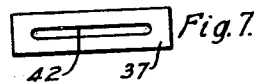
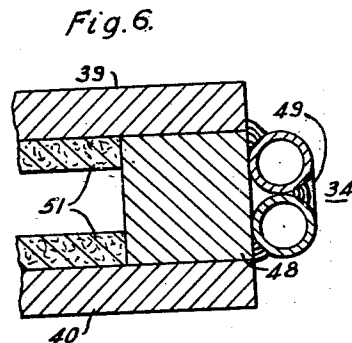
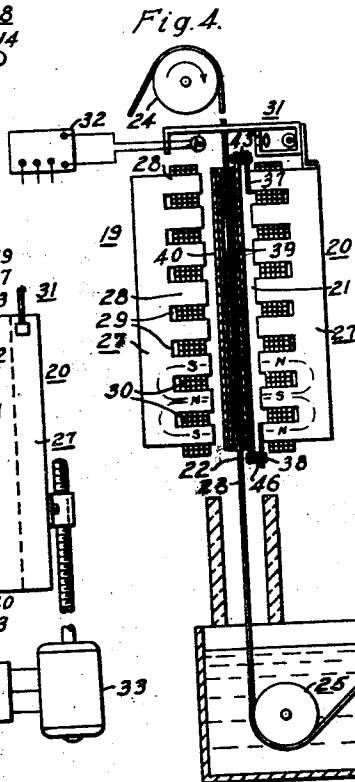
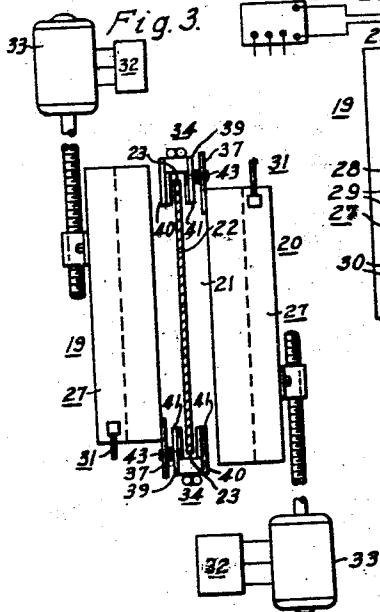
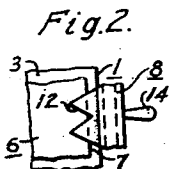
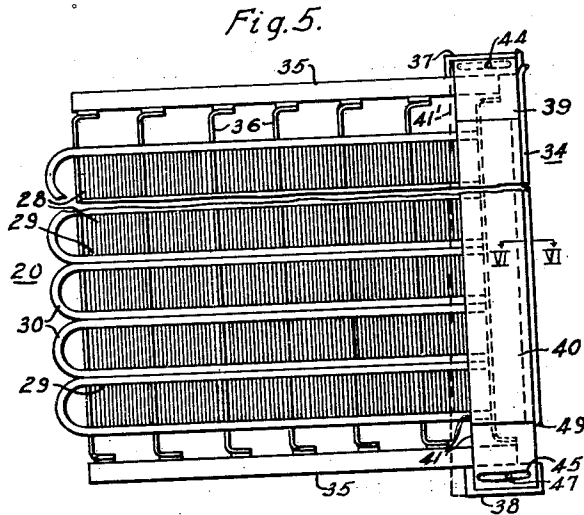
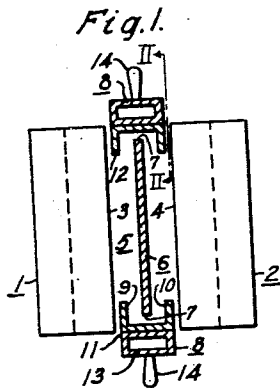


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R. M. BAKER
INDUCED HEATING OF CONTINUOUSLY MOVING METAL
STRIP WITH PULSATING MAGNETIC FLUX
Filed Sept. 9, 1944

2,448,012



WITNESSES:

H. F. Brown
M. L. Grouse

INVENTOR
Robert M. Baker.
BY
B. L. Zangwill
ATTORNEY

UNITED STATES PATENT OFFICE

2,448,012

INDUCED HEATING OF CONTINUOUSLY
MOVING METAL STRIP WITH PULSAT-
ING MAGNETIC FLUXRobert M. Baker, Pittsburgh, Pa., assignor to
Westinghouse Electric Corporation, East Pitts-
burgh, Pa., a corporation of Pennsylvania

Application September 9, 1944, Serial No. 553,381

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My invention relates, generally, to high-frequency heating; but is more particularly directed to refinements in induction-heating of elongated traveling non-magnetic material, such as strips, sheets, plates, and the like, for the purpose of controlling the quality or manner of the heating, or for maintaining the position of the material with respect to the field-establishing means, or both.

This invention is in the nature of a continuation-in-part of my copending patent-application, Serial No. 521,229, filed February 5, 1944, and of an improvement on the full disclosure thereof. It is also related to my copending patent-application, Serial No. 513,260, filed December 7, 1943.

My invention is herein described in connection with a preferred form in which elongated coilable metallic strip is passed longitudinally, or in the direction of its length, through a pulsating or alternating magnetic field for heat-treatment, the magnetic flux lines passing transversely through the faces of the strip and inducing electrical currents therein which heat the strip, a form of induction-heating generally designated as transverse-flux induction-heating. In the embodiment herein described, flux lines may be considered to pass through one face of the strip, through the strip, and then out of the other face.

A difficulty of heating non-magnetic strip-like material by means of a substantially uniform transverse flux resides in the tendency of its lengthwise portions along and near the edges or thin side-surfaces of the strip to become hotter than its intermediate central portions. For the sake of brevity, I hereinafter call such portion, which includes the edge and inner contiguous material of the strip for an extent short of the longitudinal center, as a border-portion. My associated application, Serial No. 521,229, shows and claims embodiments for counteracting or nullifying this tendency in a manner to cause the temperature distribution across the strip, from edge to edge, to be more uniform. One of the embodiments therein disclosed does this by providing weaker heat-inducing fields at the border-portions of the material. Specifically, this is done by displacing opposite cooperating magnetic-field-producing field-structures so that they are laterally out of line. Another embodiment utilizes a field-affecting means, in the form of a shield or screen, along the longitudinal borders of the magnetic field, which, in a sense, absorbs the current-inducing effect of the field along the border-portions of the traveling strip. The aforesaid patent-application, Serial No.

521,229, places emphasis on and claims the former embodiment. The instant patent-application is more concerned with embodiments using field-screening means for not only preventing excess heating of the border-portions of the strip, but for the additional purpose of centering the strip between the field-producing field-structures.

Non-magnetic strip, such as aluminum or brass, for example, is for the most part self-centering when passed through a transverse-flux induction-heating furnace, such as disclosed or referred to in my aforesaid patent-application, Serial No. 521,229. However, there may be a tendency for strip passing between the field-structures of such a furnace to rub against a pole-face, thereby scratching or otherwise marring the strip. I reason that an electrical force is created along the edges of the strip by the currents induced therein, which tends to drive such edges toward a core of a field-structure. The current induced in the strip may be considered to flow in oblong paths lying in the plane of the strip. These oblong paths have curved ends or turns in the strip border-portions, with components substantially paralleling the adjacent edge, and have straight connecting-parts extending across the width of the strip, between the end-turns, as more particularly shown in Fig. 4 of my patent-application, Serial No. 521,229. The current-flow along the straight connecting parts of the oblong path cooperates with leakage flux in the core-slots of the field-structures to provide a centering effect on moving non-magnetic strip in the air-gap, which tends to center the non-magnetic strip between the field-structures, but the current-flow in the end-turns of the oblong path reacts with the heat-inducing magnetic field thereat, giving rise to forces which tend to move the strip toward a field-structure. In any event, the strip may tend to bow crosswise in the work-passage. By the use of field-affecting means, or field-screening means, extending over the edges of the strip along the lengthwise borders of the air-gap, or work-passage, not only is overheating of the strip border-portions reduced but the tendency for the strip to migrate toward a core is practically eliminated so that the strip passes centrally through the induction-heating furnace.

50 An object of my invention resides in providing an induction-heating furnace for controllably electrically heating traveling elongated strip-like material.

55 Another object of my invention resides in providing an electrical furnace which produces a

spacial alternating field of electrical energy for heating material immersed therein, the furnace having means for limiting or preventing the field from interlinking some part of the material, although the part would otherwise be immersed inside the surface boundaries of the principal field, by principal field meaning the concentrated portions such as found in the work-passage for the material, as distinguished from, for example, leakage flux. I show my invention in a preferred form as applied to induction- or magnetic-heating, but it has broader application.

Another object of my invention is to control the concentration of a spacial alternating field of electrical energy by means other than controls or magnetic structure on the field-energizing and inducing means.

Still another object of my invention is to provide an induction-heating furnace having laterally adjustable field-structures to one or both of which a screening-means is secured for minimizing excessive heating of one or both of the border-ports of the strip and undesirable electromagnetic reaction between the field and electrical currents in these portions.

Other objects, features and innovations of my invention will be discernible from the following description thereof which is to be taken in conjunction with the accompanying generally schematic and simplified drawing, in which:

Figure 1 is a diagrammatic plan view, partly in section, of apparatus embodying my invention;

Fig. 2 is a partial elevational view, substantially along the line II—II of Fig. 1, for indicating a field-screening means along a border of the work-passage of an induction-heating furnace;

Figs. 3 and 4 are, respectively, plan and side elevational views, with parts in section and with parts omitted for clarity, of a second embodiment of my invention in which the field-structures are laterally automatically adjustable so that their positions are controlled by the positions of the edges of the strip being heat-treated;

Fig. 5 is an elevational view looking at the pole-face of a field-structure for a transverse-flux induction-heating furnace, such as that of Figs. 3 and 4;

Fig. 6 is an enlarged sectional view, substantially on the line VI—VI of Fig. 5, more clearly showing the cross-section of a preferred screening-means; and

Fig. 7 is an elevational view of a plate, secured to a field-structure, for supporting the screening means.

In Figures 1 and 2, a transverse-flux induction-heating furnace is shown in a simplified form. It comprises a pair of electromagnetic field-structures 1 and 2 having parallel flat pole-faces 3 and 4, respectively, spaced apart to form a shallow air-gap or work-passage 5. The field-structures are energized in a suitable manner with alternating-current for establishing a magnetic field having flux lines directed across the shallow part of the work-passage 5. An elongated strip 6, having edges 7, is passed through the work-passage for heat-treatment by heat generated therein when it moves with respect to the lines of the pulsating magnetic flux which can be considered to pass from one pole-face to the other. The strip 6 passes downwardly through the work-passage 5 in a longitudinal direction, that is, in the direction of the length of the strip. With non-magnetic strip having both edges in the magnetic field, the central portions of the strip are self-centering in the work-

passage while the border-ports have a tendency to be forced to a field-structure and also to overheat. For substantially reducing both of these effects simultaneously, I provide a member 8 along each longitudinal border of the work-passage 5, having plate-like legs 9 and 10 on opposite sides of the associated border-portion of the strip.

Each member 8 comprises a U-shaped member comprising the plate-like legs 9 and 10 joined together by a cross-member 11. Each leg has a free edge 12 in the work-passage, so that the U's of the members 8 face each other. Secured to the cross-member 11, in heat-exchanging relation, is a hollow member 13 through which a cooling fluid may be passed for removing heat introduced in the legs 9 and 10 when the electromagnetic field-structures 1 and 2 are energized to provide the heat-inducing transverse flux in the work-passage. Each of the legs 9 and 10 may have its free edge 12 serrated, as more particularly shown in Fig. 2, providing oblique portions which permit the shielding effect to be gradually adjusted when the members 8 are moved more or less into the work-passage 5 by operations on the handles 14, thereby changing their relative position with respect to the strip 6 and the field-structures 1 and 2.

Figs. 3 and 4 show an induction-heating furnace having automatic means for changing the lateral positions of the field-structures for controlling the relative positions of a field-structure and an adjacent strip-edge, as more particularly described and claimed in my aforesaid patent-application, Serial No. 521,229. Opposite laterally-movable field-structures 19 and 20 provide a work-passage 21 through which non-magnetic strip 22, having edges 23, moves downwardly after passing around an upper roller 24 which, with a lower roller 25, determines the general path of travel of the strip through the work-passage. Strip-moving means, represented by a pull-unit 26, pulls the strip through the induction-heating furnace.

Each of the field-structures 19 and 20 comprises comb-shaped laminations formed into a magnetic core 27 having like poles or teeth 28 and like slots 29, alternating with each other. Windings or coils 30 are fixed in the slots 29 and are so energized by any suitable alternating-current source, connected to the coils 30, that a pole on one field-structure will have a polarity opposite to that of the directly opposite pole on the other field-structure, as indicated by the N and S polarity designations in Fig. 4. Each field-structure is provided with a separate scanning-means 31 which is fastened to one side of the top of the associated field-structure for providing a light beam cut by a strip-edge. A control means 32, associated with each scanning means 31, is electrically connected thereto and responds in accordance with the extent to which a strip border-portion interrupts the light beam. The response correspondingly controls the energization of a reversible motor 33 for the associated field-structure. Energization of a motor 33 causes a field-structure to move in one direction or the other, depending upon the displacement of the strip with respect to the associated edge of the substantially parallel lateral side of the associated field-structure. The control is preferably such that each lateral side of a field-structure is maintained a predetermined distance from the closest edge of the strip.

In the embodiment of Figs. 1 and 2, the

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screening-means are separate from the field-structures so that they can be independently adjusted, but the screening-means can be fixed or adjustably secured to the field-structures, as shown in Figs. 3, 4 and 5. In this last embodiment a screening-means 34 is secured to each field-structure for movement therewith. It comprises an elongated U-shaped member for controlling the effect of the transverse magnetic field on the border-portions of the strip 22, and for separating or screening this transverse magnetic field from the field produced by the parts of the induced currents flowing in the portion of the strip, which lies within the screening-means 34.

Fig. 5 indicates, in a limited way, a practical form of a field-structure having a screening-means thereon. The field-structure comprises a frame which includes top and bottom channel-bars 35 and equally spaced frame-members 36. Laminations of a general form shown in Fig. 4 are clamped, in any suitable manner, between the frame-members 36 so as to provide the core 27. The core has an outer planar pole-face consisting of the extremities of the teeth 28. A field-structure of this sort is described in greater detail and claimed in the R. M. Baker et al. patent-application, Serial No. 542,380, filed June 27, 1944.

A small plate 37 is secured to the upper channel-bar 35 and a small plate 38 is secured to the lower channel-bar, the plates being along the side of the pole-face which is maintained relatively inside of a strip-edge. The plates 37 and 38 adjustably support the screening-means 34 which comprises a relatively near plate-like member 39 and a relatively far plate-like member 40, considered with respect to the field-structure with which they are associated. The members 39 and 40 are of the same width with each having a straight free edge 41 at a longitudinal side of the screening means, which lies inside the magnetic field between the field-structures. The far member 40 is as long as the field-structure, but the near member 39 is longer, having ends protruding beyond the ends of the member 40, so that a screening-means can be secured to the plates 37 and 38 in a manner permitting its free edges to be adjustably positioned parallel to or at a slant to the direction of movement of the strip 22. To this end, the plate 37 has an elongated hole 42 for receiving anywhere therein a fastening bolt of a bolt and nut means 43. The bolt passes somewhat loosely through a round hole 44 in the upper protruding end of the near member 39 which can swing thereon. The lower protruding end of the member 39 comprises a curved slot 45, centered on hole 44. Any part of the slot 45 can receive a bolt of a bolt and nut means 46. This last bolt passes through a somewhat enlarged hole 47 in the plate 38. By the use of suitable spacers and nuts for the bolt and nut means 43 and 46, the edges 41 of the screening-means 34 can be placed in various different positions with respect to the associate field-structure, in an obvious manner. The dashed line 41' in Fig. 5 indicates an adjustment of the screening-means which places its edge obliquely in the work-passage, with the screening-means inserted further into the work-passage at the exit end. Preferably, the members 39 and 40 are equally spaced from the parallel median plane of the work-passage therebetween so that the members 39 and 40 for each screening-means 34 lie on opposite sides of a border-portion of the strip 22. The members 39 and 40 are abuttingly welded, or otherwise secured in good thermal

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relation, to a relatively heavy metal end-bar 48 of the same length as the member 39. Welded or soldered to the outer surface of the bar 48 are a pair of hollow metal tubes having a U-bend 49 joining their bottom ends so as to provide a continuous passage for a cooling fluid which can be admitted and withdrawn from the other ends of the tubes.

The plate-like members 39 and 40 and also the bar 43 of the screening-means are preferably, but not necessarily, of a metal having a resistivity lower than that of the strip being heat-treated. The members 39 and 40 should have a thickness equal to at least that of the "depth of current penetration" in centimeters. This "depth of penetration" is usually considered equal to

$$5030 \sqrt{\frac{P}{f}}$$

where P is the resistivity of the material of the members 39 and 40, in ohm-centimeters, and f is the frequency in cycles-per-second at which the transverse magnetic field alternates or pulsates. The thicknesses of the members 39 and 40 can be, and preferably are, greater than the "depth of penetration." If they are made less, the transverse magnetic field between the field-structures, in effect, penetrates the screening-means 34, so that some of the flux gets through for heating the edge-portions of the strip and reacting with the current-flow therealong.

By means of tests an indication can be obtained of the manner in which a strip is heat-treated when the screening-means occupies different positions. A hardness traverse across the width of the strip is preferred for obtaining the temperature distribution therealong. By variously adjusting the screening-means, skill coming with experience, an adjustment can be found for a given material which will provide a heat-treatment across the width of the strip of utilizable uniformity, within a variation in temperature which, from actual tests, I approximate at 5% for aluminum. I can not state exactly how far a screening-means should overlap the strip. About one-third to one-half of a pole pitch seems to be the average overlap for aluminum sheet with the extending portions of the screen-members 39 and 40 extending laterally beyond the end-bar 48 a width of about two-thirds of the pole pitch of the field-structures. If the overlap or the width of the extending portion is insufficient the screening of the magnetic field may not be so thorough. If too great, more heat may be lost in the screening-means than is necessary. It is also desirable to skew the screening-means, so that the straight edges 41 are oblique to the parallel frame-members 36 and the length-direction of the teeth 28. This makes the effect of the screening-means more gradual as the strip passes into and through the induction-heating means.

The spacing between the members 39 and 40 should be sufficient to receive, with satisfactory working clearance, the thickest strip expected to be treated, but I prefer to make the spacing greater so that the members can be faced with an insulating lining 51 without decreasing the clearance. Preferably, the lining is of some soft insulating material, such as asbestos board, and at least as long as the far member 40 so that sparking between the metal of the screening-means and the strip is minimized, and so that any occasional rubbing or contact of the strip on the inner sides of the screening-means will not seriously mar or

scratch the surfaces of strip having surface finishes which must be protected during heat-treatment. The extreme edge of the strip should also clear the screen-bar 48 sufficient to minimize the possibility of contact or sparking therebetween.

While I have described my invention in a manner understandable to those skilled in the art, and in forms which I now prefer, it is apparent that refinements and improvements and other embodiments may be made, utilizing the teachings and principles of my invention herein described. I claim as my invention:

1. Transverse-flux heating-apparatus having a relatively shallow and wide work-passage for receiving elongated strip-like material for heat-treatment, said heating-apparatus comprising, in combination, means for establishing a pulsating magnetic field across the shallow part of the work-passage, for introducing heat into the material, and means comprising a screen along a border of the work-passage, extending only partially across a wide side of the work-passage, for screening both faces of a longitudinal edge-portion of the material from said field, whereby to decrease the tendency for electromagnetic reaction between said material edge-portion and said field to affect the heating across the width of the material.
2. The combination with a transverse-flux induction-heating means including a work-passage, and means for moving strip-like material in a certain direction through said work-passage, said induction-heating means comprising flux-producing means having a distinct field-structure on each side of said work-passage, for providing an alternating magnetic field in said work-passage; of a metallic screening-means along a border of the work-passage, for providing a field-screen between said field-structures, on the one hand, and a longitudinal portion along an edge of the material, on the other hand, said metallic screening-means comprising an elongated non-magnetic metallic member having an edge inside the field, extending in said direction.
3. The invention of claim 2, characterized by said metallic screening-means having passages for cooling fluid along a portion thereof which is opposite to its said edge.
4. The combination with a transverse-flux induction-heating means including a work-passage, and means for moving strip-like material in a certain direction through said work-passage, said induction-heating means comprising flux-producing means having a distinct field-structure on each side of said work-passage, for providing an alternating magnetic field in said work-passage; of a metallic screening-means along a border of the work-passage, extending in said direction, for screening a portion of the material from the field, said metallic screening-means comprising a non-magnetic metallic member having an edge inside the field, extending in said direction, and means securing said member to a field-structure.
5. The combination with a transverse-flux induction-heating means including a work-passage, and means for moving strip-like material through said work-passage in a certain direction, said induction-heating means comprising flux-producing means having a distinct field-structure on each side of said work-passage, for providing an alternating magnetic field in said work-passage; of a plurality of spaced elongated non-magnetic metallic members extending in said direction along each border of the work-passage, each

member being between one of said field-structures and a medial part of the work-passage, whereby to retain the material centrally in said work-passage.

6. The invention of claim 5, characterized by said members having an edge in said field, and means for removing heat introduced into said members by said field, comprising a passage for fluid along a portion opposite to the edge.
7. In combination, a transverse-flux induction-heating means including a work-passage through which strip-like material can be moved longitudinally, said induction-heating means comprising flux-producing means having a field-structure on each side of said work-passage, for providing an alternating magnetic field in said work-passage, means for moving one of said field-structures with respect to the other for changing the flux distribution of said field in said work-passage, and a screening-means along a longitudinal edge of one of said field-structures for screening a portion of the material from said field, said member being attached to one of said field-structures.
8. In combination, a transverse-flux induction-heating means including a work-passage through which strip-like material can be moved longitudinally, said induction-heating means comprising flux-producing means having a distinct field-structure on each side of said work-passage, for providing an alternating magnetic field in said work-passage, means for laterally moving one of said field-structures with respect to the other, and metallic screening-means longitudinally along both sides of the work-passage, for screening both longitudinal portions of the material which are near and along an edge thereof from the field, each of said metallic screening-means comprising two non-magnetic metallic members having an edge inside the field, each of said screening-means being secured to a different one of said field-structures.
9. The invention of claim 8, characterized by each of said screening-means having an edge in said field oblique to the direction of travel for said material.
10. In combination, a transverse-flux induction-heating means including a work-passage through which strip-like material can be moved longitudinally, said induction-heating means comprising flux-producing means having a distinct field-structure on each side of said work-passage, for providing a pulsating magnetic field in said work-passage, means for laterally moving one of said field-structures with respect to the other, and metallic screening-means along each longitudinal border of the work-passage, for screening both longitudinal portions of the material along its edges from the field, each of said screening-means being generally U-shaped in cross-section and provided with passages for cooling fluid in the cross-member of the U.
11. In combination, a transverse-flux induction-heating means including a work-passage through which strip-like material can be moved longitudinally, said induction-heating means comprising flux-producing means having a field-structure on each side of said work-passage, for providing a pulsating magnetic field in said work-passage, supporting means for supporting one of said field-structures for movement laterally of said work-passage so that it can follow an edge of the moving strip-like material, and a screening-means longitudinally along the work-passage for screening a border portion of the material so that the field is screened therefrom, said screen-

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ing-means being attached to said movable field-structure for movement therewith.

12. An electromagnetic structure of a type described, comprising a core having a plurality of alternating poles and slots, the pole-faces lying in a generally flat surface, metallic field-screening means, and means attaching said metallic field-screening means to said core in front of said surface, said metallic screening-means being narrower than said core.

13. The invention of claim 12, characterized by said poles and slots being elongated and generally parallel, and said metallic screening-means comprising a non-magnetic metallic member spanning a plurality of poles and slots.

14. An invention including that of claim 13 but characterized further by said non-magnetic metallic member having an edge-portion obliquely passing across the face of a plurality of said poles and slots.

15. The invention of claim 12, characterized by said poles and slot being elongated and generally parallel, and said metallic screening-means being elongated in a direction transverse to the length of said poles and along an edge of said core.

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16. The invention of claim 12, characterized by said poles and slots being elongated and generally parallel, and said metallic screening means comprising a non-magnetic metallic member spanning a plurality of poles and slots, said metallic screening means being provided with means providing a water passage in heat exchanging relation to said member.

ROBERT M. BAKER.

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