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A1

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(54) High pressure water shot peening.

(57) High pressure water shot peening is used to process the surface of metallic material, regardless of the surface configuration. By impacting the surface with a supersonic water jet for a predetermined minimum time dependent on the feed rate, the surface is cleaned and decontaminated. When the jet is directed against the inner surface of a tubular member at 2200-2800 ft./sec. for a predetermined dwell time in the range of 0.3 to 0.6 seconds, in./min. a compressive stress is induced in the surface which increases the local micro-hardness of the material. When the jet is impacted against the surface at a velocity in this range, using a self-rotating peener as illustrated, the induced stress is of sufficient magnitude to reduce the susceptibility of the surface to stress corrosion cracking.

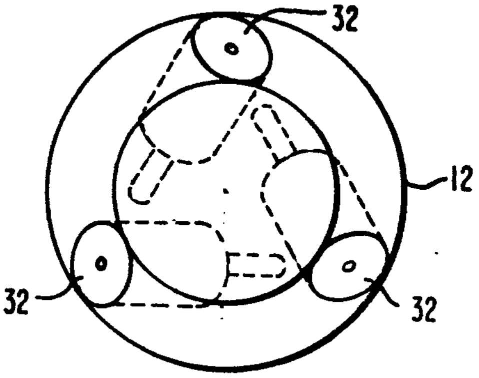

FIG. 2

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HIGH PRESSURE WATER SHOT PEENING

BACKGROUND OF THE INVENTION

This invention relates generally to a method and apparatus for treating the surface of a metallic material with a fluid jet, and, more particularly, for inducing a compressive stress in the surface of a metallic material with a supersonic liquid jet, in order to bring about stress-relieving in the metallic material.

Many conventional metal working and metal forming operations introduce deleterious residual tensile stresses into the metal which is worked on. It is well known that the presence of residual tensile stresses in metallic surfaces increases their susceptibility to stress corrosion cracking.

Cracking because of stress corrosion is particularly detrimental in nuclear steam generator tubes since through-the-wall cracks permit undesirable co-mingling of primary fluid, which has been heated by circulation through the nuclear reactor core and contains radioactive particles, with the secondary fluid known as feedwater, contaminating the feedwater.

In-situ annealing of steam generator tubes is not a very-practical method of removing the residual stresses. Methods developed to decrease the susceptibility of the tube wall to stress corrosion cracking by reducing the level of residual tensile stresses on the inner surface of the tubes include kiss rolling, roto peening, and shot peening. Each method has limitations and drawbacks as hereinafter discussed in detail, noting that the nuclear steam generator in question has a tubesheet and a channel head.

The kiss rolling process consists of subjecting the tube to a controlled diametrical deformation using a tool with rotating rollers. This method requires precise tool positioning, is difficult to implement, and requires controlled torque values to achieve the required 0.3 to 0.5% diametrical deformation. In addition, the process is not efficient beyond the tubesheet of the steam generator.

The roto peening process requires special flap assemblies. This method also requires high rotational speeds (on the order of 3000 to 3500 rpms), frequent flap replacement, subsequent cleaning by swabs dipped in methanol, and does not provide full coverage of the tubesheet area due to limitations in access imposed by the curvature of the channel head work envelope. Furthermore, the process is very slow, rendering it impractical for large industrial peening applications such as the approximately 6000 tubes in each nuclear steam generator. An additional drawback with respect to the use of this method in nuclear steam generators is the production of airborne radioactive contamination.

The shot peening process has been utilized for many years for stress-relieving by inducing compressive stresses in the surfaces of metals. In the case of relatively thin tubes, such as those in steam generators, the control of the process is somewhat delicate since excessive peening can produce detrimental tensile stresses in the outer skin of the tube. In addition, the "glass" shots, which are known to be used primarily for peening non-ferrous materials, may contaminate the surface of the tube material. Shot peening of nuclear steam generators, like roto peening, produces airborne radioactive contamination.

All of the aforementioned methods, if applied without caution, have the potential of introducing residual stresses as high as those intended to be relieved. What is needed is a stress relieving method of inducing compressive stresses in the surface of metallic materials which is effective, easy to control, and which does not create airborne contamination.

SUMMARY OF THE INVENTION

The invention in its broad form resides in a method of stress-relieving by peening a surface of a metallic member, the method characterized by the steps of:

generating jet means comprising liquid moving at a predetermined supersonic velocity;

impacting said supersonic liquid jet means against said surface to be processed; and

continuing to impact said supersonic liquid jet means against said surface being processed for a predetermined dwell time to effect the stress-relieving thereof.

A preferred embodiment described herein provides a method of processing a surface of a metallic material by directing a coherent, high velocity, supersonic liquid jet through a nozzle into contact with the surface of the metallic material to be processed. As described herein, the supersonic liquid jet is directed into contact with the surface with a high impact energy for increasing the local micro-hardness of the material. The liquid jet is preferably directed into contact with the surface at a velocity in the range of (2200 to 2800 feet) 730 meters to 930 meters per second for a dwell time in the range of 0.3 to 0.6 seconds, which is controlled by the feed rate of the nozzle.

BRIEF DESCRIPTION OF THE DRAWINGS

A more detailed understanding of the invention can be had from the following description of a preferred embodiment, given by way of example and to be understood in conjunction with the attached drawing in which:

Figure 1 is a cross-sectional view in elevation of the preferred embodiment of the self rotating nozzle for inducing compressive stresses in tubular members;

Figure 2 is a cross-sectional view in elevation of the nozzle taken along the line II-II in Figure 1;

Figure 3 is a cross-sectional view in elevation of an alternative embodiment of the self rotating nozzle;

Figure 4 is a view in perspective of the high pressure water shot peening apparatus installed in a steam generator, a portion of which is shown in cross section; and

Figure 5 is a chart depicting local microhardness of the material treated versus distance from the treated surface.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention is useful for processing any metallic surface. However, the invention will be described in a preferred embodiment constructed for use in stress relieving, decontaminating, and cleaning tubular heat exchanger tubes, particularly those found in a nuclear steam generator.

Referring to Figure 1, the preferred embodiment of high pressure water shot peening apparatus 10 has a generally elongated nozzle means, which may include a nozzle head 12 non-rotatably and fluidly connected to a rotating nozzle part 14. The fluid connection between nozzle head 12 and rotating nozzle part 14 may be sealed by a sealing means, such as aluminum bronze lens closure 16. Nozzle head 12 and rotating nozzle part 14 are fluidly connected to a non-rotating intermediate connector means, such as non-rotating connector part 18 and connector 19. The fluid connection between rotating nozzle part 14 and non-rotating connector part 18 may be sealed through two pair of spring actuated sealing devices 20, which may be manufactured from "Teflon" (Trademark) material, and two sets of polyurethane backup rings 22. The fluid connection between non-rotating connector part 18 and connector 19 may be sealed by aluminum bronze lens closure 24.

High pressure pump means, such as high pressure pump 26 depicted in Figure 4 and described in detail hereinafter, may be fluidly linked to connector 19 through high pressure flexible hose 28 and coupling 30.

Disposed within nozzle head 12 are orifice means, such as replaceable orifices 32 depicted in Figures 1 and 2. For the present application, the preferred orifices are manufactured from sapphire with a diameter between 0.15 mm to 0.5 mm - (0.006 and 0.020 inches) and are available from Flow Industries, Kent, Washington. The best results are achieved with an orifice with a diameter between 0.2 mm to 0.3 mm (0.008 and 0.012 inches). The preferred embodiment includes three orifices disposed within nozzle head 12 and offset at an acute angle with respect to the axis of nozzle head 12. This offset angle A, which is preferably 45° for conditioning the inner surface of steam generator tubes, provides for the optimum impact angle of the fluid jet issuing from the orifices 32 to strike the tube surface. A secondary purpose for angling of the orifices is for forcing nozzle head 12 and rotating nozzle part 14 into engagement with non-rotating connector part 18 so that no rigid attachment means between rotating nozzle part 14 and non-rotating connector part 18 is required.

Figure 2 illustrates the orientation of orifices 32 with respect to a radial plane of nozzle head 12. Each orifice is oriented at an offset with respect to a radial plane through nozzle head 12. This orientation causes nozzle head 12 and rotating nozzle part 14 to rotate with respect to non-rotating connector part 18 when fluid is supplied through orifices 32.

In order to avoid axial forces on nozzle head 12 and rotating nozzle part 14 which would tend to dislodge nozzle part 14 from non-rotating connector part 18, a fluid path is provided through non-rotating connector part 18 which results in the fluid entering rotating nozzle part 14 in a radial direction, as observable in Figure 1. Fluid supplied from high pressure pump 26, shown in Figure 4, flows through coupling 30, through connector 19, and into connector part 18. The fluid travels through annular groove means, such as axially inclined groove 34 and into radial groove means, such as radial groove 36. The fluid then flows out of non-rotating connector part 18 and into radial duct means in rotating nozzle part 14, such as radial ducts 38. The fluid thereafter traverses rotating nozzle part 14 through central axial bore means, such as central axial bore 39, which communicates fluidly with orifices 32. Rotation of rotating nozzle part 14 within non-rotating connector part 18 requires sealing devices 20 and backup rings 22 to act as bearing as well as seals therebetween. An alternative embodiment of the high pressure water shot peening apparatus 10a is depicted in Figure 3. Rotating nozzle part 14a is axially maintained rigidly between thrust bearings 40a and is rotatably supported by needle bearings 40b and bronze bearings 40c. Rotating nozzle part 14a is sealed to connector 19a by seals 41, which are axially retained by seal retaining means such as seal retaining bushing 42. Use of this embodiment eliminates the need for the radial groove means of the preferred embodiment since water flowing axially through central axial bore 39a will not cause the rotating nozzle part 14a to separate from connector 19a since rotating nozzle part 14a is axially engaged by thrust bearings 40a.

Figure 4 depicts a system for processing the inner surfaces of the tubular members comprising a nuclear steam generator. This preferred embodiment could also be used to process other tubular members. The high pressure water shot peening apparatus 10 is inserted into the steam generator channel head 43 through an aperture, such as manway 44. Apparatus 10 is supported by a supporting means, such as support arm 46, which is suspended from tubesheet 48. Support arm 46 may include apparatus holder 50, which is movable along the axis of arm 46, and may be configured so that it can rotate around a pivot 52 along its axis of attachment so that apparatus 10 may be inserted into any of the tubes 54 in the steam generator tubesheet 48. While a typical nuclear steam generator contains several thousand tubes, only five of these tubes 54 are shown in Figure 3.

For apparatus 10 to effectively process the interior surface of tubes 54, an axial nozzle moving means, such as belt-driven axial nozzle moving mechanism 56, is required. In order to induce a compressive stress in the inner surface of tubes 54 with the apparatus hereinbefore described, high pressure pump 26 must be capable of supplying liquid at a pressure of at least 20.6850 kPa (30,000 psi) with a preferred pressure of at least 24.1325 kPa (35,000 psi). Pumps of this type are manufactured by Flow Industries, Kent, Washington. High pressure pump 26 of the preferred embodiment is driven by a 75 hp electric motor rated at 240/460 VAC. For ease in accessing each steam generator tube 54, high pressure pump 26 is fluidly connected to nozzle means at coupling 30 through flexible high pressure hose 28. High pressure hose take-up reel 58 may be employed to simplify handling. Suction pump 60 and its associated hardware may be used to remove waste water and debris.

The above-described apparatus comprises a self rotating high pressure water shot peening apparatus for processing the inner surface of steam generator tubes by impacting the surface with a supersonic liquid jet means at a predetermined velocity. The method of the invention applies with equal force to processing of a surface of any metallic member.

In operation, a liquid, preferably water, is pressurized by high pressure pump 26 of Figure 4 to at least 20.6850 kPa (30,000 psi) and preferably to 24.1325 kPa (35,000 psi). The pressurized liquid is delivered through flexible high pressure hose 28 to the nozzle means at coupling 30. Referring to Figure 1, the high pressure liquid flows through coupling 30, through connector 19, and into non-rotating connector part 18. Within non-rotating connector part 18, the high pressure liquid is directed through axially inclined groove 34 into radial groove 36. From radial groove 36, the pressurized liquid passes into radial duct 38 in rotating nozzle part 14 of the nozzle means. The liquid flows from radial duct 38 through central axial bore 39 into nozzle head 12 and into fluid communication with orifices 32. The high pressure liquid is discharged through orifices 32 in a direction offset with respect to the radius of nozzle head 12, as depicted in Figure 2. The effect of this high pressure liquid discharge at an angle with respect to the radius is the creation of a rotational force in nozzle head 12 and rotating nozzle part 14. This rotational force causes nozzle head 12 and rotating nozzle part 14 to rotate with respect to non-rotating connector part 18. Orifices 32 are offset at an acute angle with respect to the axis of nozzle head 12 for directing the liquid jet issuing therefrom into contact with the tube surface at the optimum impact angle. In addition, discharging of high pressure liquid through orifices 32 at an acute angle with respect to the axis of nozzle head 12 causes an axial force on nozzle head 12 and rotating nozzle part 14, enabling rotating nozzle part 14 to remain in engagement with non-rotating connector part 18 without axial connecting means for resisting uncoupling by fluid pressure.

The high pressure liquid discharge through orifices 32 is impacted against the inner surface of tube 54 at a predetermined supersonic velocity. For inducing a compressive stress in the surface of a steam generator tube 54, which is manufactured of Inconel, the preferred supersonic velocity at which the pressurized liquid impacts the interior surface of tube 54 is in the range of 2200 to 2800 feet per second (671 to 854 meters per second). The preferred impact velocity for stress relieving of tubes of different compositions varies with the material. Also, tube cleaning, decontaminating, and other processing may generally be performed with lower impact velocities. In order to achieve the required stress on the metallic surface, the supersonic liquid jet must be impacted against the surface for a predetermined minimum time which is referred to as the dwell time. For steam generator Inconel 600 tube material, the preferred dwell time is in the range of 0.3 to 0.6 seconds. This dwell time is dependent upon the tube material and is controlled by the feed rate of the apparatus through the tube. This feed rate is achieved through proper control of axial nozzle moving means, such as axial nozzle moving mechanism 56 for the preferred method of stress relieving steam generator tubes. Axial nozzle moving mechanism 56 translates apparatus 10 axially into steam generator tubes 54 at a predetermined feed rate. The preferred axial feed rate for steam generator stress relieving has been determined to be in the range of 1.0 to 2.0 inches per minute (0.025 to 0.050 meters per minute). Stated alternatively, the preferred feed rate is in the range of 0.003 to 0.006 ipr (includes per revolution of the nozzle head 12), which is 7.6×10^{-5} to 15.2×10^{-5} meters per revolution.

Impacting the supersonic liquid jet against the metallic surface at the requisite supersonic velocity and for the period of time resulting from axial movement at the requisite feed rate increases the local micro-hardness of the metallic surface without affecting the outer surface of the tube. The increase in local micro-hardness brought about by high pressure water shot peening is observable in Figure 5, which is a plot of local micro-hardness versus distance in mils from the inside surface. The resulting surface hardness values are very similar to those obtained by conventional shot peening and roto peening.

The supersonic liquid jet produced by the high pressure pump and directed against the metallic surfaces through orifices can be used to dislodge and remove the radioactive oxide layer from the surface of metallic materials, such as steam generator tubes. While the predetermined supersonic velocity and feed rate for inducing compressive stress in the metallic surface would be effective in removing the radioactive oxide layer, higher or lower impact velocities and feed rates could be equally effective for decontamination. Removal of this oxide layer by the self rotating tube processing apparatus hereinbefore described is effective for tube cleaning and decontamination purposes.

For cleaning, decontaminating, or inducing a compressive stress in the surface of non-tubular metallic members, the same pump and orifices could be used. However, the nozzle means would have to be changed so that the liquid jets would strike the surface with sufficient force and for a minimum period of time to achieve the desired processing. However, the use of a high pressure liquid jet for processing a metallic surface is equally applicable to metallic surfaces of any configuration.

Claims

1. A method of stress-relieving by peening a surface of a metallic member, the method characterized by the steps of:

generating jet means comprising liquid moving at a predetermined supersonic velocity;

impacting said supersonic liquid jet means against said surface to be processed; and

continuing to impact said supersonic liquid jet means against said surface being processed for a predetermined dwell time to effect the stress-relieving thereof.

2. The method according to claim 1, wherein said processing of said surface of said metallic member comprises inducing a compressive stress in said surface.

3. The method according to claim 2, wherein said predetermined supersonic velocity at which said liquid is moving is in the range of 2200 to 2800 ft./sec. (671 m./sec. to 854 m./sec.).

4. The method according to claim 3, wherein said predetermined dwell time during which said liquid jet is impacted against said surface is in the range of 0.3 to 0.6 seconds, said predetermined dwell time being achieved by translating said jet along said surface at a feed rate of 1.0 to 2.0 in./min. (0.025 to 0.050 m./min.).

5. The method according to claim 4, wherein said liquid comprises water.

6. The method according to claim 1, also including processing of said surface of said metallic material by cleaning to remove any debris, coating, and scale attaching to said surface.

7. The method according to claim 6, wherein said processing of said surface of said metallic material comprises decontaminating said metallic material by removing any radioactive oxide layer adhering to said surface.

8. The method according to claim 7, wherein said liquid comprises water.

9. The method according to claim 1, wherein said tubular member comprises a nuclear steam generator tube and said predetermined dwell time is in the range of 0.3 to 0.6 seconds.

10. The method according to claim 1, wherein said predetermined feed rate of said jet is in the range of 0.003 to 0.006 inches per revolution (ipr) of said rotating jet means (7.6×10^{-5} to 15.2×10^{-5} meters per revolution).

11. An apparatus for processing the interior surface of a tubular member, which apparatus comprises:

nozzle means characterized by:

orifice means provided within said nozzle means for producing jet means at a predetermined supersonic velocity from a pressurized liquid and for directing said jet means against said interior surface of said tubular member;

rotation means for rotating said nozzle means and said orifice means about the axis of said nozzle means, said axis of said nozzle means being substantially coaxial with respect to the axis of said tubular member;

axial nozzle moving means for moving said nozzle means along said axis of said nozzle means; and

high pressure pump means for supplying said pressurized liquid to said nozzle means and said orifice means.

12. The apparatus according to claim 11, further comprising non-rotating intermediate connector means for mechanically and fluidly connecting said nozzle means with said high pressure pump means.

13. The apparatus according to claim 19, wherein said rotation means comprises the orientation of said orifice means in a first direction offset with respect to the radius of said nozzle means in a radial plane of said nozzle means, said orifice means being provided at said orientation for causing said nozzle means to automatically rotate with respect to said non-rotating intermediate connector means about said axis of said nozzle means when said liquid is discharged through said orifice means.

14. The apparatus according to claim 13, wherein said nozzle means further comprises the offset of said orifice means at an acute angle with respect to said axis of said nozzle means in an axial plane through said nozzle means, said offset being provided for causing said nozzle means to be forced into engagement with said non-rotating intermediate connector means when said liquid is discharged through said orifice means.

15. The apparatus according to claim 14, wherein disposed within said non-rotating intermediate connector means are annular groove means and radial groove means for redirecting the axial flow of said liquid from said high pressure pump means into flow in a radial direction and into radial duct means disposed within said nozzle means, said radial duct means being provided for transporting said liquid to a central axial bore means disposed within said nozzle means, said central axial bore means fluidly connecting said radial duct means with said orifice means for transporting said liquid from said high pressure pump means through said annular groove means and said radial groove means disposed within said non-rotating intermediate connector means, then through said radial duct means, said central axial bore means, and said orifice means disposed within said nozzle means and for propelling said liquid against said inner wall of said tubular member without creating an axial force on said nozzle means which would tend to disengage said nozzle means from said intermediate connector means.

16. The apparatus according to claim 15, wherein said processing comprises inducing a compressive stress in said interior surface of said tubular member.

17. The apparatus according to claim 16, wherein said high pressure pump means supplies said liquid to said nozzle means and said orifice means at a pressure of at least 30,000 psi and said jet means is directed against said interior surface of said tubular member at a velocity in the range of 2200 to 2800 ft./sec. for a predetermined dwell time in the range of 0.3 to 0.6 seconds, said predetermined dwell time being achieved by axially translating said nozzle means through said tubular member at 1.0 to 2.0 in./min. (0.025 to 0.050 m./min.), which corresponds to 0.003 to 0.006 inches per revolution of said nozzle means (7.6×10^{-5} to 15.2×10^{-5} meters per revolution).

18. The apparatus according to claim 17, wherein said liquid comprises water.

19. The apparatus according to claim 18, wherein said tubular member comprises a nuclear steam generator tube.

20. The apparatus according to claim 15, wherein said processing comprises cleaning by removing any debris, coating, and scale attaching to said surface.

21. The apparatus according to claim 20, wherein said liquid comprises water.

22. The apparatus according to claim 15, wherein said processing of said interior surface of said tubular member comprises decontaminating said surface by removing the radioactive oxide layer adhering thereon.

23. The apparatus according to claim 22, wherein said liquid comprises water.

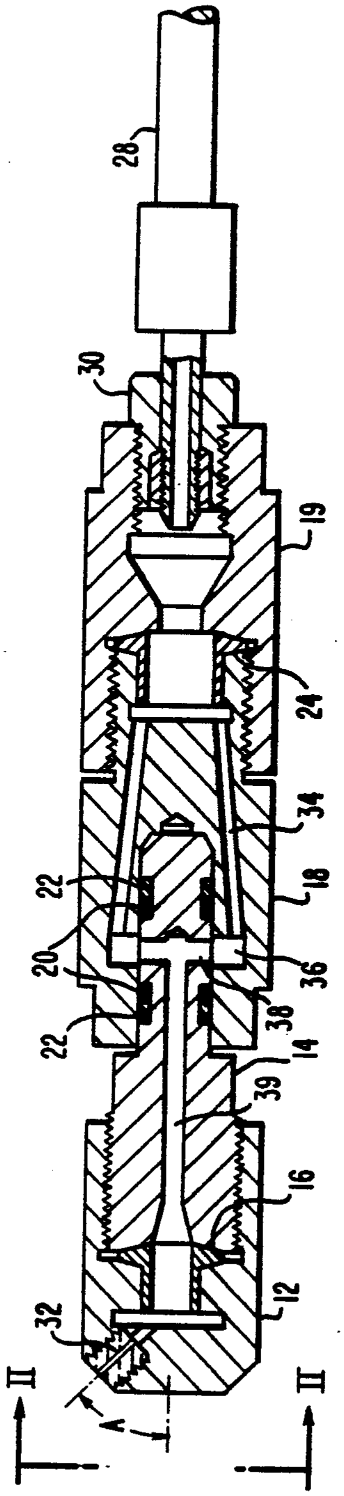


FIG. 1

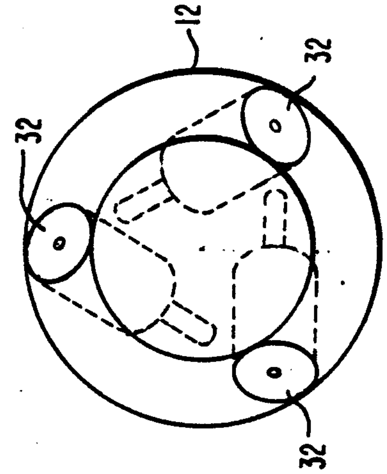
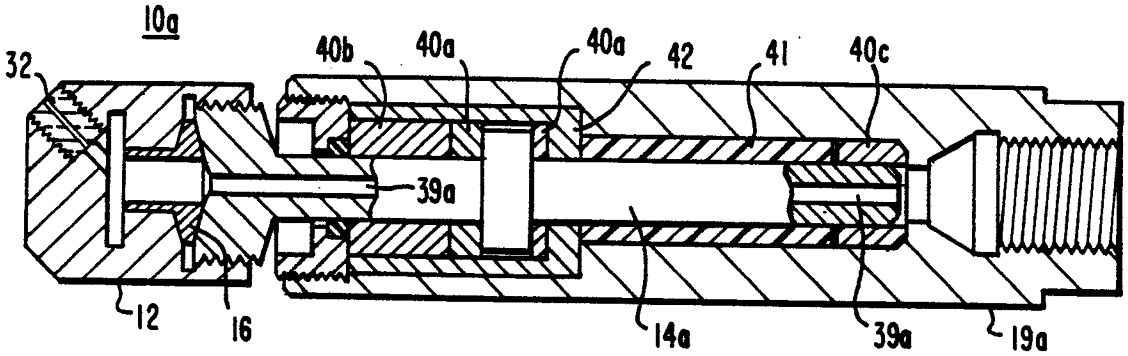


FIG. 2


10a
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40b
40a
40a
42
41
40c
39a
12
16
14a
39a
19a

FIG. 3

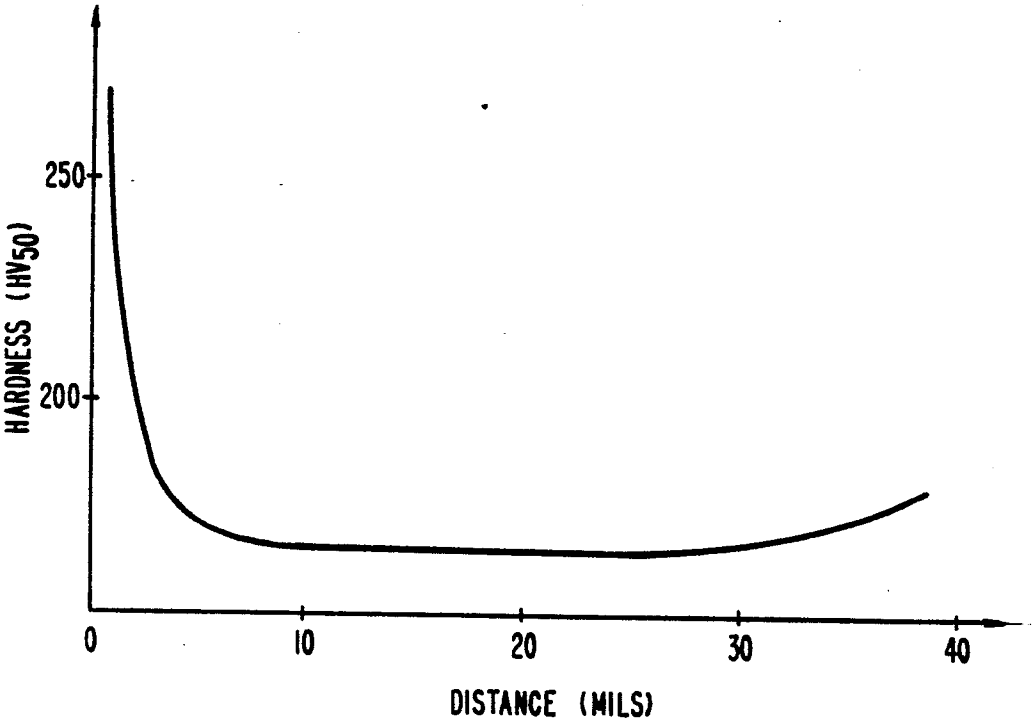
HARDNESS (HV50)
250
200
0
10
20
30
40
DISTANCE (MILS)

FIG. 5

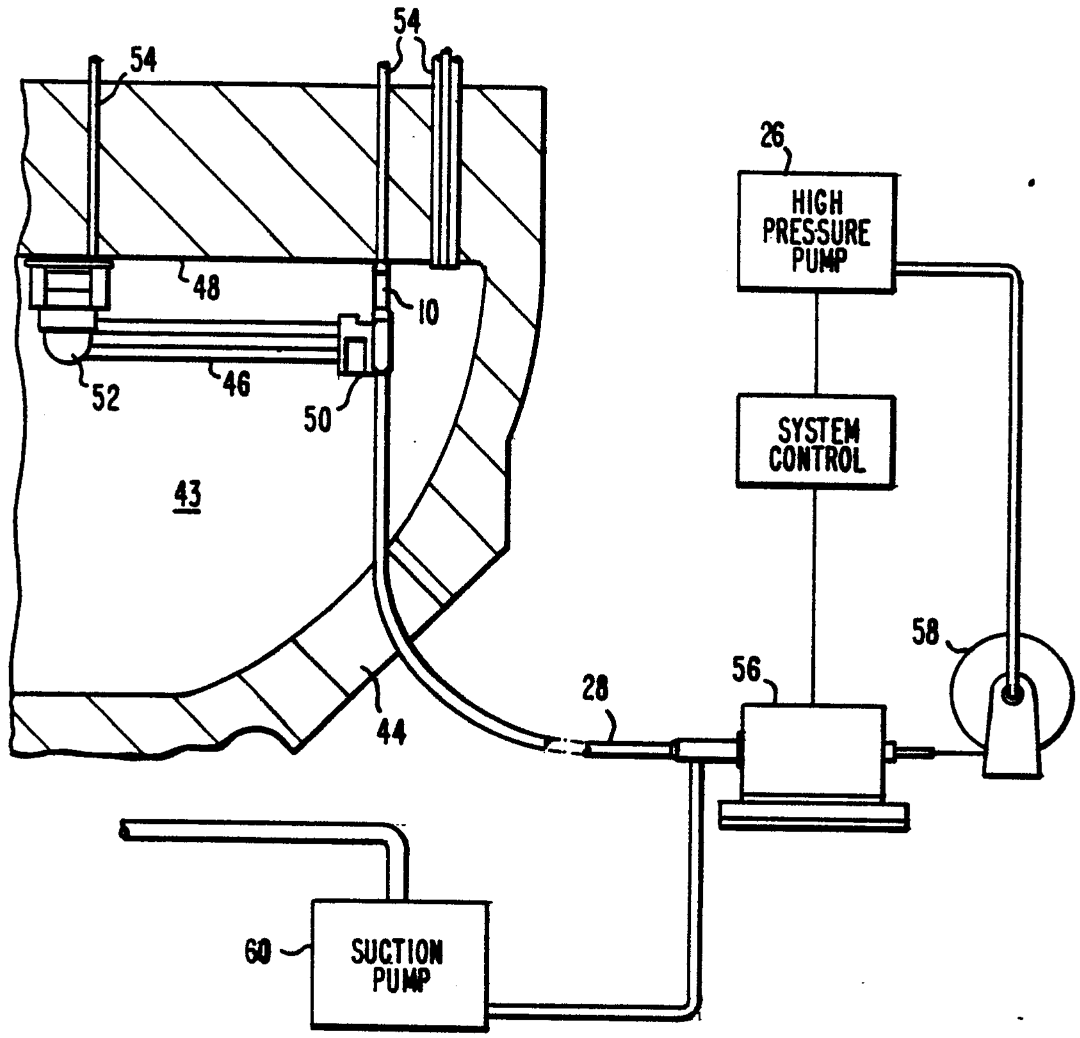
54
54
26
HIGH PRESSURE PUMP
48
10
52
46
50
SYSTEM CONTROL
43
58
56
28
44
60
SUCTION PUMP

FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 86 30 6633

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	DE-A-2 111 445 (F. ERDMANN-JESNITZER) * Whole document *	1,2,5, 11	C 21 D 7/06 B 08 B 9/02 B 08 B 3/02
X	CH-A- 275 352 (L.H. ROSENMUND) * Whole document *	11-13	
X	US-A-3 987 963 (A. PACHT) * Claims; figures; column 2 *	11-13	
A	FR-A-2 551 996 (ELECTRICITE DE FRANCE)	1	
A	BE-A- 883 798 (K.I.C. SMET)	11	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A	METALWORKING PRODUCTION, vol. 109, no. 34, 25th August 1965, page 53, London, GB; R.E. LAYTON: "Internal shot peening"		C 21 D B 08 B
A	DER NEUERER, vol. 15, no. 4, 1966, page 161: "Wasser verfestigt Stahl" * Left-hand column *	1,5,17	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	12-12-1986	MOLLET G.H.J.

CATEGORY OF CITED DOCUMENTS

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