United States Patent

Howell

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[54] **SCANNING TYPE INDUCTION HEATING**

[72] Inventor: **Charles N. Howell**, Poland, Ohio

[73] Assignee: **Ajax Magnethermic Corporation**, Warren, Ohio

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[52] **U.S. Cl.** **219/10.71**, 219/10.75, 219/10.79

[51] **Int. Cl.**.....**H05b 5/06**

[58] **Field of Search**..219/10.43, 10.61, 10.69, 10.71, 219/10.75, 10.77, 10.79

[56] **References Cited**

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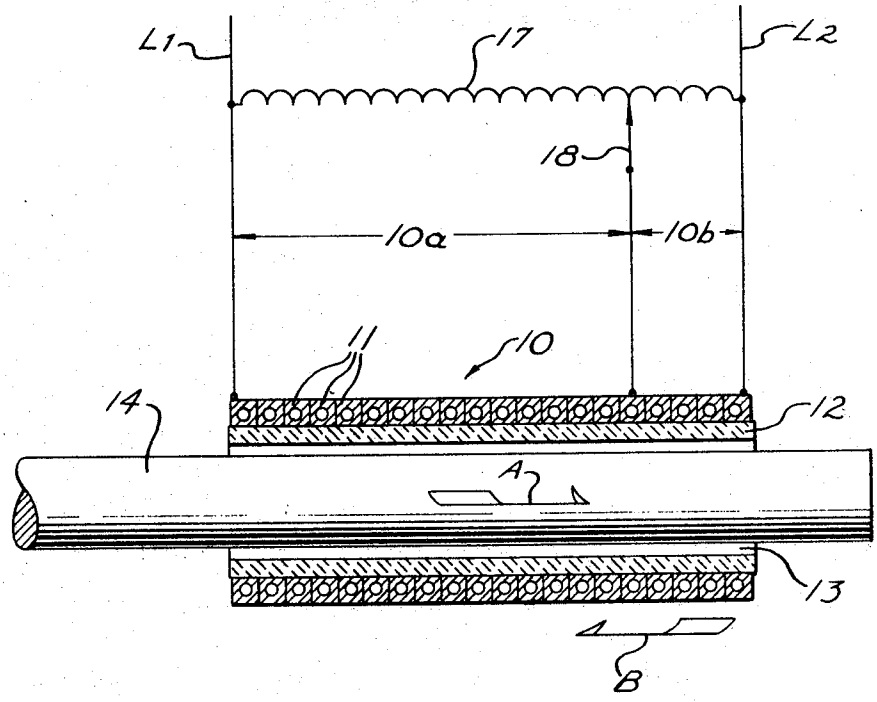
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Primary Examiner—J. V. Truhe
Assistant Examiner—B. A. Reynolds
Attorney—J. H. Slough

[57] **ABSTRACT**

There is disclosed herein means for providing progressive or scanning type induction heating of an elongated workpiece by means of a multiturn induction coil wherein there is continuous relative axial movement between the load and the coil. Means are provided for tapping a part or parts of the induction coil toward the exit end thereof whereby a separate voltage adjustment may be made at the tapped section or sections wherefor the temperature of the moving load is highest toward the exit end of the inductor.

17 Claims, 8 Drawing Figures



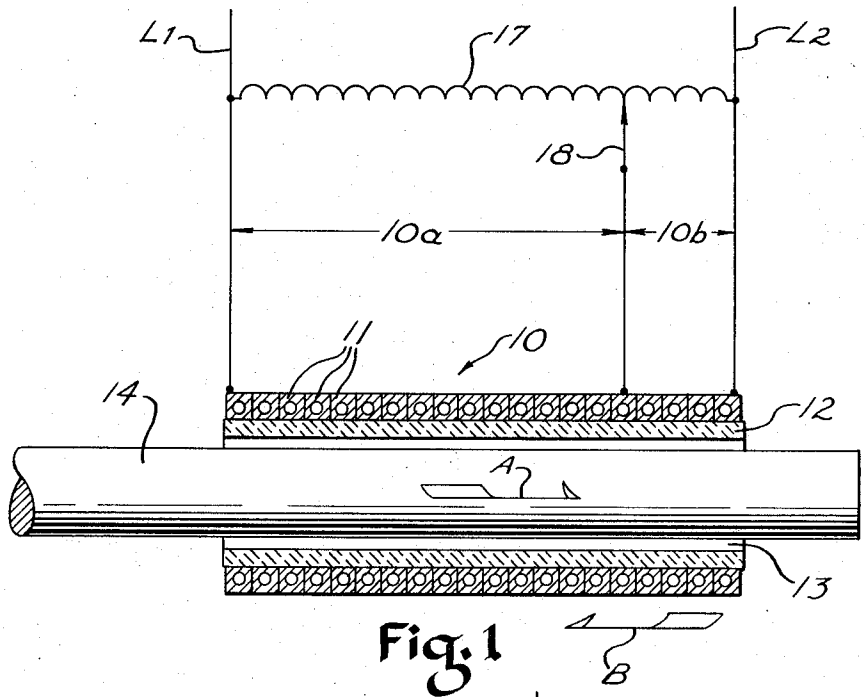


Fig. 1

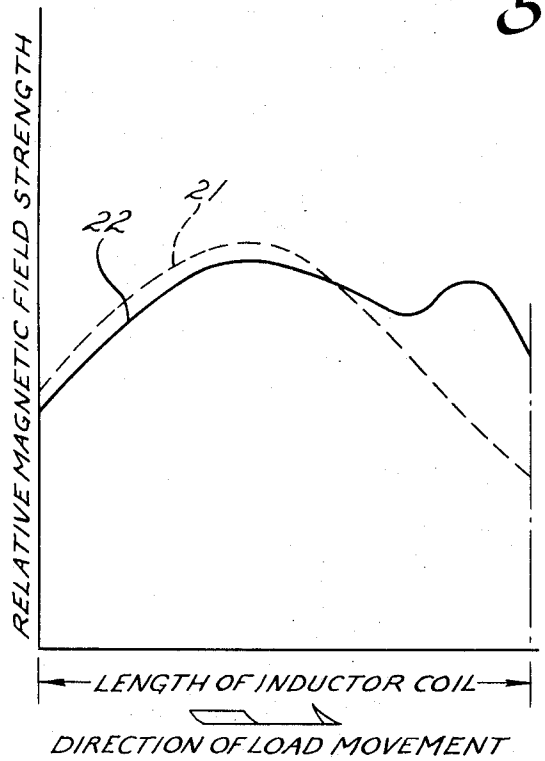


Fig. 2a

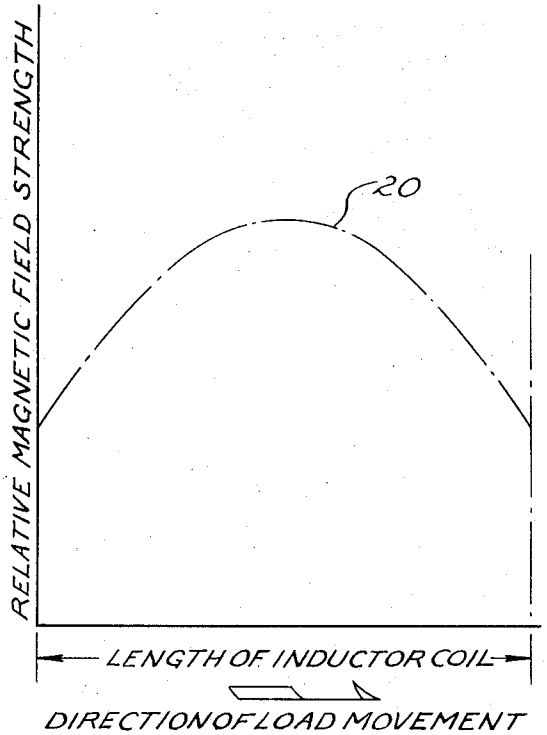


Fig. 2b

INVENTOR
Charles N. Howell
BY
J. H. SLOUGH
ATTORNEY

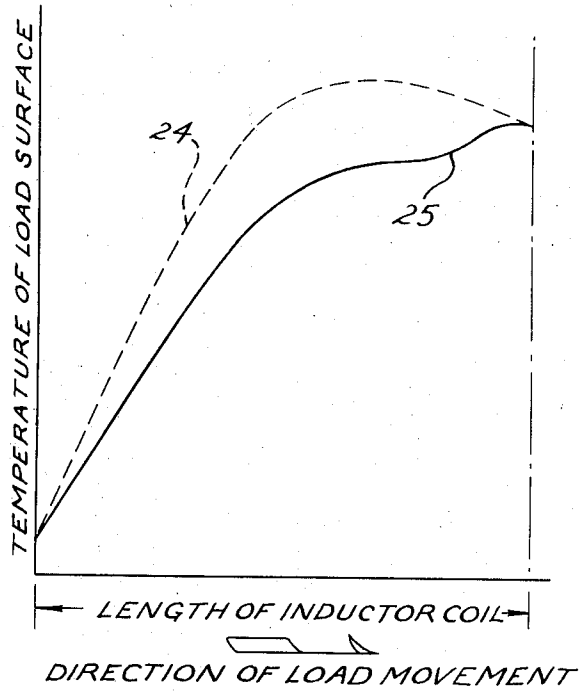


Fig. 3

INVENTOR
Charles N. Howell
BY
J. H. SLOUGH
ATTORNEY

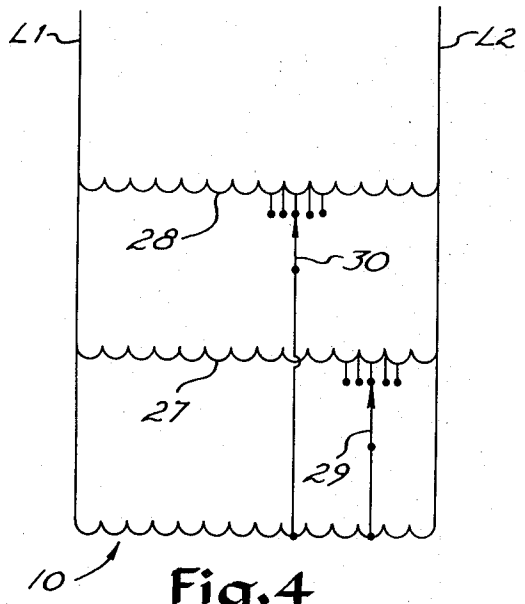


Fig. 4

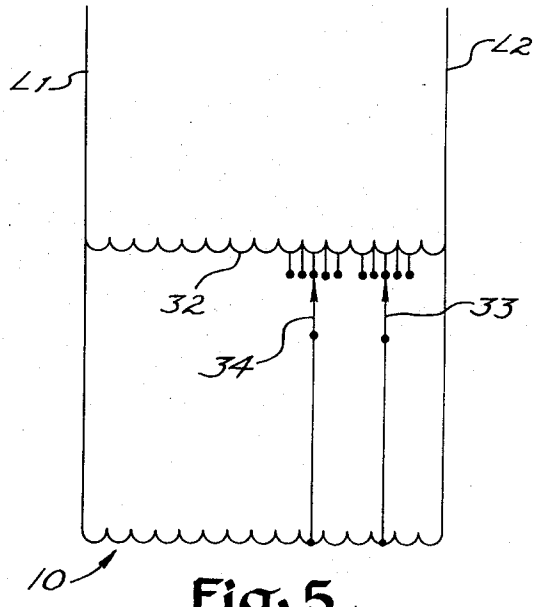


Fig. 5

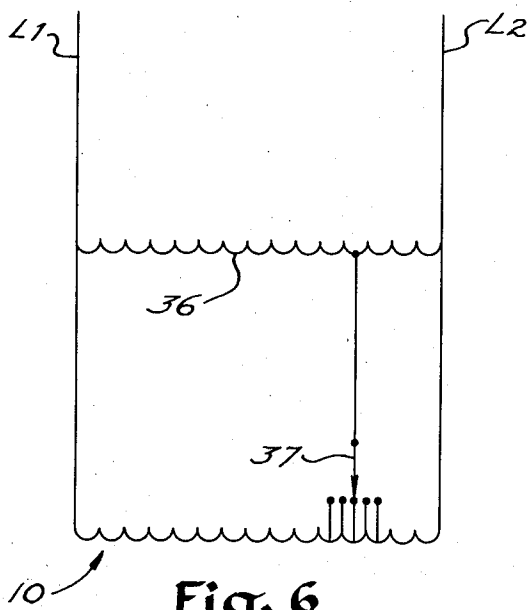


Fig. 6

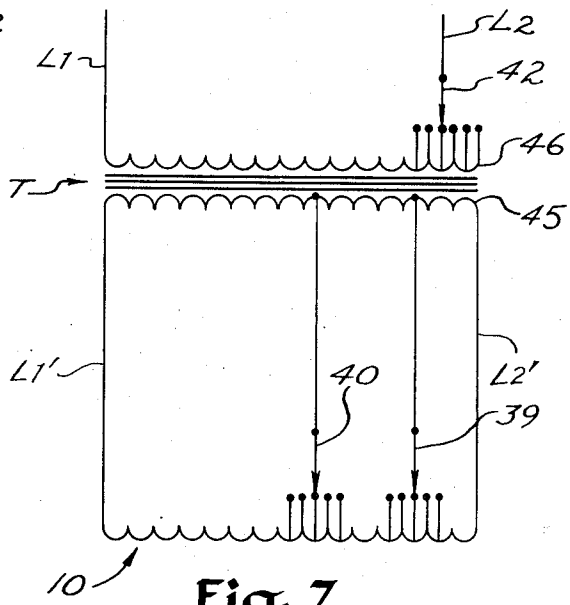


Fig. 7

INVENTOR
Charles N. Howell
BY
J. H. SLOUGH
ATTORNEY

SCANNING TYPE INDUCTION HEATING

This invention relates to induction heating and particularly to progressive or scanning type induction heating of an elongated workpiece within an induction coil wherein there is continuous relative axial movement between said coil and the workpiece.

In the scan type induction hardening of an elongated steel load, such as a steel cylinder, it is well known to utilize a solenoid type inductor; and where a deeper hardened case depth is required, a multiturn solenoid type induction coil is usually used.

Due to the characteristics of the magnetic field within the induction coil, a load continually passing therethrough reaches its highest temperature axially inwardly from the exit end of the coil. In order to have the load at the proper quenching temperature as it leaves the induction coil, it is necessary to overheat the load within the coil. Excessive temperatures produce in the steel microstructure a condition called "grain growth". Too much "grain growth" decreases the resistance of the steel to quench cracking, fatigue cracking, and spalling in service.

The present invention is directed to providing an induction coil wherein the power distribution along the coil is rearranged to overcome this grain growth or coarsening. This is accomplished by tapping a part or parts of the coil toward the exit end so that separate voltage adjustment at these tapped sections may be made to provide different zones of heating. Increasing the voltage at the tapped sections raises the power level thereof relative to the power level at the untapped section and will thus cause the cylinder's hottest spot to be located toward the exit end of the inductor.

It is an object of this invention to provide scan type induction heating means wherein an elongated, continuously moving load reaches its highest temperature substantially as it emerges from the induction coil.

Another object of the invention is to provide a scan type, multiturn solenoid induction coil having means for redistributing the voltage whereby to raise the power level thereof proximate to the exit end of said coil.

Still another object of this invention is to provide scan type induction heating means for a continuously moving, elongated load which will prevent hardened microstructure grain size growth in the load and improve the load's resistance to quench cracking, fatigue cracking, and spalling in service.

Other objects of the invention and the advantages thereof will be apparent from the following description and the accompanying drawings, in which said drawings:

FIG. **1** is a simplified, sectional view of a multiturn induction coil and load passing therethrough showing one form of electrical connection for accomplishing the objects of this invention;

FIG. **2***a* is a diagram showing, by way of comparison, the distribution of magnetic field strength axially along an energized induction coil while scan heating a carbon steel cylinder, both with and without applying the teaching of the present invention;

FIG. **2***b* is a diagram showing the distribution of magnetic field strength axially along an energized, empty, conventional, multiturn solenoid inductor;

FIG. **3** is a diagram showing the distribution of load surface temperature over the axial length of the energized induction coil while scan heating a carbon steel cylinder, both with and with out application of the present invention; and

FIG. **4–7** are simple electrical diagrams showing different ways of connecting an induction coil to a power source according to the present invention.

Referring now to the drawings in all of which like parts are designated by like reference numerals, in FIG. **1** there is shown a multiturn solenoid type induction coil **10** made up of a plurality of helical turns **11** of a preferably hollow, liquid cooled inductor. The induction coil **10** is typically provided with a refractory lining **12** which defines a central opening **13** therein through which an elongated load or workpiece such as a steel cylinder **14** is passed for continuous heating. Arrows A and B indicate the directions of relative movement between the cylinder **14** and the induction coil **10**. It will be readily understood that for the purposes of this invention either the induction coil **10** may be fixed and the cylinder **14** moved longitudinally therethrough or said cylinder may be held in a fixed position with said induction coil being moved relative thereto.

A voltage source for energizing the induction coil **10** is provided diagrammatically by leads L1 and L2 with the lead L2 being disposed adjacent to the right-hand or exit end of the inductor as shown. An autotransformer **17** is connected across the leads L1 and L2 and provided with a tap switch **18** whereby the induction coil **10** is electrically divided into an untapped section **10***a* and a relatively smaller tapped section **10***a* disposed adjacent to its exit end. It will be readily understood that adjustment of the autotransformer to increase the voltage in the untapped portion **10***a* will thereby shift the distribution of power generated in the work cylinder **14** toward the exit end of the inductor.

The diagrams of FIGS. **2***a* and **2***b*, and **3** graphically illustrate the effect of the present invention as applied to the scan type induction hardening of, for example, a steel cylinder. When alternating current is passed through an inductor, a magnetic field is generated within the inductor. When a load such as a steel cylinder is place in the inductor, it is the strength of the magnetic field which determines the power generated within the load. The strength of the magnetic field is not uniform along the length of the inductor as indicated by the dotted line **20** in FIG. **2***b*, said dotted line indicating the approximate relative field strength along the length of an energized induction coil which is empty or which heats a non-ferrous material. Quench hardenable steels have properties which make the more easily magnetized than air or nonferrous materials whereby for a given level of inductor current a carbon steel cylinder will have a much greater magnetic field strength than a nonferrous cylinder of the same dimensions. However, as the carbon steel is heated, this magnetic effect is reduced, and when the temperature passes a certain critical point called the Curie point (1300°–1400° F.) it loses its magnetic properties. In scan hardening of a carbon steel cylinder it is necessary to heat the cylinder beyond the Curie point and as a result the relative field strength along the length of the inductor is further changed giving an even more reduced field strength toward the exit end of the inductor. This last mentioned phenomenon is illustrated by the dot-dash broken line **21** in the diagram of FIG. **2***a*.

Since the power generated in the workpiece is proportional to the square of the magnetic field strength, there could be a substantial reduction in the power generated in the workpiece as it approaches the exit end of the inductor.

Thus it will be seen that in untapped induction coils, as the cylinder or load being heated progresses through the coil toward the exit end, the heat losses due to radiation, convection, and conduction tend to increase while the heat generated within the cylinder tends to decrease. Experience has shown that where deep hardening is being done, the power density is such that the surface temperature of the cylinder actually decreases as it passes through the exit end portion of the induction coil. This means that the highest cylinder surface temperature is reached not at the coil exit but somewhere closer to the axial center of the inductor. Therefore, in order to attain the minimum quench temperature needed at the exit end of the inductor whereby to develop full hardness in the cylinder, said cylinder must be overheated somewhere inwardly toward the medial portion of the induction coil whereby when it leaves the coil, the temperature thereof will not have dropped below minimal quenching temperature. It is such overheating and excessive temperatures which produce in the steel microstructure a condition called "grain growth" which will decrease the resistance of the steel to quench cracking, fatigue cracking, and spalling in service.

The present invention corrects the above situation and reduces the tendency to grain coarsening by tapping a part or parts of the induction coil toward the exit end thereof whereby a separate voltage adjustment can be made at this point. By raising the voltage level in the tapped section **10***b* and thereby relatively decreasing it in the untapped section **10***a*, a magnetic field strength distribution along the length of the inductor somewhat as indicated by the full line **22** of FIG. **2***a*, is attained. From the practical standpoint of the surface temperature achieved, this comparison is illustrated in FIG. **3** where the dotted line **24** illustrates the pattern of heat distribution over the length of the induction coil when the present invention is not applied whereas the full line shown at **25** indicates such temperature pattern when the present invention is utilized. Thus it will be clearly seen that in use of the present invention, the temperature is highest at the exit end of the induction coil thereby eliminating the need for overheating the load further back in said coil. This allows a reduction in the maximum temperature to which the cylinder is heated for hardening.

FIGS. **4–7** illustrate alternative approaches to applying the present invention whereby a certain tapped section or sections near the exit end of the inductor are provided with different voltages. In each simple electrical diagram, the induction coil is generally indicated at **10** with voltage being supplied by the leads L1 and L2.

In FIG. **4**, the induction coil **10** is provided with two zones of control by means of two autotransformers **27** and **28** having tap switches **29**, **30**, respectively, adjacent to the exit end of the coil. In this way, the voltage and, therefore, the heating potential of the coil can be increased toward the exit end in steps.

FIG. **5** also shows a two-zone control including a single autotransformer **32** having two tap switches **33** and **34** adjacent to the exit end of the induction coil.

FIG. **6** shows a single-zone control adjacent to the exit end of the induction coil which comprises a fixed autotransformer **36** and a tap switch **37** providing for adjustment at the induction coil.

The final example of FIG. **7** is, again, a two-zone control comprising tap switches **39** and **40** adjustably connecting a secondary winding **45** of a main transformer T with the induction coil **10** adjacent to the exit end thereof. An additional tap switch **42** is provided in the lead L2 and adjustably connects lead L2 to the primary winding **46** on the opposite side of said transformer. Leads L1′ and L2′ connect the ends of the secondary winding **45** to the ends of the induction coil **10**.

All of the above examples of electrical connections provide means whereby the hottest point of a relatively moving load in a solenoid type induction coil occurs proximate to the exit end of the coil whereby to reduce the maximum temperature to which the load is heated and at the same time provide the necessary quenching temperature at said exit end.

It will be understood that many changes in the details of the invention as herein described and illustrated may be made without, however, departing from the spirit thereof or the scope of the appended claims.

I claim:

1. In a scanning type induction heater, a multiturn solenoid type induction coil having an entrance end and an exit end and adapted to continuously progressively heat an elongated load projecting through said coil whereby the highest load temperature is attained adjacent to said exit end, the load and coil traveling axially with respect to each other during heating; means for energizing said coil to heat the load to quenching temperature, said energizing means including means to apply relatively increased voltage to that portion of said coil adjacent to said exit end wherefore every portion of the moving load attains a uniform maximum temperature proximate to said exit end.

2. In a scanning type induction heater as set forth in claim **1**: means modifying the power distribution including means electrically dividing the portion of said coil adjacent to said exit end into at least two adjacent zones whereby to increase the voltage in steps toward the exit end of said induction coil.

3. In a scanning type induction heater as set forth in claim **1**: said means for energizing said coil comprising power leads connected to the ends of said induction coil; an autotransformer connected in parallel with said induction coil; and tap means adjustably connecting an exit end portion of said induction coil with said autotransformer whereby the voltage in the tapped portion of said coil is increased relative to the untapped portion thereof to attain maximum temperature in the load proximate to said exit end.

4. In a scanning type induction heater as set forth in claim **3**: said tap means being located at said autotransformer for adjustment with respect thereto.

5. In a scanning type induction heater as set forth in claim **3**: said tap means being located at said induction coil for adjustment with respect thereto.

6. In a scanning type induction heater as set forth in claim **1**: said means for energizing said coil comprising

power leads connected to the ends of said induction coil; a pair of autotransformers connected in parallel with said induction coil; and a pair of adjustable tap means connecting an exit end portion of said induction coil with respective of said autotransformers whereby said exit end portion is divided into two zones of control for increasing the voltage in said zones relative to the untapped portion of said coil in steps toward said exit end whereby the spot at which the load attains maximum temperature is proximate to said exit end of said coil.

7. In a scanning type induction heater as set forth in claim 1: said means for energizing said coil comprising power leads connected to the ends of said induction coil; an autotransformer connected in parallel with said induction coil; a pair of tap means adjustably connecting an exit end portion of said coil at two axially spaced points along said coil and autotransformer whereby said exit end portion is divided into two zones of control for increasing the voltage of said exit end portion relative to the untapped portion of said coil in steps toward said exit end whereby the spot at which the load attains maximum temperature is proximate to said exit end of said coil.

8. In a scanning type induction heater as set forth in claim 1: said means for energizing said coil comprising a main transformer having primary and secondary windings; a pair of power leads connected adjacent to the ends of said primary winding, one of said leads being adjustably connected to said primary winding by tap means; means connecting the ends of said secondary winding to said induction coil; and an additional pair of tap means adjustably connecting an exit end portion of said coil at two axially spaced points along said coil and secondary winding whereby said exit end portion is divided into two zones of control for increasing the voltage relative to the untapped portion of said coil in steps toward said exit end whereby the spot at which the load attains maximum temperature is proximate to said exit end of said coil.

9. In a scanning type induction heater as set forth in claim 1: said means for energizing said coil comprising a main transformer having primary and secondary windings; a pair of power leads connected adjacent to the ends of said primary winding, one of said leads being adjustably connected to said primary winding by tap means; means connecting the ends of said secondary winding to said induction coil; and tap means adjustably connecting an exit end portion of said induction coil with said secondary winding whereby the voltage in the tapped portion of said coil is increased relative to the untapped portion thereof and whereby the spot at which the load attains maximum temperature is proximate to said exit end of said coil.

10. In a scanning type induction heater, a multiturn solenoid type induction coil having an entrance end and an exit end and adapted to continuously progressively heat an elongated load projecting through and having relative axial movement with respect to said coil and bringing every portion of said load to its highest temperature adjacent to said exit end; means for energizing said coil including power leads connected to the ends of said induction coil; transformer means connected across said power leads in parallel with said induction coil; tap means connected between said transformer means and induction coil whereby said induction coil is divided axially into a tapped section adjacent to said exit end and an untapped section extending form said entrance end to said tapped section; said tap means providing an increased voltage level in said tapped section relative to said untapped section and shifting the distribution of power generated in the load toward the exit end of said induction coil whereby the temperature of every portion of the moving load reaches its highest level adjacent to said exit end.

11. In a scanning type induction heater as set forth in claim 10: said transformer means comprising an autotransformer connected in parallel with said induction coil.

12. In a scanning type induction heater as set forth in claim 11: said tap means being adjustably connected at said autotransformer for adjusting the voltage level in said sections of said coil.

13. In a scanning type induction heater as set forth in claim 11: said tap means being adjustably located at said induction coil for adjusting the voltage level in said sections thereof.

14. In a scanning type induction heater as set forth in claim 10: said untapped section being of greater axial extent than said tapped section.

15. In a scanning type induction heater as set forth in claim 10: said transformer means comprising a pair of autotransformers each connected in parallel with said induction coil; said tap means comprising a pair of adjustable taps connecting an exit end portion of said coil with respective of said autotransformers whereby said tapped section is divided into two zones of control for increasing the voltage in said zones relative to said untapped section in steps toward said exit end.

16. In a scanning type induction heater as set forth in claim 10: said transformer means comprising an autotransformer; said tap means comprising a pair of adjustable taps connecting an exit end portion of said coil at two axially spaced points along said coil and autotransformer whereby said exit end portion is divided into two zones of control for increasing the voltage in said zones relative to said untapped section in steps toward said exit end.

17. In a scanning type induction heater as set forth in claim 10: said transformer means comprising a main transformer having primary and secondary windings; said power leads comprising incoming lead portions connected adjacent to the ends of said primary winding, one of said incoming lead portions being adjustably connected to said primary winding; said power leads including connector lead portions connecting the ends of said secondary winding to the ends of said induction coil; said tap means being adjustable at said coil whereby voltage in the tapped portion of said coil is increased relative to the untapped portion thereof.

* * * * *