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R. F. ARNOLDY

2,428,825

METHOD OF CONTROLLING DISTORTION, STRAIGHTENING DISTORTED
OBJECTS, AND/OR ALTERING THE SHAPE OF METAL OBJECTS

Filed Feb. 27, 1941

2 Sheets-Sheet 1

Fig. 1.

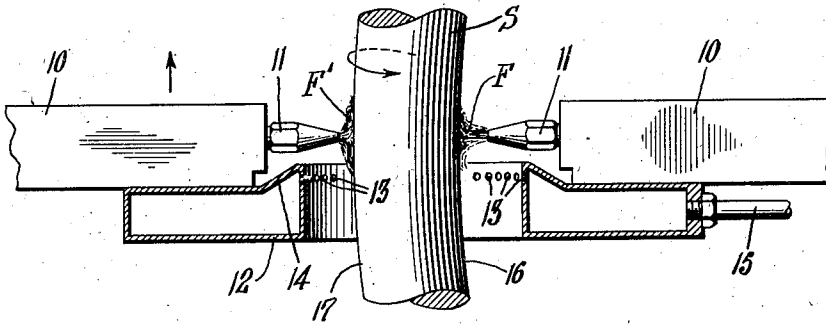
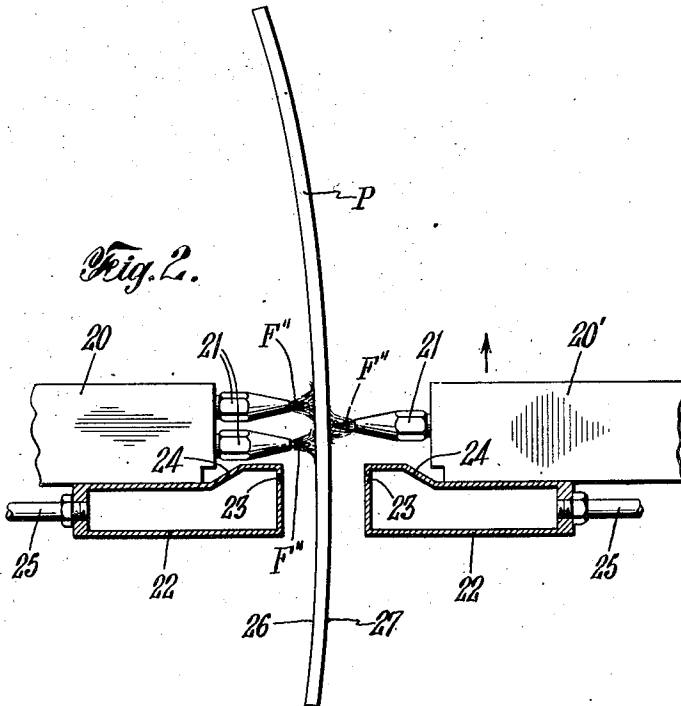


Fig. 2.



INVENTOR
ROMAN F. ARNOLDY
BY

R. F. Arnoldy
ATTORNEY

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2 Sheets-Sheet 2

Fig. 4.

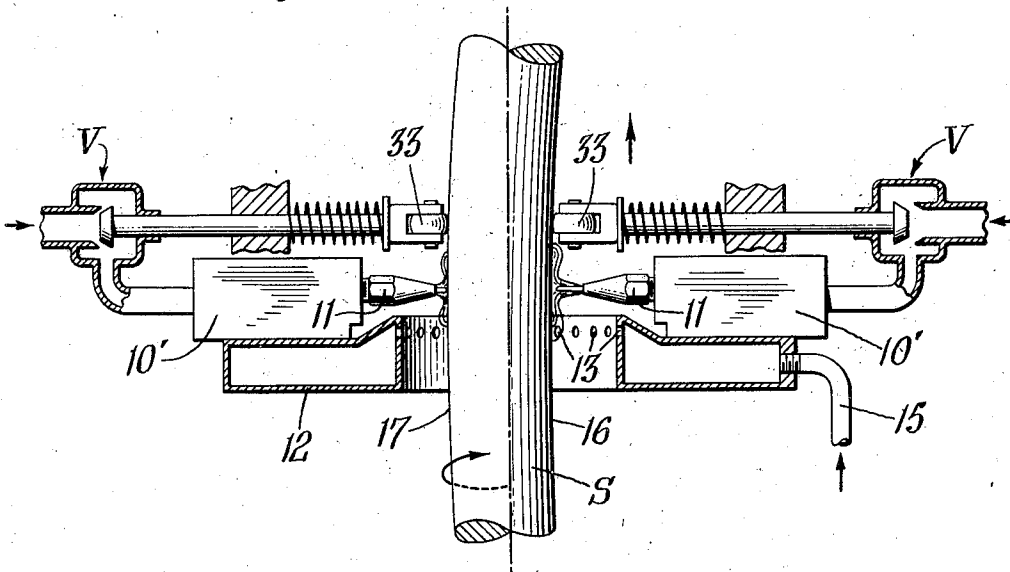
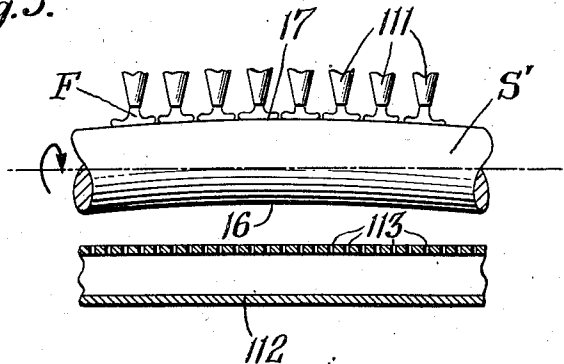


Fig. 3.



INVENTOR
ROMAN F. ARNOLDY
BY *R. Greenwald*
ATTORNEY

UNITED STATES PATENT OFFICE

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METHOD OF CONTROLLING DISTORTION,
STRAIGHTENING DISTORTED OBJECTS,
AND/OR ALTERING THE SHAPE OF METAL
OBJECTSRoman F. Arnoldy, Houston, Tex., assignor to
The Linde Air Products Company, a corpora-
tion of Ohio

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1

This invention relates to the control and/or alteration of the shape of metal objects, including the control of distortion and the straightening of distorted metal objects by heating, and also to the heat treatment or surface hardening and simultaneous straightening of distorted metal objects, such as shafts, rounds, plates, bars, and the like, by differential heating. The principles of this invention are particularly applicable to flame straightening and simultaneous flame hardening, flame strengthening, or other flame treatment, wherein differential heating and/or hardening is effected by high temperature heating flames, such as those produced by a combustible mixture of oxygen and acetylene.

Control of distortion is a problem of fundamental importance in the production of machine parts. Distorted shafts do not run true, tending to whip in their bearings, while distorted surfaces on plates, bars, or the like, cause obvious difficulties in the assembly and operation of machines. Furthermore, in the manufacture of machine parts to only fairly close tolerances, the effects of distortion have heretofore been overcome only by straightening in presses, by grinding, or by machining—each an expensive operation—to restore the desired straightness or dimensions. Distortion is also a problem of particular importance in localized surface hardening, or other heat treating operations. Often, a shaft or other machine part cannot be finished to the ultimately desired dimensions prior to hardening or heat treatment, because an allowance must be made for metal to be removed later in overcoming the effects of distortion. Moreover, a hardened surface normally cannot be machined easily, and an expensive grinding operation is usually the only manner in which hardened metal can be removed.

Distortion is not always a warpage, or convexity or concavity, of what should be a straight surface. For instance, a relatively thin tubular article, such as a pump liner, may be distorted along a cylindrical element, may become out-of-round, or may become larger or smaller in diameter though still remaining perfectly round. Also, a metal article which is being flame strengthened at a fillet or other point of stress concentration, may become distorted at or adjacent the fillet, or elsewhere. In other words, distortion is not always uni-dimensional, but may be bi-dimensional, or even tri-dimensional.

Among the objects of this invention are: to provide a novel method of controlling and/or altering the shape of a metal object by heating; to

2

provide a novel method of straightening distorted metal objects by heating; to provide a method of simultaneously straightening and surface hardening a metal article, by which previous distortion may be minimized or eradicated and any tendency toward new or further distortion is automatically obviated; to provide a method of flame hardening, flame strengthening, or otherwise locally treating a surface of a metal object, and simultaneously eradicating or minimizing previous distortion and automatically preventing new or further distortion; to provide a novel method of straightening, or simultaneously surface hardening and straightening, a distorted cylindrical article such as a shaft; to provide a method of surface hardening or heat treating, and simultaneously straightening, a distorted or warped plate, bar, or the like; to provide a method of flame strengthening or surface hardening selected surface portions, and simultaneously straightening, a distorted metal article having fillets or other surface configurations at which stresses tend to concentrate; and to provide such methods which may be carried out easily and effectively by heating. Other objects and novel features of this invention will become apparent from the following description and accompanying drawing, in which:

Fig. 1 is a vertical sectional view, illustrating the straightening of a distorted shaft in accordance with this invention, the amount of distortion of the shaft being exaggerated for clarity of illustration;

Fig. 2 is a side elevation, partly in vertical section, illustrating the straightening of a distorted plate in accordance with this invention, the amount of distortion of the plate being exaggerated for clarity of illustration;

Fig. 3 is a fragmentary diagrammatic view illustrating a modified manner of straightening a distorted shaft according to the invention; and

Fig. 4 is a diagrammatic vertical sectional view illustrating the straightening of a distorted shaft in still another modified manner according to the invention.

This invention will first be explained in connection with the simultaneous surface hardening and straightening of a distorted shaft, or similar cylindrical article formed of hardenable metal. In accordance with this invention, successive longitudinal portions, or circumferential zones, of the shaft are locally but differentially heated to a depth which is primarily dependent upon the amount of distortion, a greater amount of heat being applied to a side of the shaft that

3

is concave relatively to the desired straightness than to the opposite side of the shaft which is convex relatively to the desired straightness to heat the concave side to a greater depth. It is necessary that the depth to which the concave side of the shaft is heated shall be appreciable in relation to the diameter of the shaft.

The successive heated surface portions are cooled relatively rapidly, and preferably immediately after heating, to prevent flow of residual heat and localize the straightening operation, as well as to effect surface hardening. When the surface on the concave side is heated to a higher temperature than the surface on the convex side—as will normally be the case when high temperature heating flames or electric arcs are utilized as the source of localized high temperature heat—the temperature of the surface on the concave side will be slightly or even greatly above the critical range, depending upon the amount of distortion to be removed. The substantially immediate cooling of the heated surface portions has a further advantage, in that grain growth—which occurs in a much shorter time when ferrous metal is held at temperatures considerably above the critical—is inhibited.

It will be understood, of course, that reference to convex and concave sides of the shaft does not necessarily refer to a shaft which is bowed or bent over its entire length, but also refers to local portions of the shaft which are bowed or bent. Thus, it is possible to straighten a shaft, one longitudinal portion of which is bowed or bent in one transverse direction and other portions of which are bowed or bent in other transverse directions. For example, one portion may have its greatest convexity at 0° and its greatest concavity at 180°, another portion may be bowed in a reverse direction, having its greatest convexity at 180° and its greatest concavity at 0°, while other portions may have their greatest concavity at 90°, 270°, or any other angle around the circumference of the shaft. All such variations in the circumferential position of convexity and concavity of different longitudinal portions of the shaft may be automatically compensated for by the method of this invention.

To carry out the method of this invention, it is preferred to use high temperature heating flames, preferably those produced by a combustible mixture of gases, such as a combustible mixture of oxygen and acetylene. However, it will be understood that other sources of localized high temperature heat, such as electric arcs or an electric-induction heating element or elements carrying high frequency current, may be used.

To straighten a distorted shaft, or to straighten and simultaneously surface harden a distorted shaft composed of hardenable metal, apparatus adapted to employ "mushroom-type" heating flames may be used, such as disclosed in my Patent No. 2,310,384, issued February 9, 1943, with certain changes as hereinafter indicated. As illustrated in Fig. 1, such apparatus may include a ring of blowpipe heads 10 having tips 11 provided with outlets adapted to direct heating flames F and F', and a ring-shaped cooling medium header 12 mounted below the blowpipe heads and provided with outlets 13 adapted to direct a plurality of cooling liquid jets, against adjoining circumferential surface zones of a shaft S which is rotated and moved downwardly. The header 12 is provided with an upwardly extending section 14 which permits the quenching out-

4

lets 13 to be located closely adjacent tips 11 from which the heating flames are directed. The cooling medium, supplied through a tube 15, is preferably water, although it may be desirable to use other types of cooling medium, such as oil or air, particularly when the shaft being treated is composed of certain types of steel, such as those commonly termed "air-hardening."

To carry out the method of this invention, and to provide "mushroom-type" heating flames, the blowpipe heads 10 are moved inwardly toward the shaft a sufficient distance so that, as the shaft rotates, the concave side 16 of a distorted portion of the shaft will intercept a higher rate of heat transfer zone of the heating flames, and the convex side 17 of the distorted portion will intercept a lower rate of heat transfer zone of the heating flames. It has been ascertained that a greater transfer of heat to a surface occurs when the surface intercepts an oxy-acetylene heating flame at a zone within the length of the inner cone—preferably at a distance of 60% to 80% of the length of the inner cone measured outwardly from its base adjacent the orifice from which the heating gas discharges—than when the surface intercepts the flame at the point of highest temperature, which lies a short distance beyond the outer end of the inner cone. Also, the transfer of heat becomes less when the surface intercepts the heating flame at a zone lying between the orifice from which the heating flame is discharged and the zone of maximum heat transfer. Thus, the heating flame F is intercepted at a zone of higher rate of heat transfer by the concave side 16, while the heating flame F' is intercepted at a zone of lower rate of heat transfer, closer to the orifice from which flame F' issues, by the convex side 17. The spreading or "mushrooming" of the heating flames, characteristic of inner cone interception, is indicated on the drawing, and will be recognized by those carrying out the method of this invention. It will be understood, of course, that as the shaft S rotates, the flame F will be intercepted by the convex side 17, as it comes around, at substantially the same zone as is shown for flame F', i. e., the position of concave and convex sides 16 and 17, and the amount of interception of flames F and F', will be reversed from that shown in the drawing. It will also be understood that a plurality of heating flames, spaced circumferentially of the shaft, are preferably used.

When heated in the foregoing manner, each successive portion of the concave side of the shaft receives a greater amount of heat than successive portions of the convex side, and successive portions of straight sides between the convex and concave sides, if present, receive an intermediate amount of heat. As a result of such differential heating, the depth to which heat penetrates on the concave side is greater, and a greater volume of metal is heated on the concave side. Of course, care must be taken to center the shaft accurately, to obtain the best results. Also, it is desirable to use relatively short, stubby flames, so that a slight variation in interception will produce a relatively large variation in the amount of heat transferred.

A particular advantage of the above and similar set-ups is that control of distortion is automatic—that is, over a straight or undistorted portion of the shaft there is no differential in case produced, whereas over any distorted portion the differential in depth of case produced is proportional to the amount of distortion, due

to differences in the amount of interception of the heating flames. Thus, previous distortion is minimized or eradicated, and any tendency toward new or further distortion is automatically obviated.

In so carrying out the method of this invention, there are several variable factors which, of course, may be adjusted in accordance with the shaft or object being treated. Among these are the permissible limits of case depth and distortion, the surface hardness desired, the size and number of heating flames, the proportions of the constituents of the combustible mixture, the distance between the discharge orifices and any specific portion of the shaft, the speed of rotation of the shaft, the relative speed of traverse of the heating flames and cooling jets with respect to the surface of the shaft, and others. However, it will be found that adjustment of such variables to values which will give the desired results can easily be made by those skilled in the art. As an example of an operation in which a distorted shaft was simultaneously surface hardened and straightened to a point within permissible limits, but not as a limitation upon the scope of this invention, the following is illustrative:

The shaft to be treated was $1\frac{1}{4}$ in. in diameter and 3 ft. in length, was formed of SAE-1045 steel, and the greatest initial distortion was 0.185 in., measured by moving a $\frac{1}{4000}$ in. dial indicator along the shaft when mounted between centers on a lathe. Four heating heads, each provided with two tips having outlets of No. 56 drill size, were positioned 90° apart around the shaft, the ends of the tips being spaced $\frac{3}{8}$ in. from the mean surface of the shaft. A conventional blowpipe supplied a combustible mixture of oxygen and acetylene to the four heads, equal amounts of oxygen and acetylene being supplied at an oxygen pressure of 35 lbs. per sq. in. gage. Water was supplied to a ring quench block mounted directly beneath the four blowpipe heads, and provided with a plurality of outlets for discharging jets of water, at 4 lbs. per sq. in., against successive circumferential heated surface zones. The shaft was mounted in a vertical position and rotated at approximately 300 R. P. M., while a relative longitudinal speed of traverse of approximately 5 to 6 in. per min. was effected. When the entire surface of the shaft had been hardened, by heating and cooling successive circumferential zones beginning at the lower end of the shaft, it was found that the distortion had been reduced to 0.048 in., a reduction of 74%. The average surface hardness was 73 scleroscope, and the average depth of the hardened case was $\frac{1}{8}$ in., the case depth being approximately $\frac{1}{2}$ in. over the lowest initially concave and $\frac{3}{8}$ in. over the highest initially convex portions—a differential in case depth of $\frac{1}{8}$ in. thus being produced.

In case the desired amount of distortion is not removed by the first treatment, the treatment can be repeated to remove the total desired amount of distortion in steps, or by increments, since the change in shape or removal of distortion in each step is permanent, and the results of a plurality of treatments are cumulative to a certain extent. Of course, a relatively greater amount of distortion sometimes can be removed in a single treatment, by reducing the relative speed of longitudinal traverse, using more intense or a greater number of heating flames, or altering some other condition or conditions, to obtain a greater depth of case and a greater dif-

ferential in depth of case between the lowest concave and highest convex portions.

The method of this invention may also be utilized in straightening a distorted shaft without hardening. To remove the same amount of distortion, the depth of heating and the differential in depth of heating concave and convex portions normally are substantially the same as when the surface is hardened, depending, of course, on the influence of possible differences in the coefficients of expansion and elasticity, tensile strength, or other properties of the metal of which the article being treated is composed. In any event, simultaneous straightening and hardening of one article will provide a clear basis for straightening another article having substantially the same relative amounts of distortion. Also, when the shaft to be treated is composed of non-hardenable metal, as for example, very low-carbon steel or non-ferrous metal or alloy, the temperatures to which the various surface portions are heated may be based upon the temperatures for a corresponding shaft composed of hardenable metal.

However, when it is desired to straighten but not surface harden a shaft composed of hardenable metal, it is desirable to limit the temperature to which any portion of the surface is heated to the critical range. For a shaft similar to one which has been straightened and hardened, but having a lesser amount of distortion and consequently requiring a lesser depth of heating, the surface temperatures can be reduced by increasing the relative rate of traverse of the heating flames. An example of the foregoing is the treatment of an SAE-1015 steel shaft $1\frac{1}{4}$ in. in diameter and 3 ft. long, but having a maximum distortion of only 0.015 in. A set-up similar to that previously described, in connection with treatment of an SAE-1045 steel shaft of the same size, was employed, except that the ends of the tips were spaced $\frac{3}{8}$ in. from the mean surface of the shaft, and a relative speed of traverse of 7.5 in. per min. was effected. At the conclusion of treatment, it was found that the maximum distortion had been reduced to 0.003 in., a reduction of 80%.

For a shaft composed of hardenable metal having a greater amount of distortion, but which is not to be hardened, it may prove adequate to apply a lesser amount of heat for a greater length of time, such as by reducing the number or size of the heating flame and reducing the relative rate of traverse, in order to heat to the desired depths without heating any portion of the surface to a temperature sufficient to cause hardening upon cooling. Or, which is usually preferable, the total amount of distortion can be overcome by repeating the treatment several times, since, as pointed out previously, the results of several treatments are cumulative.

The principles of this invention also may be utilized in straightening, or simultaneously surface hardening and straightening, a distorted metal plate, bar, or the like. A distorted metal plate having two oppositely disposed, parallel, normally plane surfaces, such as plate P of Fig. 2, may be treated by traversing each of the opposite surfaces with a set of heating flames F'', following closely by cooling jets discharged from a pair of headers 22. Both sets of heating flames and cooling jets are preferably closely spaced, extending across the width of each surface, and each set is preferably disposed directly opposite the other. Heating flames F'', which are discharged from suitable orifices in tips 21, in turn mounted in heads 20, are shown in the position customarily

used prior to this invention—i. e., intercepted by the surfaces 26 and 27 at the points of highest temperature, just beyond the ends of the inner cones. Flames F'' as positioned in Fig. 2, not only illustrate how the principles of this invention may be applied with heating flames spaced as employed prior to this invention, but also illustrate a slightly different manner of accomplishing differential heating. For straightening, or simultaneously straightening and hardening, plate P in the manner shown in Fig. 2, head 20 is provided with two rows of tips 21, extending transversely of plate P, so as to heat relatively concave side 26 of the plate to a greater depth than the relatively convex side 27, against the latter of which only one row of heating flames is directed from the tips carried by head 20'. Heads 20 and 20' extend transversely the full width of plate P, and constitute an example of means for discharging relatively wide heating flames substantially the width of plate P. Also, heads 20 and 20' may be reciprocated transversely during relative longitudinal movement of plate P, and heads 20 and 20' and header 22, in the direction of the arrow. During such relative longitudinal movement, successive portions of concave surface 26 will be heated to a greater depth than the successive portions of convex surface 27, and such successive portions of each surface will be cooled by jets discharged through outlets 23 in headers 22. Similar to header 12 of Fig. 1, each of headers 22 is provided with an upwardly extending portion 24 which permits the cooling outlets 23 to be located closely adjacent the heating flames. Each header 22 is supplied with a cooling medium, preferably water, through a tube 25.

It will be understood, of course, that differential heating of plate P, or any other similar article, may be accomplished in a manner similar to that illustrated in Fig. 1, in connection with the treatment of shafts, by positioning the heating flames so that convex portions of either surface, will intercept lower rate of heat transfer zones, while concave portions of either surface, will intercept higher rate of heat transfer zones.

When the metal of which the plate is composed is hardenable, and the plate is to be straightened but not surface hardened, it may be necessary to adjust the number or size of flames and the relative rate of traverse, to limit the temperature to which various surface portions are heated, as before. Or, the total amount of distortion may be overcome by several treatments, the results of which are cumulative, as pointed out previously.

A distorted bar, normally square or rectangular in shape, may be straightened by heating opposite sides. The set-up employed may be substantially the same as that utilized in connection with the treatment of plates. Other distorted metal objects having normally substantially flat surfaces may be straightened, or simultaneously straightened and surface hardened, in a similar manner.

There are several alternative methods of accomplishing differential heating to effect straightening, any of which may be used if desired. For instance, as indicated diagrammatically in Fig. 3, a distorted shaft S' may be rotated beneath a series of heating flame nozzles 111 which extend longitudinally from one end of the shaft to the other and which are spaced closely together so that the flames F tend to overlap. The heating flames are so positioned, as explained in the description of the procedure illustrated in Fig. 1, that convex surface portions 17 will intercept lower rate of heat transfer zones of the flames,

and concave surface portions 16 will intercept higher rate of heat transfer zones of the flames. As soon as the surface of the shaft is heated to the desired temperature, a cooling spray or a plurality of jets of cooling medium projected from orifices 113 in an elongated header 112 may be directed against the surface, or the shaft may be dropped into a bath of cooling medium.

Again, differential heating may be accomplished by varying the size and heating effect of the flames. As disclosed in Fig. 4, for example, a suitable finger or roller 33, positioned as near the heating flames as practical and adapted to engage the surfaces 16 and 17 being heated, may be provided for actuating suitable valves V which control the flow of the combustible mixture from each blowpipe head 10' or to a group of adjacent heating flames. As the roller 33 rides over a concave or convex surface portion 16 or 17, it partially opens or closes the valve V associated therewith. Thus, as the valve V opens further, the size of the heating flames controlled thereby is increased and more heat is applied to the concave surface portion 16. Similarly, as the valve V partially closes less heat will be applied to the convex surface portion 17. Moreover, the amount of heat supplied will be proportional to the amount of distortion, and the desired differential in depth of heating will be obtained.

The foregoing arrangement may be utilized in connection with the shaft treating apparatus previously described, in which four blowpipe heads are positioned 90° apart. With four rollers 33, which individually cause a variation in the size of the heating flames discharged from the tips of each head in accordance with the distance between any one group of tips and the surface portion being heated by the group, concave surface portions will receive a greater amount of heat than convex surface portions. Also variations in the distance between any tip and the surface portion being heated by the same, will automatically compensate for the variation in length of the heating flames. That is, when the heating flame becomes longer, it is directed against a concave surface portion, which is spaced a greater distance from the end of the tip. Similarly, when the heating flame becomes shorter, it is directed against a convex surface portion, which is closer to the end of the tip. As a result, while still obtaining the desired differential heating, the tips can be positioned so that the surface always intercepts the heating flames at highest temperature or highest rate of heat transfer zones, thus enhancing the efficiency of heating in relation to the amounts of heating gases used.

In addition to shafts or cylindrical objects, the arrangement in which a roller or finger controls the size of a heating flame or group of heating flames can be utilized in straightening, or simultaneously straightening and hardening, plates, bars, and the like. The operation of the finger or roller is substantially as previously described, i. e., as the heating flames pass over a concave surface portion they automatically become larger and longer, and as they pass over a convex surface portion, they automatically become smaller and shorter. Opposite surfaces may be heated, as explained previously in connection with the treatment of plates, bars, and the like.

The finger or roller arrangement may also be used in treating objects which are normally curved in the direction of traverse, merely by causing the blowpipe heads to follow a path parallel to the normal or desired surface line or

shape, and utilizing the finger or roller to vary the size of the heating flames in accordance with deviation from the desired shape. Furthermore, various other ways in which differential heating can be accomplished, including the use of electric arcs or an electric induction heating element or elements, will readily suggest themselves to those skilled in the art.

The principles of this invention may also be utilized in straightening a distorted metal object and simultaneously strengthening selected portions thereof, more particularly portions which are subject to stress concentrations, such as shoulders, fillets, and the like. For instance, a corner or shoulder on a metal object may be hardened to increase the tensile strength of the metal of the shoulder, so that higher stresses will be resisted. A rotating part having a shoulder may be heated differentially for straightening, in the same manner as a shaft or other cylindrical object. At the same time, the surface of the shoulder or other portion of stress concentration is heated to an appreciable depth to a temperature at or above the critical range. In some instances, it will be necessary only to harden the shoulder or other portion of stress concentration, and at the same time produce a differential in case which will be adequate to remove distortion. In other instances, it may be necessary to produce a differential in case over the portion to be strengthened, and also heat differentially other surface portions to remove distortion. The latter portions may or may not be hardened, as desired. In still other instances, the portion to be strengthened may not be distorted, so that an even depth of case should be produced thereover, while differential heating is applied to the distorted portions of the object. In carrying out the method of this invention, as applied to simultaneous or concurrent strengthening and hardening, the apparatus used may be substantially the same as previously described in connection with simultaneous straightening and hardening shafts and cylindrical objects, plates, bars, and the like, and other straight or curved metal objects.

In addition to the control of distortion and straightening of distorted objects, the principles of this invention may also be employed in deliberately altering the shape of metal objects. In one sense, of course, a deliberate alteration of the shape of a metal object, even though straight, may be only one phase of the removal of distortion. That is, if the object is straight, but should be bent, then it may be considered to be distorted from its ultimate desired or "normal" shape. However, for the sake of clarity, a distinction is made herein between the straightening of a distorted object and the alteration of the shape or configuration of a straight object, since it is usually desirable to employ a slightly different technique in the two instances.

A slight bend may be produced in a shaft, rod, or the like, by differential heating. A surface portion extending along a cylindrical element or elements on one side of the shaft or rod is heated to a greater depth than the corresponding surface portion on the opposite side of the shaft or rod, so that the surface portion heated to the greater depth will become convex or displaced outwardly and the surface portion heated to the lesser depth will become concave or displaced inwardly. Also, a shaft or rod which is bent to less than the desired degree may be further bent by a similar treatment.

Deliberate alteration of the shape of a straight object will more often be practiced in the case of non-rotating parts, such as bars, plates, or the like, since it is not often desired to produce a rotating part which is not straight. The desired alteration in shape of a bar, plate, or the like is accomplished by differential heating, in a manner similar to that employed in straightening, whereby a surface portion which is to become convex or displaced outwardly is heated to a greater depth than an opposite surface portion which is to be displaced inwardly.

For example, the heating flames on one side of the object can be disposed so that side of the object intercepts zones of a higher rate of heat transfer, and the heating flames on the opposite side disposed so that zones of a lower rate of heat transfer are intercepted. Or, a greater number or larger size of heating flames may be used on one side than on the opposite side. Instead of being rotated, a shaft may be reciprocated through, say, about a quarter of a turn or less, so that successive portions of one side are heated to a greater depth than successive portions of the opposite side as the shaft is traversed. The side of the shaft or other object heated to the greater depth will become convex, and the side heated to the lesser depth will become concave. The surface of the object may or may not be hardened, as desired.

Deliberate alteration in shape also may be accomplished simultaneously with strengthening, in which limited portions subject to high stress concentration are hardened in a manner similar to that just indicated.

A possible theoretical explanation of the method of this invention may be deduced by considering the effect of heating, to various depths, one side only of a plate or bar of relatively short length. (This plate or bar may also be considered to be a longitudinal increment of the various objects straightened or altered in shape in accordance with the method of this invention.) Assume that the upper side only is heated and that the heated surface is quenched to produce a hardened case, although substantially the same results will be produced when the heated surface is cooled while the temperature is below the critical range, or the object is composed of non-hardenable metal. Then, under the four following conditions, the following results will ensue:

Condition I.—The depth of heating is sufficient only to produce a very thin case. This case is so thin that the volume of the remainder of the metal will be sufficient to withstand any expansion or contraction of the case. Thus, during heating, the case will tend to expand, but such expansion will be resisted and the heated metal will be stressed above the elastic limit and be permanently compressed. As the heated metal cools, the volume of the remainder of the metal will be sufficient to resist any stresses imposed by such cooling and the case will be in tension. However, no change in the size or shape of the object is produced.

Condition II.—The depth of heating is such that a light case is produced. This case is of such depth that the remainder of the metal has just sufficient volume and strength to resist the expansion of the case during heating but not the contraction during cooling. Thus, the heated metal will be restrained from expanding, will be stressed above the elastic limit, and will be permanently compressed. However, when the heated metal cools, the contraction stresses produced by

cooling will be greater than the stresses produced by the case tending to expand during heating, because of the previous compression. Consequently, the contraction of the case during cooling will pull the ends of the upper surface upwardly, and the upper surface of the plate or bar will become concave.

Condition III.—The depth of heating is such that a medium case, or a case of appreciable depth, is produced. The volume of the remainder of the metal is not sufficient to resist entirely the expansion of the case during heating, and the upper surface will bow outwardly at the middle, or become convex, during heating. Thus, while the heated metal will not expand quite as much as if it were free, the stresses therein will be below the elastic limit, and there will be no permanent compression of the heated metal. However, the lower central portion of the remainder of the plate or bar, due to bending moments, will be stressed above the elastic limit, and a permanent compression or deformation will be produced. Consequently, when the heated metal cools, the permanent deformation of the under side will be sufficient to prevent the former from returning to its original straight shape, with the result that the upper surface will remain bowed upwardly at the middle, or convex in shape.

Condition IV.—The depth of heating is such that a very heavy case is produced. The volume of unheated metal is insufficient to resist expansion of the heated metal, and a permanent elongation of the unheated metal occurs when the heated metal expands. Upon cooling of the heated metal, since the unheated metal has a greater length than it did before, it will be able to resist contraction to a greater extent, and thus cause the upper surface to bow upwardly at the ends, or become concave.

It is of particular importance to note that in Condition II and Condition IV, the upper surface of the bar is concave after treatment, whereas in Condition III the upper surface of the bar is convex. This apparently explains why, with the production of a medium case or case of appreciable depth on the concave or low side of the shaft, the concave side will tend to become convex—i. e., will tend to be straightened; and also, why, when a differential case depth is produced, with the deeper case on the concave side, the concave side will tend to become straightened. It will also be evident that in the straightening of distorted objects, or the alteration of the shape of objects, in accordance with this invention, a practical application of the reversal of the direction of bowing of the case, in going from Condition II to Condition III, is apparently made.

Condition IV is believed to be largely of theoretical importance, except in the case of relatively thin objects heated on one side only, since, from a practical standpoint, case depths of such relative magnitudes are not often produced, at least upon thicker objects. Also, if a medium case and a very heavy case were produced on opposite sides of the object, the result would, in most instances, be merely heating entirely through the object.

The above theoretical explanation also apparently accounts for the conditions when the outer surface of an object is hardened—i. e., a lighter case or Condition II tending to produce a permanent contraction, and a medium case or Condition III tending to produce a permanent expansion.

From the foregoing description, it will be ap-

parent that this invention provides a simple and efficacious method of simultaneously surface hardening and straightening a distorted metal object, of simultaneously straightening and strengthening selected portions of a distorted metal object, or of merely straightening a distorted metal object. Also, this invention provides an effective method of intentionally altering the shape of a metal object, with or without hardening, strengthening or other localized surface treatment.

While the method of this invention has been described as particularly adapted to be carried out by the use of high temperature heating flames, in various ways, it is to be understood that other sources of localized high temperature heat, such as electric arcs or electric induction heating elements, as pointed out previously, may be used. It is to be further understood that various other changes in the method of this invention may be made which will not depart from the spirit and scope thereof, as defined in the appended claims.

What is claimed is:

1. A method of altering the shape of a metal object which comprises locally heating surface portions on opposite sides of said object to different depths, the depth of heating and differential in depth being sufficient to produce a relative outward displacement of the surface portion heated to the greater depth; and cooling said heated surface portions.

2. A method of altering the shape of a metal object as defined in claim 1, in which said opposite surface portions are heated by high temperature heating flames so disposed that surface portions to be heated to a greater depth intercept heating flame zones having a higher rate of heat transfer than the zones intercepted by other surface portions.

3. A method of altering the shape of a metal object as defined in claim 1, in which a greater number of heating flames are applied to surface portions to be heated to a greater depth, than to other surface portions.

4. A method of altering the shape of a metal object as defined in claim 1, in which heating flames having a larger size are applied to surface portions to be heated to a greater depth and heating flames having a smaller size are applied to surface portions to be heated to a lesser depth.

5. A method of altering the shape of a metal object and simultaneously surface hardening at least a portion of the surface of said object, at least the surface portions to be hardened being formed of quench hardenable metal, such method comprising locally heating surface portions on opposite sides of said object to different depths, the depth of heating and differential in depth being sufficient to produce a relative outward displacement of the surface portions heated to the greater depth, and at least the surface portions to be hardened being heated to a temperature at or above the critical range; and cooling said heated surface portions, the surface portions to be hardened being cooled at a sufficiently rapid rate to harden the same.

6. A method of straightening a distorted metal object, which comprises locally heating at least the distorted surface portions of said object to an appreciable depth but differentially in such a manner that surface portions which are concave relatively to the desired straightness are heated to a greater depth than opposite surface portions which are convex relatively to the desired

13

straightness; and cooling such heated surface portions, the respective depths of heating being chosen to produce a permanent surface expansion on the originally concave side and a permanent contraction on the originally convex side after said cooling.

7. A method of straightening a distorted metal object as defined in claim 6, in which differential heating is accomplished by effecting a relative traversal of the surface of said object by a plurality of high temperature heating flames and said heating flames are so positioned that surface portions which are concave intercept higher rate of heat transfer zones of said heating flames than the opposite surface portions which are convex.

8. A method of straightening a distorted metal object as defined in claim 6, in which the surface of said object is traversed by a plurality of heating flames and in which the size of said heating flames is varied in such a manner that larger heating flames are applied to surface portions which are concave and smaller heating flames are applied to the substantially opposite surface portions which are convex.

9. A method of straightening and simultaneously surface hardening a distorted metal object formed of quench hardenable metal, which comprises locally heating the surface of said object to a temperature at least as high as the critical range and to an appreciable depth but differentially in such a manner that surface portions which are concave relatively to the desired straightness are heated to a greater depth than the substantially opposite surface portions which are convex relatively to the desired straightness; and cooling such heated surface portions to harden the same, the respective depths of heating being chosen to produce a permanent surface expansion of the originally concave side and a permanent contraction of the originally convex side after said cooling.

10. A method of straightening a distorted cylindrical metal object, which comprises rotating said object about its longitudinal axis; locally heating successive circumferential zones of at least the distorted surface portions of said object to an appreciable depth but differentially in such a manner that surface portions which are concave relatively to the desired straightness are heated to a greater depth than the substantially opposite surface portions which are convex relative to the desired straightness; and cooling such heated surface portions, the respective depths of heating being chosen to produce permanent surface expansion of the originally concave side and permanent surface contraction of the originally convex side after said cooling.

11. A method of straightening a distorted cylindrical metal object as defined in claim 10, in which a plurality of heating flames positioned about a circumferential zone of said surface are so spaced with respect to said surface that the surface portions which are concave intercept higher rate of heat transfer zones of said flames than surface portions which are convex, and in which a relative movement between said flames and said surface in the direction of the longitudinal axis of said object is effected.

12. A method of straightening a distorted cylindrical metal object as defined in claim 10, in which a plurality of heating flames disposed longitudinally of said object are so spaced with respect to said surface that the surface portions which are concave intercept higher rate of heat

14

transfer zones of said flames than the surface portions which are convex as said object rotates.

13. A method of straightening a distorted metal object having oppositely disposed and normally substantially flat surfaces, which comprises effecting a simultaneous relative traversal of each surface by a plurality of high temperature heating flames so positioned that the surface portions which are concave relatively to the desired straightness intercept higher rate of heat transfer zones of said heating flames so as to be heated to a greater depth than the opposite surface portions which are convex relatively to the desired straightness, the respective depths of heating being chosen to produce permanent surface expansion on the originally concave side and permanent contraction on the originally convex side after the object has cooled to normal temperature.

14. A method of straightening a distorted metal object having oppositely disposed and normally substantially flat surfaces, which comprises effecting a relative traversal of each surface by a plurality of high temperature heating flames; varying the relative size of said flames in such a manner that surface portions which are concave relatively to the desired straightness are heated to a greater depth by larger heating flames and the opposite surface portions which are convex relatively to the desired straightness are heated to a smaller depth by smaller flames; and cooling such heated surface portions, the respective depths of heating being chosen to produce permanent surface expansion on the originally concave side and a permanent contraction on the originally convex side after said cooling.

15. A method of straightening and simultaneously surface hardening a distorted metal object formed of quench hardenable metal, which comprises locally heating successive surface portions of said object to a temperature at or above the critical range by effecting a relative traversal of the surface of said object by a plurality of high temperature heating flames so positioned that surface portions which are concave relatively to the desired straightness intercept higher rate of heat transfer zones of said heating flames so as to be heated to a greater depth than the substantially opposite surface portions which are convex relatively to the desired straightness; and cooling such heated surface portions at a sufficiently rapid rate to harden the same, the respective depths of heating being chosen to produce a permanent surface expansion of the originally concave side and a permanent contraction of the originally convex side after said cooling and hardening.

16. A method of simultaneously surface hardening and straightening a distorted cylindrical metal object formed of quench hardenable metal, and having some surface portions which extend a greater distance than desired from the normal longitudinal axis of said cylindrical object when straight, and other surface portions which are closer than desired to the normal longitudinal axis of said cylindrical object when straight, such method comprising locally heating successive surface portions of said object to a temperature at or above the critical range by directing a plurality of heating flames against a circumferential zone of the surface of said object; rotating said object about an axis of rotation substantially coinciding with said normal longitudinal axis; effecting relative movement between said heating flames and such rotating object in the direction

15

of said axis of rotation while maintaining said heating flames so positioned that those surface portions of the object relatively closer to said axis of rotation intercept higher rate of heat transfer zones of said flames than those surface portions relatively farther away from said axis of rotation, whereby relatively closer surface portions are heated to a greater depth than surface portions relatively farther away; and cooling said surface portions at a sufficiently rapid rate to harden the same, such heating and cooling also serving to straighten said object during the surface hardening operation.

ROMAN F. ARNOLDY.

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