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(54) APPARATUS FOR PROVIDING A RESIDUAL STRESS DISTRIBUTION IN THE SURFACE OF A PART

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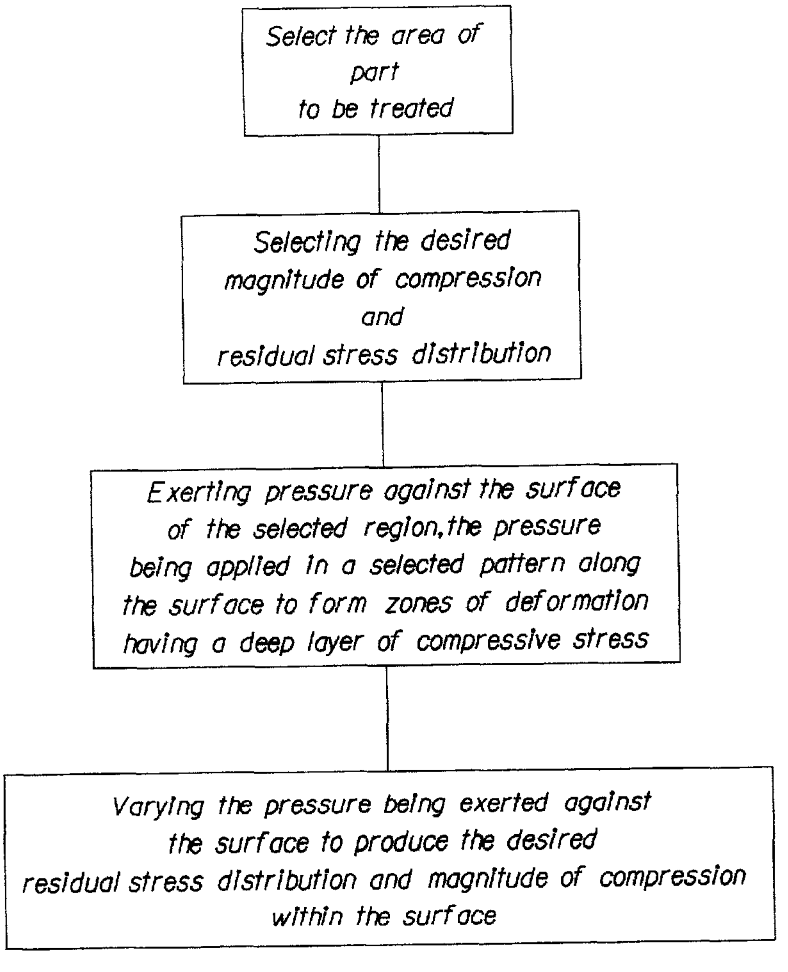
(52) **U.S. Cl.** **29/90.01**

(57) **ABSTRACT**

The present invention is a novel method and an apparatus for implementing the method of inducing a layer of compressive residual stress along the surface of a part comprising the steps of selecting a region of the part to be treated; selecting the magnitude of compression and the residual stress distribution to be induced in the surface of the selected region of the part; exerting pressure against the surface of the selected region, the pressure being applied in a selected pattern along the surface to form zones of deformation having a deep layer of compressive stress; and varying the pressure being exerted against the surface to produce the desired residual stress distribution and magnitude of compression within the surface.



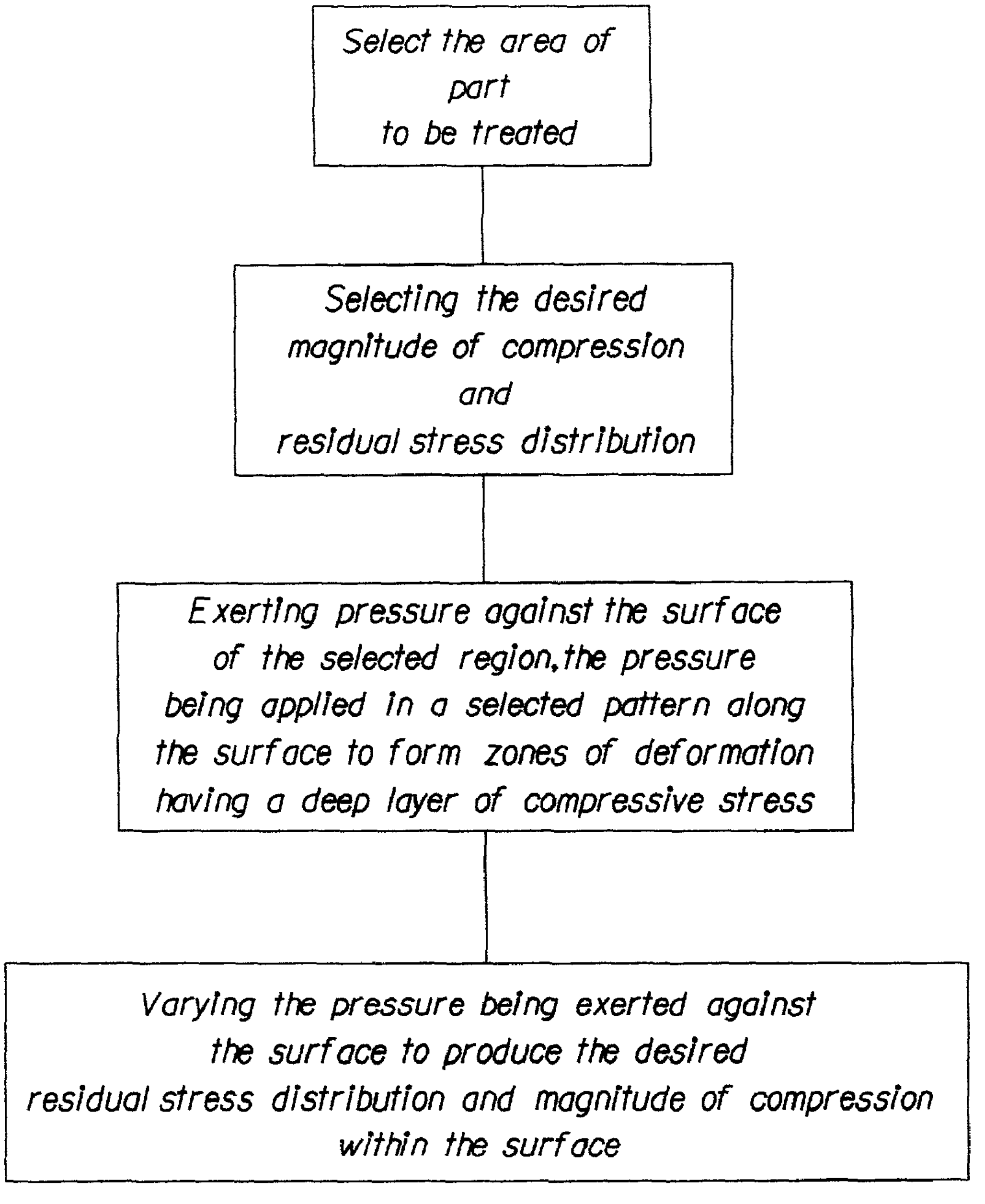

Select the area of part to be treated
Selecting the desired magnitude of compression and residual stress distribution
Exerting pressure against the surface of the selected region, the pressure being applied in a selected pattern along the surface to form zones of deformation having a deep layer of compressive stress
Varying the pressure being exerted against the surface to produce the desired residual stress distribution and magnitude of compression within the surface

Fig. 1

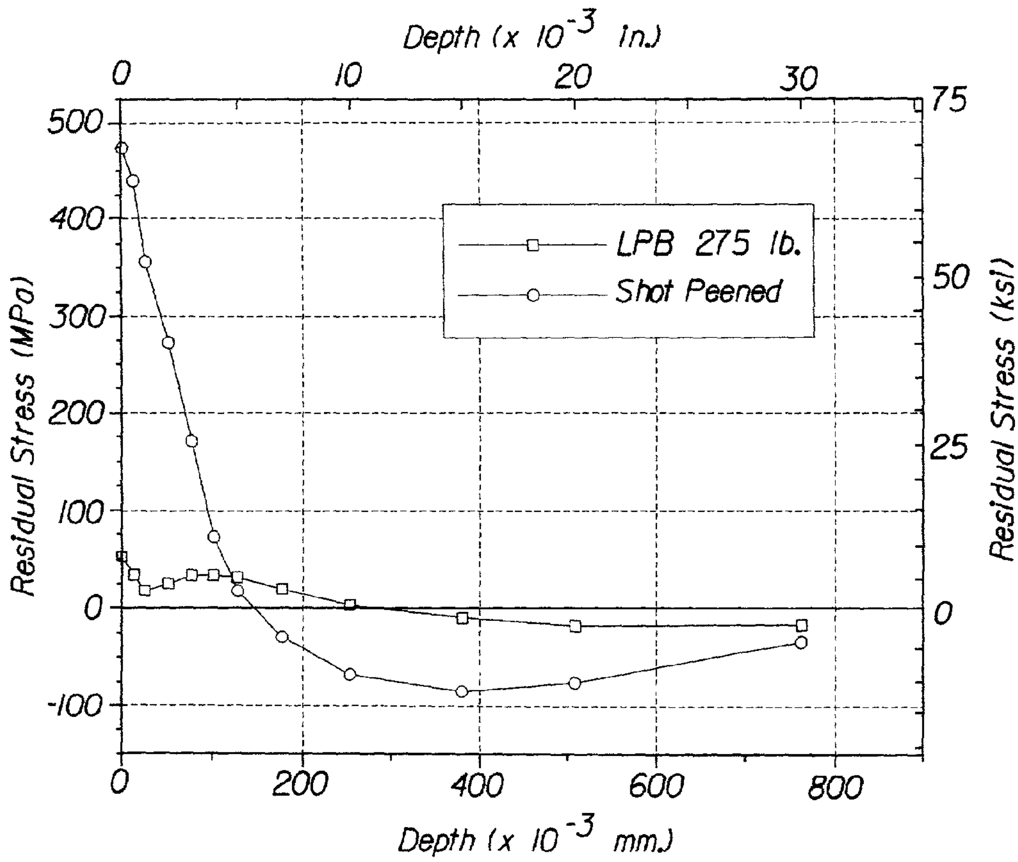

Depth (x 10^-3 in.)
0
10
20
30
500
400
300
200
100
0
-100
Residual Stress (MPa)
75
50
25
0
Residual Stress (ksi)
LPB 275 lb.
Shot Peened
0
200
400
600
800
Depth (x 10^-3 mm.)

Fig. 2

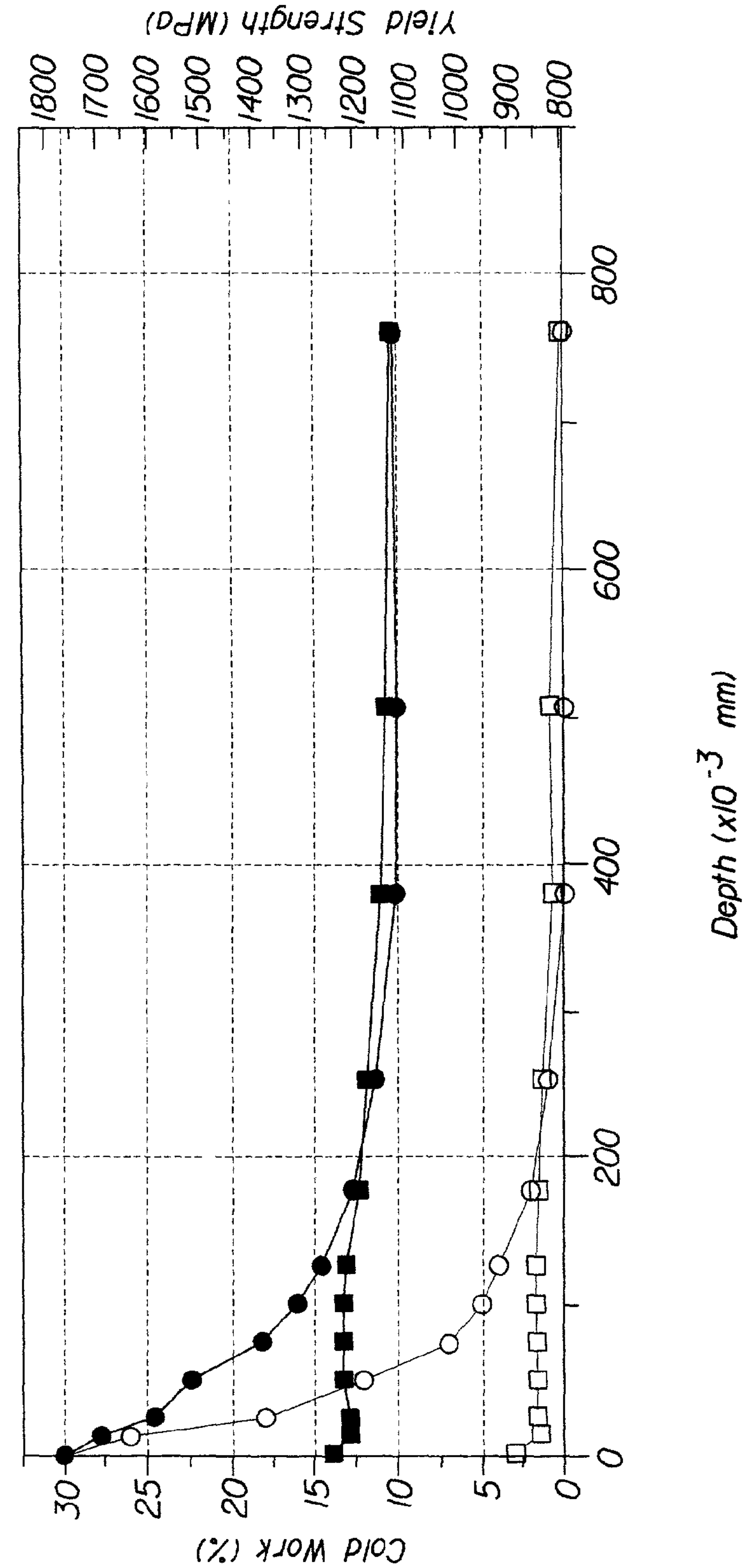

Yield Strength (MPa)
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
Cold Work (%)
30
25
20
15
10
5
0
Depth (x10^-3 mm)
0
200
400
600
800

Fig. 3

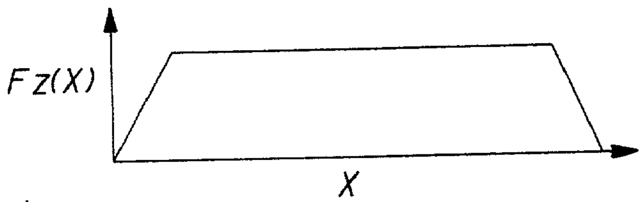
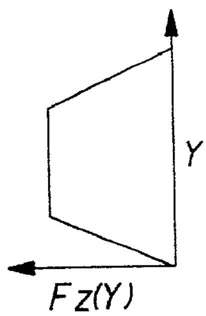


Fig. 4A



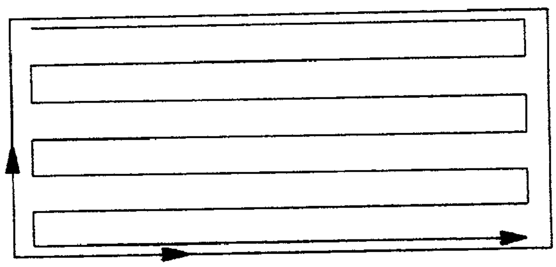


Fig. 4C

Fig. 4B

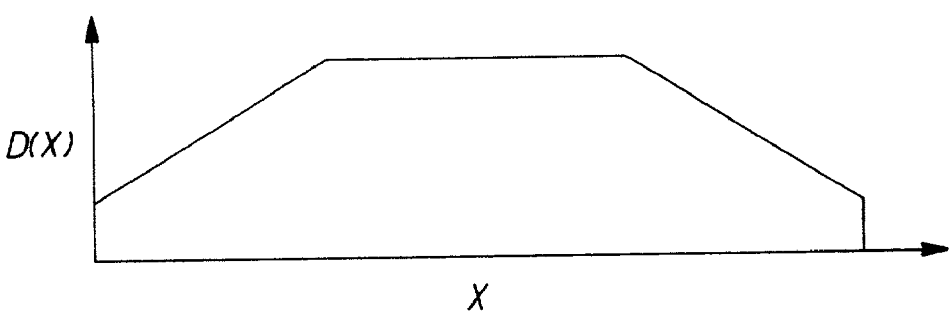


Fig. 5A

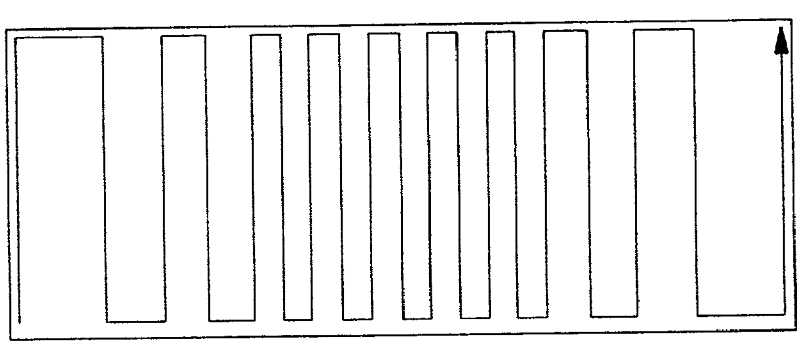


Fig. 5B

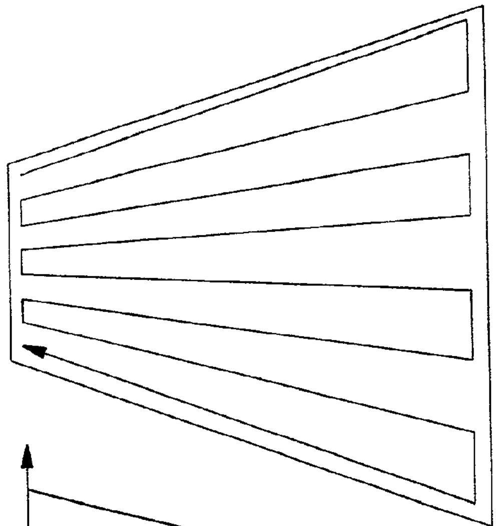


Fig. 6B

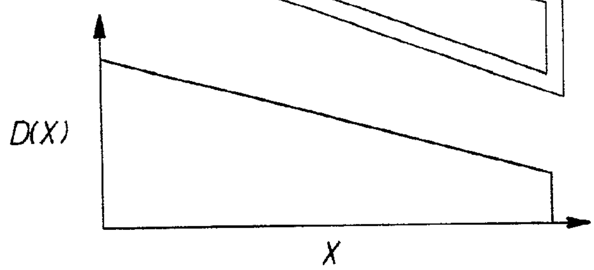


Fig. 6A

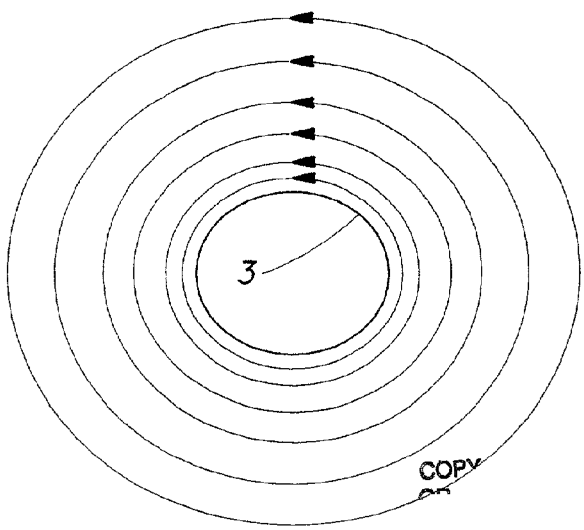


Fig. 7

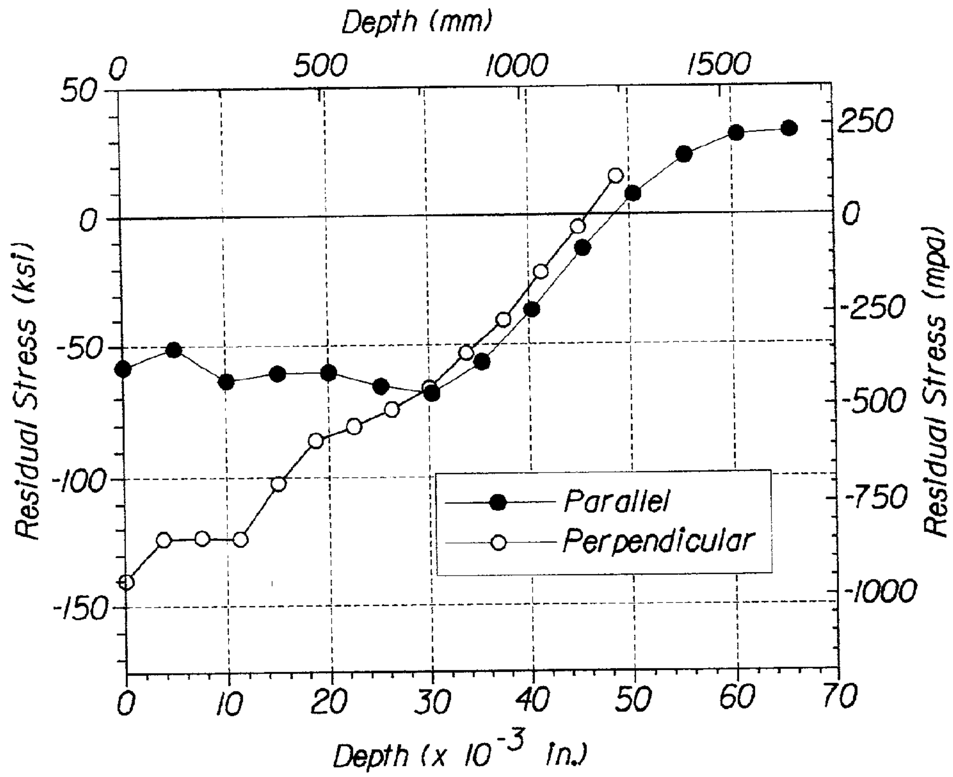

Depth (mm)
0
500
1000
1500
50
0
-50
-100
-150
250
0
-250
-500
-750
-1000
Residual Stress (ksi)
Residual Stress (mpa)
Parallel
Perpendicular
0
10
20
30
40
50
60
70
Depth (x 10^{-3} in.)

Fig. 8

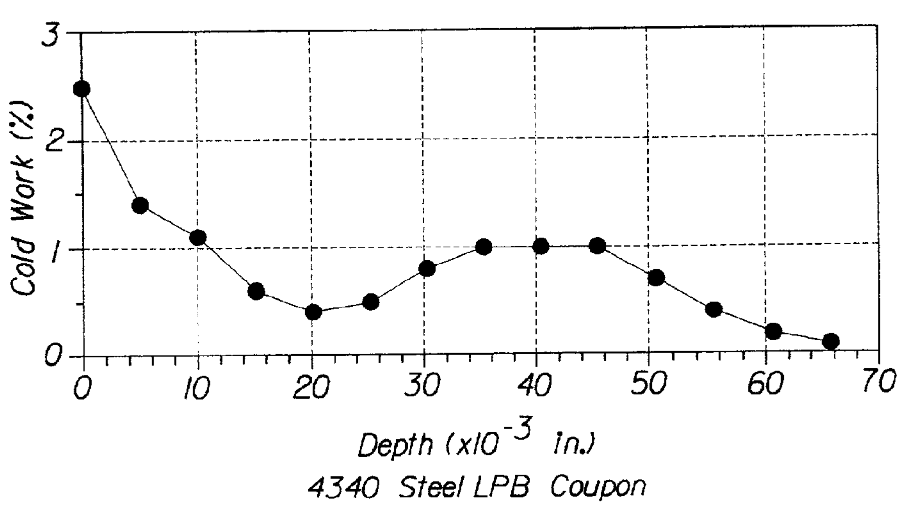

3
2
1
0
Cold Work (%)
0
10
20
30
40
50
60
70
Depth (x10^{-3} in.)
4340 Steel LPB Coupon

Fig. 9

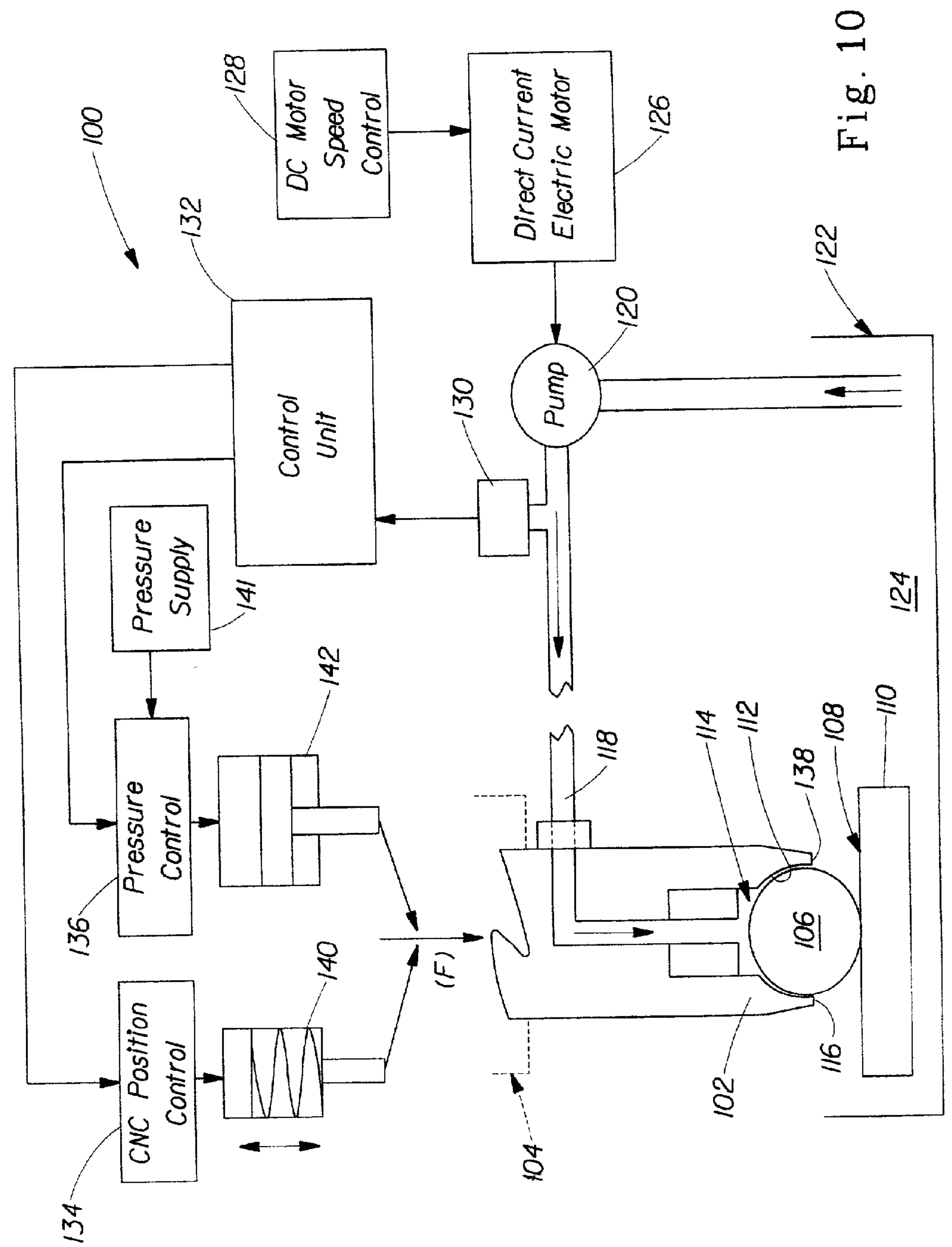

100
128
DC Motor Speed Control
Direct Current Electric Motor
126
132
Control Unit
Pump
120
122
130
Pressure Supply
141
124
142
Pressure Control
136
118
114
112
138
108
110
106
CNC Position Control
134
140
(F)
102
116
104

Fig. 10

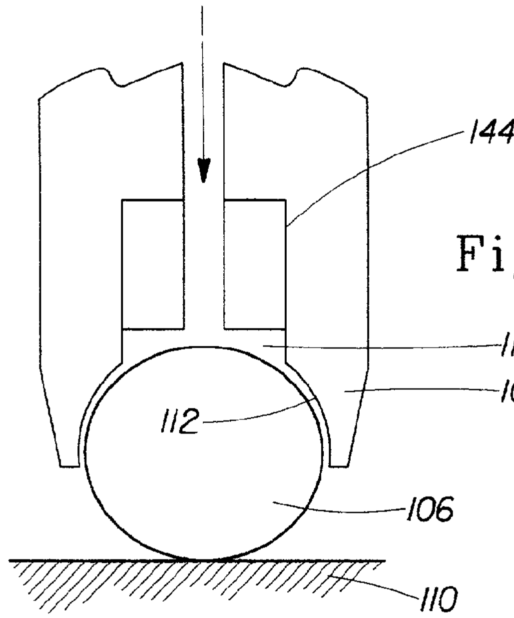


Fig. 11

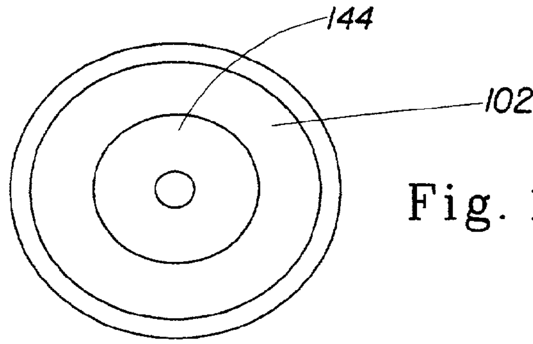


Fig. 12

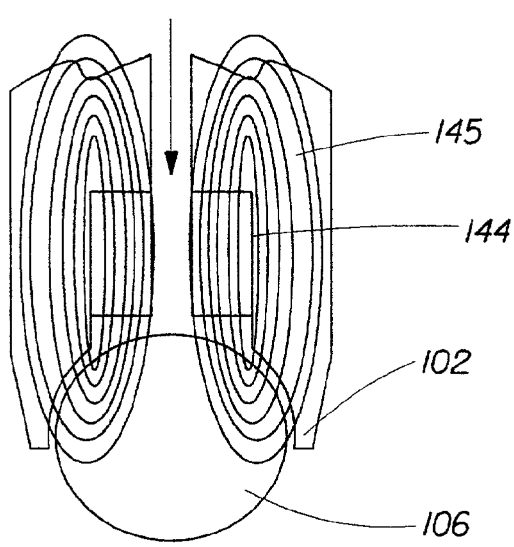


Fig. 13

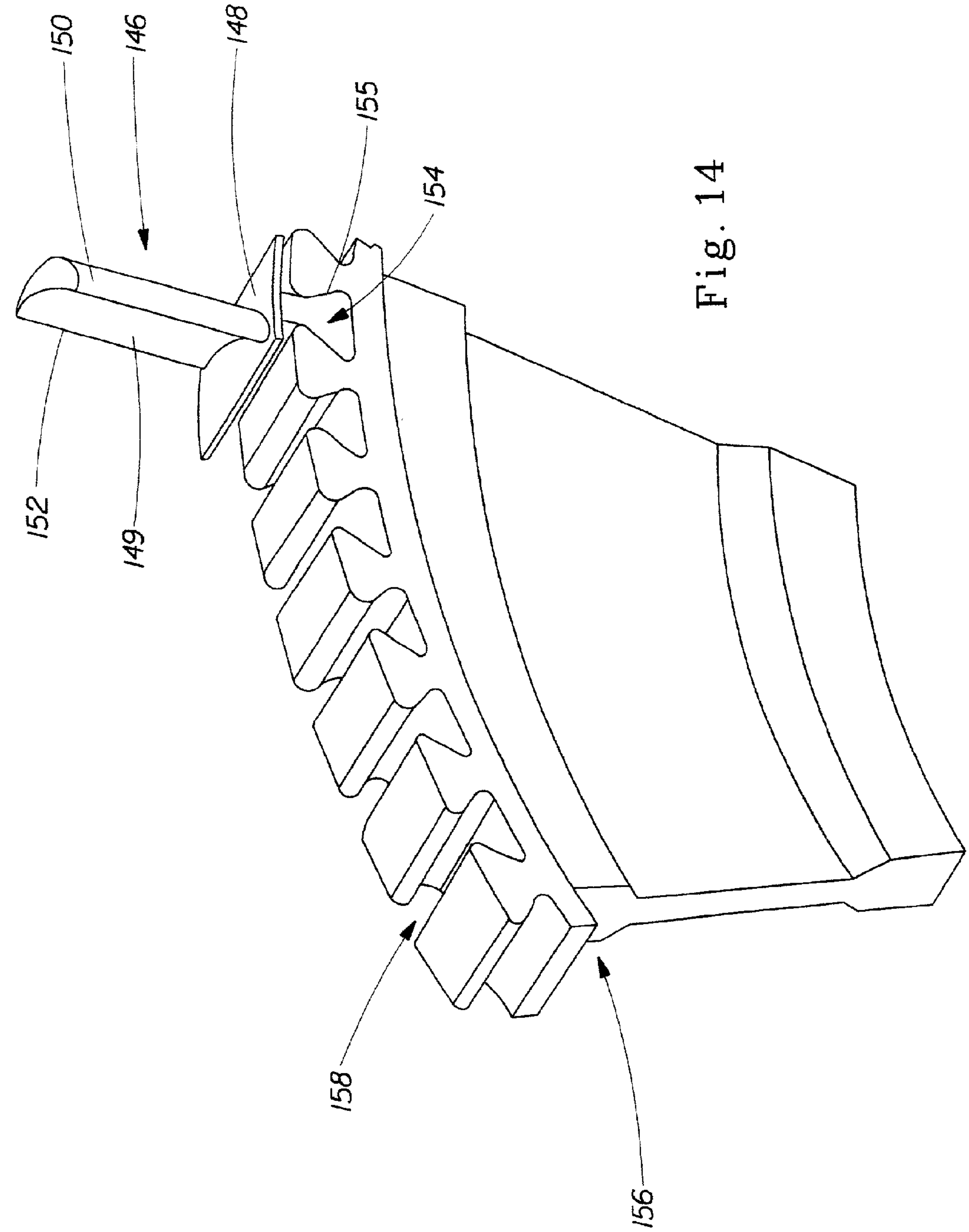


Fig. 14

APPARATUS FOR PROVIDING A RESIDUAL STRESS DISTRIBUTION IN THE SURFACE OF A PART

RELATED PATENT APPLICATIONS

[0001] The present Application deals with related subject matter in co-pending U.S. patent application entitled METHOD FOR REDUCING TENSILE STRESS ZONES IN THE SURFACE A PART, filed on the same day as the present application and having the same inventor in common.

BACKGROUND OF THE INVENTION

[0002] This invention relates to a method and an apparatus for imparting residual stress in the surface of a part and, more particularly, to a method of inducing a selected compressive residual stress distribution within the surface of a part to improve fatigue and stress corrosion performance of the part and an apparatus for implementing the method.

[0003] Surface residual stresses are known to have a major effect upon the fatigue and stress corrosion performance of component parts. Tensile residual stresses, which can develop during manufacturing processes such as grinding, turning, or welding are well known to reduce both fatigue life and increase sensitivity to corrosion-fatigue and stress corrosion cracking of the part. Further, many parts that are subjected to high dynamic stresses or have areas where stress concentrations occur, such as blades and the rotor disks of turbo machinery, are prone to crack initiation and relatively rapid crack growth. The blades typically comprise an airfoil portion, a platform for partially defining a surface for fluid flow there over when the blade is mounted to the rotor disk, and a root portion having retention grooves which engage in corresponding axially extending complementary grooves of the disk. During engine operation, the rotor disk and the blade are subjected to large centrifugal loads that produce high dynamic stresses that may cause high cycle fatigue along portions of the rotor disk and the blade causing cracking and possible failure of the part. Further, the leading edge of the airfoil is often subjected to damage caused by the impact of foreign objects in the fluid stream. Such impact often results in cracks forming along the leading edge that may result in failure of the blade.

[0004] It is well known that compressive residual stresses induced in the surface of a part can increase fatigue life and reduce susceptibility to corrosion-fatigue and stress corrosion cracking. There are currently several methods used in industry for inducing compressive stress in the surface of a metal part and the particular method selected has been dependent on factors such as the dimensions and shape of the part, its strength and stiffness, the desired quality of the finished surface, the desired physical properties of the finished part, and the expense of performing the operation.

[0005] One method commonly used in industry to induce compressive stress in the surface of a part is shot peening, whereby a plurality of metallic or ceramic pellets are projected mechanically or through air pressure to impinge the surface of the part. While such a method is relatively inexpensive and is preferred for many applications, shot peering is unacceptable for parts requiring a superior finish or requiring a greater depth of compressive stress penetration and has also been found to be unacceptable for parts requiring localized or well defined compressive stress regions. Further, for parts such as a rotor disk for use in turbo machinery, the bore surfaces of the rotor disk are subjected to low levels of plastic strain (typically between about 0.2% to about 0.5%) when the rotor disk is accelerated to full speed. If the surfaces have been highly cold worked, such as during shot peening, the cold worked compressive surface material will not yield in tension while the lower yield strength interior material will yield during engine operation. On unloading, such as when the rotor speed is reduced, the surface is driven into tension and will remain in tension, reducing its fatigue life, for the remaining life of the component.

[0006] Another method commonly used in industry to induce compressive stress in the surface of a part is laser shock peening, whereby multiple radiation pulses from high power pulsed lasers produce shock waves on the surface of the part to produce a high magnitude localized compressive stress within a particular region. Unfortunately, however, laser shock peening is relatively expensive and time consuming making it unacceptable for many applications.

[0007] A method which have been developed and is widely used in industry to improve surface finish, fatigue life, and corrosion resistance by deforming the surface of a part is burnishing whereby a rotary or sliding burnishing member is pressed against the surface of the part in order to compress the microscopic peaks in the surface into adjacent hollows. Burnishing operates to develop compressive stresses within the part by yielding the surface in tension so that it returns to a state of compression following deformation.

[0008] The burnishing apparatus utilized for working the surface of a part typically comprise a plurality of cylindrical rollers or balls which contact the surface of the part with sufficient pressure to induce a compressive stress therein. Unfortunately, sharp surface demarcation typically exists along the boundaries of the burnished area often resulting in tensile residual stresses being formed along such boundaries. As disclosed herein, it has been found that gradually reducing the pressure being exerted by the burnishing member to reduce the magnitude of compression at the boundaries will reduce the build up of tensile residual stress. Further, it has been found that by controlling the compressive residual stress distribution and the magnitude of compression, the tensile stress distributions within a part may be offset or distributed in such a manner as to optimize the fatigue and/or stress corrosion performance of the part. Until now, however, a method and apparatus have not been developed that permitted the residual stress distributions and the magnitude of compression to be controlled in such a manner as to optimize fatigue performance for a specific applied stress distribution.

[0009] Consequently, a need exists for a relatively inexpensive, relatively time efficient method and apparatus for implementing the method for improving the physical properties of a part by inducing a layer of compressive stress in the surface of the part, which is effective for use with complex shaped surfaces, and which permits the magnitude of compression and the residual stress distributions to be produced on a surface to achieve optimum fatigue performance and stress corrosion performance of the part.

SUMMARY OF THE INVENTION

[0010] The novel method of the present invention for inducing a layer of compressive residual stress along the surface of a part comprises the steps of selecting a region of the part to be treated; selecting the magnitude of compression and the residual stress distribution to be induced in the surface of the selected region of the part; exerting pressure against the surface of the selected region, the pressure being applied in a selected pattern along the surface to form zones of deformation having a deep layer of compressive stress; and varying the pressure being exerted against the surface to produce the desired residual stress distribution and magnitude of compression within the surface.

[0011] In another preferred embodiment of the invention, the step of exerting pressure against the surface of the selected region included performing a burnishing operation using a burnishing apparatus having a burnishing member for exerting pressure against the surface of the selected region of the part to produce a zone of deformation having a deep layer of compression.

[0012] In another preferred embodiment of the invention, the pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 5.0%.

[0013] In another preferred embodiment of the invention, the pressure being exerted on the surface of the part induces a deep layer of compression within the surface having associated cold working of less than about 3.5%.

[0014] In another preferred embodiment of the invention, whereby the step of exerting pressure on the surface of the part is performed by a burnishing operation using a burnishing apparatus having a burnishing member for exerting pressure against the surface of the selected region to induce a deep layer of compression within the surface having associated cold working of less than about 5.0 percent.

[0015] In another preferred embodiment of the invention, whereby the step of exerting pressure on the surface of the part is performed by a burnishing operation using a burnishing apparatus having a burnishing member for exerting pressure against the surface of the selected region to induce a deep layer of compression within the surface having associated cold working of less than about 3.5 percent.

[0016] In another preferred embodiment of the invention, whereby the selected pattern operates to vary the spacing between the zones of deformation to produce the desired residual stress distribution.

[0017] In another preferred embodiment of the invention, the step of selecting the magnitude of compression includes the step of programming a control unit to automatically adjust the pressure being exerted against the surface of the part.

[0018] In another preferred embodiment of the invention, the step of exerting pressure against the surface of the selected region includes performing a burnishing operation and the step of programming a control unit to control the direction of movement of a burnishing member to produce the desired stress distribution.

[0019] In another preferred embodiment of the present invention the step of varying the pressure being exerted against the surface of a part includes the steps of programming a control unit to adjust the pressure being exerted by a burnishing member against the surface of the part, and programming the control unit to direct the burnishing member over the part in a selected pattern to obtain the desired residual stress distribution.

[0020] In another preferred embodiment of the present invention, the step of varying the pressure being exerted against the surface of a part includes the step of gradually varying the magnitude of compressive stress in the areas immediately adjacent to the boundaries of the selected region.

[0021] In another preferred embodiment of the present invention, a method of inducing a layer of compressive stress in the surface of a part comprises the steps of inducing a deep layer of compression within the surface and inducing a more shallow layer of compressive stress within the surface of the selected region.

[0022] In another preferred embodiment of the present invention, a method of inducing a layer of compressive stress in the surface of a part comprises the steps of inducing a deep layer of compression within the surface and removing a layer of material along the surface being in low compression or tension.

[0023] In another preferred embodiment of the present invention, the method of inducing a layer of compressive stress in the surface of a part comprises the steps of programming a control unit to adjust the pressure being applied by the burnishing member against the surface of the part; programming the control unit to direct the burnishing member over the part in a predetermined pattern to induce a layer of compressive stress in the surface of the part; and applying a secondary process to impart a relatively shallow layer of compressive residual stress along the surface of the part to produce the desired residual stress distribution.

[0024] The novel apparatus for implementing the method of the present invention utilizes a burnishing process for inducing a layer of compressive residual stress having a preselected magnitude of compression and a desired stress distribution. In particular, the burnishing apparatus comprises a burnishing member for applying pressure against the surface of the selected region of the part to produce a zone of deformation having a deep layer of compression and a preselected magnitude within the surface. The burnishing apparatus further comprises means for moving the burnishing member in a predetermined pattern across the selected region to produce a desired residual stress distribution.

[0025] In another preferred embodiment of the invention the burnishing apparatus for implementing the burnishing method of the subject invention comprises a burnishing member for applying pressure against the surface of a part to induce a layer of compressive stress therein; means for adjusting the pressure being applied against the surface of the part by the burnishing member; and means for directing the burnishing member over the surface of the part in a predetermined pattern to provide the desired residual stress distribution.

[0026] In another preferred embodiment of the invention, the burnishing apparatus for implementing the burnishing method of the subject invention is coupled to a control unit for automatically controlling the movement, position, and application pressure of the burnishing member.

[0027] In another preferred embodiment of the invention, the burnishing apparatus for implementing the burnishing method of the subject invention comprises means for supplying a constant flow of fluid to support the burnishing member.

[0028] In another preferred embodiment of the invention, the burnishing apparatus for implementing the burnishing method of the subject invention comprises magnetic means for maintaining the burnishing member within the socket.

[0029] Another preferred embodiment of the invention is a blade for use in turbo machinery having having a desired stress distribution.

[0030] Another preferred embodiment of the invention is a rotor disk for use in turbo machinery comprising selected regions having desired stress distributions.

[0031] Another preferred embodiment of the invention, a part selected from the group consisting of automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and the like comprises regions of compressive residual stresses having predetermined stress distributions.

[0032] Another preferred embodiment of the invention, a part selected from the group consisting of automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and the like treated by the method comprising the step, or a combination of steps, of the present invention.

[0033] A primary object of this invention, therefore, is to provide a method and an apparatus for implementing the method of providing a part with an improved finish and with improved physical properties.

[0034] Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer on the surface of a part.

[0035] Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer that varies in magnitude of compression across the part in a predetermined pattern.

[0036] Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer having a well defined stress distribution.

[0037] Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer having a predetermined stress distribution.

[0038] Another primary object of this invention is to provide a method for forming a part having deep compression with a minimal amount of cold working and surface hardening.

[0039] Another primary object of this invention is to provide a method of inducing a relative deep layer of compressive stress and a relative shallow layer of compressive stress in the surface of the part.

[0040] Another primary object of the invention is to provide a burnishing apparatus that permits the pressure being exerted on the surface of a part to be varied to produce regions having residual stress distributions of arbitrary shape and magnitude of compression.

[0041] Another primary object of the invention is to provide a burnishing apparatus comprising means for automatically adjusting the burnishing force and the corresponding pressure being exerted against the surface of a part that increases on the high points encountered along the surface and decreases on the low points encountered along the surface of the part.

[0042] Another primary object of this invention is to provide an apparatus having a burnishing member within a socket and magnetic means for maintaining the burnishing member within the socket.

[0043] Another primary object of this invention is to provide an apparatus having a burnishing member within a socket which can be easily removed and inserted into place within the socket.

[0044] Another primary object of this invention is to provide a blade for use in turbo machinery having relatively good fatigue and stress corrosion performance.

[0045] Another primary object of this invention is to provide a rotor disk for use in turbo machinery having relatively good fatigue and stress corrosion performance.

[0046] Another primary object of this invention is to provide a method and an apparatus for implementing the method of inducing a compressive stress layer on the surface of a part which is relatively inexpensive.

[0047] Another primary object of this invention is to provide a blade for use in turbo machinery comprising regions of compressive residual stresses having predetermined stress distributions.

[0048] Another primary object of this invention is to provide a blade for use in turbo machinery having a compressive stress layer that varies in magnitude of compression across the part.

[0049] Another primary object of this invention is to provide a disk for use in turbo machinery comprising regions of compressive residual stresses having predetermined patterns of magnitude of compression and residual stress distribution.

[0050] Another primary object of this invention is to provide a part selected from the group consisting of automotive parts, aircraft parts, marine parts, engine parts, motor parts, machine parts, drilling parts, construction parts, pump parts, and the like comprising regions of compressive residual stresses having predetermined patterns of magnitude of compression and residual stress distributions.

[0051] These and other objects and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0052] **FIG. 1** is a schematic block diagram illustrating the method of the present invention;