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(54) Method for treating the surface of a rotational shaft used in fluid compressing apparatus.

(57) A method for treating the surface of a rotational shaft used in a fluid compressing apparatus includes the step of providing the rotational shaft made of an iron system metal, the step of annealing the rotational shaft (101) at a temperature between a first temperature equal to a prescribed temperature determined by adding about 50 degrees centigrade to a temperature of an ion nitridation treatment and a second temperature equal to the transformation temperature of the iron system metal, the step of forming an iron nitride layer (103,107) in the surface of the rotational shaft by performing an ion nitridation treatment at a temperature between about 450 degrees centigrade and 550 degrees centigrade, and the step of forming a phosphate layer (109) on the iron nitride layer of the surface of the rotational shaft.

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METHOD FOR TREATING THE SURFACE OF A ROTATIONAL SHAFT USED IN FLUID COMPRESSING APPARATUS

The present invention relates, in general, to methods for treating the surface of a slide movable member. In particular, the invention relates to a method for treating the surface of a rotational shaft used in a fluid compressing apparatus.

In recent years, a wide range of air conditioning capacity in an air conditioning system has been desired to meet the demand for air conditioning as a result of changes in house structures. To achieve such a desire, an inverter unit is used in the air conditioning system to expand the rotational speed of the compressor. The rotational speed of the compressor is widely changed, as compared with the air conditioning apparatus which is operated with a conventional commercial frequency, i.e., 60 Hz, and furthermore the compressor is operated at an increased air conditioning load because of the increase in the space to be air-conditioned at one time. Thus, high wear-resisting and adhesion-resisting abilities of the rotational shaft of the compressor are required to endure the above-described operational conditions. The rotational shaft transmits a driving force from a driving section, i.e., a motor, to a compressing section and is under a high temperature caused by a slide-contact with bearings.

At a high speed rotation of the compressor, a pressure-velocity value thereof, a so-called PV value, increases and a risk of adhering the rotational shaft against the bearings also increases.

On the other hand, if the rotational speed of the compressor is decreased, the amount of lubricating oil supplied to slide contacting portions between the main shaft portion of the rotational shaft and the main bearing and between the auxiliary shaft portion of the rotational shaft and the auxiliary bearing is reduced and a bearing load character as a dynamic pressure bearing also is decreased. Thus, a metal contact between the rotational shaft and the bearings is increased and the wear of the rotational shaft or the bearings may progress.

A phosphate treatment, a molybdenum disulfide treatment, and a boron nitridation treatment are well known as a method for enhancing the slide-moving ability of the bearing. Such treatments form a specific layer on the surface of the rotational shaft. The above-described treatments improve the adhesion-resisting property of the rotational shaft at the operation of an increased load condition and also improve the initial fitting between the rotational shaft and the bearings.

However, the above-described teatments form a relatively soft specific layer on the surface of the rotational shaft or the bearings. Thus, in the compressor driven by the inverter unit, if the operation of the compressor is maintained for a relatively long period at a low operational speed by which an amount of lubricating oil supplied to both the rotational shaft and the bearings tends to be insufficient, the wear of the rotational shaft or bearings may be caused by the load fluctuation of the rotational shaft or the decrease in the thickness of the lubricating oil film formed between the rotational shaft and the bearings.

To avoid the above-described problem of the rotational shaft or the bearings, the use of a material having a high hardness, or the enhancement of the surface hardness of the rotational shaft by a surface treatment are effective. However, the high hardness of the material has a drawback in its mechanical processing.

On the other hand, a high frequency quenching, a cementation, a nitridation treatment, a boronidation treatment (treatment with boron), a siliconizing, etc., are known to enhance the hardness of a metal surface. However, the above-described treatments are carried out at a fairly high temperature. For example, the temperature of the cementation is about 780 °C, and the temperature of the nitridation treatment is between five and six hundred degrees centigrade (°C).

When the basic material is treated under such a high temperature, the deformation of the basic material may occur. Thus, the above-described surface treatments are carried out in a limited field. It is difficult to apply such a surface treatment to parts used in a compressor, in particular, to a rotational shaft which has a complicated figure, and requires a high accuracy of parts less than several μ(micron).

Another surface treatment may be an ion nitridation treatment. Since the ion nitridation treatment is carried out at a relatively low temperature, as compared with other nitridation treatments, changes in the dimensional accuracy is small before and after the ion nitridation treatment is performed. Thus, the ion nitridation treatment is suitable for slide-movable parts on which a precision finishing is performed. However, such an ion nitridation treatment is unsuitable for parts, e.g., a rotational shaft, having a slit or a complicated structure.

In such an ion nitridation treatment, a glow discharge is carried out in a furnace in which a nitrogen gas or a gas mixing a nitrogen gas with a hydrogen gas is filled at an atmospheric pressure of 1 ~ 10 (torr). During the glow discharge in the furnace, if the surface of a work piece (at a cathode side) on which the surface treatment is performed is substantially flat, the glow discharge occurs uniformly in the furnace. However, if a slit (depressed portion) or the opening of a hole is formed in the surface of the work piece, a voltage potential is concentrated at the edge or the corner of the slit or the opening, and an abnormal discharge, i.e., a so-called hollow cathode discharge phenomenon, tends to occur. In the hollow cathode discharge phenomenon, if opposite surfaces exist in parallel to one another in the work piece, an intensive glow discharge occurs between the opposite surfaces. As a result, the nitridation on the opposite surfaces is promoted, as compared with other portions of the work piece. However, the temperature of the opposite surfaces of the work piece increases excessively and thus a heat-deformation on the opposite surfaces also increases. Finally, the opposite surfaces of the work piece are excessively deformed or melted under the influence of the heat. Thus, a dimensional accuracy in the work piece is greatly decreased.

Occurrence of the hollow cathode discharge depends on a degree of vacuum pressure in the furnace and the diameter of a hole, the width of a slit or the size of a gap. In general, the hollow cathode discharge tends to occur if a degree of vacuum pressure in the furnace is decreased and also if the diameter of the hole is constant over the entire length of the hole.

Accordingly, it is an object of the present invention to enhance the wear-resisting ability and the adhesion-resisting ability of a rotational shaft used in a fluid compressing apparatus.

It is another object of the invention to provide a method for treating the surface of a rotational shaft used in a fluid compressing apparatus without causing a heat deformation.

It is still another object of the invention to perform an ion nitridation surface treatment to the surface of a rotational shaft without causing a hollow cathode discharge phenomenon.

To achieve the above-described objects, a method for treating the surface of a rotational shaft used in a fluid compressing apparatus includes the step of providing the rotational shaft made of an iron system metal, the step of annealing the rotational shaft at a temperature selected between a first temperature equal to a prescribed temperature determined by adding about 50 degrees centigrade to a temperature of an ion nitridation treatment and a second temperature equal to the transformation temperature of the above-described iron system metal, the step of forming an iron nitride layer in the surface of the rotational shaft by performing the ion nitridation treatment at a temperature between about 450 degrees centigrade and 550 degrees centigrade, and the step of forming a phosphate layer on iron nitride layer of the surface of the rotational shaft.

The method for treating the surface of a rotational shaft may also includes the step of masking the hole of the rotational shaft whose diameter is between 3 mm and 20 mm and the depressed portion of the rotational shaft whose width is between 3 mm and 20 mm before the iron nitride layer is formed.

The iron nitride layer forming step may include the sub step of exhausting air in a furnace in which the rotational shaft is disposed, the sub step of flowing a prescribed gas selected from an ammonia gas, a nitrogen gas and a mixture of a hydrogen gas and a nitrogen gas into the furnace, the sub step of intermittently applying a prescribed DC voltage between the rotational shaft and the wall surface of the furnace so that the rotational shaft acts as a cathode and the wall surface of the furnace acts as an anode for forming an ion sheath on the surface of the rotational shaft by sputtering the rotational shaft, the sub step of increasing the temperature of the rotational shaft, the sub step of executing the ion nitridation treatment to the surface of the rotational shaft, and the sub step of decreasing the temperature of the rotational shaft to the temperature at which an oxidation of the rotational shaft does not progress as an inert gas is entered into the furnace.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

These and other objects and advantages of this invention will become apparent and more readily appreciated from the following detailed description of the presently preferred embodiment of the invention, read in conjunction with the accompanying drawings, wherein :

FIGURE 1 is a cross sectional side view of a rotary type fluid compressor with an accumulator ;
FIGURE 2 is an enlarged cross sectional segmentary view of a rotational shaft shown in FIGURE 1 ;
FIGURE 3 is a flow-chart showing a surface treatment of one embodiment of the present invention;
FIGURE 4 is a flow-chart showing a detailed process of an ion nitridation treatment shown in FIGURE 3 ;
FIGURES 5(a), 5(b), 5(c), and 5(d) are explanatory views illustrating the surface treatment shown in FIGURE 3 ;
FIGURE 6 is a cross sectional segmentary view showing the surface state of a rotational shaft ;
FIGURE 7(a) is a graph showing an amount of the wearing depth of each slid-contact portion of the rotational shaft and the bearing shown in FIGURE 1 after 1000 hours operation ;
FIGURE 7(b) is a graph showing the surface roughness of each slide-contact portion of the rotational shaft and the bearing after 1000 hours operation ;
FIGURE 8 is a graph showing a relationship between a hollow cathode discharge occurring voltage and the diameter of a hole or the width of a slit when the pressure in the furnace is varied ;
FIGURE 9 is an explanatory view showing masking elements and portions of rotational shaft to be masked in a second embodiment of the invention;

FIGURE 10 (a) is a segmentary perspective view showing one example of the second embodiment ;

FIGURE 10 (b) is a segmentary perspective view showing another example of the second embodiment ;

FIGURE 11 is a partly cross sectional segmentary view showing rotational shaft with a masking rod in a third embodiment ; and

FIGURE 12 is an enlarged view showing a relationship between the opening edge of rotational shaft and a curved depressed portion formed in the masking rod in the furnace.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will now be described in more detail with reference to the accompanying drawings.

Referring to FIGURE 1, a fluid compressing apparatus 21 includes a driving unit 23 located at an upper portion in a casing 25 and a compressing unit 27 arranged at a lower portion in casing 25.

Driving unit 23 includes a motor 29 composed of a stator 29a and a rotor 29b. Compressing unit 27 includes a pair of cylinders 31a and 31b. A rotational shaft 33 fixed to rotor 29b extends through the pair of cylinders 31a and 31b and is rotatably supported by both a main bearing 35 disposed at the upper side of the pair of cylinders 31a and 31b and an auxiliary bearing 37 disposed at the lower side of the pair of cylinders 31a and 31b. A main shaft portion 33a of rotational shaft 33 is supported by main bearing 35 and an auxiliary shaft portion 33b thereof is supported by auxiliary bearing 37. A portion of rotational shaft 33 exposed in one of the cylinders 31a is provided with a first crank 39a and a portion of rotational shaft 33 exposed in the other cylinder 31b is provided with a second crank 39b. A first roller 41a is fixed on the outer surface of first crank 39a and a second roller 41b also is fixed on the outer surface of second crank 39b. A partition plate 43 is interposed between the pair of cylinders 31a and 31b. Thus, a first compressing chamber 45a is defined by main bearing 35, partition plate 43 and one of the cylinders 31a. A second compressing chamber 45b also is defined by auxiliary bearing 37, partition plate 43 and the other cylinder 31b. A pair of intake openings 47a and 47b is respectively formed in the corresponding outer surface of the pair of cylinders 31a and 31b. One end of a pair of pipes 49a and 49b is inserted into the corresponding intake openings 47a and 47b and the other end thereof is inserted into an accumulator 51, which separates a liquid refrigerant and a gaseous refrigerant.

A first valve cover 53a is formed at main bearings 35 and a second valve cover 53b also is formed at auxiliary bearing 37 to temporarily receive therein a pressurized refrigerant output from each compressing chamber 45a, 45b.

As shown in FIGURE 2, an oil passage 55 is formed in rotational shaft 33 along its longitudinal direction. The lower end portion 37a of auxiliary bearing 37 and the opening 33a of the extended end of rotational shaft 33 is closed with a plate 57. Outer surface of plate 57 is supported by second valve cover 53b to receive a force of rotational shaft 33 in a thrust direction. An oil intake opening 59 is formed at the center of plate 57 to supply a lubricating oil stored in casing 25 to each slide-contact portion of rotational shaft 33 through oil passage 55 formed in rotational shaft 33.

Oil passage 55 is formed in rotational shaft 33 so that it has a large diameter path 55a extending from opening 33a to a mid-portion above the location of first crank 39a and a relatively small diameter path 55b from the mid-portion to the upper end thereof. The upper end portion of large diameter path 55a corresponds to a location at which rotational shaft 33 is rotatably supported by main bearing 35 to supply a sufficient amount of lubricating oil to each slide-contact portion of rotational shaft 33. A conventional oil pump mechanism 61 is provided in large diameter path 55a of oil passage 55 to ensure a sufficient supply of lubricating oil to the upper end of rotational shaft 33.

A first lateral hole 63a is formed in a portion of rotational shaft 33 corresponding to main bearing 35 to supply lubricating oil from large diameter path 55a to main bearing 35 therethrough. A second lateral hole 63b is formed through first crank 39a to supply lubricating oil from large diameter path 55a to the surface of first crank 39a therethrough. A third lateral hole 63c also is formed through second crank 39b to supply lubricating oil from large diameter path 55a to the surface of second crank 39b therethrough. The above-described rotational shaft 33 is made of an iron system metal material. The iron system metal material may be foundries, e.g., a flaky graphite cast iron, a spheroidal graphite cast iron, etc., a steel, e.g., a nitrified steel, a carbon steel, etc., or an iron system sintered material.

A surface treatment to the above-described rotational shaft 33 will now be described.

As shown in FIGURE 3, an annealing process for eliminating a distortion (hereinafter referred to as an annealing process) is performed on rotational shaft 33 at a prescribed temperature in step ST1a. An internal stress is caused by a difference in the cooling speed of each different portion of rotational shaft 33 when rotational shaft 33 is cast . Thus, with the annealing process, such an internal stress is eliminated. A processing distortion in rotational shaft 33 by a rough machining process also is eliminated. The prescribed temperature is located between a temperature obtained by adding 50 degrees centigrade (°C) to an ion nitridation treatment temperature, e.g., 450 ~ 550 degrees centigrade (°C), and a transformation temperature of the above-described iron system metal material. The annealing may be carried out in an atmosphere of an inert gas or in the air.

After the annealing process is completed, rotational shaft 33 is taken out from the furnace. Thus, an oxidation progresses in the surface of rotational shaft 33. This oxidation occurs in the surface of rotational shaft 33 which is annealed not only in the air but also in an inert gas. An oxide produced in the surface of rotational shaft 33 causes the loading or the glazing of a grinding wheel during the grinding process, and thus the grinding ability of the grinding wheel is decreased. In addition, the oxidation layer formed in the surface of rotational shaft 33 causes unevenness of the surface of rotational shaft 33, and a concentration of discharge may occur during the spattering process resulting in a prolonging of the period of the spattering process. Thus, the wire-buffing is carried out on the surface of rotational shaft 33 to remove the oxidation layer from the surface of rotational shaft 33 in step ST1b.

The ion nitridation treatment is carried out on rotational shaft 33 in step ST1c. Detail processes of the ion nitridation treatment are shown in FIGURE 4. The ion nitridation treatment includes a vacuum exhaustion process (step ST2a), a spattering process (step ST2b), a temperature increase process (step ST2c), a nitridation process (step ST2d) and a temperature decrease process (step ST2e).

In the vacuum exhaustion process (step ST2a), rotational shaft 33 is disposed in the vacuum reaction furnace, and the exhausting operation is carried out at an order of less than 0.1 (Torr). At this time, no air leakage from the vacuum reaction furnace should be confirmed.

In the spattering process (step ST2b), an ammonia gas, a nitrogen gas or a mixture of the ammonia gas and the nitrogen gas is entered into the vacuum reaction furnace. DC voltage is intermittently applied between rotational shaft 33 and the wall surface of the vacuum reaction furnace at an interval of several µsec.~ several hundreds msec. In this case, rotational shaft 33 acts as a cathode and the wall surface of the vacuum reaction furnace is grounded. However, the above-described DC voltage is applied between rotational shaft 33 and the wall surface of the vacuum reaction furnace so that the wall surface of vacuum reaction furnace acts as an anode. During the spattering process, ammonium ions or nitrogen ions impinge on the surface of rotational shaft 33 to clean the surface of rotational shaft 33. Oil on the surface of rotational shaft 33 is driven out and is exhausted to the outside of the reaction region, e.g., the vacuum reaction furnace. Thus, the discharge is stably generated between rotational shaft 33 and the wall surface of the vacuum reaction furnace and the thin ionic sheath is finally formed on the entire surface of rotational shaft 33.

In the temperature increase process (step ST2c), the applied DC voltage and the pressure in the vacuum reaction furnace are gradually increased to increase the impinging energy and the increase of impinging ions results in an increase in the temperature of rotational shaft 33.

In the nitridation process (step ST2d), the nitridation temperature is set at 450 ~ 550 degrees centigrade (°C). The iron elements which are driven out from the surface of rotational shaft 33 by nitrogen ions are joined to other nitrogen ions to adhere on the surface of rotational shaft 33, as an iron nitride. Thus, a chemical compound layer is formed on the surface of rotational shaft 33 by the progress of the above-described adhesion. At this moment, iron elements joined to the nitrogen ions are not sufficiently adhered on the surface of rotational shaft 33 if the nitridation temperature is low. In addition, a diffusion layer produced by diffusing a part of nitrogen of the iron nitride adhered on the surface of rotational shaft 33 toward the inside of rotational shaft 33 also is rarely formed in the surface of rotational shaft 33. If the nitridation process is carried out at a temperature less than 450 degrees centigrade (°C), the wear-resisting ability of rotational shaft 33 is unsatisfied. If the nitridation temperature is excessively low, the form of the chemical compound layer and the diffusion layer on the surface of rotational shaft 33 is insufficient, as described above, and the composition of the chemical compound layer, e.g., a γ'-phase and ε-phase ratio, is changed.

On the other hand, if the nitridation temperature is greater than 550 degrees centigrade (°C), the nitridation to rotational shaft 33 progresses sufficiently. However, it is difficult to maintain an accuracy in the deformation of less than several micron which is generally required of the rotational shaft of the fluid compressing apparatus.

In the temperature decrease process (step ST2e), the temperature of rotational shaft 33 is decreased to a temperature at which no oxidation on the surface of rotational shaft 33 progresses, and the oxidation of the surface of rotational shaft 33 is avoided by flowing an inert gas, e.g., nitrogen gas, into the vacuum reaction furance.

As shown in FIGURE 3, the removing process is carried out after the above-described ion nitridation process has been completed to remove the unreacted remains in the surface of rotational shaft 33 (ST1d). The unreacted remains include a defective nitrified portion of rotational shaft 33 and the outer-most surface layer of rotational shaft 33 which has not been densified during the ion nitridation process. During the above-described temperature decrease process of the ion nitridation treatment, since rotational shaft 33 is disposed in the atmosphere in which nitrogen gas remains under a temperature of 400 ~ 500 degrees centigrade (°C) for a constant period, the defective nitrified portion is formed in the surface of rotational shaft 33. However, if the vacuum reaction furnace is evacuated immediately after the nitridation process is carried out to avoid the above-described defective nitrified portion, the densification in the surface of rotational shaft 33 is not completed and the surface of rotational shaft 33 is rough, as compared with the surface of rotational shaft 33 before the nitridation process is carried out. Thus, such unreacted remains in the surface of rotational shaft 33 are removed. In step ST1d, a ball burnishing, a so-called barrel polishing, is performed on the surface of rotational shaft 33, for example. After the removing process (step ST1d) is carried out, a phosphate film forming process is executed in step ST1e. The phosphate film forming process may be a conventional manganese phosphate treatment.

The above-described surface treatment will now be described in more detail with reference to FIGURE 5.

Base metal 101 shown in FIGURE 5(a) may be an iron system metal material, e.g., foundries, a steel or an iron system sintered material. When the above-described ion nitridation treatment is performed on the surface of base metal 101, a chemical compound layer 103 is formed on the surface of base metal 101 and an unreacted remains 105 also is produced in the outer-most surface of chemical compound layer 103, as shown in FIGURE 5(b). A diffusion layer, i.e., a nitrogen diffusion region, 107 is also produced in base metal 101. The above-described chemical compound 103 is composed of a γ'-phase (Fe_4N) and an ε-phase ($Fe_{2\sim3}$ N). If a mixture of a nitrogen gas and a hydrogen gas is used and the compositional ratio thereof is 50% : 50% when the ion nitridation treatment is carried out, a large number of areas of chemical compound layer 103 become a γ'-phase. If a ratio of the nitrogen gas is increased, chemical compound layer 103 is a mixture state of a γ'-phase and an ε-phase.

When chemical compound layer 103 is mainly formed by the ion nitridation treatment, the thickness of chemical compound layer 103 is set at about one ~ several μm, and the thickness of diffusion layer 107 is set at about ten μm. After chemical compound 103 is formed, unreacted remains 105 of the outer-most surface of chemical compound layer 103 are removed, as shown in FIGURE 5(c). If unreacted remains 105 are not removed, unreacted remains 105 cause the adhesion between rotational shaft 33 and bearings 35 and 37. If the phosphate film is formed on chemical compound layer 103 without removing unreacted remains 105, the phosphate film tends to be peeled from chemical compound layer 103. Base metal 101 is dipped into a phosphate treating liquid, e.g., a manganese phosphate treating liquid, after unreacted remains 105 are removed, and is dried to form phosphate film 109 on the surface of chemical compound layer 103, as shown in FIGURE 5(d).

If a spheroidal graphite cast iron is used as a base metal, the oscillational rotation of rotational shaft 33 caused by a high frequency driving of the fluid compressing apparatus is decreased because of a high stiffness thereof. Since the wear-resisting ability of base metal 101 is enhanced by the above-described surface treatment, the stiffness and the manufacturing cost of a material of the base metal is preferentially considered rather than the wear-resisting ability of the material when the material of the base metal is determined. Thus, a STKM (Carbon Steel Tube for Machine Structural Purposes) provided in the Japanese Industrial Standard G 3445 may be used as a base metal. A SCM (Chromium Molybdenum Steel) provided in the Japanese Industrial Standard G 4105 may also be used as a base metal.

As described above, the temperature of the ion nitridation treatment is low, as compared with that of other nitridation treatments, e.g., a sulfonitrizing treatment, a gas soft nitriding treatment, etc. Thus, when the ion nitridation treatment is performed, changes in the dimensional accuracy are minimized before and after the surface treatment is executed. In addition, a polishing of the hardened outer-most surface of the base metal is not needed after the nitridation treatment is performed. Selecting a usable rotational shaft from a plurality of nitrified rotational shafts also is not needed after the final polishing and the ion nitridation teatment are performed. The rotational shaft on which the ion nitridation treatment is performed has a good wear-resisting property and also a high mass-productivity. Furthermore, since the phosphate film is formed on the surface of chemical compound layer 103 of rotational shaft 33 after unreacted remains 105 of chemical compound layer 103 are removed, the adhesion between rotational shaft 33 and bearings 35 and 37 is avoided. The abrasion of the surface of rotational shaft 22 caused by the slide-contact between rotational shaft 33 and bearings 35 and 37 is also avoided. An initial fitting of rotational shaft 33 to bearings 35 and 37 also is enhanced. This is because the phosphate film is relatively soft, as compared with chemical compound layer 103.

As shown in FIGURE 6, when diffusion layer 107 is finally obtained on rotational shaft 33, the thickness of chemical compound layer 103 is set at less than 1 μm, and the thickness of diffusion layer 107 is set at about 30 to 100 μm. The above-described diffusion layer 107 and chemical compound layer 103 are once formed on the surface of base metal 101 (rotational shaft 33) by the ion nitridation treatment. Then, the above-described removing process is performed to remove chemical compound layer 103 including the outer-most layer of diffusion layer 107. After that, the phosphate film 109 is formed on the surface of diffusion layer 107. Since, diffusion layer 107 is relatively soft compared with chemical compound layer 103, a post processing can be performed to base metal 101 after diffusion layer 107 is formed in the surface of base metal 101.

Experiments were carried out by samples made by the above-described processes. A spheroidal graphite cast iron was used as a base metal. The annealing process was performed on a rotational shaft at 600 degrees centigrade (°C) for 2 hours after an initial processing (e.g., a lathe processing) was carried out to the base metal to make the rotational shaft.

After that, the ion nitridation treatment was carried out. The rotational shaft was disposed in an atmosphere of ammonia ($N_2 : H_2 = 1 : 3$), and was maintained under a glow discharge of 500 ~ 1000 V at 500 degrees centigrade (°C) for about 5 hours. Thus, a 3 μm chemical compound layer and a 20 μm diffusion layer were formed on the surface of the rotational shaft. The removing process was carried out for several minutes to remove the unreacted remains of the outermost surface of the chemical compound layer. Then, the manganese phosphate treatment was further performed on the chemical compound layer of the rotational shaft to form a manganese phosphate film on the surface of the chemical compound layer at several μm. In the rotational shaft obtained by the above-described processes, a deformation of the surface thereof was less than several μm. A practical experiment was carried out in a fluid compressing apparatus using the above-described rotational shaft. The fluid compressing apparatus was operated at different first and second conditions described hereinafter. In the first condition, the fluid compressing apparatus was operated intermittently for 1000 hours under a high load state. The driving frequency was 30 Hz. The output pressure of the fluid compressing apparatus was 20 kg/cm^2 and the suction pressure thereof was 4kg/cm^2. In the second condition, the fluid compressing apparatus was operated continuously for 1000 hours under a liquid back state in which a liquid refrigerant is taken into the fluid compressing apparatus. The driving frequency was 135 Hz. The output pressure of the fluid compressing apparatus was 10 kg/cm^2 and the suction pressure thereof was 6 kg/cm^2. Results of the experiment are shown in FIGURES 7(a) and 7(b).

FIGURES 7(a) and 7(b) show relative slide-moving characteristics of main and auxiliary shaft portions 33a and 33b of the rotational shaft 33 and main and auxiliary bearings 35 and 37 shown in FIGURE 1. FIGURE 7(a) shows an amount of each wear depth of main and auxiliary shaft portions 33a and 33b and main and auxiliary bearings 35 and 37. FIGURE 7(b) shows each surface roughness of main and auxiliary shaft portion 33a and 33b and main and auxiliary bearings 35 and 37. In FIGURES 7(a) and 7(b), the geometrical symbol (Δ) indicates results of a first experiment in which the rotational shaft treated by the ion nitridation process was used under the above-described first condition. The geometrical symbol (○) indicates results of a second experiment in which the rotational shaft treated by the ion nitridation process was used under the above-described second condition. The geometrical symbol (▲) indicates results of a third experiment in which the conventional rotational shaft which is not treated by the ion nitridation process was used under the first condition, and the geometrical symbol (●) also indicates results of a fourth experiment in which the conventional rotational shaft was used under the second condition for the purpose of the comparison.

As can be seen in FIGURES 7(a) and 7(b), with the use of the rotational shaft treated by the ion nitridation process, the wear amount of the rotational shaft is decreased and the surface roughness thereof also is improved, as compared with the use of the conventional rotational shaft.

The rotational shaft, the surface of which has diffusion layer 107 shown in FIGURE 6, was practically made by the following conditions.

The ion nitridation treatment was carried out on the rotational shaft after the annealing process was performed on the rotational shaft, similar to the above-described processes by which the chemical compound layer finally remains on the surface of the rotational shaft. The rotational shaft was disposed in an atmosphere of ammonia ($N_2 : H_2 = 1 : 1$) and was maintained under a glow discharge of 500 ~ 1000 V at 550 degrees centigrade (°C) for 15 hours. Thus, about a 2 μm chemical compound layer and about a 70 μm diffusion layer are respectively formed in the surface of the rotational shaft. The removing process is carried out to remove the chemical compound layer and a part of the diffusion layer from the rotational shaft. In this case, the chemical compound layer and a part of the diffusion layer at a thickness of 15 μm from the surface of the rotational shaft were removed. As a result, the surface hardness of the rotational shaft showed about 500 ~ 600 by the Vickers hardness test. Thus, the surface hardness of the rotational shaft was enhanced, as compared with the base metal, the surface hardness of which is about 300 in the Vickers hardness. The phosphate film of several μm was finally formed on the diffusion layer of the rotational shaft.

In the above-described rotational shaft on which the diffusion layer and the phosphate film are formed, a high accuracy in the processing similar to that of the conventional iron cast rotational shaft can be achieved. Furthermore, a greatly improved initial fitting and an enhanced wear-resisting property of the rotational shaft were observed when the rotational shaft was used in a fluid compressing apparatus.

A second embodiment of the present invention will now be described.

FIGURE 8 shows changes in the voltage (a hollow cathode discharge occurring voltage) at different pressures in a reaction furnace when a diameter of hole or a width of slit of the rotational shaft is varied in the ion nitridation treatment. In FIGURE 8, a solid curve PR1 shows changes in the hollow cathode discharge occurring voltage when the pressure in the reaction furnace is ten and several (Torr), and a solid curve PR2 shows changes in the hollow cathode discharge occurring voltage when the pressure in the reaction furnace is several (Torr). A solid curve PR3 also shows changes in the hollow cathode discharge occurring voltage when the pressure in the reaction furnace is one (Torr). A range between Ra and Rb shows changes in the voltage in each pressure described above when the temperature in the reaction furnace is maintained at 450 ~ 580 degrees centigrade (°C).

As can be seen in FIGURE 8, the voltage drop occurs within a range of 3 ~ 20 mm in relation to the diameter of hole or the width of slit of the rotational shaft even if the pressure in the reaction furnace is varied. Thus, a hollow cathode discharge phenomenon occurs in the rotational shaft having the hole or the slit of the above-described range when the ion nitridation treatment is performed on the surface of the rotational shaft.

As shown in FIGURE 9, first, second and third lateral holes 63a, 63b and 63c are formed in rotational shaft 33. In general, the inner diameter of first lateral hole 63a is 3 ~ 20 mm. A first depressed portion 121a is formed in a circumferential surface above first crank portion 39a of rotational shaft 33. A second depressed portion 121b also is formed in a circumferential surface between first and second crank portions 39a and 39b. In general, the width of first and second depressed portions 121a and 121b is about 3 ~ 20 mm.

In this embodiment, a bar-shaped masking pin 123 is inserted into first lateral hole 63a as shown in FIGURE 10(a) to avoid occurrence of the hollow cathode discharge phenomenon. The diameter of the top portion of masking pin 123 is slightly smaller than that of first lateral hole 63a and the diameter of the remaining portion of masking pin 123 is substantially the same as that of first lateral hole 63a. Thus, masking pin 123 is easily inserted into or taken out from first lateral hole 63a.

First and second ring-shaped masking collars 125a and 125b are fitted into the corresponding first and second depressed portions 121a and 121b, as shown in FIGURE 10(b). Thus, the hollow cathode discharge phenomenon which would occur in first and second depressed portions 121a and 121b can be avoided. First ring-shaped masking collar 125a has an inner diameter slightly smaller than the outer diameter of first circumferential depressed portion 121a. Second ring-shaped masking collar 125b also has an inner diameter slightly smaller than the outer diameter of second circumferential depressed portion 121b. First and second ring-shaped masking collars 125a and 125b respectively have a slit 127a, 127b traversing the surface thereof. Thus, first ring-shaped masking collar 125a is elastically attached to first circumferential depressed portion 121a by forcibly extending collar 125a from slit 127a. Second ring-shaped masking collar 125b also is attached to second circumferential depressed portion 121b by the same operation as described above. First and second ring-shaped masking collars 125a and 125b are preferably made of a spring steel. A third depressed portion 121c formed in a circumferential surface of rotational shaft 33 just below second crank portion 39b may be covered with a ring-shaped masking collar (not shown) similar to the above-described first and second ring-shaped masking collars 125a and 125b if the width of third depressed portion 121c is greater than 3 mm.

With the above-described embodiment, a hollow cathode discharge does not occur because of the masking elements, e.g., pin or collar. The temperature of the surface of rotational shaft 33 defining first lateral hole 63a does not excessively increase during the ion nitridation treatment and the temperature of each surface of rotational shaft 33 defining first and second depressed portions 121a and 121b does not also increase in excess. Thus, a partial heat deformation does not occur in the surface of rotational shaft 33.

A third embodiment of the present invention will now be described. In this embodiment, a rod 151 made of a material similar to that of rotational shaft 33 is used to avoid a hollow cathode discharge occurring in large diameter path 55a of oil passage 55 formed in rotational shaft 33. Rod 151 is inserted into large diameter path 55a when the ion nitridation treatment is performed, as shown in FIGURE 11. In addition, a curved depressed portion 151a is formed in the circumferential surface of rod 151 opposite to the inner edge of rotational shaft 33 to maintain a suitable distance between the surface of rod 151 and the opening edge of large diameter path 55a.

In this embodiment also, a hollow cathode discharge occuring in large diameter path 55a of rotational shaft 33 is avoided by rod 151 inserted in large diameter path 55a. The temperature in the surface which defines large diameter path 55a does not increase excessively. Thus, a partial heat deformation does not occur in the surface of rotational shaft 33 which defines large diameter path 55a. In addition, since a suitable distance is maintained between the surface of rod 151 and the opening edge of large diameter path 55a by curved depressed portion 151a of rod 151, nitrogen ions are uniformly implanted into the outer surface of rotational shaft 33 including an edge surface portion 153 of rotational shaft 33 shown in FIGURE 12. The wear-resisting ability of edge surface portion 153 of rotational shaft 33 is enhanced, and thus edge surface portion 153 of rotational shaft 33 maintains a smooth rotation against plate 57 shown in FIGURE 2 for an extended operational period.

In the above-described embodiment, if the pressure in the furnace in which the ion nitridation is carried out is regulated at a suitable value, the use of masking pin 123 is not required.

The present invention has been described with respect to specific embodiments. However, other embodiments based on the principles of the present invention should be obvious to those of ordinary skill in the art. Such embodiments are intended to be covered by the claims.

Claims

1. A method for treating the surface of a rotational shaft used in a fluid compressing apparatus, including the steps of :
   providing the rotational shaft made of an iron system metal having a transformation temperature ;
   annealing the rotational shaft at a temperature selected between a first temperature equal to a prescribed temperature determined by adding about 50 degrees centigrade to a temperature of an ion nitridation treatment and a second temperature equal to the transformation temperature of the iron system metal ;
   forming an iron nitride layer in the surface of the rotational shaft by performing the ion nitridation treatment at a temperature between about 450 degrees centigrade and 550 degrees centigrade ; and
   forming a phosphate layer on the iron nitride layer of the surface of the rotational shaft.

2. A method according to claim 1 further including the step of removing an oxide film produced by the annealing step from the surface of the rotational shaft before the iron nitride layer is formed.

3. A method according to claim 1 or 2 further including the step of removing unreacted remains produced by the iron nitride layer forming step from the surface of the iron nitride layer of the rotational shaft before the phosphate layer is formed.

4. A method according to claim 3, wherein the iron nitride layer includes a diffusion layer and a chemical compound layer formed on the diffusion layer, and the chemical compound layer is removed when the unreacted remains are removed to expose the diffusion layer.

5. A method according to any preceding claim, wherein the rotational shaft has a hole whose diameter is between 3 mm and 20 mm, and wherein the hole of the rotational shaft is masked when the iron nitride layer is formed.

6. A method according to any preceding claim, wherein the rotational shaft has a depressed portion whose width is between 3 mm and 20 mm, and wherein the depressed portion of the rotational shaft is masked when the iron nitride layer is formed.

7. A method according to any preceding claim, wherein the iron nitride layer forming step includes the sub steps of :
   exhausting air in a furnace in which the rotational shaft is disposed ;
   flowing a prescribed gas selected from an ammonia gas, a nitrogen gas and a mixture of a hydrogen gas and a nitrogen gas into the furnace;
   intermittently applying a prescribed DC voltage between the rotational shaft and the wall surface of the furnace so that the rotational shaft acts as a cathode and the wall surface of the furnace acts as an anode to form an ion sheath on the surface of the rotational shaft ;
   increasing the temperature of the rotational shaft ;
   executing the ion nitridation treatment to the surface of the rotational shaft ; and
   decreasing the temperature of the rotational shaft to the temperature at which an oxidation of the rotational shaft does not progress, as an inert gas is entered into the furnace.

8. A method according to claim 7, wherein the rotational shaft has an oil supply hole for supplying lubricating oil, and the hole is masked when the ion nitridation treatment is performed to form the iron nitride layer on the surface of the rotational shaft except the masked hole.

9. A method according to claim 8, wherein the oil supply hole of the rotational shaft has an opening edge portion, and the oil supply hole is masked by an elongated rod tightly inserted into the oil supply hole through the opening edge portion.

10. A method according to claim 9, wherein the elongated rod has a curved depressed portion at the circumferential surface thereof, and the elongated rod is inserted into the oil supply hole so that the curved depressed portion is disposed opposite to the opening edge portion of the oil supply hole.

11. A method for treating the surface of a rotational shaft used in a fluid compressing apparatus including the steps of :

providing the rotational shaft made of an iron system metal having a transformation temperature ;

annealing the rotational shaft at a temperature selected between a first temperature equal to a prescribed temperature determined by adding about 50 degrees centigrade to a temperature of an ion nitridation treatment and a second temperature equal to the transformation temperature of the iron system metal ;

removing an oxide film produced by the annealing step from the surface of the rotational shaft ;

forming an iron nitride layer in the surface of the rotational shaft by performing the ion nitridation treatment at a temperature between about 450 degrees centigrade and 550 degrees centigrade ;

removing unreacted remains produced in the iron nitride layer forming step from the surface of the iron nitride layer of the rotational shaft ; and

forming a phosphate layer on iron nitride layer of the surface of the rotational shaft.

12. A method according to claim 11, wherein the iron nitride layer includes a diffusion layer and a chemical compound layer formed on the diffusion layer, and the chemical compound layer is removed when the unreacted remains are removed to expose the diffusion layer.

13. A method according to claim 12, wherein the rotational shaft has a hole whose diameter is between 3 mm and 20 mm, and wherein the hole of the rotational shaft is masked when the iron nitride layer is formed.

14. A method according to claim 12 or 13, wherein the rotational shaft has a depressed portion whose width is between 3 mm and 20 mm, and wherein the depressed portion of the rotational shaft is masked when the iron nitride layer is formed.

FIG.1

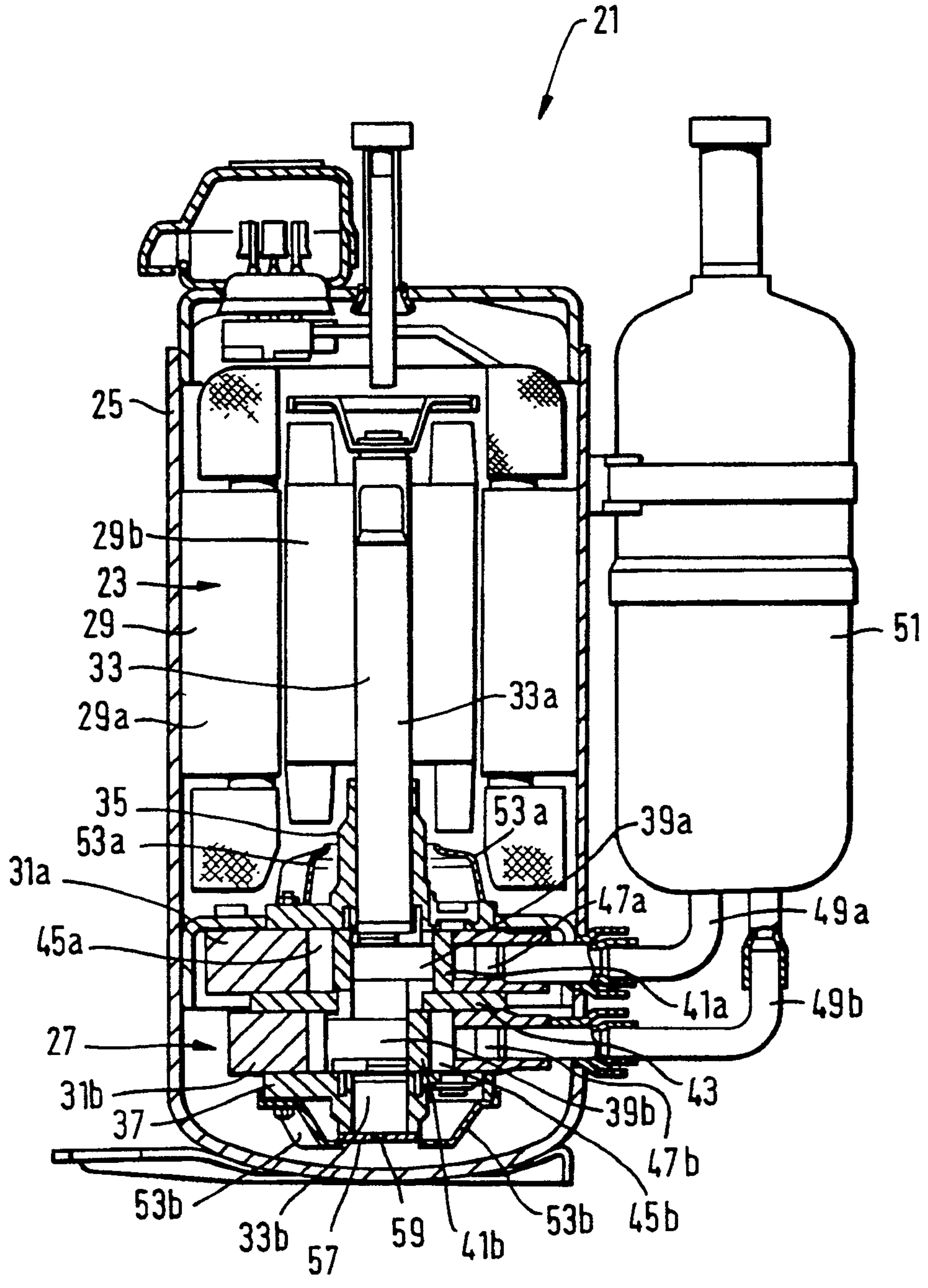

21
25
29b
23
29
33
29a
33a
51
35
53a
53a
39a
31a
47a
49a
45a
41a
49b
27
43
31b
39b
37
47b
53b
45b
53b
33b
57
59
41b

FIG.2

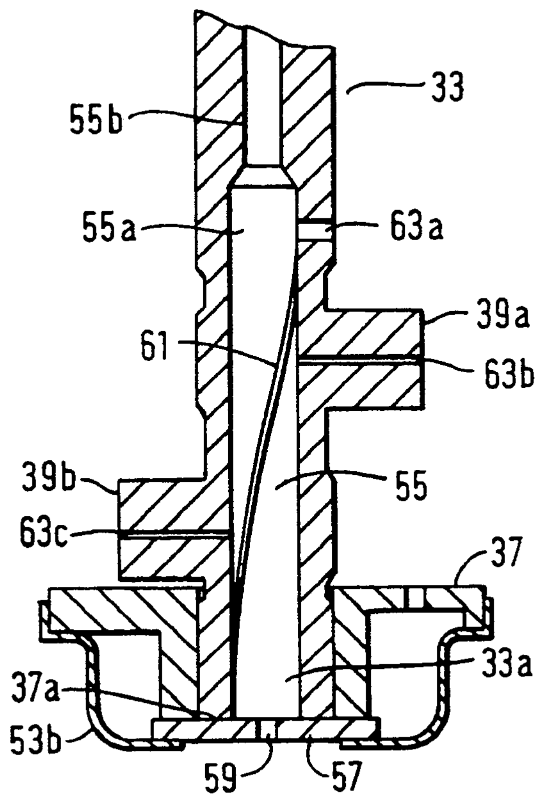

33
55b
55a
63a
39a
61
63b
39b
55
63c
37
33a
37a
53b
59
57

FIG.6

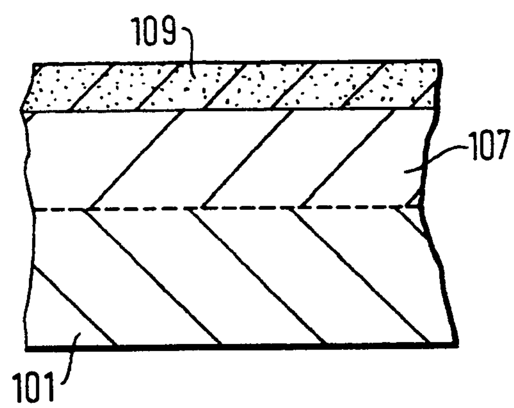

109
107
101

FIG.3

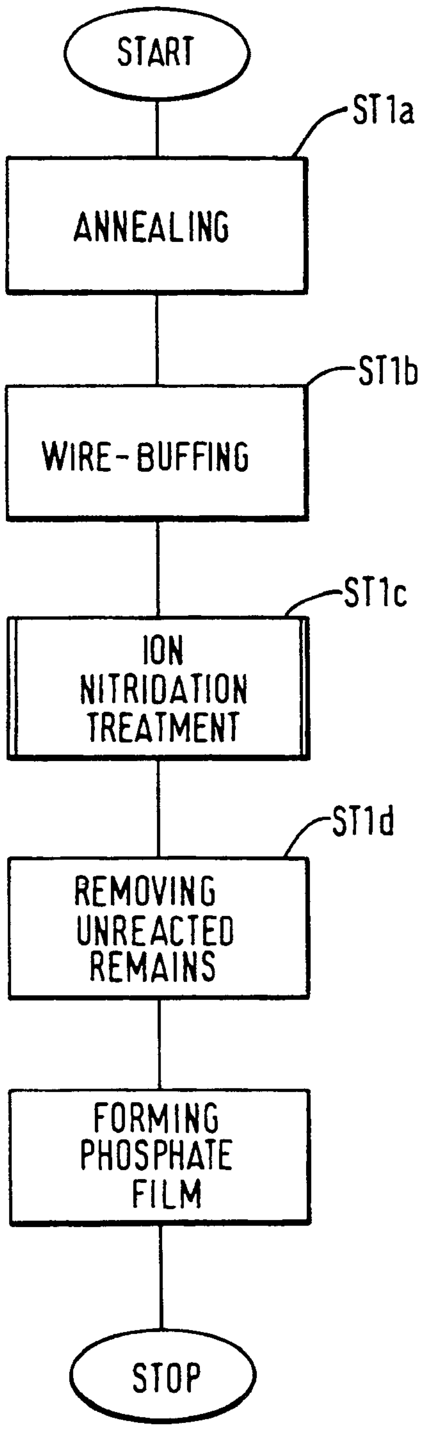

START
ST1a
ANNEALING
ST1b
WIRE-BUFFING
ST1c
ION
NITRIDATION
TREATMENT
ST1d
REMOVING
UNREACTED
REMAINS
FORMING
PHOSPHATE
FILM
STOP

FIG.4

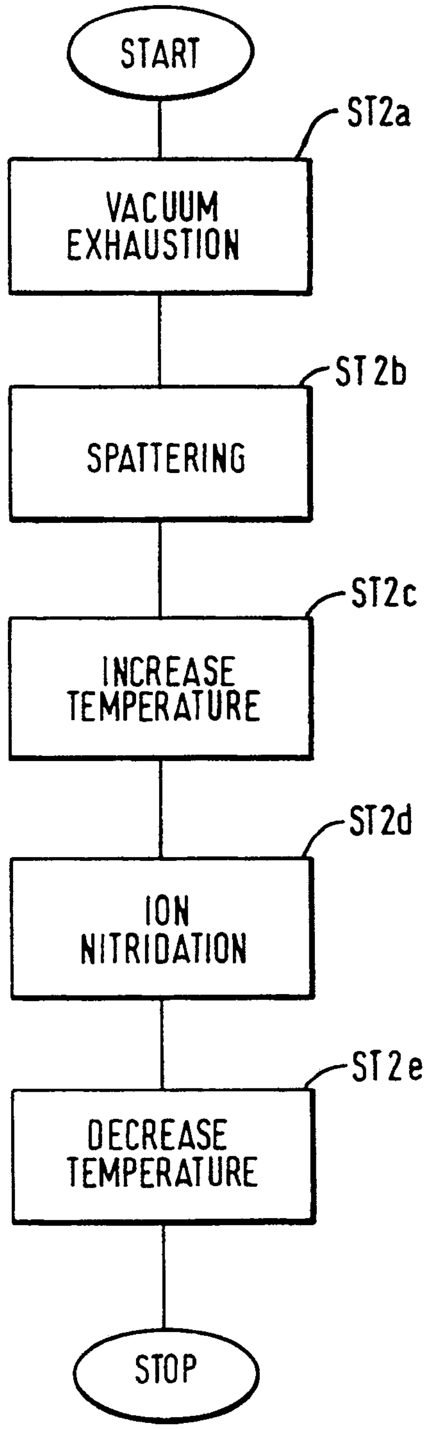
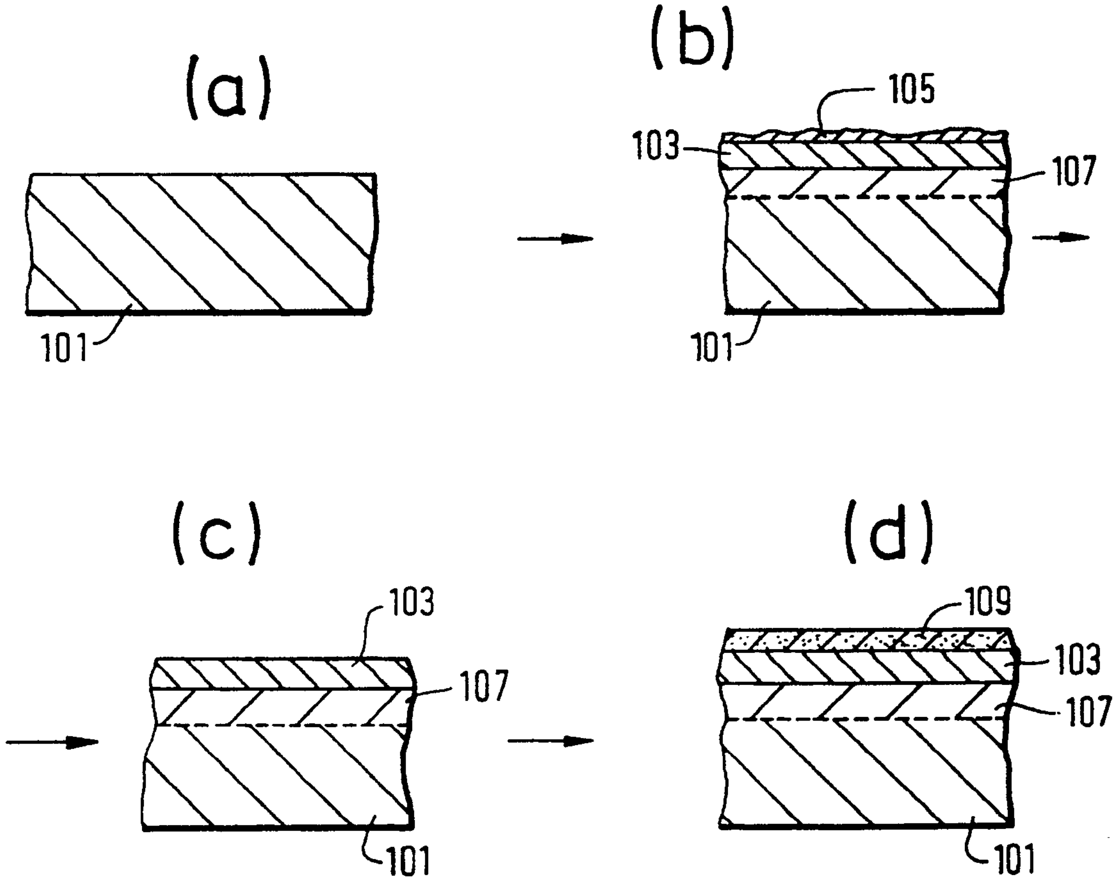

START
ST2a
VACUUM
EXHAUSTION
ST2b
SPATTERING
ST2c
INCREASE
TEMPERATURE
ST2d
ION
NITRIDATION
ST2e
DECREASE
TEMPERATURE
STOP

FIG. 5



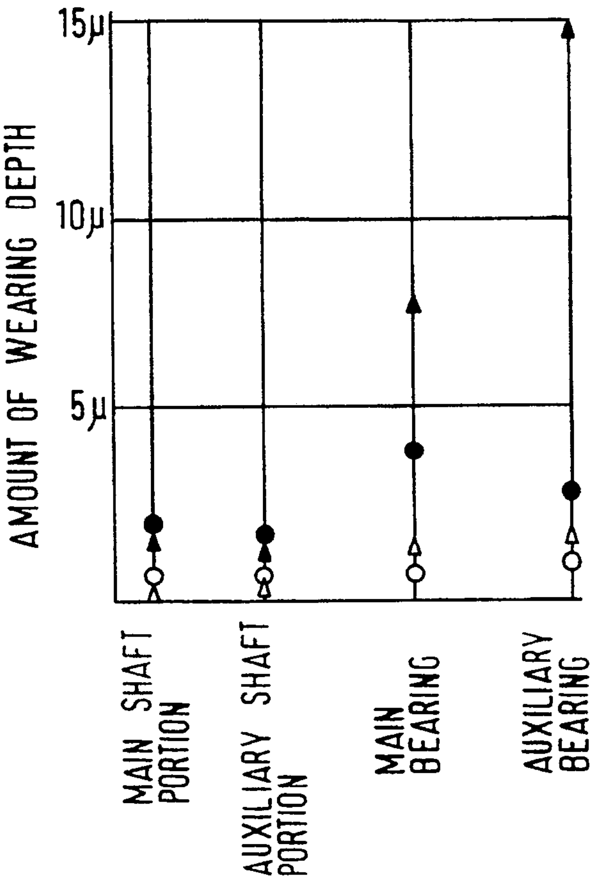

15μ
10μ
5μ
AMOUNT OF WEARING DEPTH
MAIN SHAFT PORTION
AUXILIARY SHAFT PORTION
MAIN BEARING
AUXILIARY BEARING

FIG.7(a)

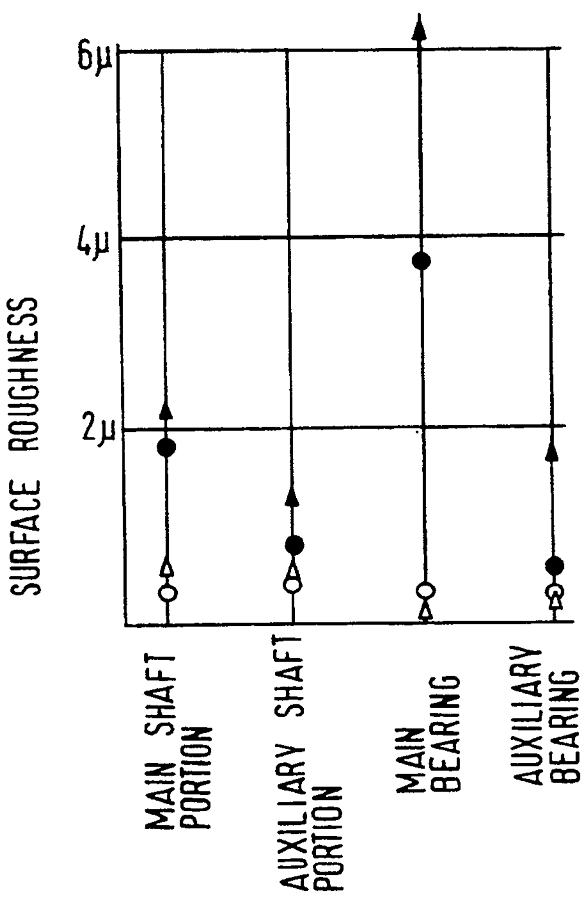

6μ
4μ
2μ
SURFACE ROUGHNESS
MAIN SHAFT PORTION
AUXILIARY SHAFT PORTION
MAIN BEARING
AUXILIARY BEARING

FIG.7(b)

FIG.8

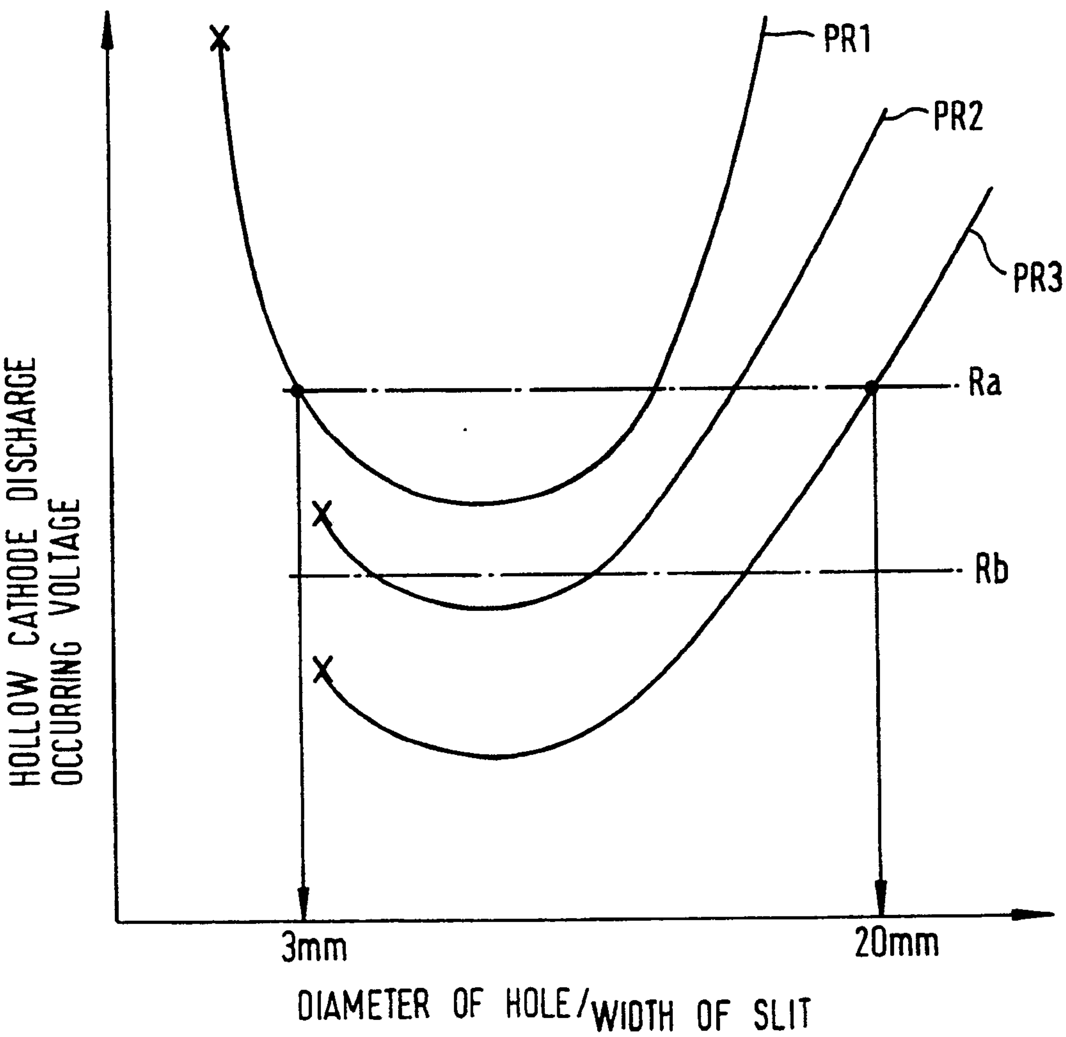

PR1
PR2
PR3
Ra
Rb
HOLLOW CATHODE DISCHARGE OCCURRING VOLTAGE
3mm
20mm
DIAMETER OF HOLE/WIDTH OF SLIT

FIG.9

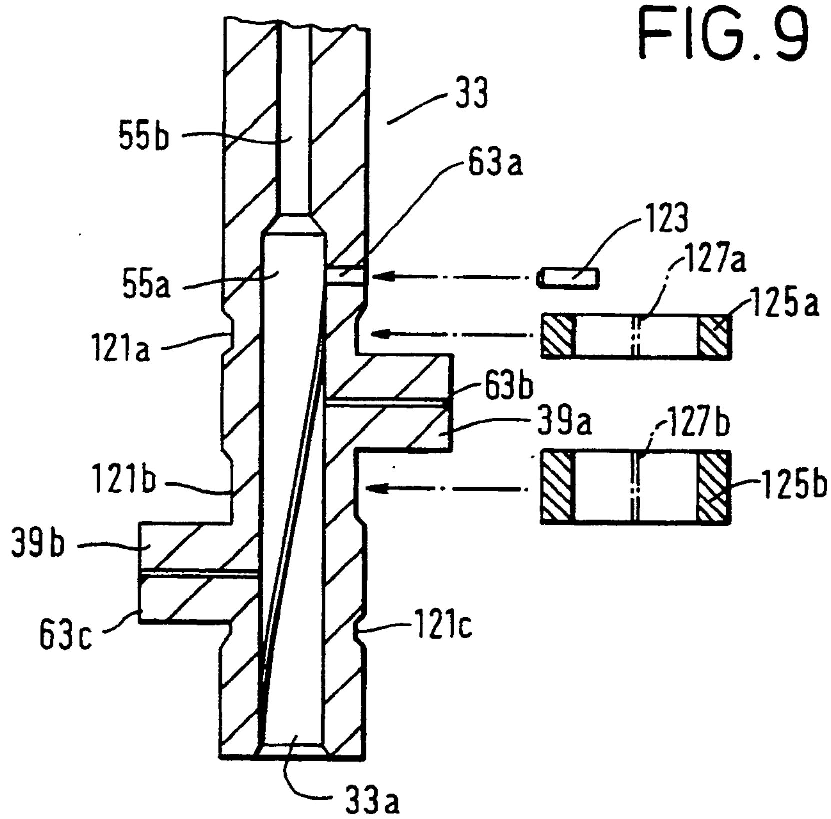
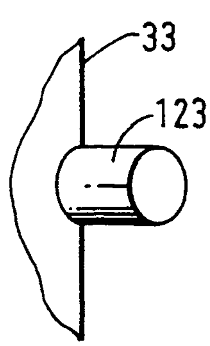
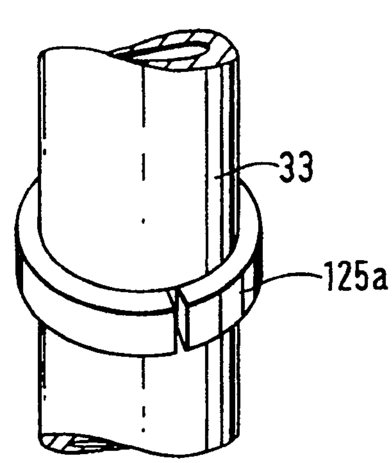


FIG.10

(a)



(b)



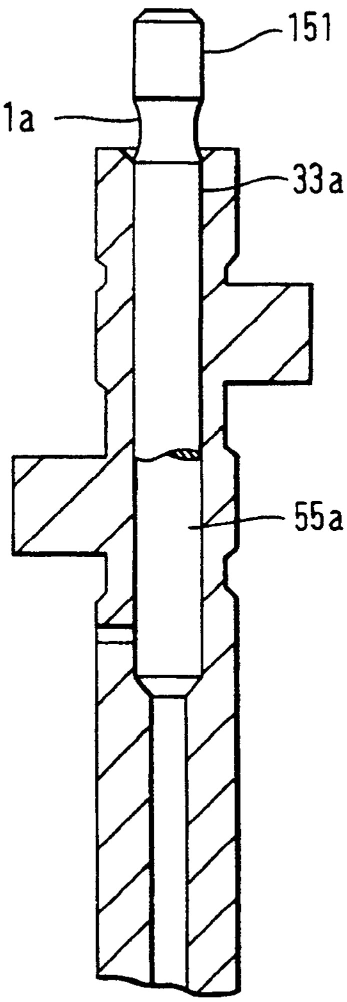
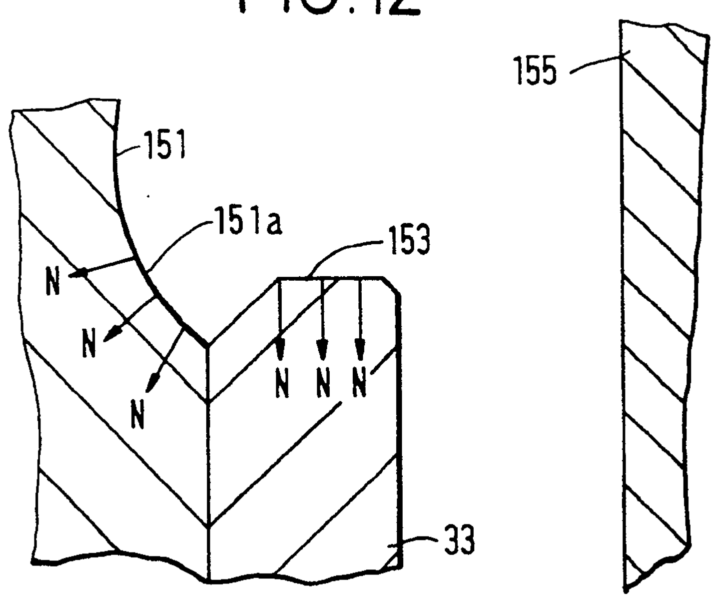


FIG.11

FIG.12



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EUROPEAN SEARCH REPORT

Application Number

EP 91 30 1008

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.5)
Y	PATENT ABSTRACTS OF JAPAN, vol. 8, no. 93 (C-220)[1530], 27th April 1984; & JP-A-59 9166 (PAAKAA NETSUSHIYORI KOGYO K.K.) 18-01-1984 * Abstract *	1	C 23 C 8/80
Y A	US-A-4 579 355 (TAKEO KOOROKI) * Claims 1-2; column 2, line 33 * * Column 2, lines 45-48 *	1 3,4	
A	PATENT ABSTRACTS OF JAPAN, vol. 8, no. 205 (C-243)[1642], 19th September 1984; & JP-A-59 93 870 (SANYO DENKI K.K.) 30-05-1984 * Abstract *	1,7	
A	DE-A-2 853 542 (KODAK) * Claims 1-4; page 5, lines 1-3 *	1	
A	GB-A-2 170 825 (LUCAS INDUSTRIES) * Claims 1-4 *	1	**TECHNICAL FIELDS SEARCHED (Int. Cl.5)**
A	THIN SOLID FILMS, vol. 95, no. 2, September 1982, pages 195-207, Lausanne, CH; O.T. INAL et al.: "Structural characterization of some ion-nitrided steels" * Page 196, points 2.1,2.2 *	1,7	C 23 C
A	PATENT ABSTRACTS OF JAPAN, vol. 4, no. 155 (C-29)[637], 29th October 1980; & JP-A-55 100 982 (HITACHI SEISAKUSHO K.K.) 01-08-1980 * Abstract * --- -/-	1,7	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17-05-1991	ELSEN D.B.A.

CATEGORY OF CITED DOCUMENTS

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Page 2

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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.5)
A	PATENT ABSTRACTS OF JAPAN, vol. 4, no. 155 (C-29)[637], 29th October 1980; & JP-A-55 102 465 (HONDA GIKEN KOGYO) 05-08-1980 * Abstract * ---	1	
A	US-A-2 851 387 (SIDNEY LOW) * Claim 1 * ---	2	
A	US-A-3 397 092 (W.R. CAVANAGH) * Claims 1,2,4,5; column 1, line 43; column 3, lines 10-27 * ---	3	
A	FR-A-2 604 188 (FRAMATOME) * Claims 1-8 * ---	5,7,8	
A	DE-C- 742 505 (AKTIENGESELLSCHAFT VORMALS SKODAWERKE) * Figures 1,2; claim 1 * -----	6	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17-05-1991	ELSEN D.B.A.

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