Oct. 3, 1944. E. BENNETT 2,359,285

INDUCTION FURNACE

Filed July 17, 1942

FIG. 1.

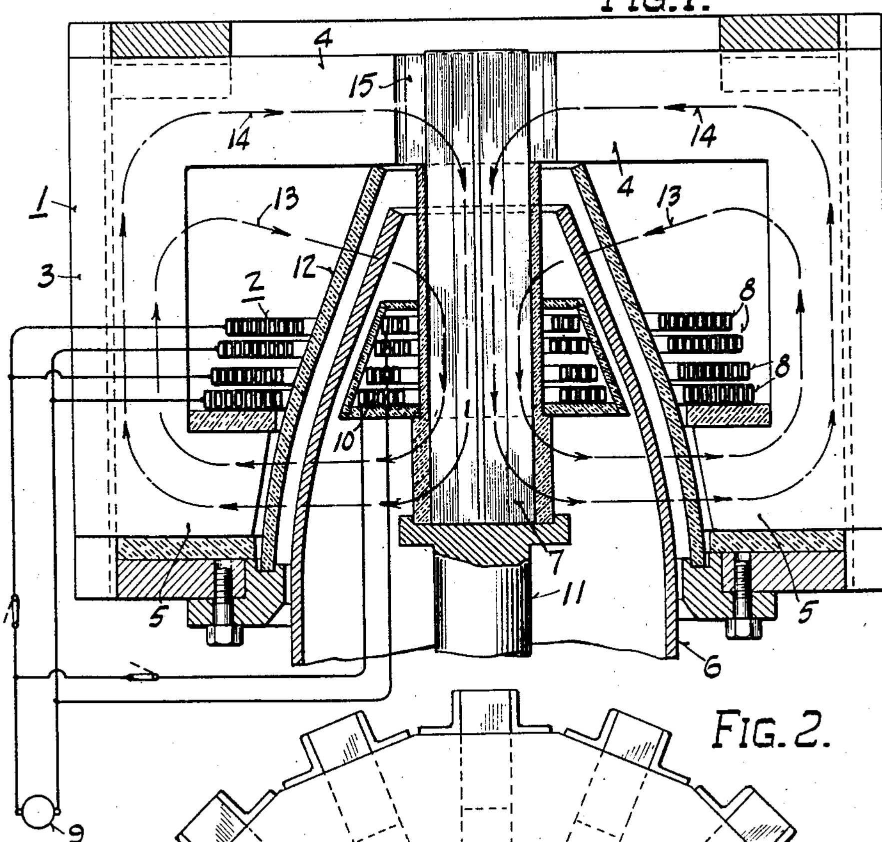
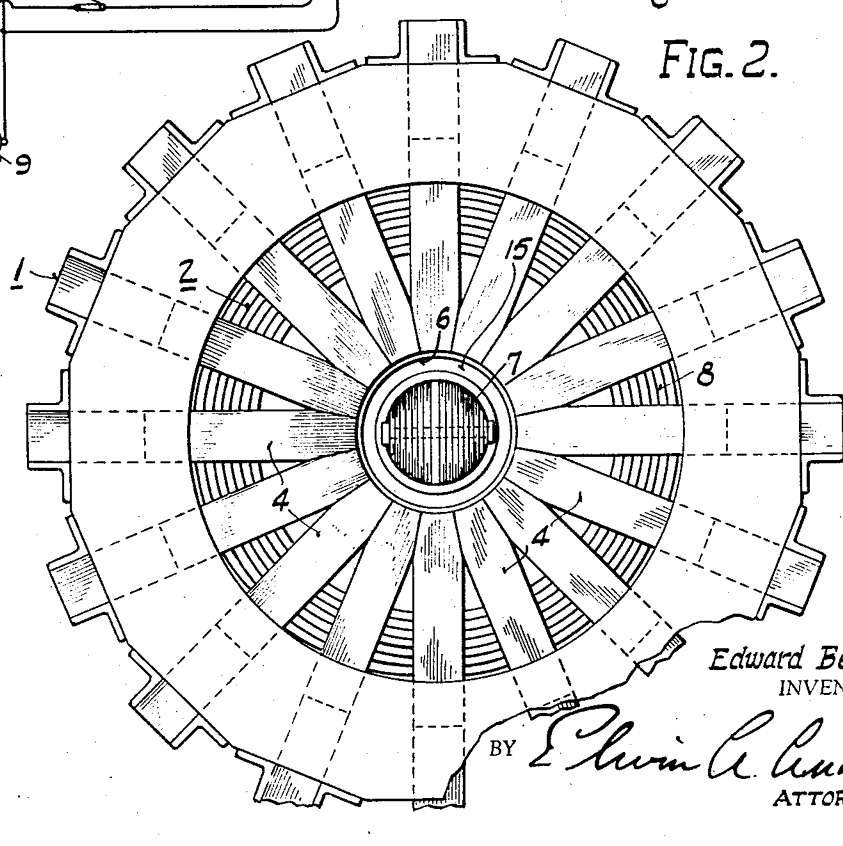


FIG. 2.



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INDUCTION FURNACE

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3 Claims. (Cl. 219—13)

This invention relates to an induction furnace for heating tubular conductive articles by magnetically inducing alternating heating currents circumferentially of the article.

The invention has been applied in the heating of aerial bomb casings preparatory to forging operations for closing the forward end portion of a tube to form the nose of the bomb. In such forging operations, as, for instance, described in the application of Warren F. Heineman, Serial No. 410,833, filed September 15, 1941, for Method of making bomb shells, it is desirable to heat only a predetermined end portion of the blank, leaving a fairly sharp line of heat gradient between that and the cooler body of the blank. This requires that the heating operation be fast so as not to obtain too much conduction of heat to the colder part of the blank. In practice the end of the blank is heated to the required forging temperature in a fraction of a minute.

Difficulties arise in heating a blank in so short a time. High frequency induction heating was found to be unsatisfactory for heating thick tubular bodies such as are employed in making bomb casings, due to the tendency to heat the metal on the surface and not to effectively heat that beneath the surface. With high frequency heating the metal at the surface of the blank may be raised to the melting point while that a short distance beneath is still cold.

Another difficulty in applying induction heating to partially formed blanks in making bomb casings lies in the fact that where substantially all of the magnetic flux passes axially through the center of the part being heated, the difference in diameter of different portions of the section being heated leads to a difference in resistance to the flow of the induced current between the portion of smallest diameter and that of largest diameter resulting in a lack of uniformity of heating between the smaller end portion of the blank and the larger body portion in proportion to the I^2R values in the two portions.

In order to satisfactorily forge a blank in making bomb casings, there should be a substantial uniformity in temperature between the different portions of the part of the blank being forged.

The principal object of the present invention is to obtain a more uniform or a controlled nonuniform heating of the section of the blank to be forged or heated.

In carrying out the invention, low frequency energizing current is employed and the energizing coils and the magnetic core are constructed and arranged to obtain a differential distribution of magnetic flux axially of the article more nearly proportional to the differences in resistance of the several circumferential portions of the article being heated, or, in the event a predetermined nonuniformity of heating is desired, a differential distribution of magnetic flux axially of the article to obtain the same.

An embodiment for carrying out the invention is illustrated in the accompanying drawing in which:

Figure 1 is a vertical central section through a furnace and showing the blank in position for heating; and

Fig. 2 is a top plan view, parts being broken away.

The furnace comprises, in general, the magnetic core structure 1 and energizing coils 2.

The core structure 1 comprises outer vertical legs 3 with upper horizontal legs 4 extending inwardly toward the center, and similar lower horizontal legs 5 extending inwardly to a position adjacent the tubular blank 6, being heated. An axial or central leg 7 is disposed vertically within the upper end of the blank 6 and bridging the gap between the upper and lower legs 4 and 5, respectively, to provide a path for the magnetic flux produced by the energizing coils 2.

The coils 2 are of the flat type comprising a number of flat turns 8 of copper tubing encircling the blank 6 in substantially close proximity thereto and connected to a suitable source 9 of low frequency alternating current. A similar group of coils 10 is disposed inside of the blank to encircle the central core leg 7. A vertically movable pedestal 11 supports the inner coils 10 and core leg 7. The coils 2 and 10 may be used together, or either set may be eliminated, leaving the other to supply the magnetomotive force for the induction furnace. Water is flowed through the tubing of the coils for cooling purposes during operation of the furnace and a heat insulation shell 12 is placed between the blank 6 and the core 1 and coils 2 to prevent radiation of heat from the blank to the core and coils.

The blank 6 is illustrated as the upper end of a tubular bomb casing after it has been partially formed with its partially closed end uppermost. It is first placed over the pedestal 11 and then raised vertically with it into the furnace through a central opening in the lower leg 5 of the outer core structure. The upper end of the blank 6 extends to a position near the upper horizontal legs 4 of the core.

The cycle of the current employed should be below 500 alternations or pulsations per second and preferably is 60 cycles per second since this cycle is readily supplied from commercial current sources without the addition of costly equipment. The current should be of single phase and instead of alternating current, it is possible to employ pulsating currents.

When employing low cycle currents, as above described, magnetic core elements of relatively low flux impedance should be provided in order to obtain a maximum flux with consequent maximum heating effect. The core structure 1 illustrated is particularly adapted for this purpose since the outer structure is composed of a plurality of sections of substantially radially disposed vertical laminations which reduce eddy current losses and provide a relatively high efficiency flux path. The central core leg may be constituted of a single series of longitudinally extending laminations as shown, or the laminations may be arranged in quadrants to extend in a more nearly radial direction.

In carrying out the invention, the flux traversing the central leg 7 at the upper smaller diameter end of the blank 6 should be less than the flux traversing the same leg lower down, where the blank is nearly its largest diameter. This is accomplished by forcing a leakage path for the flux through the walls of the blank as illustrated by the arrows 13, the main flux path through the core structure being illustrated by the arrows 14.

A gap 15 is provided between the inner edge of the upper leg 4 and the circumference of the central leg 7 of the core structure. The high reluctance of the gap 15 tends to force stray flux directly through the shorter path 13 which is nearer to the energizing coils 2 and which bleeds flux from the upper end of the central core leg 7. This reduces the flux passing through the upper smaller end of the blank 6 and thereby reduces its rate of heating to more nearly that of the lower portion of the section of the blank being heated.

Another factor which should be considered and which may vary depending upon the shape of the article, is the location of the energizing coils 2. The exact location of the coils 2 and the number of turns therein will depend upon the shape of the article being heated. In the drawing the coils 2 are shown disposed near the lower end of the furnace, leaving the upper end substantially free of energizing coils. If the blank were cylindrical it would be desirable to distribute the coils all along the section being heated in order to obtain uniform heating conditions. However, for blanks of substantially uniform thickness, as the upper end of the blank gets smaller in successive stages of forging more and more flux should be diverted from passing through the smaller end of the blank and yet caused to pass through the larger end. By dropping the coils away from the upper end of the blank a little farther for each successive heating and forging operation the diverting of the flux is more nearly proportional to the need. The respective coils may either be dropped out by means of switches or successive furnaces may be employed having the different coil distributions described.

Where the blank gets thicker as the end is contracted in diameter, the greater counter-magnetomotive force of the greater heating current in the thickened nose opposes the establishment of flux through the nose, and makes a lesser displacement of the primary coils toward the larger diameter end of the blank necessary. In such case, the coils can be placed nearer to the longitudinal center of the blank portion being heated to compensate for the raising of the center of area of the cross section taken on the longitudinal axial plane of the blank wall. The location of the coils may also depend upon whether the process being employed is one of successive reheating with the utilizing of a conservation of heat from one step to another, as set forth in applicant's co-pending application Serial No. 451,281, filed July 17, 1942. Where considerable conservation of heat is obtained, as distinguished from heating a relatively cold blank, the added thickness of the nose may not require any additional ampere turns to heat the nose within the time provided for the heating cycle.

In general the resultant magnetomotive force of the primary coils should have its center offset from the center of area of the cross section taken on the longitudinal axial plane of the blank wall that is to be heated, toward the end of largest diameter. This offsetting of the center of the primary magnetomotive force, together with the gap 15 effects a reduction in the flux threading the small end of the blank and in the circumferential voltages induced in the shorter heating current paths in the small end. As a result the induced current densities are kept at the desired uniformity over the entire section of the heated end, and the heating energy supplied to the nose portion of the article is prevented from becoming excessive.

Either the offsetting of the center of primary magnetomotive force or the employment of a gap in the core structure may be sufficient in a given instance, but it is preferred to employ both means of limiting the flux at the small end of the blank, the former means enticing a leakage of flux through the wall of the blank and the latter compelling such leakage by reason of the increased reluctance at the end of the core structure farthest from the coils.

The placing of the primary coils 2 at the bottom of the furnace, immediately adjacent the leg 5 of the core structure 1, serves to effect a high flux density through the wall of the blank at this location and to cut off the flux from passing downwardly. As a result there is a very sharp line of heat gradient in the blank at this point. By extending the core structure upwardly and around the end of the blank substantially above the coils, there is a lower flux density radially through the wall of the blank above the coils and a more readily controlled heating effect in this region.

The invention constitutes a practical solution for the uniform heating of tubular sections of varying diameter, and its principles may be employed to obtain either a substantial uniformity of heating of such a blank or a predetermined nonuniformity of heating thereof.

In some cases the upper leg 4 of the core structure may be closed in the center and the upper end of leg 7 be dropped to provide the air gap or added reluctance between it and the leg 4.

While the invention has been described as applied to the heating of a tapered tubular blank of nonuniform diameter, it is also applicable to the heating of other types of blanks including tubes of uniform inside or outside diameter and tapered in thickness. It is also applicable where a predetermined nonuniform heating of a cylindrical tube or other shaped blank is desired.

Various embodiments of the invention may be employed within the scope of the claims.

The invention is claimed as follows:

1. In low frequency electric induction heating of tubular blanks, the method of compensating for differences in resistance to the circumferential flow of heating current in different adjacent longitudinal regions of the blank being heated where a central core element passes axially through said regions to provide a flux path of high permeability separate from the blank, comprising offsetting the center of the magnetomotive force of the primary winding longitudinally toward the region of higher resistance to promote the diversion of flux from said central core element radially through the wall of the blank in the region of lower resistance and thereby provide a greater amount of axial flux passing through the core in the region of the blank of higher resistance than in the region of lower resistance.

2. In low frequency electric induction heating of tubular blanks, the method of compensating for differences in resistance to the circumferential flow of heating current in different adjacent longitudinal regions of the blank being heated where a central core element passes axially through said regions to provide a flux path of high permeability separate from the blank, comprising offsetting the center of the magnetomotive force of the primary winding longitudinally toward the region of higher resistance, and providing a high reluctance in the flux path at the end of the lower resistance region opposite the center of magnetomotive force, to promote leakage of flux from said central core element radially through the wall of the blank in the region of lower resistance of the blank and thereby reduce the amount of axial flux passing through the core in said region.

3. In low frequency electric induction heating of tubular blanks, the method of compensating for differences in resistance to the circumferential flow of heating current between a partially closed end portion and an adjacent body portion to be heated where a central core element passes axially through said regions to provide a flux path of high permeability separate from the blank, comprising providing a high reluctance in the flux path at the end of the core element adjacent the partially closed end of the blank to promote by-passing of said partially closed end of the blank by the flux and thereby reduce the amount of flux passing axially through the core element in the region of the partially closed end of the blank as compared to the amount of flux passing axially through the core element in the region of the adjacent body portion of the blank.

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