United States Patent

Kasper

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[54] METHOD AND APPARATUS FOR TUNING A MULTI-TURN INDUCTION HEATING COIL

[72] Inventor: **Robert J. Kasper**, Seven Hills, Ohio

[73] Assignee: **Park-Ohio Industries, Inc.**, Cleveland, Ohio

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[52] **U.S. Cl.**.....**219/10.75**, 219/10.79, 336/137

[51] **Int. Cl.**.....**H05b 9/02**

[58] **Field of Search**.....219/10.79, 10.75; 336/115, 336/137

[56] **References Cited**

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Primary Examiner—J. V. Truhe
Assistant Examiner—Hugh D. Jaeger
Attorney—Meyer, Tilberry and Body

[57] **ABSTRACT**

In an induction heating device including a multiturn induction heating coil and at least one conductor extending from the coil to a power supply, which conductor is closely adjacent the outer periphery of the coil, there is provided means for adjusting the spacing between the conductor and the coil to tune the coil with an alternating frequency power supply.

6 Claims, 8 Drawing Figures

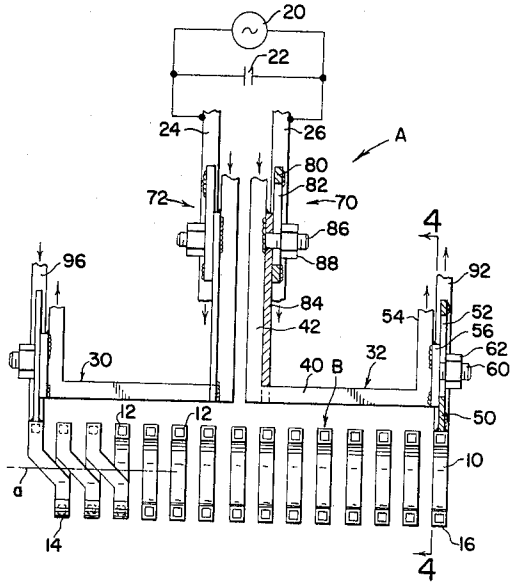


FIG. 1

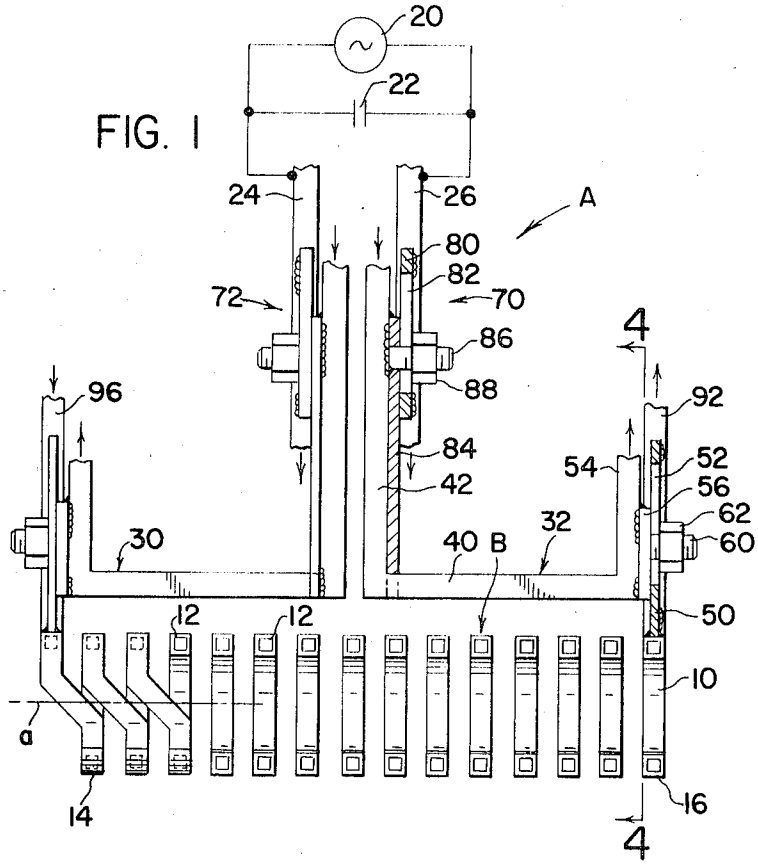


FIG. 2

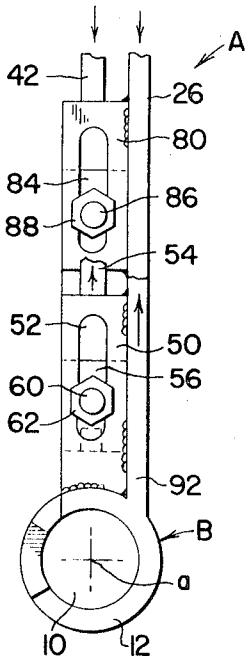


FIG. 3

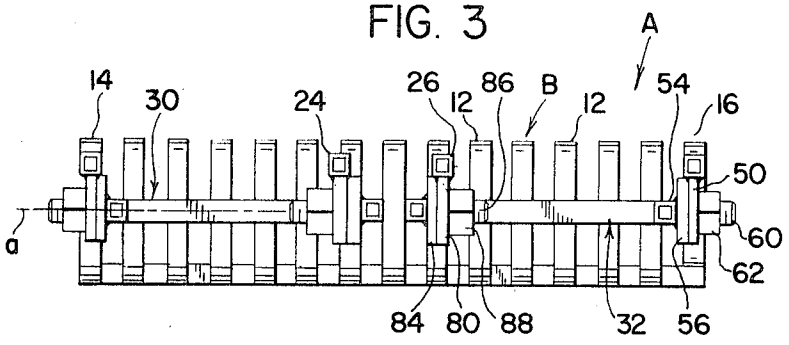
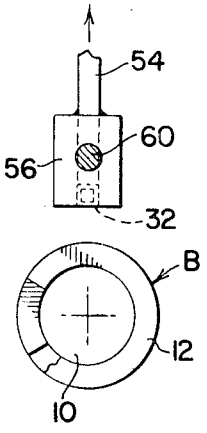
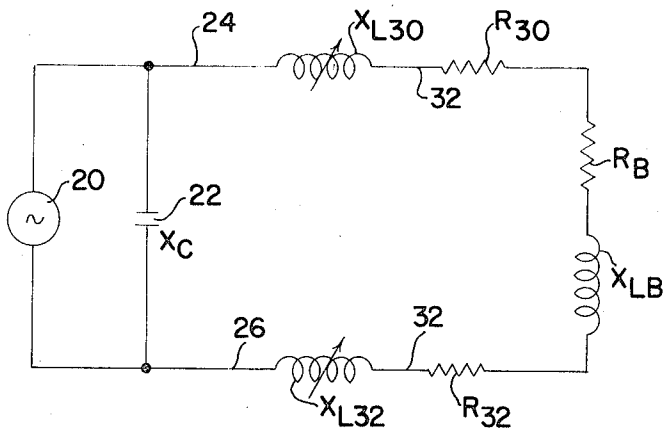


FIG. 4



INVENTOR.
ROBERT J. KASPER
BY
Meyer, Tilberry & Body
ATTORNEYS

FIG. 5



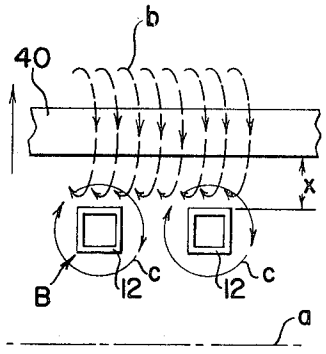


FIG. 7

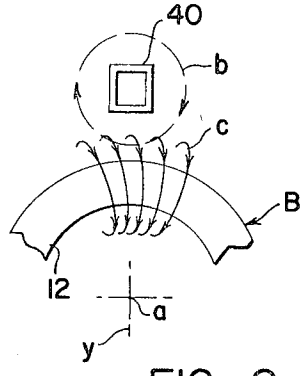
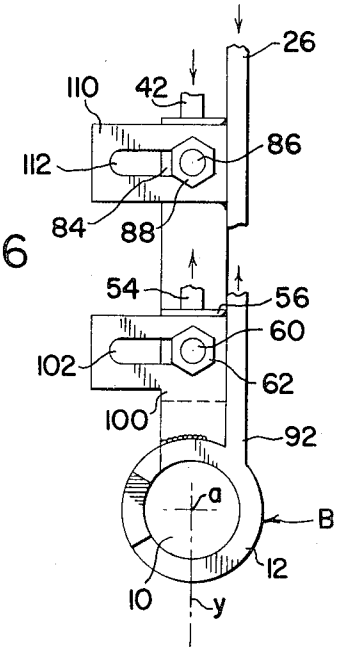


FIG. 8

FIG. 6



INVENTOR.
ROBERT J. KASPER
BY
Meyer, Tilberry & Body
ATTORNEYS

METHOD AND APPARATUS FOR TUNING A MULTITURN INDUCTION HEATING COIL

This invention relates to the art of induction heating and primarily to a method and apparatus for tuning a multi-turn induction heating coil used for induction heating.

The invention is particularly applicable for use in tuning a multi-turn induction heating coil of the type used for heating workpieces as they pass through the central workpiece receiving passageway of the coil and it will be described with particular reference thereto; however, it should be appreciated that the invention has much broader applications and may be used for tuning various other induction heating coils.

It is common practice to heat workpieces, such as forging billets, by progressively moving them through the central workpiece receiving passageway of a multi-turn induction heating coil. This coil is connected across the output leads of an alternating current power supply by a conductor arrangement which generally includes two closely spaced bus bars which extend to the coil and two conductors extending in opposite directions from the respective bus bars to the ends of the coil. A capacitor is included in the output circuit of the power supply to adjust the power factor of the installation. This capacitor is used to create inductive reactance which is balanced with the inductive reactance of the coil for tuning the total installation. The inductive reactance of the coil itself varies with the workpiece being heated. Consequently, the actual use of the coil must be considered when designing a coil for a particular use. The coupling between the leads or conductors adjacent the coil also affects the inductive reactance of the assembly including the coil and these conductors. This variable is not generally affected by the workpiece being heated; however, it is affected by the existence of ferromagnetic material close to the conductors.

The procedure for calculating the design of the assembly including the coil and the two leads or conductors extending along one side of the coil involves the calculation of the expected parameters which will affect the total inductive reactance of this assembly. It is not too difficult to compute the inductive reactance caused by the coil itself, taking into consideration the workpieces which are to be heated; however, it is difficult to calculate the effect of the leads extending along the side of the coil. These leads carry current which creates a mutual inductance between these leads and the coil proper. This mutual inductance varies substantially by the particular surroundings in which the assembly is to be used which surroundings can not be accurately determined when designing the spacing of these leads from the coil. Consequently, often coil assemblies including the closely spaced leads have not operated satisfactorily and require a substantial re-engineering.

The present invention is directed toward a method and a design of the coil and coil leads extending along the side thereof, which method and design can be used to tune the multi-turn induction heating coil installation with the power supply at the actual heating installation. This greatly simplifies the engineering difficulties in providing a properly tuned installation.

In accordance with the present invention, there is provided an improvement in an induction heating coil including two input leads extending axially along the length thereof, which improvement is the incorporation of means for adjustably shifting the conductors with respect to the coil periphery to change the mutual reactance between the conductors and the coil.

In accordance with another aspect of the present invention there is provided a method for tuning a multi-turn induction heating coil, which method includes adjusting the spacing between the input leads extending axially along the coil and the coil itself after the coil has been placed into the induction heating installation.

The primary object of the present invention is the provision of a method and apparatus for tuning a multi-turn induction heating coil, which method and apparatus may be employed after the coil is placed in the induction heating installation.

Another object of the present invention is the provision of an induction heating coil having two axially extending input leads which coil incorporates means for adjusting the spacing between the coil and the axially extending leads.

These and other objects and advantages will become apparent from the following description taken together with the accompanying drawings in which:

FIG. **1** is a side plan view showing, somewhat schematically, the preferred embodiment of the present invention;

FIG. **2** is an end elevational view of the structure shown in FIG. **1**;

FIG. **3** is a top elevational view of the structure shown in FIG. **1**;

FIG. **4** is a partial cross-sectional view taken generally along line **4—4** of FIG. **1**;

FIG. **5** is a wiring diagram showing, somewhat schematically, the operation of the present invention;

FIG. **6** is a side elevational view similar to FIG. **2** illustrating a modification of the present invention;

FIG. **7** is a partial schematic view illustrating the operating characteristics of the preferred embodiment of the invention shown in FIGS. **1–4**; and,

FIG. **8** is a partial schematic view illustrating an operating characteristic of the embodiment of the invention illustrated in FIG. **6**.

Referring now to the drawings wherein the showings are for the purpose of illustrating preferred embodiments of the invention only and not for the purpose of limiting same, FIGS. **1–4** show an induction heating installation A including a multi-turn induction heating coil B having an internal workpiece receiving passage **10**, a series of turns **12**, spaced terminal ends **14**, **16** and a central axis *a*. An alternating current power supply, schematically illustrated as generator **20**, is used for energizing the coil B, in accordance with known induction heating practices. The power factor of the heating installation is corrected by an appropriate capacitor **22** connected between bus bars **24**, **26**, which are relatively fixed with respect to the power supply **20**. In practice, the bus bars **24**, **26** are electrically connected onto the coil B by relatively rigid conductors extending between the ends **14**, **16** and the bus bars. These conductors are formed as a unit with the induction heating coil to provide an integral assembly.

In the illustrated embodiment of the invention shown in FIGS. **1–4**, the conductors extending between the bus bars **24,26** and the coil ends **14**, **16** are generally L-shaped conductors **30**, **32**. These conductors are substantially identical; therefore, conductor **32** will be described in detail, and this description will apply equally to the conductor **30**. Two generally orthogonal portions, i.e., axially extending element **40** and radially extending element **42**, form the primary elements of the conductor **32**.

Referring now briefly to FIG. **7** the operating characteristic of the installation illustrated in FIGS. **1–4** is schematically illustrated. Current flow through the element **40** creates a field b, while at the same time the current flow through the turn **12** of the coil B creates a series of fields *c* which are generally orthogonal to the field *b*. The interaction between these intersecting fields controls the mutual inductance and, thus, controls the voltage drop along the lead or element **40**. External ferromagnetic structures can also affect these fields and, thus, change the mutual inductance caused by the interaction of these fields. The present invention relates to a structure and method which utilizes the principle illustrated in FIG. **7** as a means for tuning the complete heating circuit of the induction heating installation. The spacing *x* between the turns **12** and element **40** directly affects the level of mutual inductance between these elements. In accordance with the present invention, there is provided means for actually adjusting the spacing *x* after the coil has been positioned in the induction heating device. In this manner, the mutual inductance between the element **40** and the turns **12** can be adjusted to change the inductive reactance in the heating circuit and tune the heating circuit with respect to the capacitor **22** in the out-

put circuit of generator **20**. Although a variety of structures could be used for adjusting the spacing *x*, in accordance with the preferred embodiment of the invention, there is provided a means for shifting the conductor **40** radially with respect to the coil turns **12**. This function could be accomplished by a variety of structural details. In accordance with the illustrated embodiment of the invention, the means for adjusting the spacing *x* with respect to the conductor **32** will be described in detail. This description, of course, applies equally to the adjustment of the conductor **30** with respect to the turns **12** at the opposite end **14** of the coil B. The support plate **50** is secured onto coil **10** adjacent end **16**, and this plate is provided with an elongated opening **52** extending generally radially from the axis *a*. Leg **54** is an integral part of conductor **32** and is provided with a plate **56** onto which is mounted an outwardly extending stud **60**. This stud extends through elongated opening **52** and threadably receives an appropriate fastening device, such as nut **62**. By using this structure, the coil B could be moved away from the conductor **32** to change the mutual inductance between the element **40** and the coil turns **12**; however, this concept is not employed in the illustrated embodiment of the invention. It has been found that the position of the coil B is generally fixed with respect to other auxiliary equipment, so that it is not practical to change the actual position of the coil. In view of this, it would be possible to shift the conductor **32** away from the coil to change the mutual inductance at element **40**. This is the concept illustrated.

To allow such movement, without moving the power supply **20**, an adjustable connection is required between element **42** and bus bars **24**, **26**. A variety of arrangements could be used for this adjustable connection; however, in accordance with the preferred embodiment of the present invention, adjustable couplings **70**, **72** are provided. These couplings are substantially identical; therefore, only coupling **70** will be described in detail. This description will apply equally to the coupling **72**. A plate **80** is fixed upon bus bar **26** and is provided with an elongated hole or opening **82** extending generally radial of the axis *a*, as best shown in FIG. **2**. Plate **82** is secured onto element **42** and carries an outwardly extending stud **86** protruding through opening **82**. An appropriate fastening device, such as nut **88** is threadably received upon stud **86** for clamping the coupling **70** into a variety of adjusted positions.

After the coil B has been secured onto bus bars **24**, **26** and the appropriate capacitor **22** has been incorporated, the electrical characteristics of the coil are determined for use with a selected workpiece. Thereafter, the nuts **62**, **88** are loosened and the conductors **30**, **32** are shifted with respect to the coil until the circuit of the induction heating installation A is properly tuned. Thereafter, the nuts **62**, **88** are tightened and the induction heating installation is ready for service. Of course, several adjustments may be necessary before the final tuning has been accomplished.

FIG. **5** is a schematic wiring diagram to illustrate, somewhat briefly, the operating characteristics of the invention so far described. Capacitor **22** has a capacitive reactance X_C. The leads or conductors **30**, **32** have inductive reactances X_{L30}, X_{L32}, and resistances R_{30} and R_{32}, respectively. The coil itself has an effective resistance R_B and an effective inductive reactance X_{LB}. By adjusting the spacing between the elements **40** and the turns **12**, as shown in FIG. **7**, the mutual inductance between these elements is varied. This is illustrated as an adjustment of the inductive reactances X_{L30} and X_{L32} in FIG. **5**. In this manner, the circuit shown in this figure can be tuned after the coil has been properly positioned for heating.

A majority of the induction heating installations requires a cooling system. A variety of cooling systems could be used; however, as illustrated in FIGS. **1–4**, the bus bars **24**, **26** are hollow and coolant is pumped therethrough. Coolant is circulated into element **42**, through element **40** and out element **54**. To cool the coil B, the coil is formed from a hollow conductor having an inlet **90** and an outlet **92**. In this manner, the various elements of the installation are cooled by circulation of a coolant therethrough.

Referring now to FIG. **6**, a modification of the present invention is illustrated. In accordance with this modification, the conductor **32** is moved in a direction generally normal to plane *y* extending through axis *a*. This is substantially perpendicular to the adjustment described in FIGS. **1–4**; however, the same basic result is obtained, i.e., the mutual inductance between the elements **40** and the turns **12** is changed by varying the effect between the fields *b*, *c*. In this embodiment, like parts have the same numbers as the parts in FIGS. **1–4**. A plate **100** has an opening **102** extending generally perpendicular to leg **54**. In this manner, the conductor **32** may be moved in the direction of the elongated opening **102**. A plate **110** is secured onto element **42** and has an opening **112** extending perpendicular to element **42**. Referring now to FIG. **8**, when the nuts **62**, **88** are loosened, the elements **40** may be moved in the direction of the arrow to change the mutual inductance between the fields *b*, *c*. This has the same effect in tuning the heating circuit as described in detail above. Other arrangements could be used for changing the distance between the element **40** and the turns **12**. Elongated holes extending in various directions could be employed to accomplish this change in spacing. It is also possible to enlarge the width of the element **40** to change the mutual inductance between this element and the turns of the coil.

Having thus described my invention, I claim:

1. In an induction heating device including a multi-turn induction heating coil having a central axis, an outer periphery and spaced ends, a first conductor connected onto one of said ends and extending axially of said coil and adjacent said periphery, and a second conductor connected onto the other of said ends, said conductors being adapted for connection to an alternating current power supply means for energizing said coil whereby current flow in said first conductor and said coil results in a mutual inductance between said first conductor and said coil and affects the reactance of said first conductor, the improvement comprising: means for adjustably shifting said first conductor with respect to said coil periphery to change the mutual inductance between said first conductor and said coil.

2. The improvement as defined in claim **1** wherein said adjustable shifting means includes means for shifting said first conductor in a direction generally radial of said coil.

3. The improvement as defined in claim **1** wherein said adjustable shifting means includes means for shifting said first conductor in a direction generally normal to a plane defined by the axis of said coil.

4. In an induction heating installation including a multi-turn induction heating coil having several turns, a central axis and spaced ends, a pair of leads, each of which is electrically connected adjacent one of said spaced ends of said coil, a source of alternating current having two generally fixed output bus, means for connecting one of said leads to each of said generally fixed output bus, wherein said leads extend generally axially of said coil and adjacent said coil and whereby the fields around said leads are inductively coupled with the fields around the turns of said coil, the improvement comprising: means for adjusting the spacing between said leads and said coil to vary the inductive coupling between said leads and said coil turns.

5. In an induction heating device including a multi-turn induction heating coil having a central axis, an outer periphery and spaced ends, a first conductor connected onto one of said ends and extending axially of said coil and adjacent said periphery, a second conductor connected onto the other of said ends, said conductors being adapted for connection to an alternating current power supply means with two output leads for energizing said coil whereby current flow in said first conductor and said coil results in a mutual inductance between said first conductor and said coil and affects the reactance of said first conductor and a power factor correcting capacitor connected across said output leads, the improvement comprising: means for adjusting the mutual reactance between said first conductor and said coil to tune said coil with said capacitor.

6. A method of tuning a multi-turn induction heating coil including at least one lead extending axial of said coil and closely spaced therefrom, said method comprises the steps of:

a. connecting said coil onto a power supply station having a power factor correcting capacitor and output bus bars; and,

b. adjusting the spacing between said lead and said coil to tune said coil and lead with said power supply station.

* * * * *