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(54) METHOD FOR IMPARTING RESIDUAL COMPRESSIVE STRESS IN METAL PARTS

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(57) **ABSTRACT**

A method of hardening metal parts, such as a rotor or drive link, and parts thus produced. Preferably the method includes imparting residual compressive stresses into the metal parts and uses various small ball type structures to create small compressions in the surfaces of the metal parts. The compressions apply residual stresses to the parts, which strengthen the metal. The substantial uniform ball type structures are pressed into the metal part to control the application of stress into the part and maintain substantial uniform properties within the metal part, which resists future stresses as the part is used in its desired machinery and/or processes.

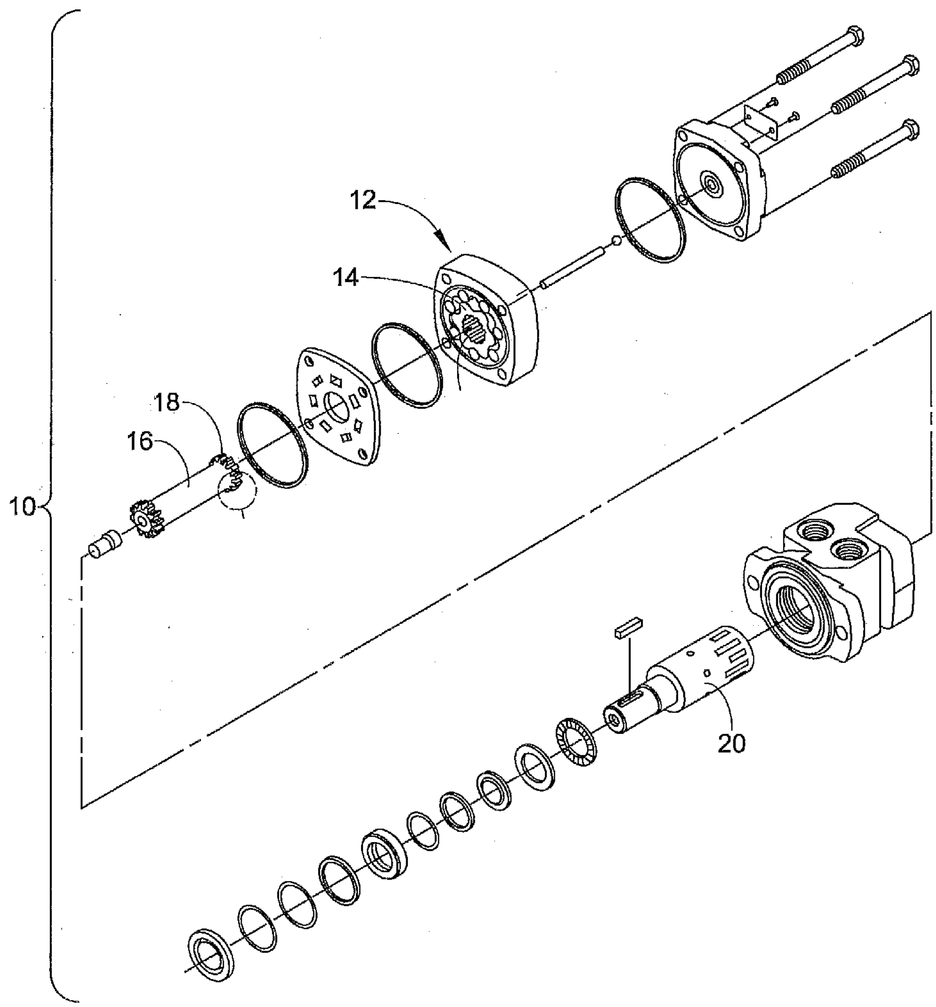
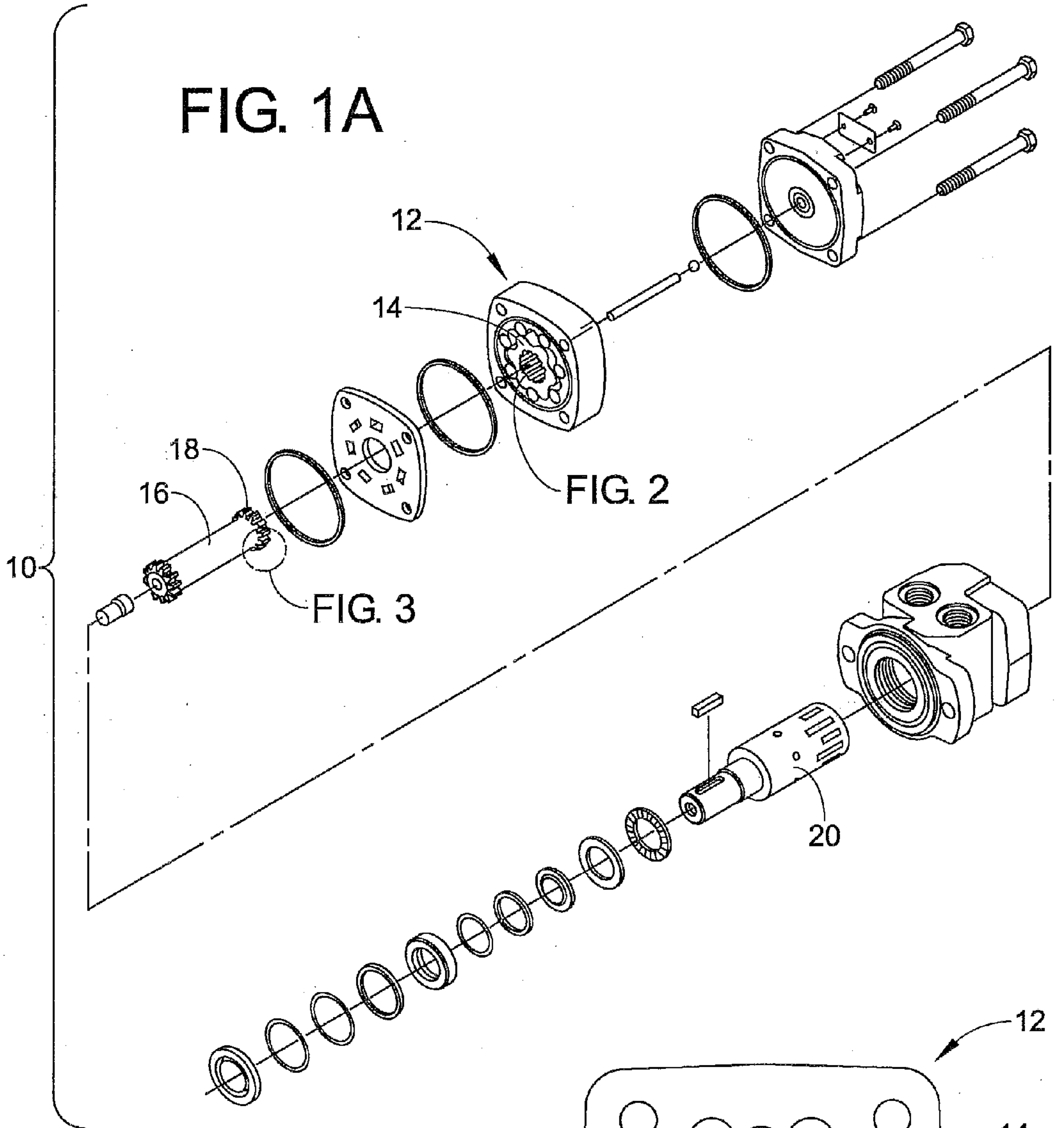


FIG. 1A



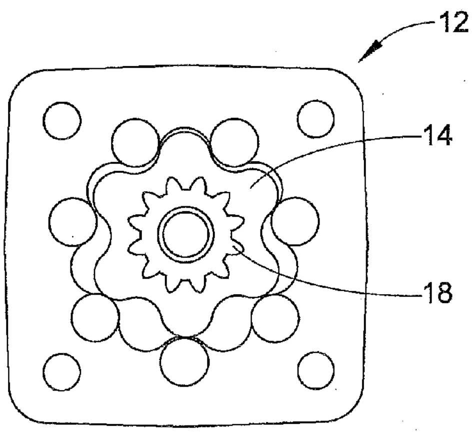




FIG. 1B

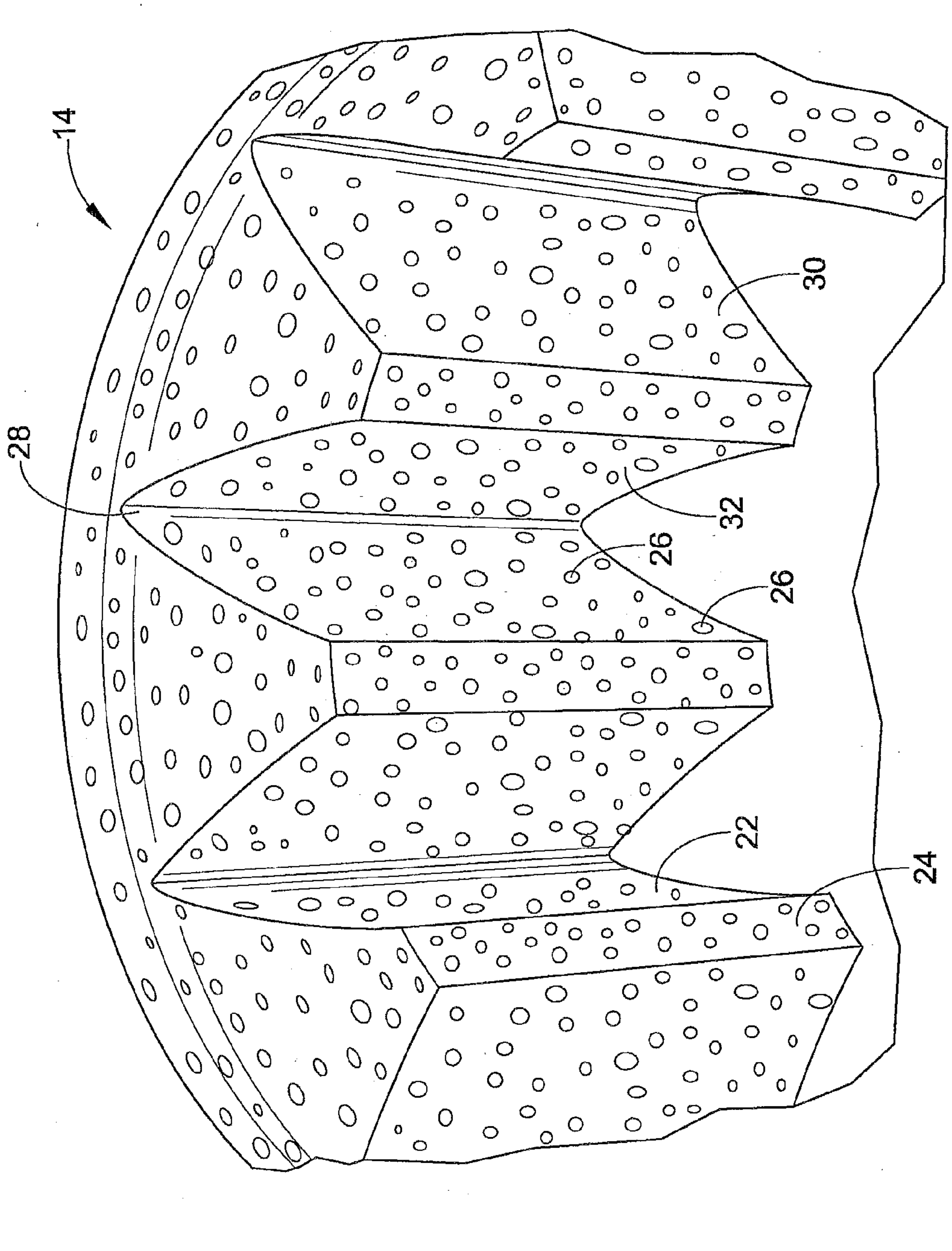



FIG. 2

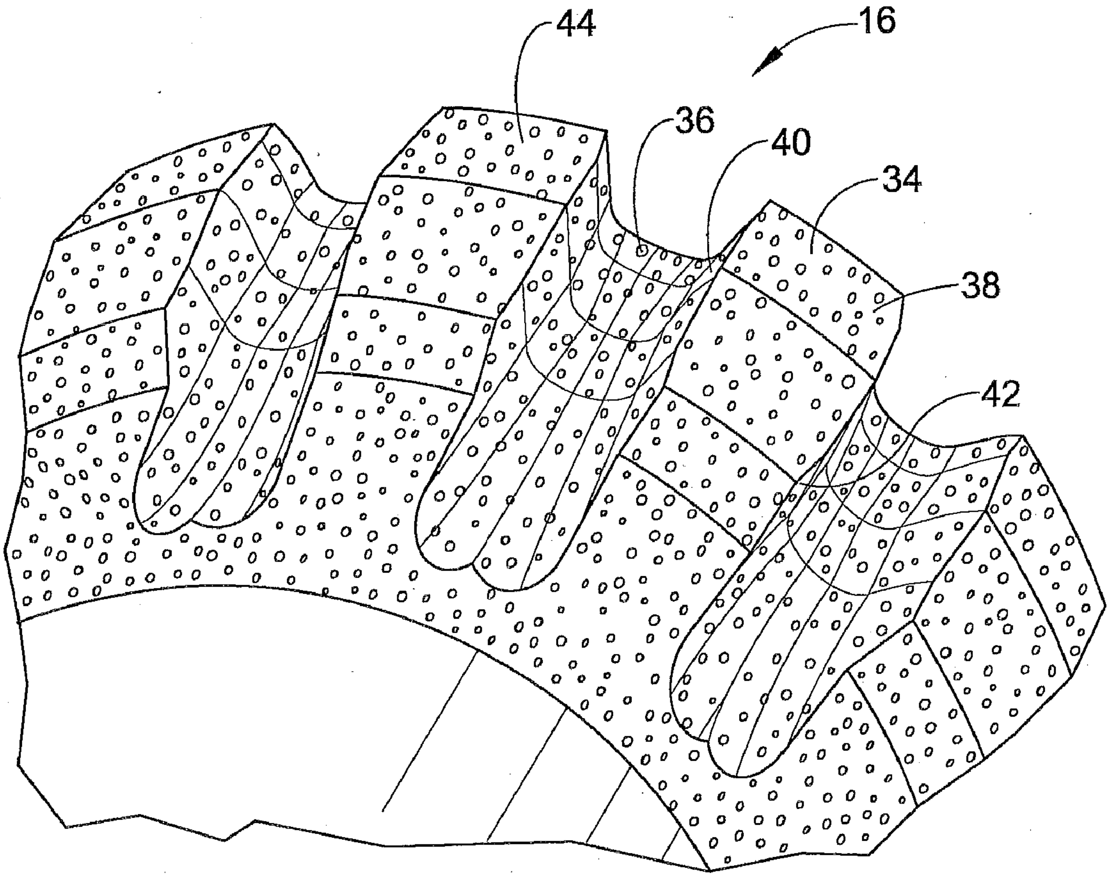



FIG. 3

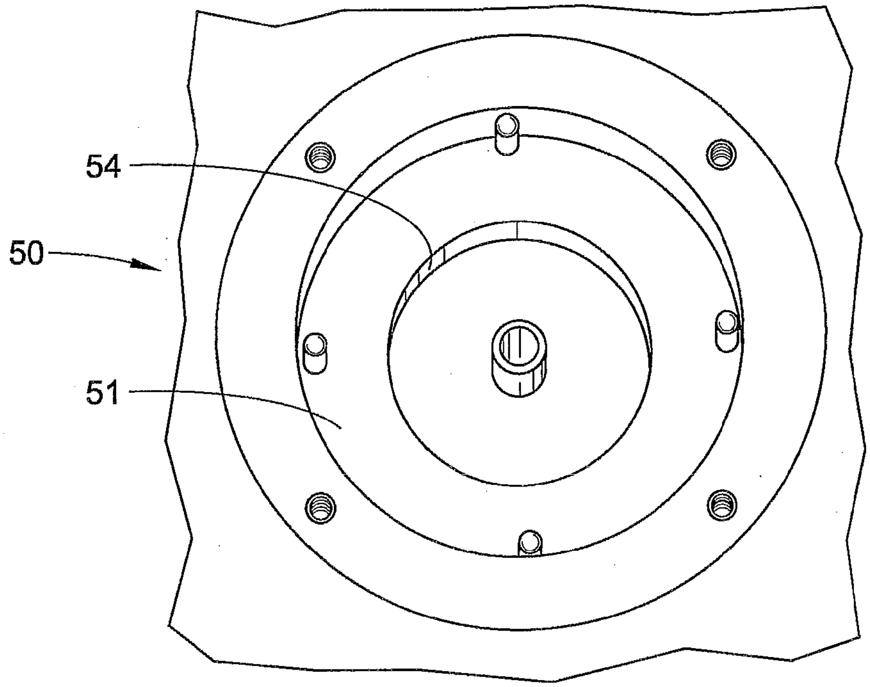



FIG. 4A

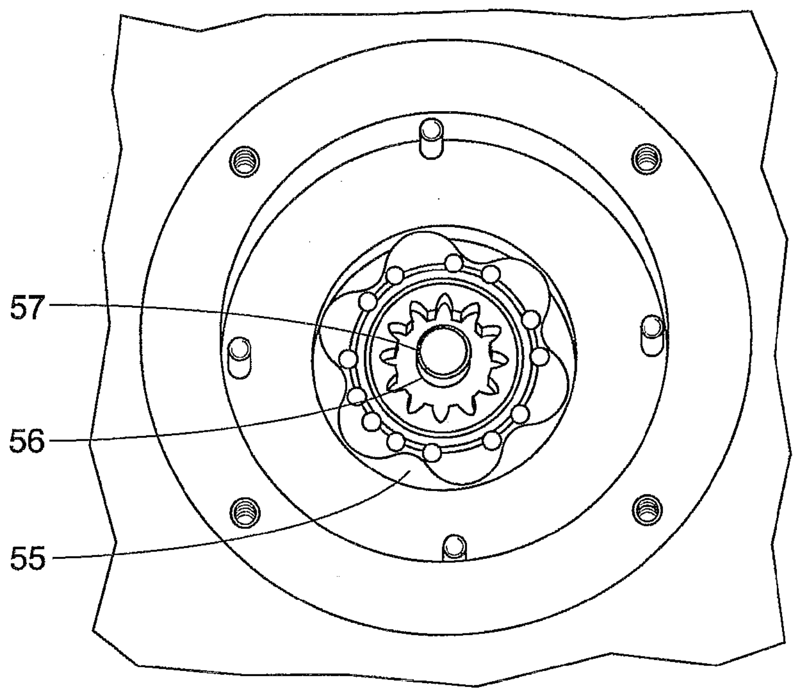



FIG. 4B

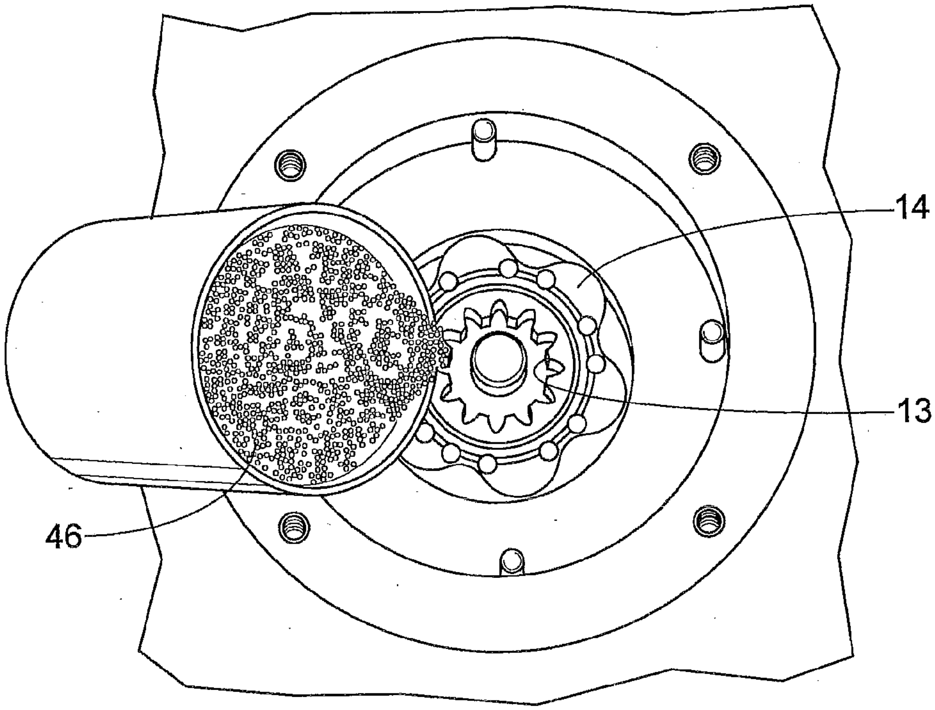



FIG. 4C

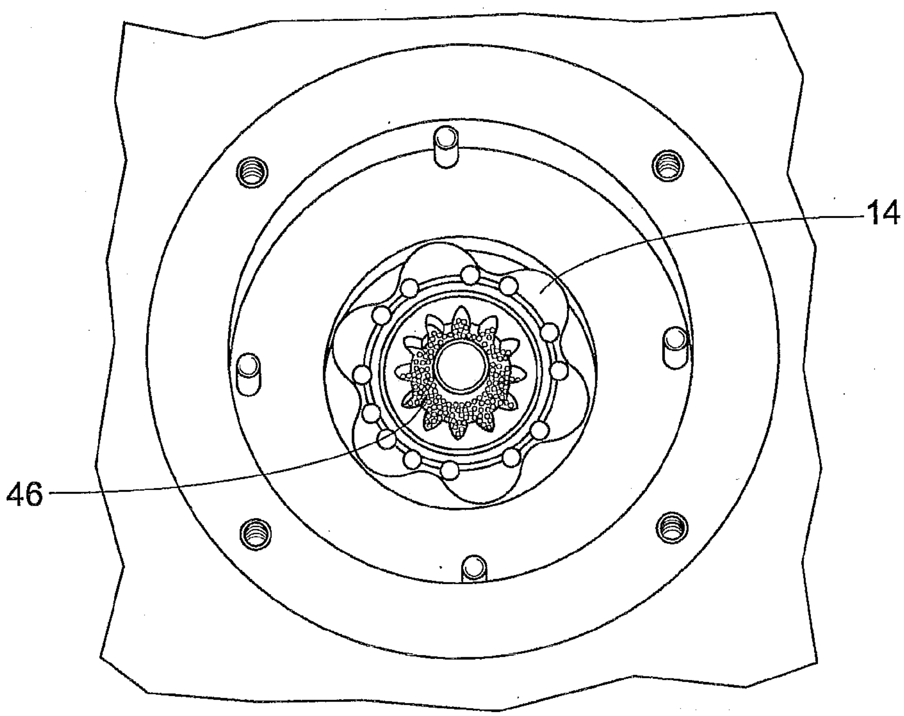



FIG. 4D

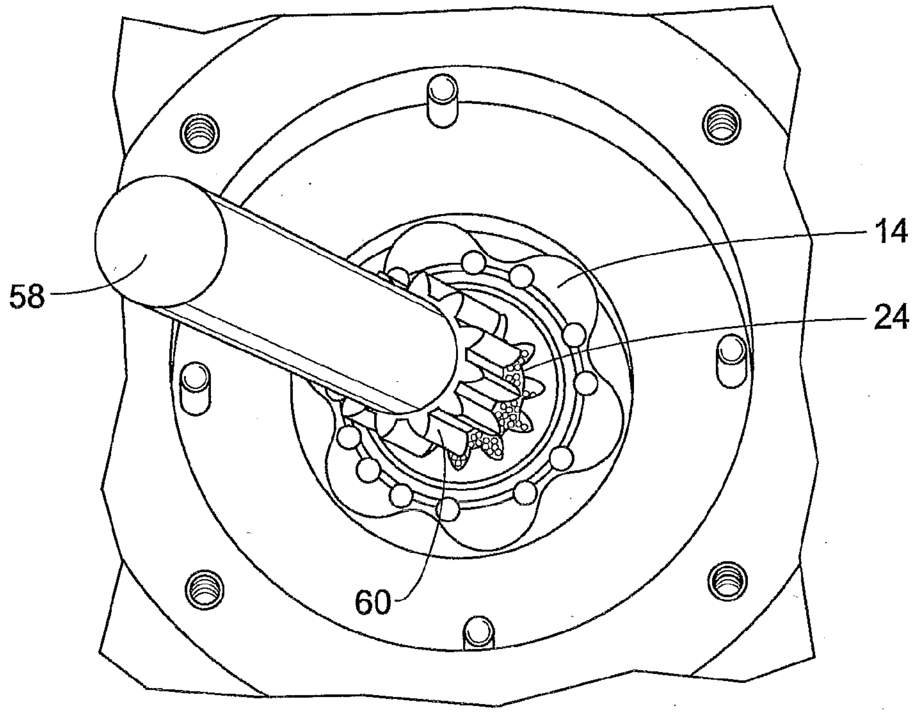



FIG. 4E

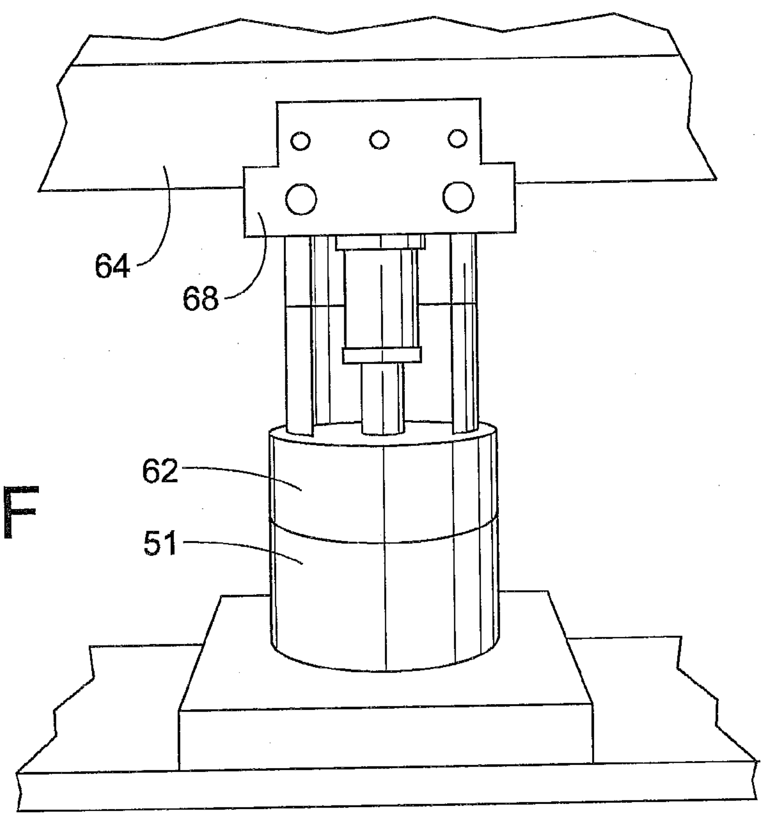



FIG. 4F

# METHOD FOR IMPARTING RESIDUAL COMPRESSIVE STRESS IN METAL PARTS

## CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application is a Non-Provisional Utility application which claims benefit of co-pending U.S. Provisional Patent Application Ser. No. 60/733,221 filed Nov. 3, 2005, entitled "METHOD FOR IMPARTING RESIDUAL COMPRESSIVE STRESS IN METAL PARTS" which is hereby incorporated by reference.

## BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to increasing the wear characteristics of metal. More specifically, this invention relates to increasing the fatigue life, or hardening the metal, by imparting compressive stresses, such as residual compressive stresses, in the metal.

[0003] It is known in the art to use small spherical items, such as shot or balls, to change various characteristics in the properties of a work piece. In most examples this shot is sent, or fired through the air, by a machine that imparts kinetic energy into the shot and directs the shot at the work piece. The shot then impacts against the work piece. This process is typically known as shot peening.

[0004] Various attempts in the art have been made in order to try and improve this shot peening process. For example, U.S. Pat. No. 4,689,921 discloses improving a ceramic turbine rotor by rotating the rotor in abrasive grindstones to round the edges of the rotor.

[0005] U.S. Pat. No. 5,125,191 discloses putting a work piece into a closed chamber and moving the work piece or chamber in an abrasive medium located in the chamber to adjust the characteristics of the work piece. This patent discusses by using the abrasive nature of the medium to generally smooth the work piece. This patent hones or abrades machine parts but does not impart any compressive stress on the work piece or affect the overall fatigue life of the work piece.

[0006] U.S. Pat. No. 6,490,899 and U.S. Patent Application Publication 2003/0115922 generally disclose the use of ultrasonic energy to peen the blades of a rotor. These disclosures are generally focused on the external surfaces of those blades.

[0007] U.S. Pat. No. 4,974,434 discloses a controlled shot peen method and a device for bending or leveling a work piece by shot peening. This patent fails to recognize the benefits of imparting compressive stresses in a work piece or the capability of increasing the fatigue life of internal components of a work piece.

[0008] U.S. Pat. No. 6,009,980 discloses a ductal iron vehicle hub and a method for producing the same. This patent uses the conventional method of "shooting" the shot at the work piece and does not teach, and fails to realize the benefit of, adding compressive stresses to the internal components of a work piece.

[0009] The advantage of having the capability of improving the fatigue life on the internal components of a metal part can be very beneficial in the application of rotors as used in engines or motors. The rotor typically has numerous teeth that project inwardly towards the axis. These teeth are used to transmit the torque and power from one portion of the motor to the next, typically from the shaft to the drive output. At any given moment only one internal tooth of the rotor could be engaged with the drive link. As such, a large amount of stress can be applied to any one individual tooth numerous times during the operation of the motor. It therefore becomes beneficial to increase the useful life, durability, and fatigue resistance of the individual internal teeth on a rotor.

[0010] What is needed then is a rotor having internal components that have been processed to increase the wear characteristics thereof and a method of producing such a rotor. Preferably this rotor has been processed by the application of compressive stresses to the individual teeth of a rotor while the method is cost effective, consistent, and reliable. Preferably the method could produce a drive link that has improved wear characteristics such that the drive link and rotor, two parts of a motor that typically experience the greatest levels of stress, can be improved such that the overall useful life and potential efficiency of the motor is increased. This needed rotor, drive link, and method of producing the same is lacking in the art.

## BRIEF SUMMARY OF THE INVENTION

[0011] Disclosed herein is a method of hardening metal parts, such as a rotor or drive link, and parts thus produced. Preferably the method includes imparting residual compressive stresses into the metal parts and uses various small ball type structures to create small compressions in the surfaces of the metal parts. The compressions apply residual stresses to the parts, which strengthen the metal. The substantial uniform ball type structures are pressed into the metal part to control the application of stress into the part and maintain substantial uniform properties within the metal part, which resists future stresses as the part is used in its desired machinery and/or processes.

[0012] Also disclosed is a method for producing a rotor. The method includes providing substantially spherical indenting elements and a metal rotor having an inner surface. The inner surface of the rotor includes a plurality of internal projections. The method includes forceably pressing the indenting elements against the inner surface of the rotor to induce compressive stresses in the inner surface to improve the fatigue life of the rotor.

[0013] Preferably the method further includes forceably compressing the entire width of the inner surface of the rotor to induce the compressive stresses therein. Each internal projection can include a first and a second side wherein the indenting elements are forceably pressed against both sides of each internal projection to induce the compressive stresses. The inner surface of the rotor can further include a circumferential base section extending between each internal projection wherein the indenting elements are pressed against the base section. The indenting elements are preferably substantially spherical and can have a diameter in the range of approximately 0.5 millimeters to approximately 0.4 millimeters.

[0014] In an alternate embodiment the method further includes using a drive link having an outer surface substantially corresponding with the inner surface of the rotor to press the indenting elements against the inner surface of the rotor to induce the compressive stresses in the rotor. The use of a drive link can induce compressive stresses in the outer surface of the drive link thereby improving the fatigue life of the drive link through the forceably pressing the indenting elements between the outer surface of the drive link and the inner surface of the rotor. The drive link can include an exterior circumference substantially mirroring the base sections of the rotor such that the indenting elements can be forceably pressed against the exterior circumference of the drive link.

[0015] Also disclosed is an improved metal rotor having an inner surface with a plurality of internal projections wherein each internal projection has an initial fatigue life. The fatigue life of the internal projections of the inner surface of the rotor have been increased by inducing compressive stresses in the internal projections to improve the overall fatigue life of the internal projections and the overall fatigue life of the rotor. The internal projections of the inner surface of the rotor have been preferably compressed under a static load by spherical indenting elements.

[0016] Also enclosed is an improved rotor and drive link combination wherein the rotor and drive link have been formed by subjecting the inner surface of the rotor and the outer surface of the drive link to compressive stresses to increase the fatigue life of the rotor and the drive link.

[0017] It is therefore a general object of the present invention to provide an improved rotor.

[0018] Another object of the present invention is to provide an improved drive link.

[0019] Another object of the present invention is to provide an improved rotor and drive link combination.

[0020] Still another object of the present invention is to provide an improved method for producing an improved rotor and/or drive link.

[0021] Still another object of the present invention is to provide a method for subjecting internal surfaces of a rotor to compressive stresses to increase the fatigue life thereof.

[0022] Another object of the present invention is to provide a method that concurrently subjects the internal surface of a rotor and the external surface of a corresponding drive link to compressive stresses to improve fatigue life of both parts.

[0023] Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon reading of the following disclosure when taken in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0024] FIG. **1**A is an exploded assembly view of a motor including an example of a drive link and rotor assembly having a rotor.

[0025] FIG. **1**B is an end view of the engaging portion of a drive link with a rotor.

[0026] FIG. **2** shows a magnified view of a rotor made in accordance with the current disclosure.

[0027] FIG. **3** shows a magnified view of a drive link made in accordance with the current disclosure.

[0028] FIGS. **4**A-**4**F show pictorial representations of a method of manufacturing a rotor and drive link in accordance with the current disclosure.

## DETAILED DESCRIPTION OF THE INVENTION

[0029] Looking generally at FIG. **1**A a motor is shown and generally designated by the numeral **10**. The motor includes among other features a rotor assembly **12** having a rotor **14** and a drive link **16** having an engagement end **18**. The drive link **16** is normally attached to a shaft **20** which provides power to the drive link **16**. This general configuration of a motor is known in the art.

[0030] However, one of the improvements of the current disclosure is the rotor **14** having an inner surface **22** with a plurality of internal projections **24**, which can also be described as teeth **24**. The rotor **14** has an initial fatigue life and more specifically the teeth **24** have an initial fatigue life wherein the initial fatigue life of the teeth **24** of the inner surface **22** of the rotor **14** have been increased by the induction of compressive stresses as indicated by depressions **26** in FIG. **2**. The manifestation of the compressive stresses by the depressions **26** in the teeth **24** improves the fatigue life of the teeth **24** of the inner surface **22** of the rotor **14**.

[0031] As best illustrated in FIG. **2**, the depressions **26** are preferably positioned along the entire width of the inner surface **22** of the rotor **14**. Additionally, the circumferential base section **28** of the inner surface **22** can also contain the depressions **26** thereby increasing the overall fatigue life of the inner surface **22**. Preferably both sides **30** and **32** of each tooth **24** have been introduced to the compressive stresses and exhibit the depressions **26**.

[0032] Also included is the drive link **16** having an outer surface **34** substantially corresponding with the inner surface **22** of the rotor **14**. The outer surface **34** of the drive link **16** also includes initial fatigue life which has been increased by the induction of compressive stresses in the outer surface **34** as manifested by depressions **36** as best seen in FIG. **3**. The external projections **38**, which can also be described as teeth **38**, of the engagement end **18** of the drive link **16** have been preferably subjected to compressive stresses along the full width of the engagement end **18** and on both sides **40** and **42** of each tooth **38**. The drive link **16**, and more specifically the engagement end **18** of the drive link **16** includes an exterior circumference **44** that substantially corresponds with the base section **28** of the rotor **14**. This exterior circumference **44** is also preferably subjected to the compressive stresses to increase the fatigue life thereof.

[0033] Now referring generally to FIGS. **4**A-**4**F, an exemplary method of producing an improved rotor and/or improved drive link is shown. The method includes providing a rotor **14** having an inner surface **22** with the teeth **24**. Spherical indenting elements **46** (FIG. **4**C), which can also be described as shot **46**, are also provided. The method includes forceably pressing the shot **46** against the inner surface **22** of the rotor **14** to induce compressive stresses in the rotor **14** to improve the fatigue life of the rotor **14**. The inducement of these compressive stresses is best illustrated by the depressions **26** as previously discussed.

[0034] The method preferably includes forceably pressing the entire width of the inner surface **22** of the rotor **14** with the shot **46** as well as both sides **30** and **32** of the each tooth **24** as well as the base section **28** between the individual teeth **24** with the shot **46**.

[0035] In a preferred embodiment the drive link **16**, with its outer surface **34** substantially corresponding with the inner surface **22** of the rotor **14**, is used to forceably press the shot **46** into the inner surface **22** of the rotor **14**. Additionally, the shot **46** can be pressed between the outer surface **34** and inner surface **22** such that both the outer surface **34** and inner surface **22** are compressively stressed, or prestressed, to increase fatigue life, durability, and wear characteristics of both the rotor **14** and drive link **16**.

[0036] Alternately described, the method can include using a static load, or fixed load, to compressively stress, at individual locations, the inner surface **22** of a rotor **14** and the outer surface **34** of a drive link **16** in order to increase the wear characteristics, for example the fatigue life, of the rotor **14** and drive link **16**. This static load can be applied through the shot **46** that can create the depressions **26** and **36** in the rotor **14** and the drive link **16**, respectively.

[0037] Referring back to FIGS. **4**A-4F, an exemplary method of producing the rotor and/or drive link can be described as follows. An assembly unit **50** is assembled to control the movement of the rotor **14** and drive link **16**. More specifically the assembly unit **50** can restrict and contain the rotor **14**, drive link **16**, and the shot **46** before, during, and after the application of the force used to impart the compressive stress in the parts **14** and **16**. The assembly unit **50** includes a bottom base **51** which can include a counter bore **54** on the center to allow various size rotors and drive links to be processed. A plunger **56** is placed into the counter bore **54** to establish a centering location for the rotor. This plunger **56** can include a plate **55** and stem **57** as shown.

[0038] Next the rotor is inserted such that the stem **57** passes through the opening **13** of the rotor **14**. The shot **46**, which can also be described as balls **46**, is inserted into the opening **13** of the rotor **14**. Preferably this shot **46** has a diameter in the range of approximately 0.5 millimeters to 4.0 millimeters. Next the shot **46** can be mixed, stirred, or otherwise shifted or moved to facilitate that the inner surface, or at least the bottom portion of the inner surface, is substantially covered with the shot **46**.

[0039] Next a plunger rod **58** is inserted onto the stem **57** of the plunger **56** and turned such that the splines **60** of the plunger rod **58** engage with the teeth **24**, which can also be described as rotor splines **24**, of the rotor **14**. In a preferred embodiment the plunger rod **58** is replaced with a drive link **16** having an engagement end **18** which corresponds to the rotor **14**. A retaining cap **62** is placed over the base **51**, which can also be described as housing **51**, and secured into place with fasteners, such as bolts. If needed a plunger alignment sleeve (not shown) can be positioned around a plunger rod to ensure proper force transfer.

[0040] Next the assembly unit **50** is positioned in the bay of a press **64**. Retaining cap spacers **66** can be applied around a plunger rod **58** to hold the retaining cap in position and to keep the cap **62** from separating from the housing **51**. The press **64** is then brought down and brought into contact with first the retaining cap spacer **66** and then the plunger rod **58**. The hammer **68** of the press **64** engages the plunger rod **58** and continues pressing until a desired force is reached. Preferably this desired force is 25 tons, but can vary according to application and the type of metal of which the rotor **14** and/or drive link **16** are comprised. Preferably this force is held for a desired period of time and then released. This length of time is preferably approximately 5 seconds but can vary as desired. Preferably the force is then reapplied for another time period to ensure the application of proper compressive stresses into the parts.

[0041] In one embodiment this application of force in the assembly unit imparts the preferred compressive stresses in the bottom section of the rotor. The assembly unit **50** can then be disassembled, the rotor flipped, and the process repeated until the other half of the rotor has been processed. In an alternate embodiment this force is applied throughout the full rotor in a single application.

[0042] Various tests have been performed on rotors made in accordance with the current disclosure. These tests determined that after more than 806,000 motor revolutions there was an absence of noticeable and/or discernible chipping, nicks, pitting, or cracks in the teeth of the rotors. This is typically unprecedented in the metal parts industry and can be explained by the theory that the compressive stresses have created depressions and resist the effects of imposed bending stresses from external loads during the operation of the motors. As such these surfaces treated are much harder and fatigue resistance is greatly improved.

[0043] Some metal items made in accordance with the current disclosure went through more than 1,000,000 test cycles before developing a failure point, or a chip on one of its teeth. The applicants are unaware of any prior art metal rotors that achieve these levels. The test data measuring the level of residual compressive stress in a metal part, or rotor, showed marked improvement in comparison to conventional metal rotors. For example, the level of residual compressive stress in a rotor made in accordance with the current disclosure measured 50,000 psi. The level of residual compressive stress in conventional rotors that had not been subject to the current disclosure measured 0 psi. In increased levels of compressive stress are believed to directly equate to longer life of the part. The test data indicates that rotors and drive links made in accordance with the current disclosure could increase this level to 150,000 psi. Additionally, parts made in accordance with the current disclosure possessed a recognizably more uniform residual compressive stress distribution than conventional parts, which can reduce the likely of weak spots in the rotor.

[0044] Additional benefits received from the exposure of the parts to the compressive stresses and the subsequent depressions formed in the parts therein could also lead to improved rotor and/or drive link performance. For example, these depressions are believed to provide locations where islands of contained fluid, such as oil or lubricant, were stored during operation of the motors. This in essence provides a self-lubricating surface that can reduce friction in the operation of the rotors, drive links and motors. This can further facilitate a longer fatigue life and reduced wear on the parts.

[0045] Thus, although there have been described particular embodiments of the present invention of a new and useful METHOD FOR IMPARTING RESIDUAL COMPRESSIVE STRESS IN METAL PARTS, it is not intended that such references be construed as limitations upon the scope of this invention except as set forth in the following claims.

What is claimed is:

1. A method for producing a rotor comprising:

(a) providing a metal rotor having an inner surface with a plurality of internal projections and substantially spherical indenting elements; and

(b) forcibly pressing the indenting elements against the inner surface of the rotor to induce compressive stresses in the inner surface to improve the fatigue life of the rotor.

2. The method of claim 1 wherein the inner surface includes a width, and the forcibly pressing of step (b) includes forcibly pressing the entire width of the inner surface to induce compressive stresses.

3. The method of claim 1 wherein the each internal projection includes a first side and a second side, and the forcibly pressing of step (b) includes forcibly pressing the indenting elements against both sides of each internal projection to induce compressive stresses in the rotor.

4. The method of claim 1 wherein the inner surface includes a circumferential base section extending between each internal projection, and the forcibly pressing of step (b) includes forcibly pressing the indenting elements against the base section.

5. The method of claim 1 wherein the forcibly pressing of step (b) includes forcibly pressing the indenting elements against the inner surface of the rotor with a drive link having an outer surface substantially corresponding with the inner surface of the rotor to induce compressive stresses in the rotor.

6. The method of claim 5 wherein the forcibly pressing of step (b) further includes inducing compressive stresses in the outer surface of the drive link to improve the fatigue life of the drive link by forcibly press the indenting elements between outer surface of the drive link and the inner surface of the rotor.

7. The method of claim 1 wherein the forcibly pressing of step (b) includes forcibly pressing indenting elements having a diameter in the range of 0.5 millimeters to 4.0 millimeters at the inner surface of the rotor.

8. A method for producing a rotor comprising:

(a) providing a metal rotor having an inner surface with a plurality of internal projections, a drive link having an outer surface substantially corresponding with the inner surface of the rotor, and substantially spherical indenting elements; and

(b) forcibly pressing the indenting elements between the inner surface of the rotor and the outer surface of the drive link to induce compressive stresses in the inner surface of the rotor to improve the fatigue life of the rotor.

9. The method of claim 8 wherein the forcibly pressing of step (b) further includes inducing compressive stresses in the outer surface of the drive link to improve the fatigue life of the drive link.

10. The method of claim 9 wherein the inner surface includes a rotor width and the outer surface of the drive link includes a drive link width, and the forcibly pressing of step (b) includes forcibly pressing both widths to induce compressive stresses.

11. The method of claim 10 wherein

(a) the inner surface includes a circumferential base section extending between each internal projection;

(b) the drive link includes an exterior circumference; and

(c) the forcibly pressing of step (b) includes forcibly pressing the indenting elements against the base section and the exterior circumference.

12. The method of claim 11 wherein the forcibly pressing of step (b) includes forcibly pressing indenting elements having a diameter in the range of 0.5 millimeters to 4.0 millimeters at the inner surface of the rotor.

13. An improved rotor comprising:

a metal rotor having an inner surface with a plurality of internal projections, the plurality of internal projections having an initial fatigue life, wherein the fatigue life of the internal projections of the inner surface of the rotor has been increased by inducing compressive stresses in the internal projections to improve the fatigue life of the rotor.

14. The rotor of claim 13 wherein the internal projections of the inner surface of the rotor have been compressed under a static load by spherical indenting elements.

15. The method of claim 13 wherein the inner surface includes a circumferential base section extending between each internal projection, each base section including an increased fatigue life by having been compressed under a static load by spherical indenting elements.

16. An improved rotor and drink link combination comprising:

a metal rotor having an inner surface with a plurality of internal projections, the plurality of internal projections having an initial fatigue life, wherein the fatigue life of the internal projections of the inner surface of the rotor has been increased by inducing compressive stresses in the internal projections to improve the fatigue life of the rotor; and

a metal drive link having an outer surface substantially corresponding with the inner surface of the rotor, the outer surface having an initial fatigue life, wherein the fatigue life of the outer surface of the drive link has been increased by inducing compressive stresses in the outer surface to improve the fatigue life of the drive link.

17. The rotor of claim 16 wherein the internal projections of the inner surface of the rotor and the outer surface of the drive link have been compressed under a static load by spherical indenting elements.

* * * * *