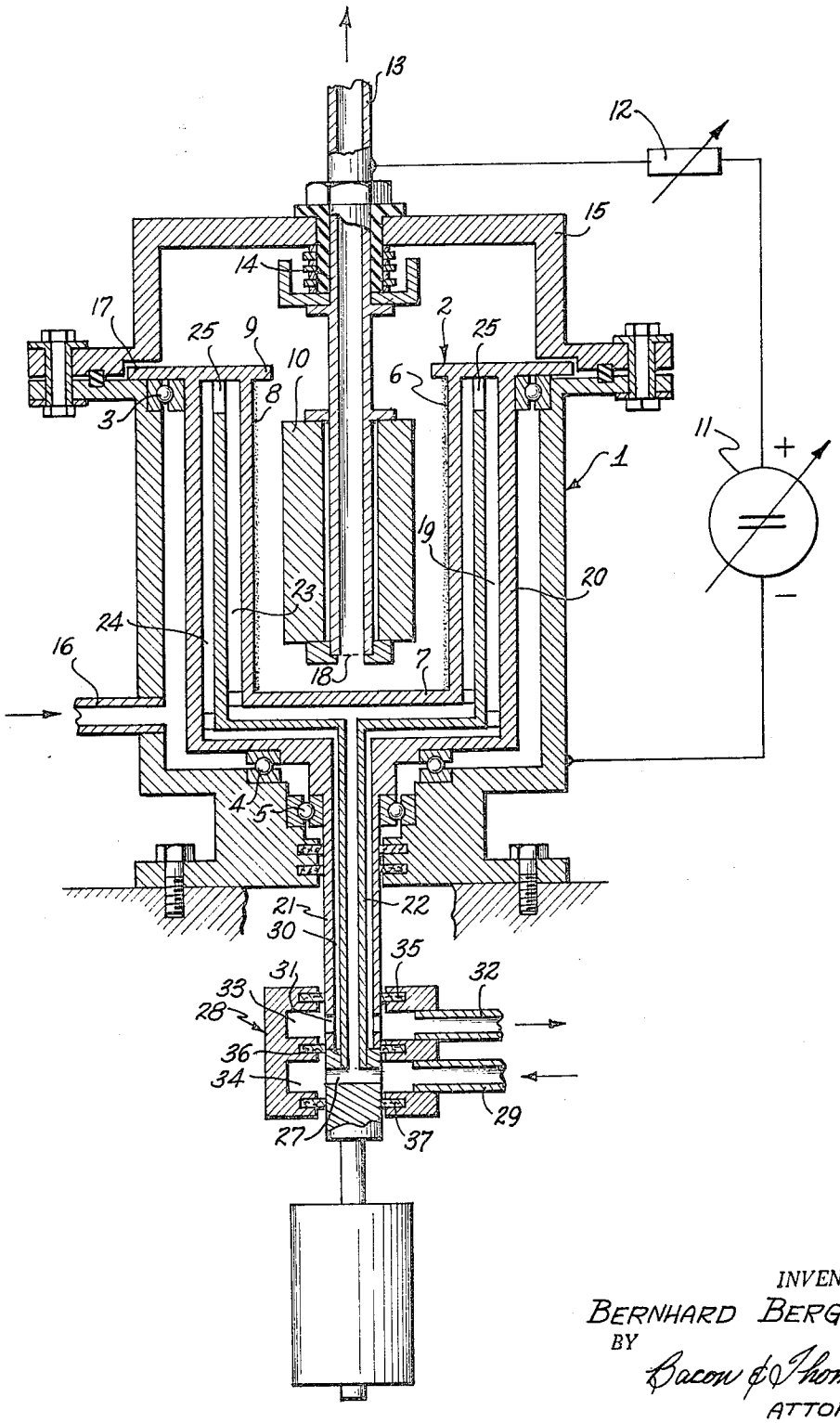
Nov. 1, 1966 B. BERGHAUS 3,282,814

METHOD AND DEVICE FOR CARRYING OUT GAS DISCHARGE PROCESSES

Filed Dec. 11, 1962



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United States Patent Office

3,282,814

Patented Nov. 1, 1966

3,282,814

METHOD AND DEVICE FOR CARRYING OUT GAS DISCHARGE PROCESSES

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Filed Dec. 11, 1962, Ser. No. 243,955
Claims priority, application Switzerland, Dec. 13, 1961, 14,398/61
9 Claims. (Cl. 204—192)

This invention relates to a method of and apparatus for working, in an electrical discharge, more particularly a glow discharge, up or on parts of particles which cannot be supported or can be supported only with disadvantage.

The expressions "parts or particles which cannot be supported or can be supported only with disadvantage" means those parts or particles which are such that because of the requirements relating to their treatment, or because of their nature, they cannot be supported at all in a gas discharge, more particularly a glow discharge, or can be supported only at the cost of substantial disadvantages.

This expression includes, firstly, all pulverulent materials which have to be treated in a gas discharge, for instance by a process in which nitriding or carburizing of the pulverulent material is effected in a glow discharge. The expression also includes small parts such as balls, screws and other mass-produced articles, which have to be subjected to a uniform surface treatment in an electrical glow discharge.

Hitherto, no practically useful method of treatment of pulverulent material in a gas discharge for a long period has been known. It would, of course, be possible to expose pulverulent material in a bowl-shaped container to the action for instance of a glow discharge, but it is certain that uniform treatment could not be reliably obtained in this way, because the action of the glow discharge on the topmost layer of the pulverulent material would certainly be stronger than on the lower layers. In one known method of treating pulverulent material, this material is finely dispersed in a carrier gas and fed into a discharge vessel through a nozzle; the carrier gas and the pulverulent material carried by this gas flow through a gas discharge which is produced at the nozzle orifice. But, in addition to the considerable expense of producing the carrier gas stream, this known method has the disadvantage that the gas discharge acts on individual particles of the pulverulent material only for a very short time, that is to say, while these particles are passing through the discharge zone. This method, therefore, cannot be used for processes in which the gas discharge has to act on the pulverulent material for a long time. Uniform surface treatment of small parts such as balls, screws and other mass-produced articles in a gas discharge has also not been possible hitherto. In order to obtain uniform treatment of all parts of the surface for instance of a ball, the gas discharge must be able to act uniformly on all parts of the surface. This, however, is not possible because the balls must each have a bearing surface, i.e., a surface in contact with some other object. It is, of course, possible to make all other parts of the surface, with the exception of the bearing surface or surfaces of contact with other balls, accessible to the gas discharge, by making the gas pressure and the other operating conditions such that a hollow-cathode type of discharge is produced between the balls, but even in this way it is not possible to obtain uniform treatment of all these other parts of the surface, because in the case of these discharges of the hollow-cathode type the intensity of the discharge

is very different at points in different positions on the surface of a ball.

Another important field of application of the present method is the cathodic disintegration of pulverulent materials. It has been known for a long time that in an electrical gas discharge the ion bombardment causes metal particles to be released from the surface of the electrode carrying the cathodic potential, and that the quantity of these metal particles released from the cathode is dependent on the discharge output intensity or, more precisely, on the ion density and the mean energy of the ions impinging on the cathode. Under certain discharge conditions which are also known, it is possible to obtain a regular loss of material from the cathode, that is to say a so-called cathode disintegration. Such cathode disintegration processes have been known for a long time and are generally used for providing objects with a coating of the disintegrated cathode material. For this purpose, these objects are introduced into a discharge vessel and one or more cathodes, which are to be disintegrated, are arranged opposite those surfaces of these objects which are to be provided with a coating. If these objects consist of electrically conductive material, then they are preferably connected so as to form the anode. During the period of the discharge part of the disintegrated cathode material is deposited on the object to be coated and forms on this object a dense covering of which the thickness depends on the duration of the treatment and on the other working conditions of the discharge.

In the known cathode disintegration processes, as a rule the electrode carrying the cathodic potential is itself disintegrated. For this reason, this electrode must be made of the material which is to form the covering on the object to be coated. This requirement, however, involves considerable disadvantages, more particularly when the material to be disintegrated is available in the form of powder and particular difficulties are encountered in making solid bodies from the material to be disintegrated, Such difficulties occur for instance when the material to be disintegrated consists of a particularly high-melting substance. In order to remove the disadvantage it would be possible to press the pulverulent material into a solid form, and thus to produce sintered bodies from the pulverulent material, or else to make solid bodies from a binding agent and the pulverulent material, or alternatively to apply the pulverulent material to the cathode with the aid of a binding agent. None of these apparent possibilities are of use in practical operation, because in each of these cases undesired formation of gas and gas eruptions are certain to occur and usually lead to fouling of the object to be coated and thus cause the adhesion of the coating to be weak and often also to lead to electrical trouble in operation. For instance, considerable eruptions of gas are certain to occur in the case of sintered bodies. The use of a binding agent is quite out of the question, because binding agents are disintegrated in a gas discharge and usually form undesirable gases. It was, therefore, important to find a practicable procedure by which pulverulent materials can be cathodically disintegrated without any need to use such aids for bringing the pulverulent material into a particular shape. The object of the invention was, therefore to find a method whereby such parts or particles which cannot be supported or can be supported only with disadvantage, can be treated in an electrical gas discharge, more particularly a glow discharge, without difficulty, and to devise an apparatus for carrying this method into effect.

According to the invention, in a method of treating parts or particles which cannot be supported, or can be supported only with disadvantage, in an electrical gas discharge, more particularly a glow discharge, this object

is achieved by the creation of centrifugal forces which act on the parts or particles and by which these parts or particles are held on a carrier member forming one electrode of the gas discharge. In order to create the centrifugal forces, the parts or particles are preferably set in rotary movement with the aid of a rotating drum which also forms a carrier member.

In carrying the method of the invention into effect for the cathodic disintegration of pulverulent materials, the centrifugal forces that are created are preferably so large that the pulverulent material is pressed against the carrier member. When a rotary drum is used as the carrier member, the speed of rotation of the drum is preferably made so great that the pulverulent material is distributed uniformly over the inner wall of the drum. Also, in the cathodic disintegration of pulverulent material the gas discharge is operated at a voltage which produces an electrical field strength sufficient to ensure that the centrifugal forces still acting on electrically charged particles that have already been detached from the cathode, will be overcome at least to such an extent that these particles do not return to the cathode again.

When the method of the invention is used for the surface treatment of metal parts or particles, more particularly balls, screws and similar mass-produced articles, by means of an electrical glow discharge, in addition to the centrifugal accelerating forces alternating in direction and acting on the parts or particles are preferably produced, by which the parts or particles are kept continuously in movement on the surface of the carrier member, in order to obtain a uniform treatment of the particles or of the surfaces of the individual parts. When a rotary drum is used as the carrier member, the speed of rotation is preferably alternately increased and decreased in order to produce the accelerating forces alternating in direction. Also, in this kind of treatment of metal parts, material may advantageously be transferred to the surface of the metal parts from the surface of the carrier member by cathodic disintegration of the latter surface.

The method of the invention is preferably carried out in an apparatus provided with a carrier member in the form of a drum connected to an at least intermittently negative pole of a voltage source, and also with means for imparting a rotary movement to the drum. This apparatus is also preferably provided with means for cooling the drum. A particularly advantageous apparatus is one provided with a drum in the form of a multi-walled trough—that is to say, a trough having a plurality of walls, one inside the other, and with a cooling system disposed between the innermost wall and the outermost wall of the trough, and with a hollow shaft which is arranged on the bottom of the trough and coaxially with the trough and through which the cooling agent is admitted and discharged and through which the energy for rotating the trough is transmitted and also with means for conducting the cooling agent into and out of the hollow shaft.

In apparatus for carrying the method of the invention into effect, the drum itself may advantageously be formed as a discharge vessel. In this case it is also possible to arrange the drum to rotate in a cooling agent, for instance in a cooling water container. In this case the outer wall of the drum is preferably provided with vanes so formed that when the drum is rotated the cooling agent is set in motion in such a way as to ensure satisfactory heat conduction. These vanes may for instance be in the form of a spiral surrounding the drum, so that the cooling agent is made to flow in the direction of the axis of the drum when the drum rotates.

Preferably, however, apparatus for carrying the method of the invention into effect is provided with a drum rotatably mounted in a stationary discharge vessel. In this case it is particularly advantageous to construct the drum in the form of a multi-walled trough as described above. Apparatus of this kind is preferably provided with driving means, arranged outside the discharge vessel, for producing the rotation of the drum and with a shaft, which extends through the wall of the discharge vessel, for connecting the driving means to the drum, and with means for producing vacuum-tight sealing at the point where the shaft passes through the wall of the discharge vessel.

Apparatus for cathodic disintegration of pulverulent material is preferably also provided with means enabling an object, which is to be coated, to be mounted within the drum. In an apparatus with a stationary discharge vessel and a rotatably mounted drum, these means are preferably so constructed and arranged that the object to be coated is stationary and the drum rotates about this object.

The object to be coated is preferably connected to the other pole of the voltage source through the intermediary of an insulated current lead-in provided with a protective gap system, this other pole being at least intermittently positive. For making the electrical connection between the object to be coated and the voltage source it is particularly advantageous to use a tubular conductor which also serves as a gas duct, preferably for the discharge of gas, and which projects into the drum. This form of construction is particularly advantageous when the drum is formed as a trough, because in this way it is possible to ensure that the gas flows into the trough and, on its way out, is made to flow over the tubular conductor projecting into the trough; this arrangement prevents the disintegrated particles from being carried out of the trough together with the gas stream. In addition, the tubular conductor can also be used for supporting the object to be coated. The tube orifice of the tubular conductor is preferably covered with one or more fine-meshed nets made of electrically conductive material, in order to prevent the formation of a gas discharge within the tube.

In apparatus for cathodic disintegration of pulverulent material, the drum is preferably made cylindrical and provided with a flat bottom. But in apparatus for the surface treatment of metal parts or particles it is more advantageous to provide the drum with a round bottom.

One form of the invention, that is to say a method of cathodic disintegration of pulverulent material, is particularly described hereunder with reference to the accompanying drawing illustrating an embodiment, chosen by way of example, of apparatus for carrying the method of the invention into effect. In the apparatus illustrated in the drawing, a drum 2 is rotatably mounted in a discharge vessel 1 by means of ball bearings 3, 4 and 5. The ball bearings are so arranged that the drum can rotate at high speed in the discharge container without any danger that the drum may fail to run smoothly. The cylindrical inner wall 6 of this drum is used as a carrier member for pulverulent material which is to be cathodically disintegrated. In order to apply the pulverulent material to this carrier member, at the beginning of the process and while the drum is still stationary, this material is first poured on the bottom 7 closing the cylindrical inner wall 6 at the lower end, and the drum is then set in rotation. The pulverulent material, which at first is located on the bottom 7, is also set in rotation by the rotary movement of the drum, whereby centrifugal forces acting on the pulverulent material are produced, so that even while the drum's speed of rotation is low the pulverulent material first slides outwards into the corner where the bottom 7 meets the inner wall 6. As the speed of rotation of the drum increases, the pulverulent material begins to be distributed along the cylindrical inner wall. The distribution of the pulverulent material along the inner wall 6 becomes more uniform as the speed of rotation of the drum becomes higher. At the same time, as the speed of rotation of the drum increases the pulverulent material is pressed progressively harder against the carrier, that is to say the inner wall 6, and at the same time is pressed together into a progres-

sively more compact mass, because the centrifugal forces acting on the pulverulent material become greater when the rotary movement of this material is more rapid. After the drum has reached a certain speed, the pulverulent material is distributed completely uniformly over the cylindrical inner wall 6 of the drum and forms a dense layer 8 of which the thickness is approximately the same everywhere and by which the inner wall 6 is completely covered. But, in order to enable this layer to be formed, the cylindrical inner wall 6 must be provided, at the top end, with a sufficiently wide rim 9 by which further upward movement of the pulverulent material can be prevented.

The breadth of this rim 9 must be greater than the thickness of the layer 8. It is important that the starting of the drum and the increase of the drum's speed of rotation should take place as slowly and uniformly as possible, more particularly while this speed is low as compared with the working speed, in order to ensure that the frictional adhesion of the pulverulent material to its carrier is maintained during the whole process of increase of speed of the drum. In order to impart the required rotary movement to the pulverulent material, accelerating forces must be imparted to this material, and these accelerating forces must not exceed the maximum permissible frictional adhesion forces.

As soon as the working speed of the drum is reached and the pulverulent material has formed a layer 8 uniformly covering the inner surface of wall 6, the cathodic disintegration of this pulverulent material can begin. At this moment, therefore, the working voltage for creating the electrical discharge causing cathodic disintegration of the pulverulent material, can be switched on.

The cathodic disintegration process then takes place as in the known methods. The cylindrical inner wall 6 must carry negative voltage, i.e. must be connected as a cathode, at least intermittently, and the object 10 which is shown in the drawing and which is to be coated with a covering layer taken from the pulverulent material, is in this case connected as an anode. It is, of course, also possible to make this object 10 neutral and to provide a separate counter-electrode which carries anodic potential at least intermittently. The working voltage for producing the electrical gas discharge is supplied by the regulable direct-current voltage source 11. Instead of this regulable direct-current voltage source it is also possible to use a direct-current voltage source with constant voltage, and a regulable series resistance 12. Instead of a direct-current voltage source, it is, of course, also possible to use an alternating-current voltage source for the current supply, as in the known cathodic disintegration methods.

The use of an alternating-current voltage source for the current supply is particularly to be recommended when the object to be coated also has to be heated or maintained at a predetermined high temperature during the coating operation. It is also possible to supply the electrical energy in the form of pulses and to provide a pulse generator for this purpose, instead of the direct-current voltage source 11.

In the embodiment illustrated in the drawing the whole drum 2 and the discharge vessel 1 carry negative, i.e. cathodic potential. In order to supply this cathodic potential, the negative pole of the direct-current voltage source 11 is connected to the discharge vessel 1. The positive pole of the direct-current voltage source is connected, through the intermediary of the preferably regulable series resistance 12, to the conductor 13 which is passed through the cover 15 of the discharge vessel by means of an insulated current lead-in 14 provided with a protective gap system. Inside the discharge vessel, the tubular object 10 is secured to the conductor 13 and consequently is electrically conductively connected to

the positive pole of the direct-current voltage source 11 and, therefore, acts as the anode of the discharge gap.

In order to carry out the cathodic disintgration process a glow discharge is preferably produced along the surface of the layer 8 and completely covers the surface formed by the layer 8. The adjustment of the discharge output density of this glow discharge on the layer 8 carrying cathodic potential is effected in the same way as the adjustment of the discharge output density in the known cathodic disintegration methods. It is important, however, that the glow discharge should be operated at a voltage at least high enough to produce a sufficient electrical field strength to ensure that the centrifugal forces still acting on particles that have already been detached from the layer 8 will be overcome at least to such an extent that these particles do not return to the cathode again. This effct of the electrical field strength can, of course, be exerted only on negatively chargd particles and also depends, of course, on the magnitude of the electrical charge on these particles and on their size or mass. Detached particles which do not have a negative charge or do not have a sufficiently large negative charge, will, therefore, inevitably return to the cathode because of the centrifugal forces still acting on these particles. Therefore, in the case of insufficient coating of the object 10, the process must be carried out at a higher voltage. If a particular discharge output density has to be maintained, then the discharge current must be correspondingly reduced by reduction of the gas pressure in the discharge vessel.

The process is preferably carried out with flowing gas. In the embodiment illustrated in the drawing, the gas is supplied to the discharge vessel through an inlet duct 16. The gas current flows through a gap formed by the bottom part and the cover of the vessel and by the rim 17 formed on the drum 2, into the actual discharge chamber. This narrow gap and the rim 17 are provided in order to prevent disintegration particles from getting into the ball bearings. In this connection is to be noted that in view of the required high speeds of the drum, considerable difficulties would be involved in supporting the drum outside the discharge vessel, because at high speeds even a slight unbalance of the drum would lead to extremely violent vibrations of the drum if the drum were supported in a bearing outside the discharge vessel. Such unbalance, however, will always occur because of slight unevenness of the distribution of the pulverulent material. The effect of the rim 17 and of the gap bounded by this rim, that is to say, the prevention of entry of disintegrated particles into the ball bearings, is further reinforced by the gas stream, because the gas flowing in through the inlet duct 16 must flow in the direction opposite to that of any particles tending to enter through the gap bounded by the rim 17. The entry of disintegrated particles into the ball bearings is thus completely prevented. In order to discharge the gas from the discharge vessel, the conductor 13 is formed as a tube. Since the orifice of this gas discharge tube formed by the conductor 13 is located at the bottom end of the drum, the gas stream is compelled to flow past the cathode and past the layer 8; this ensures satisfactory scavenging of the discharge vessel and rapid removal of any undesired gases that may be generated. The gas stream flows into the opening of the drum 2, and this is of advantage in that escape of disintegrated particles into the cover space is thus checked to a considerable extent. The tube orifice of the tubular conductor 13 which forms the gas discharge duct, is covered with one or more fine-meshed nets 18 in order to prevent the formation of a discharge within the tube.

A particular problem is the cooling of the cathodic inner wall 6 because this cooling has to be maintained during operation and, therefore, during the rotation of the drum 2. For this purpose, the drum 2 is formed as a multi-walled cylindrical trough, and is provided with

a trough-shaped intermediate wall 19 surrounding the inner wall 6, and with an outer wall 20 which is also trough-shaped and surrounds this intermediate wall, and also with a hollow shaft 21 arranged on the bottom of this trough-shaped outer wall and coaxially with the drum; inside this hollow shaft is a tube 22, which is also coaxial with the drum and which leads into the bottom of the trough-shaped intermediate wall 19. The trough-shaped intermediate wall 19 and the trough-shaped wall 20 are so shaped and arranged that two hollow spaces 23 and 24, which are also trough-shaped, are formed between the inner wall 6 and the intermediate wall 19, and between the intermediate wall 19 and the outer wall 20; connecting channels 25 provided at the top end of the intermediate wall 19 form the only communication between these two hollow spaces. The hollow space 23 communicates with a cooling agent inlet duct 29, through the tube 22 and through channels 27 provided in an extension of the hollow shaft 21 and through a transfer device 28. The hollow space 24 communicates with a cooling agent discharge duct 32, through a hollow space 30 formed between the hollow shaft 21 and the tube 22 and through channels 31 provided in the hollow shaft, and through the transfer device 28. The stationary transfer device 28 for supplying the cooling agent to the rotary shaft and for discharging the cooling agent from this shaft, is illustrated only diagrammatically. This device consists essentially of a system which forms two annular hollow spaces 33 and 34 which surround the shaft and which are sealed off from one another and from the shaft by sealing means 35, 36, and 37 which are also only diagrammatically illustrated; one of these hollow spaces communicates with the cooling agent supply duct 29 and the other communicates with the cooling agent discharge duct 32. By means of this transfer device 28 and of the previously described construction of the drum 2 and of the shaft 21 the inner wall 6 acting as the cathode can be adequately cooled even while the drum 2 is rotating. For this purpose a cooling agent supplied through the hollow space 34 and the channels 27 into the tube 22 and thence through the hollow space 23 and along the outside of the inner wall 6 and thus cools this inner wall 6. The heated cooling agent then flows away again through the communication channels 25, through the hollow space 24 and through the hollow shaft 21, i.e. through the hollow space 30, and passes through the channels 31 and the hollow space 33 into the cooling agent outlet duct 32. It is important that the intermediate wall 19 and the tube 22 should preferably consist of a material of which the thermal conductivity is as small as possible, so that as little heat as possible will be transferred, from the already heated cooling agent flowing way through the hollow spaces 24 and 30, to the cooling agent in the hollow space 23 and the cooling agent flowing through the tube 22.

It is also to be observed that the sealing means 38 for producing a vacuum-tight closure at the point where that shaft 31 passes through the wall of the discharge vessel 1, is only diagrammatically illustrated. Vacuum-tight seals for rotary shafts are already known in various forms and, therefore, do not need to be described in detail here.

The apparatus illustrated in the drawing and described above in connection with the cathodic disintegration of pulverulent materials can, of course, also be used for the surface treatment of metal parts, for instance balls, or of pulverulent material. In that case, however, it is more advantageous to use a drum which is provided with a round bottom and widens upwards, for instance conically, for the following reasons. In surface treatment it is most important that the surface of the individual parts, or of all particles of the pulverulent material, should be treated uniformly. This uniformity of treatment is obtained by means of additional accelerating forces which keep these parts or pulverulent material continuously in movement on the wall of the carrier member. Because of this continuous movement, different parts of the surfaces are always being subjected to the direct action of the glow discharge, so that on the average a uniform treatment of all parts of the surfaces or all particles of the pulverulent material is obtained.

In this movement, however, gravitational acceleration produces the effect that the parts or particles in movement are always being drawn downwards; therefore, if a cylindrical drum is used the parts or particles are unevenly distributed on the inner wall of the drum, so that the number of parts or particles per unit area of the surface increases continuously towards the bottom. This unevenness of distribution may be prevented by the use of a drum which has a round bottom and which widens conically, because when the drum has this shape the gravitational acceleration forces acting on the moving parts or particles are neutralized by centrifugal force components acting in the direction of the widening. The apparatus shown in the drawing may be provided, for this purpose, with a suitable inserted member which is cylindrical on the outside and fits exactly into the drum 2 and on the inside has the required shape with a rounded bottom and a conical widening.

During surface treatment, the apparatus operates in a manner similar to that described above in connection with the cathodic disintegration of pulverulent material, but with the following differences.

The parts or the pulverulent material to be treated have to be kept in constant movement, and, therefore, the centrifugal forces must not be so large that the parts or pulverulent material are forced against the carrier member; more precisely, the centrifugal forces must not be so large that the frictional adhesion forces proportional to the centrifugal forces can neutralize the accelerating forces. In the case of cathodic disintegration of pulverulent material, it is important that the powder should be pressed as hard as possible against the surface of the carrier member, and accordingly, the centrifugal forces should be as large as possible, but in surface treatment the parts or particles being treated have to be movable and, therefore, very much smaller centrifugal forces are required, which must only be large enough to hold these parts or particles on the carrier member. Accordingly, the working speed of rotation of the drum must be smaller. Also, in surface treatment this speed of rotation has to vary in magnitude in order to produce accelerating forces changing in direction and thus to move the parts or particles, whereas in cathodic disintegration the speed is preferably kept constant.

Also, in surface treatment, more particularly surface treatment of pulverulent material, the working voltage is lower than in the case of cathodic disintegration of pulverulent material. More particularly, in surface treatment, the voltage must not be so large that disintegration of the pulverulent material occurs or that the electrical field strength is sufficient to cause negative charged particles of the pulverulent material to be removed from the carrier member against the action of the centrifugal force.

Lastly, in surface treatment the place of the object 10 to be coated will, of course, be taken by an anode, which, however, may generally have the same shape.

Just as in the case of cathodic disintegration, the actual surface treatment is then effected as in the known surface treatment processes carried out in a glow discharge with stationary objects under treatment. For instance, a nitriding, carburizing, boronizing or siliconizing treatment or even a reducing treatment with hydrogen may be carried out. The parts or particles to be treated may also be subjected to surface cleaning, for instance, in a hydrogen atmosphere, and to heat treatment processes, for instance in an inert gas atmosphere.

Surface treatment in accordance with the method of this invention has been found extremely satisfactory, in

practice, for improving the surface of balls for ball bearings, more particularly for nitriding and carburizing these surfaces. For instance, in a treatment in an atmosphere of ammonia and hydrogen the balls are completely uniformly nitrided, as has been shown by detailed examinations of polished sections. Microscopic examination of the surfaces of the balls also showed the complete uniformity of the surface treatment. We have also succeeded in removing material from the surface of the carrier member by cathodic disintegration of the surface and transferring this material directly to the surface of the balls moving on the surface of the carrier member, so that after the process had been carried out the balls were covered with a uniform surface layer consisting of the material of the carrier member.

For carrying the invention into effect it is, of course, possible to use apparatus different from the embodiment chosen by way of example and illustrated in the drawing, and the invention as defined by the following claims is not in any way restricted to the embodiment illustrated.

I claim:

1. The method of cathodically disintegrating powdered materials in a glow discharge, comprising the steps of: producing a glow discharge in a gas in a predetermined space having an anode therein; rotating a carrier in said space and about an axis therein adjacent said anode, said carrier having a supporting surface spaced from said anode and extending generally in the direction of said axis; placing said powdered materials on said supporting surface whereby they rotate therewith and are held thereagainst by centrifugal force; and applying a cathodic potential to said carrier.

2. The method of claim 1 wherein the speed of rotation of said carrier is maintained at a sufficiently high value to effect substantially uniform distribution of said powdered materials over said surface.

3. The method of claim 1 wherein the potential applied to said carrier creates a sufficiently strong electrical field between said carrier and said anode to move charged particles, disintegrated from said materials, to said anode against the action of centrifugal force acting thereon.

4. Apparatus for cathodically disintegrating powdered materials in a glow discharge, comprising: means defining a chamber; means for circulating a gas through said chamber; an anode in said chamber; a carrier element rotatably mounted in said chamber about an axis adjacent said anode, said carrier element having a generally cylindrical wall concentric to said axis and defining a carrier surface spaced from but facing said anode; means for rotating said carrier element; and means for at least periodically applying to said carrier element a potential negative with respect to said anode.

5. Apparatus as defined in claim 4 including means for cooling said carrier element.

6. Apparatus as defined in claim 5 wherein said cooling means comprises means defining at least one coolant chamber extending around said cylindrical wall; said means for rotating said carrier comprising concentric hollow shaft means extending into said chamber, the interiors of said shaft means communicating with said coolant chamber whereby to serve as conduits for conducting a coolant medium to and from said coolant chamber.

7. Apparatus as defined in claim 4 including an insulated conductor extending into said chamber, supporting said anode and being electrically connected thereto, and means for at least periodically applying a positive potential to said conductor.

8. Apparatus as defined in claim 7 wherein said conductor is a hollow tube opening at one end into said chamber within said cylindrical wall and serving as a conduit to conduct gas from said chamber.

9. Apparatus as defined in claim 8 including a mesh of electrically conductive material extending across said one end of said tubular conductor to prevent formation of a glow discharge within said tubular conductor.

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