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(54) **Method for inductively heating valve seat inserts.**

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(73) Proprietor: **PARK-OHIO INDUSTRIES, INC.**
20600 Chagrin Boulevard
Shaker Heights Ohio 44122 (US)

(72) Inventor: **Balzer, Norbert Raymond**
1108 Brown Street
Boaz Alabama 35957 (US)

(74) Representative: **Abbie, Andrew Kenneth et al**
A.A. THORNTON & CO. Northumberland House
303/306 High Holborn
London, WC1V 7LE (GB)

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Description

Background of the Invention

This invention relates to the art of induction heating and, more particularly, to a method for inductively heating valve seat inserts for an engine component such as an engine head or the like.

The invention is particularly applicable to heating exhaust valve seat inserts in a cast aluminum engine component and will be described with particular reference thereto; however, it will be appreciated that the invention has broader applications.

Internal combustion engines generally employ frusto-conically shaped valve seats which coact with reciprocating poppet valves for controlling the flow of gases to and from the engine cylinders. The valve seats for the exhaust valves must have extremely high wear characteristics at high engine operating temperatures. To counteract such wear and increase desirable physical properties in the valve seats, the frusto-conical seat surfaces are inductively heated during engine manufacture and then quench hardened by conventional liquid or mass quenching techniques.

Induction heating of multiple valve seats in an engine component may be adapted to automatic processing in a single operation where, for example, a plurality of single turn inductors are positioned immediately adjacent the frusto-conically shaped exhaust valve seat. Such apparatus and methods are disclosed in US—E—29,046 and US—A—3,837,934 to which reference is directed. There, the inductors are independently movable on a common frame relative to the engine component and are biased toward the valve seats. The frame itself is moved into contact with the engine component so that each inductor contacts the valve seat which it is to heat. The inductors are then locked in position and the frame retracted slightly for purposes of establishing a desired magnetic coupling distance between the inductors and valve seats. After heating, the valve seat material is quenched. The foregoing patents disclose methods which have provided extremely good results when induction heating ferrous exhaust valve seats in cast iron engine components.

However, recent efforts to improve gasoline mileage and obtain vehicle weight reductions have brought about an ever increasing use of aluminum for major engine components. Although use of aluminum for manufacturing such major components provides substantial benefits insofar as weight reduction is concerned, attendant difficulties and problems have been encountered in several areas, including exhaust valve seats. Aluminum does not have sufficient strength and hardness properties to itself accommodate or comprise the valve seat surfaces. As a result of these shortcomings, it is necessary that the exhaust valve seat surfaces be provided through use of seat ring inserts constructed of a hardenable material installed in the cast aluminum engine component by suitable means such as, for example, a force fit or the like. For cost reduction purposes as well as for purposes of assuring accurate location and concentricity of the valve seat surfaces, it is highly desirable that machining of the inserts for obtaining final valve seat conformation takes place subsequent to mounting of the inserts into the engine component.

While machining of the frusto-conical valve seat surfaces does not present any significant problems, subsequent surface hardening must be performed in a manner which will not deleteriously affect the aluminum engine component and/or the pressure fit between the engine component and the ferrous metal insert. Because it is customarily necessary to harden exhaust valve seat surfaces at approximately 1700°F (927°C) and since the melting point of typical aluminum alloys employed for engine components is generally in the range of 1200°—1400°F (649—760°C), heating of and heat transfer through the seat inserts must be carefully controlled during the hardening process. Without appropriate control, the inserts may radially expand against the associated receiving bores in the engine component to destroy the pressure fit relationship therebetween and/or otherwise damage the integrity of the engine component metal adjacent thereto. In more severe cases, the aluminum engine component metal could be unacceptably brought close to its melting temperature. Both of the foregoing situations are extremely undesirable in that they can ultimately adversely affect engine operation or expected engine life. The specific heating conditions disclosed in US—E—29,046 and US—A—3,837,934 are useful in inductively heating valve seats and valve seat insert surfaces when conventional gray cast iron engine components are involved. They are not, however, as effective for use with aluminum or the like components because of the above noted problems and characteristics which are generally associated therewith. In view of these factors, the inserts were often made of expensive steel and hardened in furnaces before assembly into the engine component. This involves costly materials as well as costly post assembly machining of the hardened seat inserts.

It has, therefore, been considered desirable to develop a method for inductively heating the seat surface of ferrous seat ring inserts installed in respective recesses, or bores, of engine components for purposes of overcoming the foregoing problems. One such method and apparatus is disclosed in our EP—A—41317, published after the priority date of the present applications, in which a conducting ring in operative association with each heating inductor is used to protect the interface between the insert and engine component from heating to a temperature sufficient to loosen the insert from the recess during inductive heating of the valve seat surface.

The present invention provides an alternative method of hardening a valve seat on a ferrous valve seat insert located in a bore of an engine component using inductive heating, in which the above-mentioned problems caused by heating the valve seat surface to its hardening temperature whilst the insert is located in the engine component bore are overcome by the controlled application of high frequency power in the inductive heating of the valve seat surface.

The present invention includes a method of hardening a frusto-conical valve seat on a ferrous valve seat insert retained with a pressure fit within a bore of an engine component said method comprising the steps of:

(a) locating a generally circular inductor adjacent to and matching said insert;

(b) controlling the energization of said inductor at a frequency of between 200 and 500 kHz, a selected power of 12 to 25 kW, a power density at the seat of between 24 to 50 kW/in^2 (3.72 to 7.7 kW/cm^2) and for a period of time less than 1 second, thereby to transform the metal forming said valve seat into an austenitic structure to some predetermined depth; and

(c) thereafter quenching said valve seat material.

The invention is especially advantageous where the engine component is non-ferrous particularly, as stated above, where the engine component is aluminum. Specifically, the invention also includes a method of hardening a frusto-conical valve seat on a ferrous valve seat insert coaxially fixed in a bore of an aluminum engine component, said method comprising the steps of:

(a) locating a generally circular inductor adjacent said insert;

(b) energizing said inductor with a primary power source having a frequency of at least 200 kHz and a selected power of at least 12 kW and producing a power density at the seat of between 25 to 45 kW/in^2 (3.875 to 6.975 kW/cm^2);

(c) maintaining said inductor in an energized condition for a preselected period of time for transforming the metal forming said valve seat into an austenitic structure to a depth less than 0.035 inches (0.89 mm); and

(d) thereafter quenching said valve seat material.

DE—B—1,035,179 which has been drawn to our attention by the European Patent Office during the prosecution of this application discloses a method of hardening a valve seat in a ferrous cylinder head using inductive heating, which is carried out at a power level of 75 kW at a frequency of 360 kHz over two periods of time, the first being a few hundredths of a second in duration and the second being 0.35 seconds long, the valve seat material thereafter being quenched. This specification also refers to the hardening of ferrous valve seat inserts in a ferrous engine head, but does not disclose a different power level for the hardening of such an insert. No power density values are given in DE—B—1,035,179, but assuming a valve seat area of about 0.5 in^2 (3.23 cm^2) — i.e. the same as that in the exemplary embodiment of the present invention, described hereinafter — the power density would be about 150 kW/in^2 (23.1 kW/cm^2). That is at least 300 per cent greater than the maximum power density used in the present invention.

In order that the invention may be well understood an embodiment thereof, which is given by way of example only, will now be described in more detail with reference to the accompanying drawings, in which,

FIGURE 1 is a partial cross-sectional view illustrating the preferred manner of practicing the subject new method; and,

FIGURE 2 is an enlarged cross-sectional view of a portion of FIGURE 1 for better showing the relationship between the inductor and valve seat surface to be heated.

Detailed Description of the Preferred Embodiment

Referring now to the drawings wherein the showings are for purposes of illustrating the preferred embodiment of the invention only and not for purposes of limiting same, FIGURE 1 shows an induction heating device A disposed in operative communication with a cast aluminum engine component B. Specific details of the features and operation of induction heating device A are disclosed in detail in our US—E—29046.

More particularly, engine component B includes at least one exhaust passageway 10 having an annular valve seat insert 12 formed of cast iron and closely disposed coaxially within a recessed cylindrical exhaust port 14. A guide opening or port 16 is coaxial with exhaust port 14 and receives the stem of a conventional poppet valve (not shown) when the engine is assembled.

Annular valve seat insert 12 includes a frusto-conically shaped valve seat surface 30 which is installed into the engine component, machined and thereafter hardened. Insert 12 comprises a standard component typically constructed from steel or cast iron; however, cast iron is preferred because of costs. Installation of insert 12 into the receiving bore at exhaust port 14 may be by any one of a number of conventional methods including, for example, a pressure or force fit and the like. When a pressure fit technique is employed, the insert is normally chilled to obtain some degree of contraction and thereby more readily accommodate installation. Following installation, the insert is fixedly retained in port 14 by opposed forces particularly occurring at interface area 32 between the outer side wall of the insert and the receiving bore side wall. It will be readily appreciated that a plurality of exhaust ports with associated inserts A are typically involved with any engine component B in the same manner best described in U.S. Pat. No. Re 29.046.

Continuing with reference to FIGURE 1, induction heating device A includes a generally cylindrical electrically insulated body 40 having a somewhat smaller cylindrical electrically insulated body insert 42 extending coaxially outward from the inner end thereof. A locating pin or nose

44 extends coaxially outward from body insert 42 to accommodate locating the induction heating device coaxially of exhaust port 14 in a known manner.

Interposed between body 40 and body insert 42 of the induction heating device is a single turn inductor generally designated 50. This inductor comprises a split circular ring of copper of generally rectangular cross-section and includes a pair of spaced legs 52, 54 extending therefrom axially through body 40 and outwardly from the body outer end. Inductor 50 as well as legs 52, 54 are hollow and communicate with each other in such fashion to define a continuous fluid passageway therethrough. This passageway accommodates passage of a suitable coolant from a source (not shown) disposed adjacent to or spaced from the overall induction heating device as is known.

A power source 60 is operatively connected by leads 62, 64 to inductor 50 as at, for example, legs 52, 54, respectively. The power source comprises an oscillator having an output frequency capability generally in the range of 200—500 kilohertz (kHz) and a power capability of generally between 12—25 kilowatts (kW). In practice, it is preferred to use an oscillator having an output frequency of approximately 400 kHz to provide a radio frequency which will create a relatively low depth in the heating pattern caused by flux generated around conductor 50. Also, the preferred power is approximately 20 kW. Since the heated area of conical surface 30 is about 0.5 in^2 (3.23 cm^2), the power density is in the general range of 24 to 50 kW/m^2 (3.72 to 7.7 kW/cm^2) and is preferably 40 kW/in^2 (6.2 kW/cm^2). This is drastically higher than any power density previously used for heating the valve seats of internal combustion engines. A time delay device is advantageously incorporated between leads 62, 64 for turning the power source 60 off after a preselected heating time or interval. This heating time is quite short and less than 1 second.

In practicing the new method, aluminum engine component B will typically have a plurality of exhaust ports 14 which all have similar inserts 12 which are to be inductively heated in a simultaneous manner. Apparatus adapted for this purpose is shown in US—E—29,046 and includes means for causing induction heating device A to be positioned in an associated exhaust port 14 with locating pin 44 coaxially aligning the device relative to the exhaust port. Device A is bottomed out with inductor 50 engaging conical valve seat surface 30 of seat insert 12. Thereafter, the heating device is backed out slightly so that some preselected gap is present between the inductor and frusto-conical valve seat surface 30 to effect a desired coupling relationship therebetween.

With reference to FIGURE 2, this gap is generally designated by letter *g* and comprises a distance of approximately 0.040 inches (1 mm). While this particular gap has been found particularly suitable in most cases where a ferrous valve seat insert disposed in an aluminum engine component is to have a frusto-conical valve seat surface hardened, it will be appreciated that it may be varied somewhat as deemed necessary or appropriate for a specific application of the new method. The side or flat surface 70 of inductor 50 is generally parallel to seat surface 30 and has a width at least slightly greater than that of the seat surface.

It is necessary to prevent deleterious heating of or heat transfer through the entirety of insert 12 in the preferred environment here under discussion. It has been discovered that acceptable heating results could be obtained if seat surface 30 was quickly brought to temperature and then quenched prior to the time that any deleterious heat transfer could occur. Moreover, it is necessary at the same time to obtain a suitable depth of heating to assure that the hardened seat surface will have sufficiently high wear characteristics at high operating temperatures. To that end, it has also been discovered that a depth of generally no greater than 0.035 inches (0.89 mm) will provide wholly satisfactory results without in any way impairing engine operation or engine life. In practice, a depth of approximately 0.024 inches (0.61 mm) has been found entirely satisfactory and is preferred when using the subject new method.

Thus a high power, low time induction heating method is employed whereby seat surface 30 of seat insert 12 is sufficiently heated to an acceptable depth for purposes of transforming the seat material into the austenitic range for subsequent transformation into the martensitic range. As shown in FIGURE. 2, the depth of such transformation is generally designated by the letter *d* and may comprise a depth of up to approximately 0.035 inches (0.89 mm), although 0.024 inches (0.61 mm) is generally preferred. By using the preferred frequency of approximately 400 kHz, a relatively shallow reference depth is heated in the seat surface and by using the preferred power of approximately 20 kW to obtain a power density of about 40 kW/in^2 (6.2 kW/cm^2), the valve seat is heated to an acceptable transformation temperature at a very rapid rate. Indeed, and when using the preferred ranges noted, it has been found that a time interval of approximately 0.5 seconds will provide entirely satisfactory heating and hardening results to a depth of approximately 0.024 inches (0.61 mm).

On completion of the induction heating cycle, the seat rings or the entire engine component are subjected to quenching in a manner known in the art. Because heating of seat surfaces 30 is so rapid and is substantially limited to or isolated at these surfaces to a preselected shallow depth, there is no deleterious heating of the whole insert or heat transfer through seat inserts 12. These factors might otherwise adversely affect or alter the close fitting relationship between the seat inserts and exhaust ports. This result represents a substantial improvement over results obtained from prior known techniques in inductively heating valve seats or valve seat inserts.

Example

In using the foregoing new method, cast iron valve seat inserts have been successfully hardened to a case depth of 0.030 inches (0.76 mm) using a heat cycle of 0.5 seconds with a radio frequency oscillator (400 kHz) and a power density of 40 kW/in^2 (6.2 kW/cm^2). The advantages of using a soft cast iron insert in an aluminum cylinder head rather than a prehardened alloy steel insert resides in the fact that it permits easy machining of the soft cast insert with subsequent hardening of the valve seat by induction hardening techniques. This then achieves the requisite seat durability while, at the same time, yielding considerable improvement by way of increased productivity.

Valve seat inserts have also been hardened at a 0.2 second heat time with this new method to approximately the case depth of 0.030 inches (0.76 mm) by using considerably more than 40 kW/in^2 (6.2 kW/cm^2) power density. Even though it reduces the tendency to induce heat into the insert, the 0.5 second heating cycle is considered somewhat more tolerable in that it provides a more uniform and constant case depth.

By way of comparison, the preferred parameters of the subject method using a primary power source having a frequency of approximately 400 kHz and a power of approximately 20 kW with a heating cycle of approximately 0.5 seconds provides a case depth of approximately 0.024 inches (0.61 mm) and a hardness of "58" on the Rockwell C scale in cast iron seat inserts. Prior techniques which typically employ the same frequency at a power of approximately 7 kw with a heating cycle of approximately 7—8 seconds provides a case depth of between 0.050—0.060 inches (1.27—1.52 mm) and a hardness of "58" on the Rockwell C scale. Such parameters, while acceptable for gray cast iron engine components having integral cast iron valve seats simply will not provide suitable results in the environment of cast aluminum engine components utilizing ferrous seat ring inserts.

Claims

1. A method of hardening a frusto-conical valve seat (30) on a ferrous valve seat insert (12) retained with a pressure fit within a bore of an engine component (B) said method comprising the steps of:

(a) locating a generally circular inductor (50) adjacent to and matching said insert (12);

(b) controlling the energization of said inductor at a frequency of between 200 and 500 kHz, a selected power of 12 to 25 kW, a power density at the seat of between 24 to 50 kW/in^2 (3.72 to 7.7 kW/cm^2) and for a period of time less than 1 second, thereby to transform the metal forming said valve seat into an austenitic structure to some predetermined depth; and

(c) thereafter quenching said valve seat material.

2. A method as claimed in claim 1, wherein said step of energizing is performed at a frequency greater than 250 kHz.

3. A method as claimed in claim 2, wherein said step of energizing is performed at a frequency of approximately 400 kHz.

4. A method as claimed in claim 3, wherein said step of energizing is performed generally at a power of approximately 20 kW.

5. A method as claimed in claim 3 or 4, wherein said step of energizing is performed at a power density of 40 kW/in^2 (6.2 kW/cm^2).

6. A method as claimed in any one of claims 1 to 4, wherein said step of energizing is performed at a selected power to create a power density at said seat (30) in the range of 25 to 45 kW/in^2 (3.875 to 6.975 kW/cm^2).

7. A method as claimed in any one of the preceding claims, wherein said energization of said inductor transforms the metal forming said valve seat into an austenitic structure to a depth of less than 0.035 inches (0.89 mm).

8. A method of hardening a frusto-conical valve seat (30) on a ferrous valve seat insert (12) coaxially fixed in a bore of an aluminum engine component (B), said method comprising the steps of:

(a) locating a generally circular inductor (50) adjacent said insert (12);

(b) energizing said inductor (50) with a primary power source having a frequency of at least 200 kHz and a selected power of at least 12 kW and producing a power density at the seat of between 25 to 45 kW/in^2 (3.875 to 6.975 kW/cm^2);

(c) maintaining said inductor (50) in an energized condition for a preselected period of time for transforming the metal forming said valve seat (30) into an austenitic structure to a depth less than 0.035 inches (0.89 mm); and

(d) thereafter quenching said valve seat material.

9. A method as defined in claim 8, wherein said step of energizing is performed at a frequency in the range of 250 to 500 kHz.

10. A method as claimed in claim 8 or 9, wherein said step of maintaining is performed for transforming to a predetermined depth of approximately 0.024 inches (0.61 mm) is approximately 0.5 seconds.

Patentansprüche

1. Verfahren zum Härten eines kegelstumpfförmigen Ventilsitzes (30) an einer aus Eisenwerkstoff bestehenden Ventilsitzeinlage (12), die mit Preßsitz in einer Bohrung eines Motorteils (B) gehalten ist, wobei das Verfahren durch folgende Merkmale gekennzeichnet ist:

(a) Anordnung eines im wesentlichen kreisförmigen Induktors (50) in Nähe der und in Anpassung zu der genannten Einlage (12);

(b) Einstellung der Erregung des genannten Induktors auf eine Frequenz zwischen 200 und 500 kHz, eine ausgewählte Leistung von 12 bis 25 kW, eine Leistungsdichte am Sitz zwischen 24 und 50 kW/in^2 (3,72 bis 7,7 kW/cm^2) und für eine Zeitspanne unter 1 Sekunde, um das den Ventilsitz bildende Metall bis zu einer vorbestimmten Tiefe in den austenitischen Zustand zu überführen;

(c) Anschließendes Kühlen des Ventilsitzwerkstoffes.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß der genannte Schritt der Erregung bei einer Frequenz oberhalb 250 kHz durchgeführt wird.

3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß der genannte Schritt der Erregung bei einer Erregung von etwa 400 kHz durchgeführt wird.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß der genannte Schritt der Erregung bei einer Leistung von angenähert 20 kW durchgeführt wird.

5. Verfahren nach Anspruch 3 oder 4, dadurch gekennzeichnet, daß der genannte Schritt der Erregung mit einer Leistungsdichte von 40 kW/in^2 (6,2 kW/cm^2) durchgeführt wird.

6. Verfahren nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, daß der genannte Schritt der Erregung mit einer solchen Leistung durchgeführt wird, daß die Leistungsdichte an dem Sitz (30) im Bereich von 25 bis 45 kW/in^2 (3,875 bis 6,975 kW/cm^2) liegt.

7. Verfahren nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die genannte Induktorerregung das den Ventilsitz bildende Metall auf einer Tiefe von unter 0,035 inch (0,89 mm) in die austenitische Form überführt.

8. Verfahren zum Härten eines kegelstumpfförmigen Ventilsitzes (30) an einer aus Eisenwerkstoff bestehenden Ventilsitzeinlage (12), die koaxial in einer Bohrung eines Aluminium-Motorteils (B) festgelegt ist, gekennzeichnet durch folgende Verfahrensschritte:

(a) Anordnung eines im wesentlichen kreisförmigen Induktors (50) in Nähe der genannten Einlage (12);

(b) Erregung dieses Induktors (50) mittels einer Hauptstromquelle, die eine Frequenz von mindestens 200 kHz und eine ausgewählte Leistung von mindestens 12 kW hat und eine Leistungsdichte am Sitz von 25 bis 45 kW/in^2 (3,875 bis 6,975 kW/cm^2) erzeugt;

(c) Aufrechterhaltung des erregten Zustandes am Induktor (50) über eine vorbestimmte Zeitspanne, die ausreicht, um das den Ventilsitz (30) bildende Metall bis zu einer Tiefe, die kleiner ist als 0,035 inch (0,89 mm) in die austenitische Struktur umzuwandeln;

(d) Anschließendes Abkühlen des Ventilsitzwerkstoffes.

9. Verfahren nach Anspruch 8, dadurch gekennzeichnet, daß der genannte Schritt der Erregung bei einer Frequenz im Bereich von 250 bis 500 kHz durchgeführt wird.

10. Verfahren nach Anspruch 8 oder 9, dadurch gekennzeichnet, daß der genannte Schritt der Aufrechterhaltung des erregten Zustandes so durchgeführt wird, daß die Strukturumwandlung in etwa 0,5 Sekunden auf eine vorbestimmte Tiefe von etwa 0,024 inch (0,61 mm) erfolgt.

Revendications

1. Procédé de trempe d'une portée de soupape tronconique (30) formée sur un siège de soupape rapporté ferreux (12) retenu avec ajustement à pression dans un perçage d'un élément de moteur (B), ledit procédé comprenant les phases consistant à:

a) placer un inducteur (50) de forme générale circulaire adjacent audit siège rapporté (12) et de façon qu'il épouse la forme de ce siège;

b) règler l'excitation dudit inducteur à une fréquence comprise entre 200 et 500 kHz, une puissance choisie de 12 à 25 kW, une densité de puissance sur la portée comprise entre 3,72 et 7,7 kW/cm^2 (24 à 50 $kW/pouce^2$) et pendant une période de moins de 1 seconde, pour transformer ainsi le métal formant ladite portée de soupape en une structure austénitique sur une profondeur prédéterminée; et

c) tremper ensuite la matière de ladite portée de soupape.

2. Procédé selon la revendication 1, dans lequel ladite phase d'excitation est exécutée à une fréquence supérieure à 250 kHz.

3. Procédé selon la revendication 2, dans lequel ladite phase d'excitation est exécutée à une fréquence d'environ 400 kHz.

4. Procédé selon la revendication 3, dans lequel ladite phase d'excitation est exécutée généralement à une puissance d'environ 20 kW.

5. Procédé selon la revendication 3 ou 4, dans lequel ladite phase d'excitation est exécutée à une densité de puissance de 6,2 kW/cm^2 (40 $kW/pouce^2$).

6. Procédé selon l'une quelconque des revendications 1 à 4, dans lequel ladite phase d'excitation est exécutée à une puissance choisie pour créer une densité de puissance sur ladite portée (30) de l'intervalle de 3,875 à 6,975 kW/cm^2 (25 à 45 $kW/pouce^2$).

7. Procédé selon l'une quelconque des revendications précédentes, dans lequel ladite excitation dudit inducteur transforme le métal formant ladite portée de soupape en une structure austénitique sur une profondeur de moins de 0,89 mm (0,035 pouce).

8. Procédé de trempe d'une portée de soupape tronconique (30) formée sur un siège de soupape rapporté ferreux (12) fixé coaxialement dans un perçage d'un élément de moteur (B) en aluminium, ledit procédé comprenant les phases consistant à:

a) placer un inducteur (50) de forme générale circulaire adjacent audit siège rapporté (12);

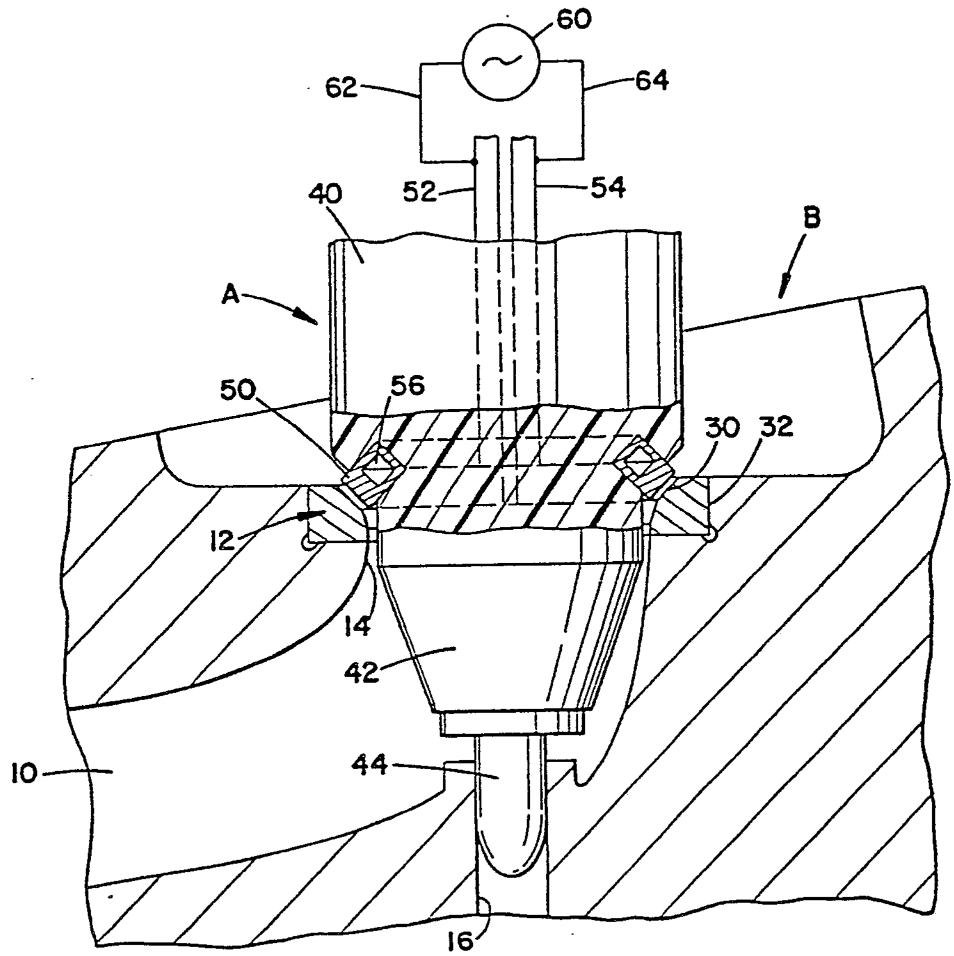
b) exciter ledit inducteur (50) avec une source de puissance primaire possédant une fréquence d'au moins 200 kHz et une puissance choisie d'au moins 12 kW et produisant une densité de puissance sur la portée comprise entre 3,875 et 6,975 kW/cm^2 (25 à 45 $kW/pouce^2$);

c) maintenir ledit inducteur (50) dans un état excité pendant une période de temps choisie à l'avance, pour transformer le métal formant ladite portée de soupape (30) en une structure austénitique sur une profondeur de moins de 0,89 mm (0,035 pouce); et

d) tremper ensuite ladite matière de portée de soupape.

9. Procédé selon la revendication 8, dans lequel ladite phase d'excitation est exécutée à une fréquence de l'intervalle de 250 à 500 kHz.

10. Procédé selon la revendication 8 ou 9, dans lequel ladite phase de maintien est exécutée pour transformer à une profondeur prédéterminée d'environ 0,61 mm (0,024 pouce) en environ 0,5 seconde.


60
62
64
52
54
40
B
A
50
56
30
32
12
14
42
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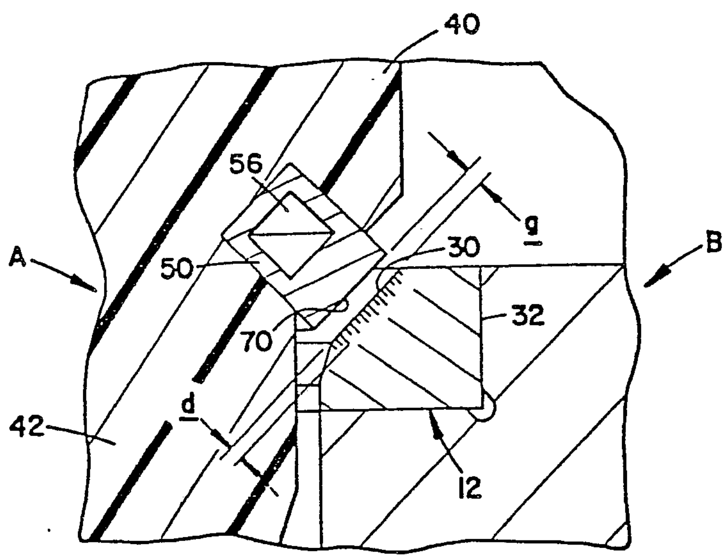
44
16

FIG. 1


40
56
g
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50
30
B
32
70
d
42
12

FIG. 2