Jan. 6, 1959 G. E. TEGEN 2,867,556

METHOD OF FLAME HARDENING

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FIG. 1

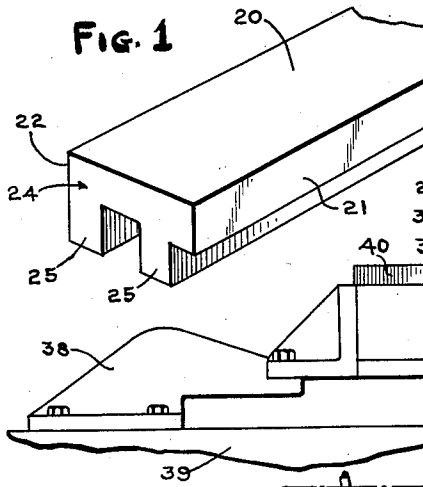


FIG. 2

FIG. 3

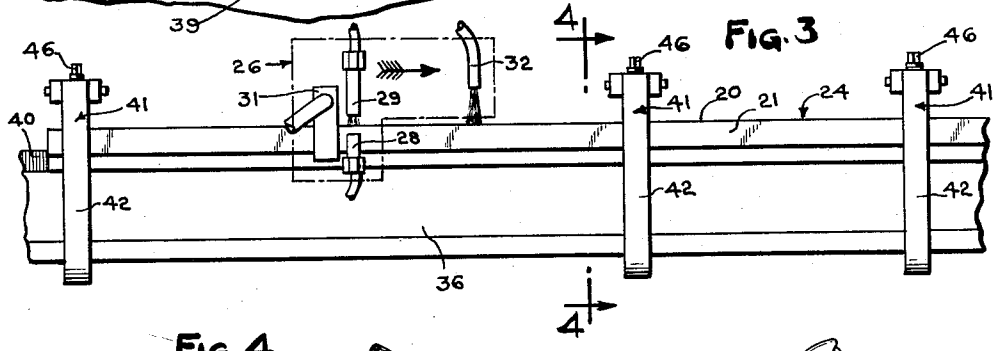


FIG. 4

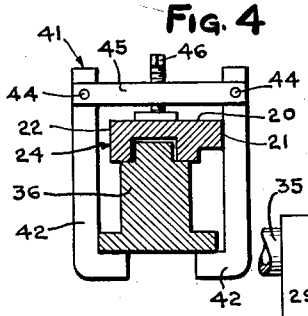


FIG. 5

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METHOD OF FLAME HARDENING

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FIG. 6

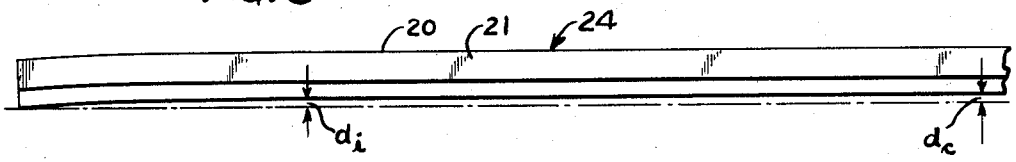


FIG. 7

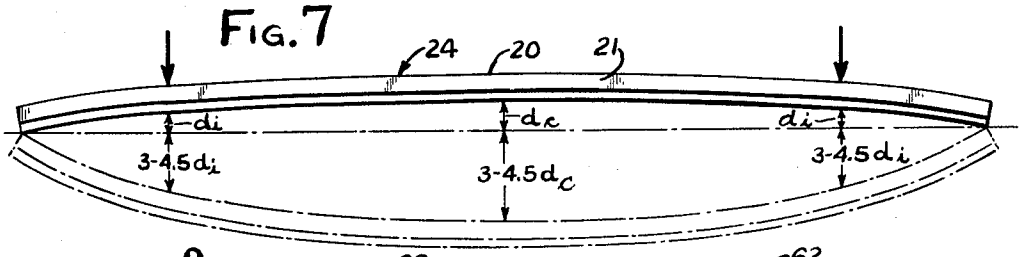


FIG. 8

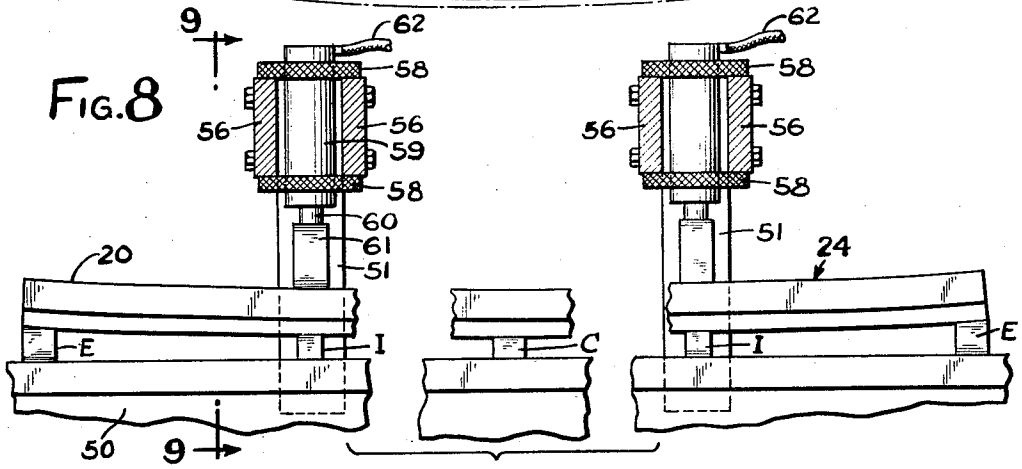
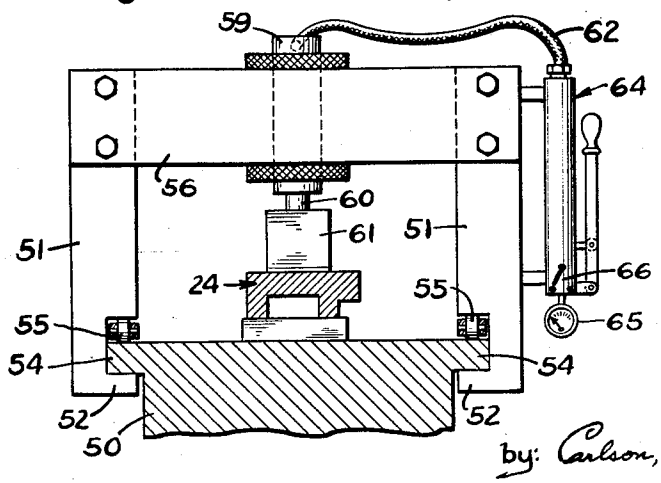


FIG. 9



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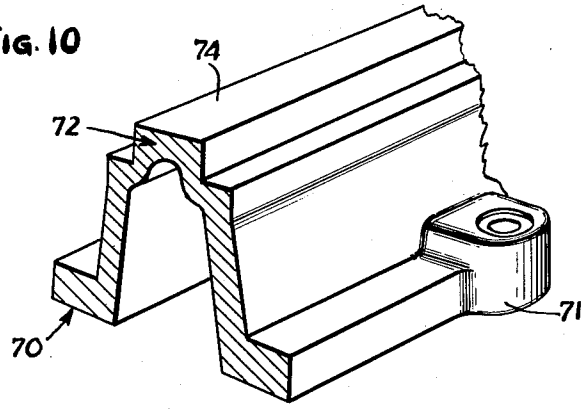
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METHOD OF FLAME HARDENING

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FIG. 10



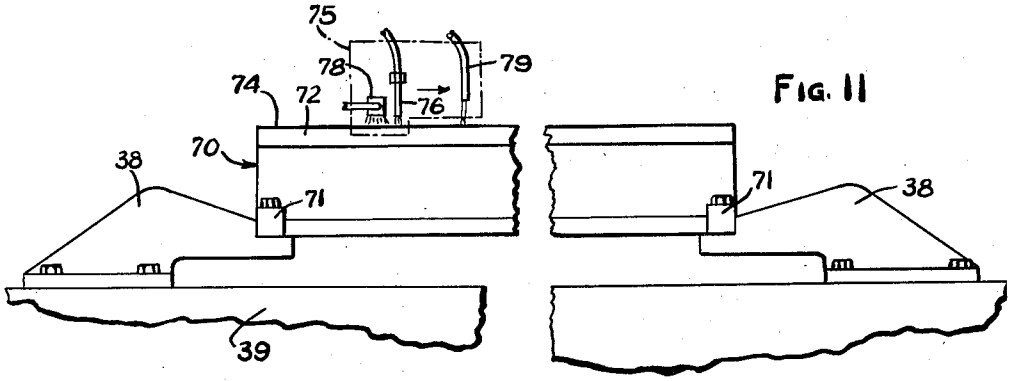


FIG. 11

FIG. 12

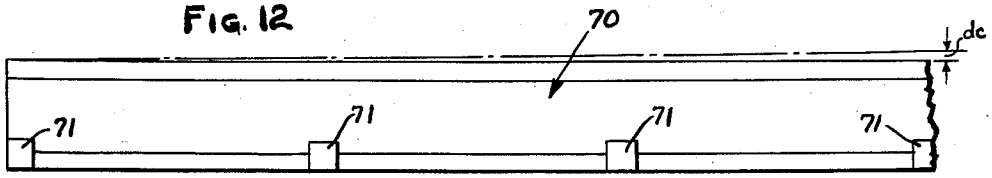
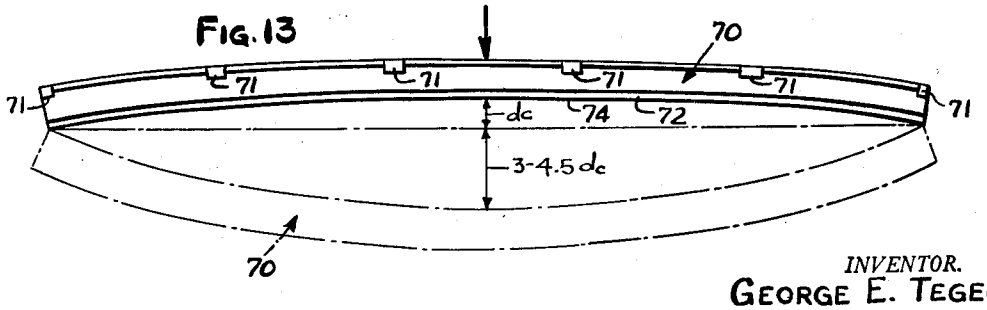


FIG. 13



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FIG. 14

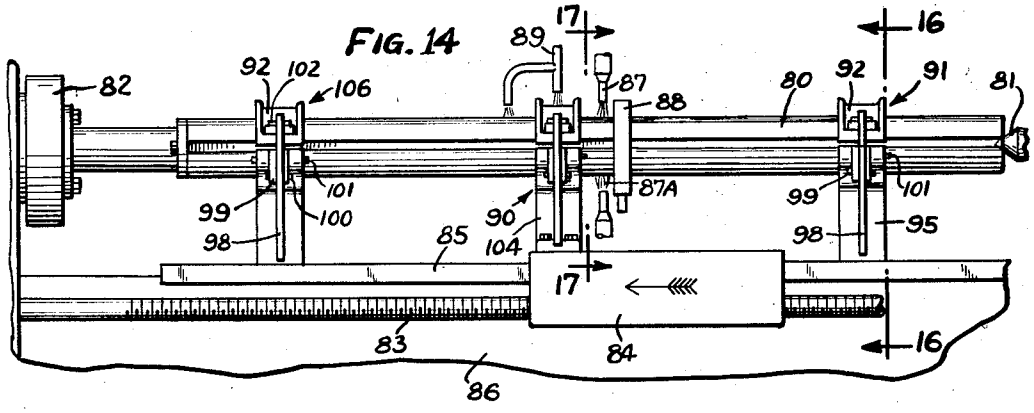


FIG. 15

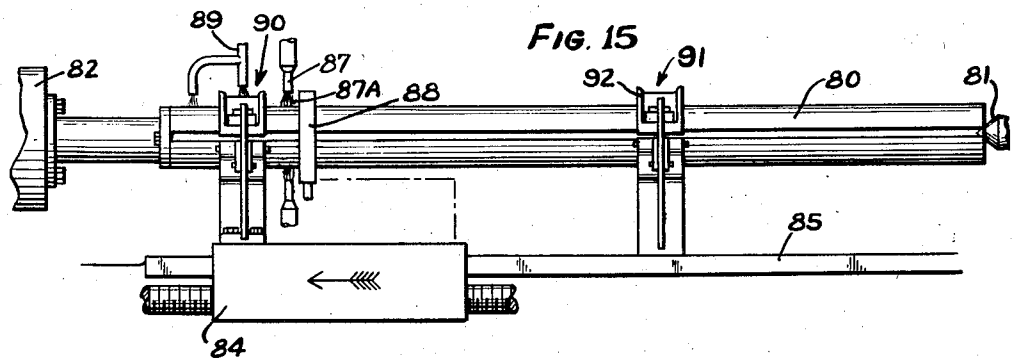


FIG. 16

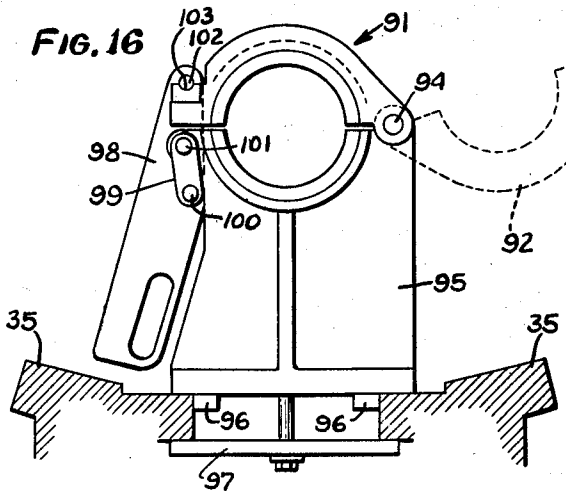
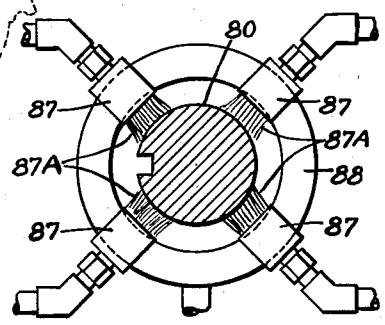


FIG. 17



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United States Patent Office 2,867,556 Patented Jan. 6, 1959

2,867,556

METHOD OF FLAME HARDENING

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Application September 18, 1953, Serial No. 381,090

8 Claims. (Cl. 148—21.56)

The present application is a continuation-in-part of my earlier application, Serial No. 187,755, filed in the United States Patent Office on September 30, 1950, now abandoned.

This invention relates to the flame hardening of relatively long bars of ferrous metal such as cast iron, such bars having lengths many times greater than their cross-sectional dimensions. The greater aim of the invention is to provide a novel method of flame hardening such bars which is simple and inexpensive and which virtually avoids distortion in the final hardened bar.

A more detailed object is to provide a method of the character just set forth and which is adapted to minimize longitudinal bowing or lateral deflection of the bar while the hardening flame and associated quench are being applied.

Another object is to adapt the improved method to the flame hardening of bars of circular cross section.

The invention also resides in the novel manner of eliminating the slight longitudinal bow that may remain in a flat surfaced bar after flame hardening by the above method.

Other objects and advantages of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings, in which:

Figure 1 is a fragmentary perspective view of an illustrative bar which may be flame hardened advantageously by the present method.

Fig. 2 is a fragmentary elevational view of the bar and its mounting during the hardening operation.

Fig. 3 is a similar view of a different portion of the bar.

Fig. 4 is a transverse sectional view taken in the plane the line **4—4** of Fig. 3.

Fig. 5 is an enlarged transverse sectional view through the bar and its mounting and detailing the hardening and quenching unit, such view being taken in a plane corresponding to the line **5—5** in Fig. 2.

Fig. 6 is a fragmentary elevational view of the bar illustrating on an exaggerated scale the bowing which may occur as a result of the flame hardening.

Fig. 7 is a diagrammatic elevational view of the longitudinally bowed bar of Fig. 6 showing on a greatly exaggerated scale, the deflections incident to longitudinal bowing and the reverse deflections incident to straightening the bar.

Fig. 8 is a fragmentary elevational view detailing the mode and mechanism for straightening the longitudinally bowed bar of Figs. 6 and 7.

Fig. 9 is a transverse sectional view taken in a plane corresponding to the line **9—9** in Fig. 8.

Fig. 10 is a fragmentary perspective view showing another form of illustrative bar which may be advantageously flame hardened and straightened in accordance with one aspect of the invention.

Fig. 11 is a fragmentary elevational view of the bar of Fig. 10 and its mounting during the hardening operation.

Fig. 12 is a fragmentary elevational view of the bar of Fig. 10 illustrating on an exaggerated scale the bowing which may occur as a result of the flame hardening.

Fig. 13 is a diagrammatic view similar to Fig. 7 but showing on a greatly exaggerated scale the bowing and reverse deflection incident to straightening the bar of Fig. 10.

Fig. 14 is a fragmentary elevational view of the apparatus used in hardening a shaft or boring bar by the improved method.

Fig. 15 is a view similar to Fig. 14 but showing a different position of the parts.

Figs. 16 and 17 are sectional views taken respectively along the lines **16—16** and **17—17** of Fig. 14.

To gain a proper perspective of the instant invention, it will be helpful at the outset to consider the general nature of flame hardening and the specific problems to which the invention is directed. Flame hardening as an art is, of course, not basically new. In general it involves forming a hardened skin or case on a metal part by heating its surface to a metallurgically critical temperature by the direct application of a controlled flame, and then quickly quenching the heated surface by the use of a fluid coolant such as oil or water. For purposes of the present application, the expression "flame hardening" connotes both the flame heating and the quenching associated therewith.

A good grade of machine tool cast iron may, for example, be flame hardened by flame heating one or more of its surfaces to a temperature of from 1425 to 1700 degrees Fahrenheit and then quenching by flooding with an oil coolant having a temperature of 60 to 90 degrees Fahrenheit. This creates a surface skin or case of hard martensitic material which may be approximately ⅛ inch in thickness.

Primarily, the process of the instant invention is directed to the flame hardening of wear surfaces on long, thin metallic structural members, which surfaces, when finished after hardening, must necessarily be straight throughout their length with uncompromising exactness. In flame hardening elongated thin bars on one side without restraining of the bars during the application of heat, it has been found that such bars may take a permanent bow of as much as one inch in eight feet. In the flame hardening process itself, a hardened skin thickness of approximately .125 inch is produced. In certain applications, for example, long thin guide bars used in the guideways of a machine tool, a final thickness of a .100 inch of hardened metal is required on the finished surface. Considering the fact that the hardened surface must be finish-ground throughout its length, the maximum lateral deviation of such way bars along the entire length of the bars, which are several feet long, must not exceed approximately .015 inch. Thus, it is clear that the workpiece, after undergoing the hardening operation, must be straight within very minute tolerances even before the finish grinding operation is instituted because the extent to which residual bows in the hardened surface can be ground down is almost negligible.

Where such exactness is required in the straightness of hardened bars, it is virtually impossible from a practical standpoint to produce a suitably straight bar for grinding by reverse bending of a hardened bar that has previously undergone gross distortion as an incident to the hardening process. In instances in which very extensive straightening must be effected by reverse bending, the straightening procedure itself induces additional bends of a nonuniform character which make the workpiece unacceptable for purposes in which the finished hardened surface must be precisely straight.

Considering the invention from its more generic aspects, a method has been provided for eliminating or

drastically minimizing longitudinal bows in relatively long bar type workpieces incident to flame hardening. This is accomplished by positively maintaining the workpiece in a straight position while the flame hardening proceeds.

Thus, the present invention, as regards the hardening of elongated bars on one side, produces, as a final result, a hardened bar which is precisely straight throughout its length. In carrying out this invention, applicant has minimized the distortion in the first instance by restraining the bar against longitudinal bowing substantially throughout its length during the application of flame to the surfaces to be hardened. As a consequence, the bowing incident to this operation is restricted to a small deviation. In accordance with a further aspect of the invention, such deviation may be accurately removed by carefully controlled reverse bending at a predetermined reduced temperature. In this respect, it will be observed that the slight bow which is removed by the final straightening operation is so slight that secondary bends are not induced as an incident to the straightening action effected.

As the invention is applied to the hardening of stock which is rotated while flames are applied to the exterior surface of the stock, restraining devices are applied to the stock along its length, both ahead of and following the flame. The purpose and need for restraining the rotating stock against longitudinal deviation will be more readily appreciated by taking into consideration the fact that the degree of hardness effected, and thus the tendency of the piece to bow, is inversely proportional to the distance of the flame from the stock. Thus minor eccentricities existing in the rotary mount or the bar due, for example, to the existence of slots or keyways, will initially produce a slight unevenness in the hardness on opposite sides of the bar surface. This unevenness, in turn, increases the initial eccentricities which, of course, further amplifies the unevenness of the hardening effected. This growing eccentricity of the bar will, unless restrained, mature into a marked longitudinal bow in the workpiece by the time the flame has traveled its length. Consequently, in the application of the invention to rotary hardening of bars, the slight nonuniformities of the hardened surface around the bar are prevented from building up to produce perceptible longitudinal distortion of the bar itself.

Referring first to Figs. 1 to 9, the improved method is there illustrated as applied to the flame hardening of flat surfaces **20**, **21** and **22** on a relatively long bar **24** which may be used as the guideway in a machine tool or the like. Such bars are ordinarily composed of cast iron and, to facilitate attachment to a machine tool bed or other support, are made of channel shape with parallel flanges **25** projecting from one side thereof. The flame hardening operation is set up to produce a hardened skin or case of about ⅛ of an inch in depth along the surfaces **20**, **21** and **22**, the hardened area along the surface **22** being approximately equal to that along the surface **21** (Fig. 5).

To harden the surfaces **20**, **21** and **22**, recourse is had to a flame hardening unit **26** which is maintained a predetermined distance from the bar **24** and moved at a uniform rate along the latter progressively from one end of the bar to the other. The hardening unit (Figs. 2, 3, and 5) comprises gas nozzles **28**, **29** and **30** which apply controlled gas flames **28A**, **29A** and **30A** to the surfaces **20**, **21** and **22**, respectively. The hardening unit **26** also comprises a following quench **31**, situated in close proximity to the nozzles **28**, **29** and **30**, and a leading quench **32** situated a substantially greater distance from the nozzles than the quench **31** and in leading relation to the nozzles. The following quench **31** serves to chill and harden the heated metal skin quickly after the flames from the nozzles have elevated it to flame hardening temperature. The leading quench **32** simply floods the bar with coolant ahead of the unit **26** and precludes travel of the heat down the bar in advance of the unit **26**, thus confining the hardening action to a localized, progressively moving area. In addition to the quenches **31**, **32**, a volume quench (not shown) may be used to flood the bar after the hardening unit **26** has passed by, the purpose of such volume quench being to accelerate final cooling of the bar to room temperature.

Both the nozzles and the quenches of the unit **26** may assume a variety of specific forms and the invention is not particularly concerned with such forms. In the present instance, the nozzles **28**, **29**, **30** happen to be of hollow box-like form with perforations or jet holes on their faces opposite the bar **24**. The nozzles are fed a combustible gaseous mixture by means of feed lines **34**. The following quench **31** in this case is a hollow spray head of bridge-like form, being fed with coolant by one or more coolant lines **35**. The quench **32** simply comprises a plurality of open ended coolant conduits.

The invention contemplates minimizing the distortion of the bar **24** by restraining the bar against longitudinal bowing at points spaced along the bar and preferably disposed on opposite sides of the flame hardening unit **26** as the latter is traversed along the bar from one end to the other. In the case of flat surfaced bars, this is accomplished as shown in Figs. 2 and 3 by placing the bar against a straight supporting member or rail **36** and applying pressure to the opposite surface **20** and at spaced points along the bar to clamp the latter firmly against the rail.

As illustrated herein, the rail **36** happens to be of heavy box-like cross section reinforced at intervals with transverse webs. The rail is attached at opposite ends to goose-neck brackets **38** rigidly mounted on a base structure **39**. The rail **36** is longer than the bar to be hardened and along its upper edge is formed with a tongue **40** which fits loosely into the channel of the bar **24**, the flanges **25** straddling the tongue **40** and resting on adjacent shoulders formed in the rail.

While the pressure for holding spaced portions of the bar **24** against the rail **36** may be derived in various way, a series of screw actuated jaw clamps **41** are employed in the present instance. Each clamp comprises two J-shaped claws **42** disposed against opposite sides of the rail and the bar thereon and hooked around the bottom flanges of the rail. At their upper ends the claws are pivotally suspended at **44** on the ends of a cross member **45** which is threaded to receive a screw **46** adapted to be tightened down against a block on the top surface **20** of the bar. One clamp is located at each end of the bar and a number of additional clamps, depending on the length of the bar, are spaced along the intermediate portion of the latter. The bar surface **20** is thus effectually held and straightened against the top of the rail, the latter extending beyond the ends of the bar.

With the bar mounted on the rail **36** and the clamps **41** applied at spaced intervals along the bar, the hardening operation is started by moving the flame hardening unit **26** along the bar begininng at one end and moving to the right as shown in Fig. 2. After the flame hardening unit **26** has passed the end of the bar and before it reaches the position shown in Fig. 3, another clamp is applied adjacent the bar end as shown in Fig. 3. Then, as the flame hardening unit approaches each successive clamp, the screw **46** thereof is loosened to permit release of the claws and removal of the clamp from the bar so that the full area of the surfaces **20**, **21** and **22** may be exposed to the hardening flames and quenches. The clamp is then reapplied to the bar at a point immediately behind the flame hardening unit as a result of which the portions of the bar on opposite sides of the hardening unit in all positions of the latter are clamped firmly against the rail and thus restrained against substantial longitudinal bowing.

After the flame hardening unit **26** has traversed the full length of the bar surfaces **20**, **21**, **22** all of the clamps **41** are retained in tightened condition so as to

maintain pressure on the bar **24** until it has cooled approximately to room temperature. At this time, the clamps are released and removed and the bar will assume a slight longitudinal bow as indicated in Fig. 6. In this condition, the bar is slightly convex when viewed from the top, being high at its center and curving downwardly toward its ends. At the center of the bar and throughout most of its length, this curvature is very gradual and substantially uniform. Toward each end of the bar, however, there is a transition point or zone where the curvature abruptly changes, becoming perceptibly sharper and remaining so down to the very end of the bar. This gives the end portions of the bar a definite downward droop or "curl." The locations of these transition zones are consistent with respect to different bars of identical dimensions. Moreover, such locations do not vary appreciably for bars of different lengths.

In accordance with another aspect of the invention, all curvature in the bar **24** is substantially eliminated and the bar is straightened to a condition well within grinding tolerances by the application of relatively low temperature heat and substantial reverse curvature, the latter being applied by precisely controlled predetermined forces which urge the bar against positive stops. The points of application of such forces are, moreover, selectively determined with a view to the curvature phenomena discussed earlier herein.

Referring more specifically to Fig. 7, it will be noted that the natural deflection at the center of the bar **24** resulting from the flame hardening operation is designated by the reference character d_c. By the same token, the deflection of the bar at the curvature transition zone adjacent each end is designated by the character d_1. In the straightening operation, it has been found empirically that the bar **24** must be subjected to a reverse curvature such that the deflections in the reverse direction are from about 3 to 4.5 times the normal deflections d_1, d_c and that the reverse deflection forces must be applied at the curvature transition zones. In addition, it has been found that in order to make the straightening of the bar permanent rather than temporary, the bar must be warmed uniformly to a temperature of approximately 225 degrees Fahrenheit at the start of the straightening operation, the bar being permitted to cool to room temperature while under the straightening load.

To accomplish the foregoing, the bar is placed with its surface **20** facing upwardly and with its ends resting upon a pair of upstanding gauge blocks E carried by a supporting bed **50** (Fig. 8). At the center of the bar between its underside and the bed **50**, there is placed a gauge block C and at each curvature transition zone there is located another gauge block I, also situated between the underside of the bar and the supporting bed **50**. The blocks C and I have lesser vertical dimensions than the blocks E. The difference in vertical dimension between the blocks E and I is equal to the amount of reverse deflection to be applied at the two transition zones and the difference in vertical dimension between the blocks C and E is equal to the reverse deflection at the center of the bar. The bar is then warmed uniformly throughout to a temperature of approximately 225 degrees Fahrenheit and the straightening forces are applied, deflecting the bar reversely against the gauge blocks E, I, and C as shown in Fig. 8. Such forces may, for example, be of the order from 35,000 to 45,000 pounds, depending upon the length of the bar, the shorter bars requiring heavier forces than the longer bars.

For the purpose of applying the straightening forces, resort is had to a pair of hydraulic jack units (Figs. 8 and 9). In the present instance, each such unit comprises a pair of upstanding struts **51** mounted in straddling relation with the support bed **50** and slidable there along, such struts having cleat portions **52** for engaging the bottom faces of bedways **54** and also having rollers **55** for facilitating sliding along the bedways. The struts **51** are spanned by a pair of spaced apart strong-backs **56** bolted or otherwise rigidly secured thereto. Situated between the strongbacks **56** and adjustably held in place by a pair of massive retainer nuts **58** is a hydraulic jack cylinder **50** having at its lower end an extendable plunger **60**. The plunger **60** is adapted to apply a straightening force to the top surface **20** of the bar through a spacer block **61**. Pressure fluid is supplied to the jack **59** via a conduit **62** from a manually actuated source **64**. The latter may conveniently be mounted on one of the struts **51** and carries an accurately calibrated dial gauge **65**, thereby enabling the operator to apply with nicety and precision a predetermined straightening force on the bar **24**. Pressure fluid may be released from the jack cylinder **59** by means of an appropriate lever valve **66**, thereby releasing the jack plunger **60**.

The bar is held in the reversely bowed condition as shown in Fig. 8 until it has cooled approximately to room temperature. When the straightening forces are released by unloading the jack plungers **60**, the bar will return automatically to a substantially straight condition. In practice, it has been found that any distortion which remains is very slight and is distributed evenly over the entire length of the bar. With such a small distortion, it is possible to finish grind the bar surfaces **20, 21, 22** to perfect flatness while leaving a hardened surface layer of approximately $\frac{3}{32}$ of an inch as is desirable at all points along such surfaces.

The method just described has been found eminently satisfactory for hardening cast iron way bars of the shape shown in Fig. 1 having the following dimensional ranges and characteristics:

Length	feet	6 to 14
Top width	inches	4 to 10
Height	do	2¼ to 3¼
Distance from curvature transition zones to ends of bar	inches	14 to 20
Straightening forces	pounds	35,000 to 45,000
Depth of case on hardened surfaces	inch	⅛
Hardness of case, Scleroscope		75

Analysis of cast iron in bars—

Combined carbon	.90 to 1.00
Total carbon	3.10 to 3.20
Nickel	Trace
Silicon	1.50 to 1.60
Manganese	1.00
Sulphur	.10 to .20
Phosphorous	.20 to .25

By way of specific example, the method just described has been utilized to produce a cast iron way bar having a cross sectional shape corresponding to that shown in Fig. 1 and having flame hardened top and side surfaces, the hardened bar being straight to an extent well within the grinding tolerances discussed earlier herein. The principal characteristics of this bar were as follows:

Length	10 feet.
Normal deflection at center, d_c	.250 inch.
Reverse deflection at center	.750 inch.
Normal deflection at curvature transition zones, d_1	.155 inch.
Reverse deflection at curvature transition zones	.500 inch.
Distance of curvature transition zones from bar ends	18 inches.
Straightening forces	39,000 pounds at each jack.

Various theoretical explanations may be devised to account at least in part for the bowing and straightening of the bar incident to carrying out the method disclosed above. However, on the basis of present observations, it is believed that the flame hardened skin on the top and side surfaces of the bar undergoes a slight increase

in length, bowing the bar longitudinally as described above. Due perhaps to the existence of less restraint and clamp leverage at the ends of the bar, the end portions of the bar assume a sharper downward curvature than the intermediate portion. The reverse deflection procedure is believed to subject the unhardened lower portion of the bar to plastic deformation so as to increase its length by an amount just sufficient to offset the increase in length of the hardened portion. This is borne out by actual measurements of the overall length of bars processed in accordance with the method disclosed herein, such measurements being taken prior and subsequent to flame hardening and straightening. These measurements show an average increase in overall length of the finished bar of from 1/16 to 1/8 of an inch.

Turning now to Figs. 10 to 13, there is shown still another type of workpiece **70** which may be flame hardened and straightened in accordance with an aspect of the present invention. This workpiece, shown in Fig. 10, is a rail-like cast iron structural shape of inverted V-shaped cross section and serves as a floor mounted auxiliary runway or guide rail for a machine tool. The piece **70** may have a plurality of transverse stiffener webs (not shown) and a series of leveling bosses **71** along its base. Running along the top of the piece **70** is a tongue or key **72** similar to the key **40** on the rail **36**.

In this case, flame hardening is applied only to the top surface **74** of the key **72**. This may be accomplished by mounting the piece **70** on the goose-neck brackets **38** of the support **39** in place of the rail **36**. The ends of the piece **70** are bolted to the brackets **38** at the end bosses **71** but the piece is otherwise left unclamped. The surface **74** is then flame hardened by means of a flame hardening unit **75** (Fig. 11) similar to the unit **26** described earlier herein but adapted to act only on the top surface **74** of the piece **70**. The unit **75** comprises a hardening flame nozzle **76**, a following quench **78**, and a leading quench **79**. When the unit **75** is traversed at a uniform rate over the length of the surface **74**, the latter becomes suitably flame hardened. In this instance, however, the workpiece **70** assumes a longitudinally bowed condition in a direction opposite to that of the bar **24**. As shown in Fig. 12, this curvature is substantially uniform over the length of the bar and makes the surface **74** concave. The deflection incident to such curvature is a maximum at the center of the piece and is designated "d_c."

This deflection may be virtually eliminated and the piece **70** straightened to within grinding tolerances by the following procedure. The piece **70** is removed from the brackets **38** on completion of the flame hardening step, is then inverted and transferred to the straightening support **50**. The piece is then warmed to a temperature of about 300 degrees Fahrenheit throughout. By means of an appropriate arrangement of gauge blocks and a hydraulic jacket unit, a predetermined straightening force is applied to the center of the piece (Fig. 13), deflecting the same reversely to an amount of about 3 to 4.5 times the normal center deflection "d_c." The piece **70** is then permitted to cool approximately to room temperature and the straightening force is relieved, whereupon the piece assumes a straight condition.

This aspect of the novel method has been applied to pieces such as shown in Fig. 10, in lengths of from 6 to 14 feet, and with straightening forces of 25,000 to 45,000 pounds. The normal deflection "d_c" of such pieces range from 1/16 to 3/16 of an inch and the reverse deflections range from 3/16 to 11/16 of an inch.

The improved method as described above may also be utilized advantageously in the flame hardening of bars of round cross section as illustrated in Figs. 14 to 17, which bars may, as shown, be slotted longitudinally as in the case of a boring bar for a machine tool. Such bars may be made of any suitable metal, for example, cast iron or steel, depending on the requirements of their use. The bar or shaft **80** is supported at one end in a tailstock **81** and at the other end is piloted onto and drivingly coupled in any suitable way to a face plate **82** by which the shaft is rotated in synchronism with a lead screw **83** for advancing a carriage **84** along the ways **85** of a bed **86**. Supported on the carriage is a flame hardening unit somewhat similar to the unit **26** and comprising a series angularly spaced flame heating nozzles **87**, a following quench **88**, and a leading quench **89** (Figs. 14, 15 and 17). The nozzles **87** are shown diagrammatically in Figs. 14 and 15 but more accurately in Fig. 17, being disposed equidistantly from the shaft surface so that each unit area of the latter is heated uniformly as the carriage progresses from one end of the shaft to the other. The following quench is in the form of a spray ring **88** from which streams of quenching fluid are directed against the shaft surface at a point spaced closely behind the advancing flames **87A**. The leading quench **89** comprises a series of open-ended conduits adapted to direct coolant against both the bar and its bearing support on the carriage.

To achieve the restraining action above referred to and prevent bowing of the shaft **80** that would cause running out of the shaft and uneven heating of its surface by the flames, spaced portions of the shaft on opposite sides of the flames **87A** may be supported in split bearings **90** and **91** which are adapted to be shifted along the shaft. Herein, the upper semicircular part **92** of the bearing **91** is pivoted at **94** on a bracket **95** which may be supported on the carriage **84** but which is, in this instance, supported on the bedways **85** (Fig. 16) and slidable along the latter. The bracket is keyed to the bed by lugs **96** and held down against the top of the ways by a cross member **97** underlying the ways.

To clamp the bearing closed, the other end of the part **92** may be forced downwardly by a toggle comprising links **98** and **99** pivotally connected to each other at **100** with the other end of the shorter link hinged on the bracket **95** at **101**. The elongated link **98** carries a pin **102** at its upper end adapted to seat releasably in a notch **103** and apply the clamping pressure as the lower end of the lever is swung inwardly as shown in full in Fig. 16. By moving the handle outwardly, the clamp may be released and the bearing opened as shown in phantom (Fig. 16).

The bearing **90** is of the same general construction and mounted on a bracket **104** bolted to the traveling carriage **84** at a point spaced ahead of the flame nozzles **87**. The part of the shaft ahead of the bearing **90** may be supported in a removable bearing **106** of the same construction as the bearing **91**.

To harden a shaft using the apparatus above described, opposite ends of the shaft are supported in the tail and head stocks and, with the carriage moved to the extereme right hand end of the shaft (oriented as viewed in Fig. 14), the bearing **90** is assembled around the adjacent shaft end and the bearing **106** located adjacent the opposite end of the shaft.

With the shaft rotating at the proper speed and with the flames playing on the right end of the shaft, the carriage is coupled to the rotating lead screw causing the bearing **90** and the flame hardening unit to advance slowly to the left along the shaft. As the flame hardening unit has passed a short distance over the shaft end, the bearing **91** is slid along the bedways and over the shaft end thus providing the desired lateral support for the shaft at a point spaced behind the flame hardening unit. This bearing is slid manually along the bed as the flame hardening unit advance continues so as to maintain the desired relatively short space between the flame hardening unit and the bearing **91** approximately constant throughout the entire hardening operation. The bearing **106** is removed in the final part of the operation as the bearing **90** approaches the end of the shaft.

By thus restraining lateral bowing of that part of the shaft immediately adjacent the area of application of the flame and the quenches, it is possible to avoid objection-

able run-out of the shaft and uneven heating and hardening of the shaft surface. For the same reason, the shaft remains undistorted during hardening.

It is to be understood that the methods disclosed herein are to be taken as preferred embodiments of my present invention, and that various modifications, alternatives, and equivalents may be practiced without departing from the spirit of my invention or the scope of the subjoined claims.

What is claimed is:

1. The method of flame hardening a longitudinal surface on a cast iron way bar or the like, said method comprising the steps of clamping the bar against a longitudinal support by means of a plurality of clamps longitudinally spaced along the length of the bar, passing a hardening flame progressively along said longitudinal surface and simultaneously directing a fluid quench on said surface in advance of and behind said flame, the quenches being situated in proximity to said flame, progressively removing individual ones of said clamps as said flame approaches and restoring said clamps after said flame has passed by, permitting said bar to cool to room temperature while still clamped, releasing said clamps and allowing said bar to assume a longitudinally bowed position, setting said bar on another support where it has freedom to bow reversely, heating said bar uniformly to a temperature of approximately 225 degrees Fahrenheit, applying a predetermined mechanical pressure at intermediate points on the bar to put a reverse bow in the same having a deflection about three times greater than that of the first mentioned longitudinally bowed position and maintaining said pressure until said bar has cooled, and relaxing said pressure permitting said bar to spring to a straight condition.

2. The method of flame hardening an elongate cast iron bar comprising the steps of clamping the bar to a straight support, flame hardening a plurality of exposed longitudinal surfaces on the said bar progressively while said bar is in clamped position, maintaining said bar in clamped position against said support until said bar has cooled approximately to room temperature, unclamping said bar and allowing it to bow convexly at its center and downward toward its ends so as to make a normal deflection, placing said bar on another support and heating the bar to a temperature of approximately 225 degrees Fahrenheit, applying to said bar a reverse deflection of from about 3 to 4.5 times said normal deflection while on said other support by applying bending loads between the center and the ends of the bar, allowing the bar to cool to room temperature while under load, and removing said bending loads whereby said bar springs to a straight condition.

3. A method of flame hardening an elongate cast iron bar comprising the steps of, clamping the bar to a straight support, flame hardening a plurality of exposed longitudinal surfaces on said bar progressively while said bar is in clamped position, maintaining said bar in clamped position against said support until said bar has cooled approximately to room temperature, unclamping said bar and allowing it to assume a convex longitudinal bow substantially uniform over its intermediate portion but becoming abruptly sharper adjacent the ends of the bar, such changes taking place at curvature transition zones, placing said bar on another support and heating the bar to a temperature of approximately 225 degrees Fahrenheit, applying a reverse curvature having a deflection about three times greater than that of said convex longitudinal bow to said bar while on said other support by applying mechanical loads at said transition zones between the center and the ends of the bar, allowing the bar to cool to room temperature while under load, and removing said mechanical loads whereby said bar springs to a straight condition.

4. The method of flame hardening a cast iron bar comprising the steps of, flame hardening a longitudinal surface of said bar while restraining the same against distortion, removing the restraint on said bar when the same has cooled to room temperature whereby said bar assumes a longitudinal curvature as a result of a dimensional change in the hardened portion, heating said bar to a temperature of approximately 200 to 300 degrees Fahrenheit, loading the bar mechanically until it assumes a reverse curvature having a deflection about three times greater than that of said first-named longitudinal curvature so as to subject the unhardened portion of said bar to plastic deformation elongating the same by an amount commensurate with the dimensional change in the hardened portion of the bar, and releasing the loading on said bar when the same has cooled to room temperature whereby said bar assumes a straight condition.

5. A method of flame hardening a relatively long piece of cast iron such as a rail or bar, said method comprising the steps of, flame hardening a longitudinal surface of said piece whereby the latter assumes a longitudinal curvature having a maximum normal deflection, heating the piece to a temperature of approximately 200 to 300 degrees Fahrenheit, loading the piece mechanically until it assumes a reverse curvature and a reverse deflection within about 3 to 4.5 times said maximum normal deflection, and releasing the loading on the piece when the same has cooled to room temperature whereby said piece assumes a substantially straight condition.

6. The method of flame hardening a rail-like workpiece of cast iron having a cross section of inverted V-shape, said method comprising the steps of, flame hardening a longitudinal upper surface of said workpiece along its total length while restraining only the ends of the same, removing the restraint on said ends after said surface of said workpiece has been flame hardened whereby said workpiece assumes a longitudinal curvature as a result of a dimensional change in the hardened portion thereof, inverting said workpiece and placing the same on a support, heating said workpiece to a temperature of approximately 300 degrees Fahrenheit, mechanically loading the workpiece at its center until it assumes a reverse curvature having a deflection about three times greater than that of the said first-named longitudinal curvature so as to subject the unhardened portion of said workpiece to plastic deformation elongating the same by an amount commensurate with the dimensional change in the hardened portion of the workpiece, and releasing the loading on said workpiece when the same has cooled to room temperature whereby said workpiece assumes a straight condition.

7. The method of flame hardening a rail-like workpiece of cast iron having a cross section of inverted V-shape, said method comprising the steps of, flame hardening a longitudinal surface of said workpiece while restraining only the ends of the same, removing the restraint on said ends after said surface of said workpiece has been flame hardened whereby said workpiece assumes a longitudinal curvature having a maximum normal deflection at the center of the workpiece, inverting said workpiece and placing the same on a support, heating said workpiece to a temperature of approximately 300 degrees Fahrenheit, mechanically loading the workpiece at its center until it assumes a reverse deflection within the range of about 3 to 4.5 times said normal deflection, and releasing the loading on said workpiece when the same has cooled to room temperature whereby said workpiece assumes a straight condition.

8. A method of flame hardening a portion of the surface of an elongated cast iron way bar or the like along the length of the bar prior to fixing the way bar on a way bed which comprises the steps of clamping the bar against a straight longitudinal support at a plurality of regions along the length of the bar, including its ends and at least one intermediate region with said surface portions exposed, passing a hardening flame progressively along said longitudinal surfaces for hardening them to a thickness of approximately ⅛ inch, simultaneously directing

a fluid quench to said surface behind said flame, progressively removing individual ones of the clamps as the flame approaches the same and restoring said clamps after the flame has passed, permitting the bar to cool to an ambient temperature, releasing the said clamps and allowing the bar to assume a longitudinally bowed position, applying heat slowly to the hardened surface of the bar to raise its temperature to approximately 225° F., shimming the bar with respect to support surfaces at its ends and intermediate points to support the bar in a reversely bowed position with about three times greater deflection than that of said first-named bowed position, clamping the bar against said shims to bow the bar and maintain the clamps until the bar has cooled, and releasing said clamps to permit the bar to return substantially to a straight condition.

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