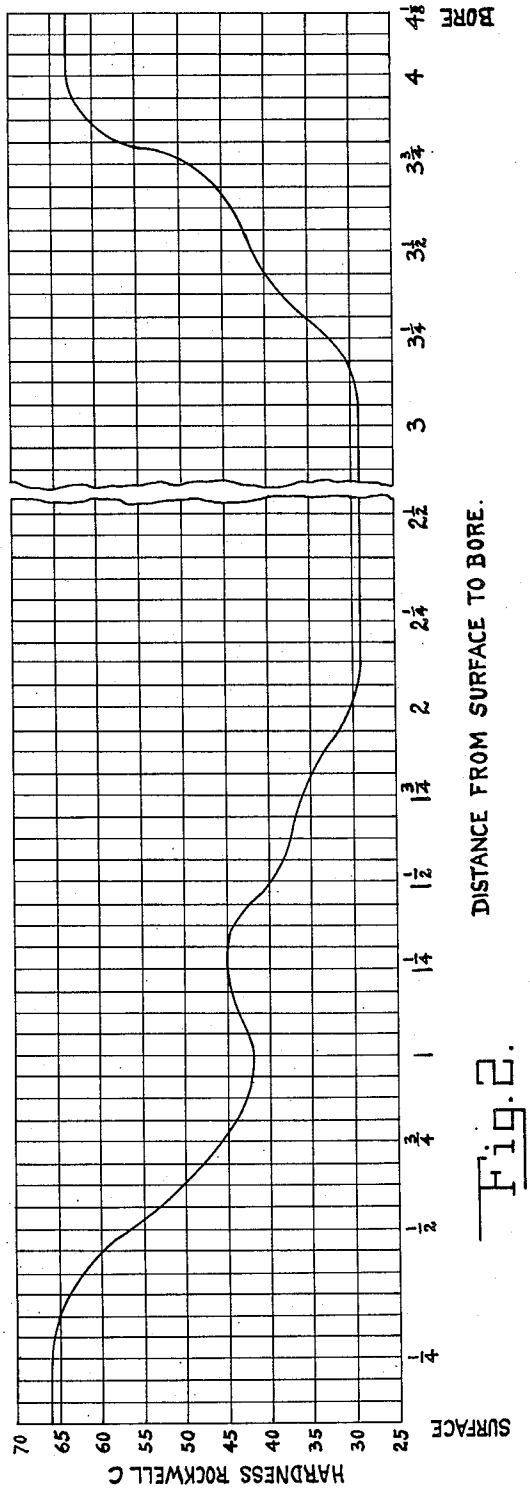


Fig. 2.

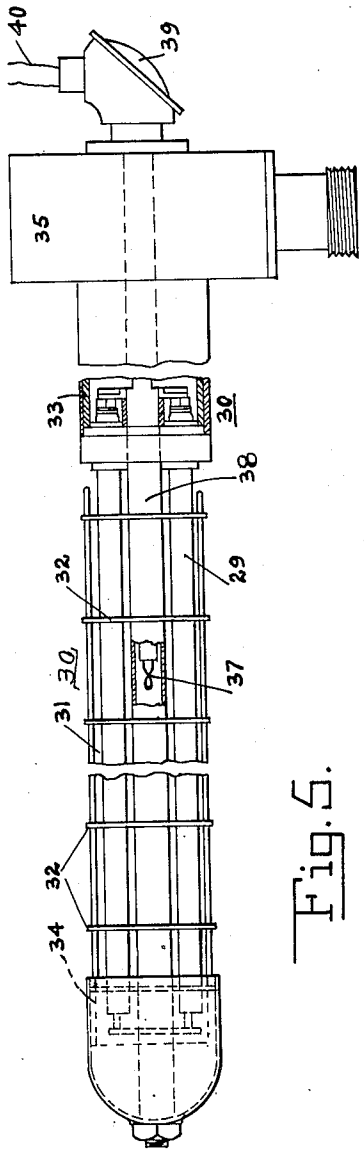


Fig. 5.

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HARDENING AND TEMPERING TUBULAR STEEL ARTICLES

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13 Claims. (Cl. 148—21.55)

This invention relates to the tempering of thick wall tubular articles. More particularly the invention relates to the tempering of heavy rolling mill rolls to adapt them for very heavy pressure rolling of steel, especially sheet and strip steel.

Cold rolling mills use an arrangement of rolls such as is diagrammatically illustrated in Fig. 1 of the drawings. In this arrangement working rolls "W," make contact with the metal being rolled and have a diameter which is much smaller than larger diameter backup pressure rolls "P," that bear against the working rolls to apply pressure to the material being rolled. The backup rolls are mounted in adjustable bearings "B" which are adjusted by mechanical gears "M" to apply pressures in the millions of pounds total pressure to the metal passing between the rolls "W." When working and rolling steel at these high pressures, it is very important that the outside face of the working rolls must be very hard to produce a good surface to the faces of sheet steel. At the same time the roll must have a high strength and toughness, otherwise a roll which has a hard outer shell and a soft core may crush under the high working pressures.

As illustrated in Fig. 1 the backup rolls are generally much larger in diameter than the working rolls and have a function which is different from the function of the working rolls. The different function of the backup roll often requires a steel alloy of different physical characteristics than the working roll and often the chemical compositions of the two rolls are different.

My experience has shown that solid working rolls made of high grade alloy steel having a diameter greater than 6 inches cannot be tempered to have satisfactory hardness, strength and toughness for cold rolling of sheet steel, especially the rolling of thin sheets (20 gauge and thinner). When the steel ingot from which large diameter rolls are made is formed from the molten metal, the impurities accumulate on the inside of the ingot and this portion of a solid roll is less uniform in composition than the outer portion, thus producing a roll which is liable to crack or fail when subjected to high pressures, even though the outer shell of the roll may be hardened and tempered. To secure the necessary outside hardness while imparting to the entire body of the roll the required strength and toughness it has been found that it is desirable to bore the center of the roll to remove much of the impurities and at the same time provide an opening by which the central portion of the roll may be heated and quenched for tempering. By being able to heat and quench a roll from the outside and also the inside it is possible to carry out a tempering, hardening, and toughening operation which will equip the roll for high pressure work. A large number of tests has shown furthermore that the proper outside hardening with the most effective strengthening and toughening from which stresses have been relieved cannot be accomplished in one heating and quenching operation, but that two distinct operations are required namely a hardening operation and a tempering operation.

The present invention is particularly applicable to the tempering of thick wall tubular tool steel articles which are to be subjected to very high pressures. Therefore the "tempering" of such articles has a special meaning in that it includes a high outer or inner surface hardening and also high tensile and yield strengths and great toughness which extend throughout the body of the article.

Heretofore, thin wall tubes such as bearing bushings have been hardened, in which electrical induction heating has been used for hardening a thin outside and inside surface of the tube, such as described in the patents of Strickland No. 2,556,236 and Vaughn No. 2,556,243. In these hardening operations the tubes are progressively heated with moving induction heaters and are progressively quenched immediately after the surfaces of the tubes are brought to the desired temperature. The hardening methods of these patents are such that thin shell inner and outer surfaces of the tube are raised to the desired hardening temperatures and quenched without the intermediate portion of the tube between the wall surfaces being raised to the critical or hardening temperature. These operations provide a tube with a thin inside and outside hardened surface with a soft unhardened core or intermediate portion. These thin wall tubes have hardened surfaces for wear with lubrication but are not suitable for high pressure rolling of metals.

The specification of rolling mill work rolls, for example, demand that a surface shell for a minimum depth of one inch on the diameter of the roll shall have a Rockwell C hardness of 58–66 plus in accordance with the type of metal to be rolled. The backup rolls require that a minimum depth of one inch on the diameter shall have a Rockwell C hardness of 39 to 58.

The characteristics and inherent nature of electrical induction heating are such that the above hardening specifications of work and backup rolls cannot be obtained with electrical induction heating. Further, a tube with a hard surface and a soft core would readily crush under working pressures and such a tube would not have a suitable tensile and yield strength or toughness to meet the requirements of pressure rolling.

The high pressures used in rolling steel requires that the necks of the rolls have great strength and therefore the inside bores of rolls 6 inches to 50 inches in diameter are about 1¼ to 6 inches in diameter. The electrical induction type heaters with their accompanying quenching apparatus are not usable in and would not have sufficient heating and cooling capacity to be effective in 1¼ to 6 inch bores of rolls which are 6 to 50 inches in diameter.

The primary object of the present invention is to provide a method for hardening and tempering a thick walled tubular roll by controlled heating by which the entire body of the roll is hardened and strengthened and the outer surface hardness penetrates into the roll at least one inch on the diameter.

Another object of the invention is to provide a method by which thick walled tubular rolling mill rolls may be hardened and tempered in a two stage treatment by which the entire body of the roll is first hardened and then the hardened roll is tempered to relieve stresses throughout the roll and to obtain a deep penetrating desired hardness at the surface and in the bore of the roll while securing a high strength and toughness throughout the body of the roll.

A further object of the invention is to provide a method and apparatus by which thick walled tubular rolling mill rolls may be hardened and strengthened by inside and outside heating and quenching and then tempering the hardened roll by controlled heating to develop the desired surface hardness and body toughness while relieving the stresses in the roll.

With these and other objects in view the invention consists in the method and apparatus for heating thick walled tubular rolling mill rolls as herein illustrated and described and particularly defined in the appended claims.

The various features of the invention are illustrated in the accompanying drawings in which:

Fig. 1 is a diagrammatic illustration of one set of rolling mill rolls in a cold rolling sheet mill showing a method of applying very high rolling pressure to a sheet of steel being rolled;

Fig. 2 is a curve diagram illustrating the hardness of a tubular roll ten inches in diameter;

Fig. 3 is a diagrammatic sectional view of a hardening furnace for treating tubular rolls;

Fig. 4 is a diagrammatic sectional view of a furnace for tempering a tubular roll;

Fig. 5 is a view in side elevation of an electrical resistance heater for use in the central bore of the roll to control the heating of the inside of the roll; and

Fig. 6 is a wiring diagram illustrating instruments for automatically controlling the electrical heater to develop desired temperatures in the roll bore.

The present invention is particularly adapted for tempering rolling mill rolls for rolling sheet steel. Due to the tremendous pressure which is applied to such rolls, particularly when cold rolling, a very accurate tempering of the roll is required. In Fig. 2 is illustrated a curve showing the hardness of a roll tempered by the method of the present invention which is especially adapted for cold rolling of sheet steel. Although the curve shows only the hardness characteristics of the roll, other physical properties must be developed in the roll by the tempering operation in order to have a roll which is satisfactory for the cold rolling operation. For example, the initial hardening operation also develops the strength of the roll. This hardening operation places stresses within the roll which are relieved during the tempering operation but the tempering must be controlled to retain hardness and toughness along with high tensile strength and high yield strength. The curve shows that the outside wall has a hardness of about 66 Rockwell C hardness while the inside hardness of the bore is about 63 Rockwell C which preferably should be 2 to 3 points Rockwell C hardness lower than the outside surface. The curve also shows that the entire body of the roll is comparatively hard and that the minimum hardness of the interior portion of the roll lies in the range of 28 to 32 Rockwell. The roll from which the curve of Fig. 2 is developed had hardness measured at one sixteenth inch increments and shows that the outside hardness slowly dropped so that the hardness at a depth of one half inch from the surface is 60 Rockwell C and the hardness at the bore remained at substantially 63 Rockwell C hardness for a depth of one quarter inch from the surface of the bore. The gradual change in the slope of the hardness curve obtained by the tempering method of the present invention insures a roll of great strength and toughness.

The curve of Fig. 2 is typical of the hardness of a rolling mill roll which is tempered for high pressure rolling and which is made of a particular steel alloy. It will be understood that this curve may differ for rolls made of different steel alloys and adapted for rolling of different types of metals. The general characteristic of the curve however will be the same in that the entire roll will be hardened, the outside surface will have a minimum hardness which extends into the roll at least one inch on the diameter and the hardness at the core will extend into the roll at least ½ an inch on the diameter.

In producing the roll described above, a two stage operation is carried out namely; a hardening stage and a tempering stage. A furnace for carrying out the hardening operation is illustrated in Fig. 3. The furnace **10** has refractory walls and is comparatively tall to harden a roll **11** which is 6 to 24 feet long while standing on an end of a rotary table **12**. A row of tangentially firing vertically arranged burners **13** is arranged at each side of the diameter of the furnace, which inject combustion gases tangentially into the furnace and around the roll. Such a furnace is illustrated and described in Ferree Patent No. 2,089,829, granted August 10, 1937. As the gases circulate around the roll they pass up through the furnace and exhaust through a stack **14**. The roll is preferably accurately centered on the table **12** and is continuously rotated by a worm drive during the heating operation in order to develop a uniform surface heat in the roll. A temperature of 1,425° F. to 1,650° F. is developed in the outside wall of the roll by the heating with the burners **13**. At the same time the roll is heated in the bore in order to obtain a sufficiently high temperature through the body of the roll to harden and strengthen the roll.

The heating on the inside or in the bore of the roll is carried out by means of an electrical heater **15**, which is carefully designed to substantially fill the bore. In fact the outside wall of the heater may rub against the bore wall of the roll as the roll is rotated. The temperature developed by the electrical heater preferably raises the temperature of the wall surface of the bore to a temperature of 30 to 100° F. less than the temperature developed in the outside wall of the roll. This simultaneous controlled heating from the inside and on the outside of the roll continues until a substantially straight line temperature gradient extends through the entire body of the roll from the outside to the wall of the bore. The two sources of heating provide a control by which the slope of the temperature gradient may be accurately controlled. Further, this temperature control may secure a uniform temperature through the body of the roll from the outside to the bore.

After the roll has been brought to the proper hardening temperatures, a cover **16** on top of the furnace is removed. The roll transported to a quenching apparatus and water is applied uniformly to the outside and the inside of the roll simultaneously to quench the roll to develop the hardness and strength therein. The application of water to the inside and outside of the roll continues until the temperature is brought below 300° F. and the water is cut off. It is important in the quenching operation that the water must be applied in uniform distribution throughout the surface (both inside and out) of the roll. It will be understood by reference to the curve of Fig. 2 that although the hardness of the roll from the outside wall to the wall of the bore is not uniform, the radial sections of the roll have a uniform temper from one end of the roll to the other end.

After the roll has been quenched and hardened the roll is put into a tempering furnace to develop the desired finished hardness and to remove stresses put in the roll during the hardening operation.

The tempering furnace is illustrated in Fig. 4. This furnace **17** is a refractory lined vertical cylindrical furnace which is sufficiently tall to support the rolls 6 to 24 feet long on end. The roll **11** is supported on a rotary table **18** which may be driven by a worm gear operating shaft **19**. For heating the outside of the roll a burner **20** is mounted at the bottom of the furnace and arranged to deliver hot gases to a blower **22** which circulates the gases through a line **21** to the top of the furnace **17**. The heating gases are circulated down around the roll as the roll is continuously rotated and the gases are drawn out of the bottom of the furnace through a conduit **23**. The hot gases entering the conduit **23** are forced by means of a blower **22** back through an inlet line **21** to the furnace. The burner is controlled to supply heated gases in sufficient volume to maintain the desired temperature of gases for heating the outside of the roll. The blower **22** maintains a uniform flow of heating gases in a closed cycle circulation through the furnace and back to the blower. A predetermined pressure is maintained in the furnace and to provide for the heated gases that are introduced by the

burner 20, a controlled proportion of the gases are exhausted through an outlet stack damper 24. The outside temperature of the roll during the tempering operation is raised to and maintained at a temperature between 250° F. and 1,150° F. in accordance with the hardness to which it is desired to maintain in the roll. A low tempering temperature will reduce the hardness of a roll only slightly and a higher temperature tempering operation will materially reduce the hardness of the roll from the initial hardness that is developed in the hardening furnace 10.

While the roll is being heated on the outside in the furnace 17 for the tempering operation, the roll is also heated on the interior by means of an electrical heater 15 which is the same type of heater as that illustrated and used in the hardening operation. This electrical heater is controlled so that the temperature developed on the surface of the bore will be from 10 to 100° F. higher than the outside surface temperature of the roll. In this way the hardness of a roll in the bore will be several degrees Rockwell C hardness lower at the bore surface than on the outside surface of the roll and will greatly decrease the existing strain. The tempering operation is carried on for sufficient length of time for the heat to penetrate through the body of the roll to develop a straight line temperature gradient from the outside to the inside of the roll. This heating operation may continue from 3 to 60 hours or more in accordance with the size of the rolls in order to develop a temper condition throughout the length of the roll and developing the necessary strength, toughness and hardness in the roll. The burner 20 is preferably a gas burner but an oil burner may be used for this heating operation. The tempering is controlled in accordance with thermocouples 25 which are mounted in the top and bottom of the furnace in order to provide a uniform heating condition in the furnace.

When the roll surfaces have been brought to the proper temperatures and maintained at the several temperatures for a sufficient time to relieve the stresses in the steel while producing the hardness desired, the roll is quenched by cutting off the supply of heat to the outside and inside of the roll. Air is circulated through the furnace around the roll and through the bore to gradually bring the temperature of the roll down to at least 400° F. If the tempering temperature is below 450° F. then the cooling is carried out to reduce the temperature of the roll about 50 degrees below the tempering temperature. Then the roll may be removed from the furnace. During the quenching stage of the roll tempering operation the cooling gases of air are circulated by means of the blower 22 from the bottom of the furnace through the conduits 23 and 21 to the top of the furnace and around the roll. At the same time a valve 26 in line 27 is opened to pass cooling gases from the bottom of the furnace through the line 27 into the blower to return to the top of the furnace. Part of the cooling gases passing into the top of the furnace through the line 21 pass down through the bore of the roll. Preferably the electric heater is removed from the roll bore before the quenching operation is started. A valve 27' is mounted in the line 27 to control the volume of cooling gases passing through the roll bore. When the inside of the roll is being heated by electrical heater 15 the valve 27' is closed.

In Figs. 3 and 4 are illustrated the use of an electrical heater for developing the desired temperatures in the bore of the roll. Although it is preferred to use electrical heating on account of the accuracy of the control of the temperature and on account of the concentration of the heat with the electrical heater, it has been found that the heating may be accomplished by means of products of combustion. As shown in Fig. 4 this bore heating operation may be accomplished by means of a gas or oil burner.

For the hardening operation the outside of the roll is heated by gas as described above. Simultaneously the inside of the roll is heated by hot gases supplied by a gas burner which would be applied to the furnace 10. This heating apparatus consists of a burner 28, a line 27, blower 22, and line 21 as illustrated in Fig. 4. Hot gases from burner 28 pass into line 27 and then into the bottom of the bore of a roll in furnace 10. Combustion gases from the top of furnace 10 pass out through line 21 and are circulated by blower 22 back through line 27 to enter the bore of the roll. The mixture of exhaust gas and fresh products of combustion may be controlled by valve 26 and the operation of the burner 28. During this operation most of the gases would exhaust through the outlet 14.

For the tempering operation when heating the bore of the roll by gas or oil the outside of the roll is heated by gas as above described. The electrical heater shown in Fig. 4 is omitted. Hot gas from the burner 20 is supplied to the top of the furnace by blower 22 for heating both the bore and outside of the roll. At this time the valve 27' is open and the volume and indirectly the temperature of the gases passing down through the bore is controlled by the valve 27'. At the same time the blower 22 draws gas through the line 23 for circulation around the roll. The gas pressure in the furnace 17 during the tempering operation is controlled by the valve 24.

When heating a roll bore by gas a comparatively small volume of heated gases may pass through the bore, so that the temperature of the heating gases must be comparatively high and thermocouples must be positioned against the surface of the bore for measuring the temperature. Furthermore, the velocity of heating gases must be high by circulation of gases by the blower 22 through lines 21 and 27 in order to carry sufficient heat into the roll through the bore to develop the desired temperature on the inside of the roll.

The construction of the electrical heater is shown more particularly in Fig. 5. This heater consists of a plurality of connected strands of heat resistance wire 29 which are mounted in a heat resistant cage 30. For heating rolls with a small bore two strands of resistance wire 29 are all that can be conveniently located within the cage 30. With heaters for operation in larger bores from two to ten or more strands of heat resistance wire may be located in the cage for the purpose of developing the desired temperature. The cage is made up of outside guard rods 31 which are accurately held in spaced position by a series of metal disks 32. Insulators 33 and 34 are mounted at each end of the cage to insulate the resistance wires 29 from the cage. A junction box 35 is mounted at the upper end of the heater which carries the electrical conductors 36 connected with the resistance wires 29. The junction box normally positioned above the top of the furnace and conductors 36 pass from the box 35 for connection with an electrical power source (not shown). For the purpose of indicating the operation of the electrical heater one or more thermocouples 37 are mounted in a tube 38 located in the center of the cage and extending through the junction box to a head 39. The thermocouples 37 are connected with electrical conductors 40 which pass through the tube 38 and head 39 and thence to a measuring instrument or meter 41 (Fig. 6). The meter 41 may be a direct reading meter for indicating the temperatures of the thermocouples.

The thermostats 37 in the tube 38 may be used for determining the temperature of the roll at the bore surface. To check the bore surface temperature, a switch 44 (Fig. 6) on the heating conductors 40 is opened and when a temperature indicator needle in the instrument 41 becomes stabilized the temperature of the bore surface is indicated. The temperature indicating instrument will become stabilized in a period of ten to twenty minutes.

Preferably the heating by the electrical heater is controlled automatically to maintain a desired temperature

within the bore of a roll. To accomplish this a well known type of temperature indicator **41** is used which is provided with manually adjustable temperature contacts that may be set to energize, through conductors **42**, a relay **43** at predetermined temperatures to operate a switch **44** that controls the heating current flowing through the conductors **36** and resistance wires **29**. In this way a desired temperature may be developed in the electrical heater in accordance with the type of electrical resistance wires used in building the electrical heater. It has been found that with an electrical resistance wires capable of operating at temperatures of approximately 1800° F. a temperature of 1600° F. to 1700° F. may be developed in the heater without destroying the resistance wires. It is important therefore to have an accurate controlling instrument so that the electrical heating circuit can be controlled to accurately develop the desired temperature.

Some rolling mills have been developed for rolling wide sheets. Such rolling mills require rolls that may have an over all length of 24 feet. When providing for the bearing necks it may be that the working body surface of the rolls will be 14 feet long and therefore heaters which are adapted for heating this type of roll must be at least 16 feet long. That is, the heater extends into the bore of the neck of the roll at least one foot each side of the working surface of the roll. This requirement of long heaters requires the use of several thermocouples for securing an accurate temperature of heating throughout the length of the bore of the roll. With bores of three inches to 7 inches in diameter it will be seen that the electric heating apparatus is quite compact in form but the heating obtained by the electric resistance develops a uniform temperature in the resistance wire and this heated wire acts to heat the inside of the bore by convection and radiation to develop the desired temperatures in the roll.

When the inside of the roll is heated by gas it is necessary to use thermocouples within the bore of the roll in order to control the fuel supply to the burner **28** and also to control the operation of the blower **22** to obtain the desired volume and velocity of heating gases. Thermocouples are also used in the furnace **10** for controlling the operation of the burners **13** in developing the hardening heat.

The burners **13**, **20**, and **28** have been illustrated and described as gas burners. It will be understood that oil burners are well adapted for the type of heating used in tube tempering. Further solid fuel, such as coal and coke, may be used as fuel for generating combustion gases for heating the outside of tubes, rolls and the like.

As outlined above the backup rolls are larger in diameter than working rolls. Therefore a longer period of heating is required for both the hardening and the tempering operation. It is necessary to control the heating and quenching for the hardening and tempering operations for backup rolls just as accurately as the heating and quenching in the treatment of working rolls. The hardening temperatures of heating for backup rolls are lower than for work rolls but much care must be used in tempering the backup rolls to develop a high strength and toughness.

The present invention is useful for tempering cannons, large rifle barrels and thick walled bushings. Such articles may require that the surface of the bore shall be harder than the outside of the tubular article. The use of simultaneous inside and outside heating may develop any desired hardness on the inside and outside surface of tubular articles.

The preferred form of the invention having been thus described, what is claimed as new is:

1. A method of tempering thick walled tubular articles comprising uniformly heating the outside of the article with products of combustion to raise the temperature of the outside of the roll in the range of 1425° to 1650° F., simultaneously applying a separate source of heating to the inside bore of the article to raise the temperature of the inside of the article in the range of 1395° to 1550° F. and to maintain a temperature gradient between the inner bore surface and the outside surface so that the outside surface is always 30 to 100° F. higher than the bore surface temperature holding the article under heat until the entire body of the roll is raised above its critical temperature, quenching the article on the outside and in the bore rapidly and uniformly to obtain a deep penetrating hardness in the outside and the inside surfaces of the article to cool the article below 300° F., thereafter tempering the article to relieve stresses by separately controlled heating on the outside and in the inside of the bore to develop temperatures in the range of 250° to 1150° F. on the outside surface and the inside surface at 10 to 100° F. above the outside surface, continuing the drawing heating for a period of hours to relieve the strain in the article then cutting off the heat and quenching the article in the furnace with the circulation of cooling air and combustion gases until the medial body temperature of the article is reduced at least 50° F. below the tempering temperature.

2. A method of hardening a thick walled tubular article comprising uniformly applying heat to the outside surface of the tube while standing on end in a furnace to raise the temperature of the outside of the tube in the range of 1425° to 1650° F. simultaneously applying a separate source of heat through the bore of the tube to raise the temperature of the bore surface above the critical temperature in the range of 1395° to 1550° F. continuing the controlled heating to develop a straight line temperature gradient from the outside to the inside of the tube with the inside temperature 30° to 100° F. below the outside temperature and rapidly applying quenching water simultaneously to the inside and outside surface to quickly reduce the medial temperature of the tube below 300° F.

3. A method of tempering a tubular article which has been hardened as defined in claim 2 comprising applying heat to the outside surface of the tube while standing on end in a furnace, to uniformly raise the temperature of the outside of the tube in the range of 250° to 1150° F., simultaneously applying a separate source of heat through the bore of the tube to raise the temperature of the inside of the bore in the range of 260° to 1250° F., continuing the controlled heating for a sufficient period to develop a straight line temperature gradient from the inside to the outside of the tube walls with the inside temperature 10° to 100° higher than the outside temperature, thereupon quenching the tube by the circulation of gases through and around the tube to uniformly cool the tube walls to a temperature about 400° F. or about 50° below the temperature of final heating if the final heating temperature is below 400° F.

4. The method of tempering tubular rolling mill rolls as defined in claim 3 in which the rolls stand on end and are heated by a cyclic circulation of hot gas passing down around the rolls from top to bottom.

5. The method of tempering tubular rolling mill rolls as defined in claim 3 in which the rolls are brought to temperature when using hot gaseous products of combustion and air quenched by passing the heated gases and cooling air down through and around the rolls when standing on end.

6. The method of tempering tubular rolling mill rolls as defined in claim 3 in which the rolls are brought to a hardening temperature by passing hot gases of combustion upwardly around the outside of the roll while heating the inside of the roll with electrical resistance heating, quenching the heated roll with water to harden it, then heating the hardened roll to a tempering temperature by passing hot gases downwardly around the outside of the roll while simultaneously heating the inside of the roll with electrical resistance heating, then quenching the roll by circulating air downwardly around

and through the roll to develop hardness and relieve stresses in the roll.

7. The method defined in claim 1 in which the heating on the inside of the bore is carried out by electrical resistance heating.

8. The method of tempering tubular articles as defined in claim 1 in which the heating in the bore of the article is carried out with a separate cyclic circulation of products of combustion of a fuel.

9. A metal rolling mill roll hardening method as defined in claim 1 in which the heating in the hardening operation is carried on for a period which will produce a substantially straight line temperature gradient through the roll while raising the outside of the roll to a temperature which when the roll is quenched rapidly will produce a hardness of 58 to 66 Rockwell C hardness which extends into the roll for a distance greater than one inch on the diameter of the roll.

10. A rolling mill roll tempering method as defined in claim 1 in which the hardening and tempering temperatures are controlled to provide a thick walled roll such that the minimum hardness of any portion of the roll between the outside and inside surfaces is greater than 28 Rockwell C and the hardness of the sections extending inwardly from the inside and outside surfaces has a Rockwell C hardness between 55 and 66 with the hardness of the inside section being two to three points Rockwell C less than the outside section.

11. The method of uniformly hardening the inner and outer surfaces of thick walled tubular steel articles of the character described, comprising separately heating the entire inner and outer surfaces of the article until the entire body thereof is above the critical temperature and having a decreasing temperature gradient of 30 to 100° F. between the outer surface and the inner surface, uniformly quenching the entire inner and outer surfaces thereof until a medial body temperature less than the tempering temperature is obtained, reheating the article

by separate applications of heat to the inner and outer surfaces until the outer surfaces are at tempering temperature, continuing heating of the inner surface to at least 50° F. above the tempering temperature while maintaining the outer surface at tempering temperature, maintaining said temperatures to establish a uniform temperature gradient between the inner and outer surfaces, then cooling the article until the medial body temperature is at least 50° F. below tempering temperature by controlled circulation of a cooling gas in contact with the inner and outer surfaces thereof.

12. A method of uniformly hardening the inner and outer surfaces of a steel work roll as defined in claim 11 wherein the roll is initially heated to 1500 to 1650° F. in the outer surface before quenching, is reheated to a tempering temperature of 250 to 1050° F. on the outer surface, and has a hardness differential of about three points Rockwell C between the inner and outer surfaces thereof after cooling.

13. The method of uniformly hardening the inner and outer surfaces of a steel alloy back up roll as defined in claim 11 wherein the roll is initially heated to 1450 to 1600° F. in the outer surface before quenching, is reheated to a tempering temperature of 390 to 1090° F. on the outer surface, and has a hardness differential of about three points Rockwell C between the inner and outer surfaces thereof when cooled.

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