

Oct. 21, 1969

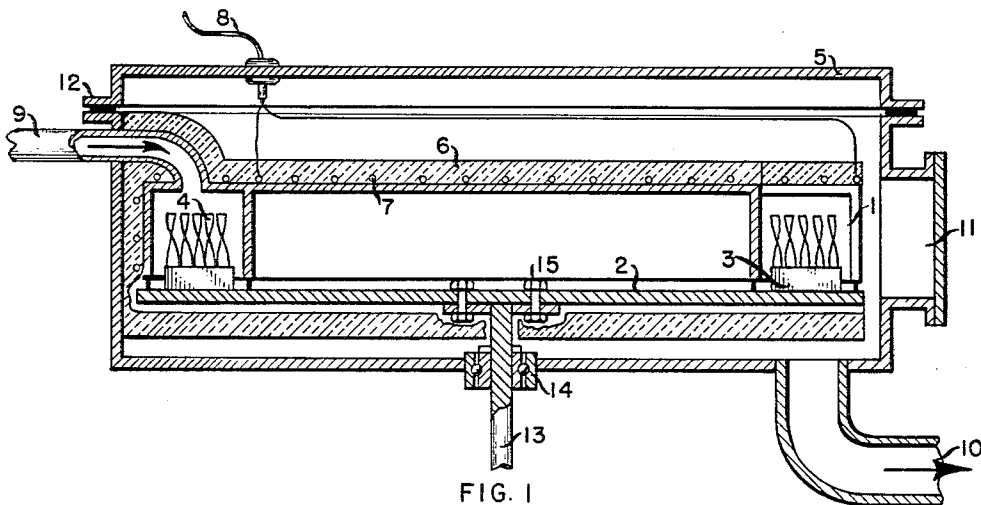
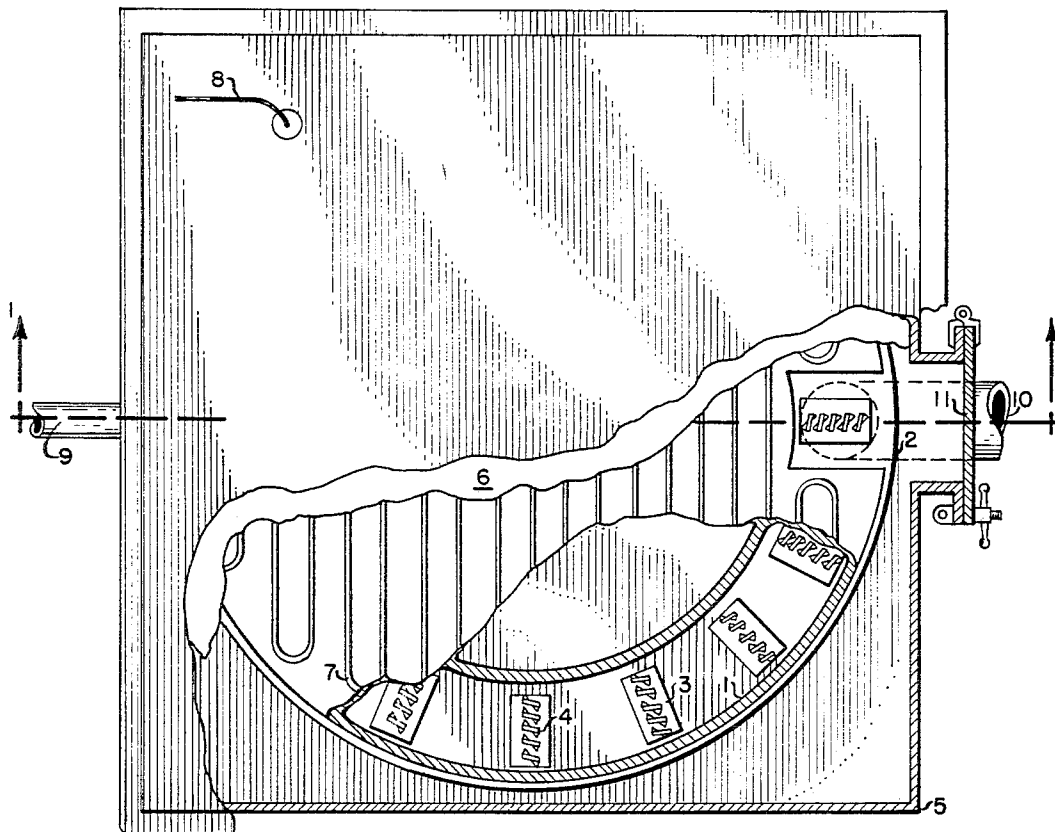
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**3,473,954**

## METHOD AND APPARATUS FOR TUNNEL PLATING

Filed Dec. 8, 1965

5 Sheets-Sheet 1



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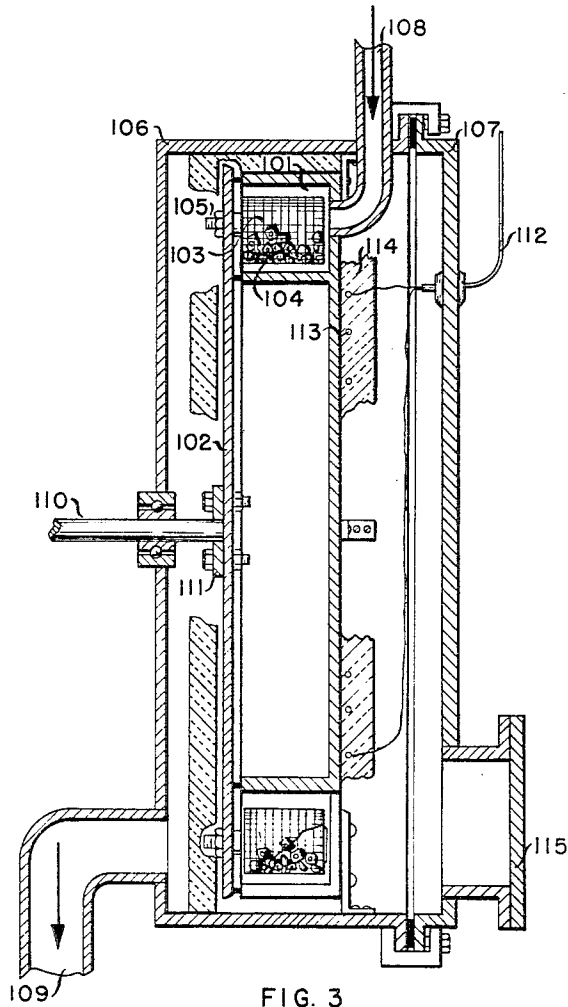


FIG. 3

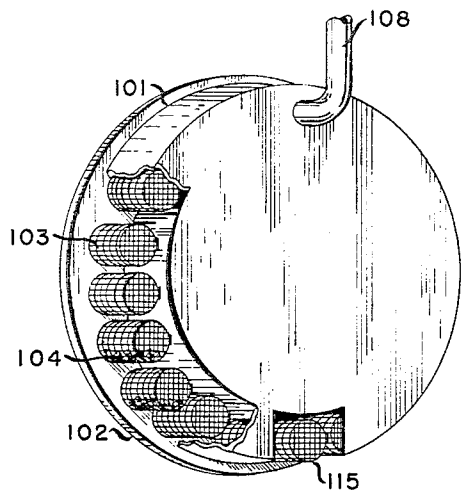


FIG. 4

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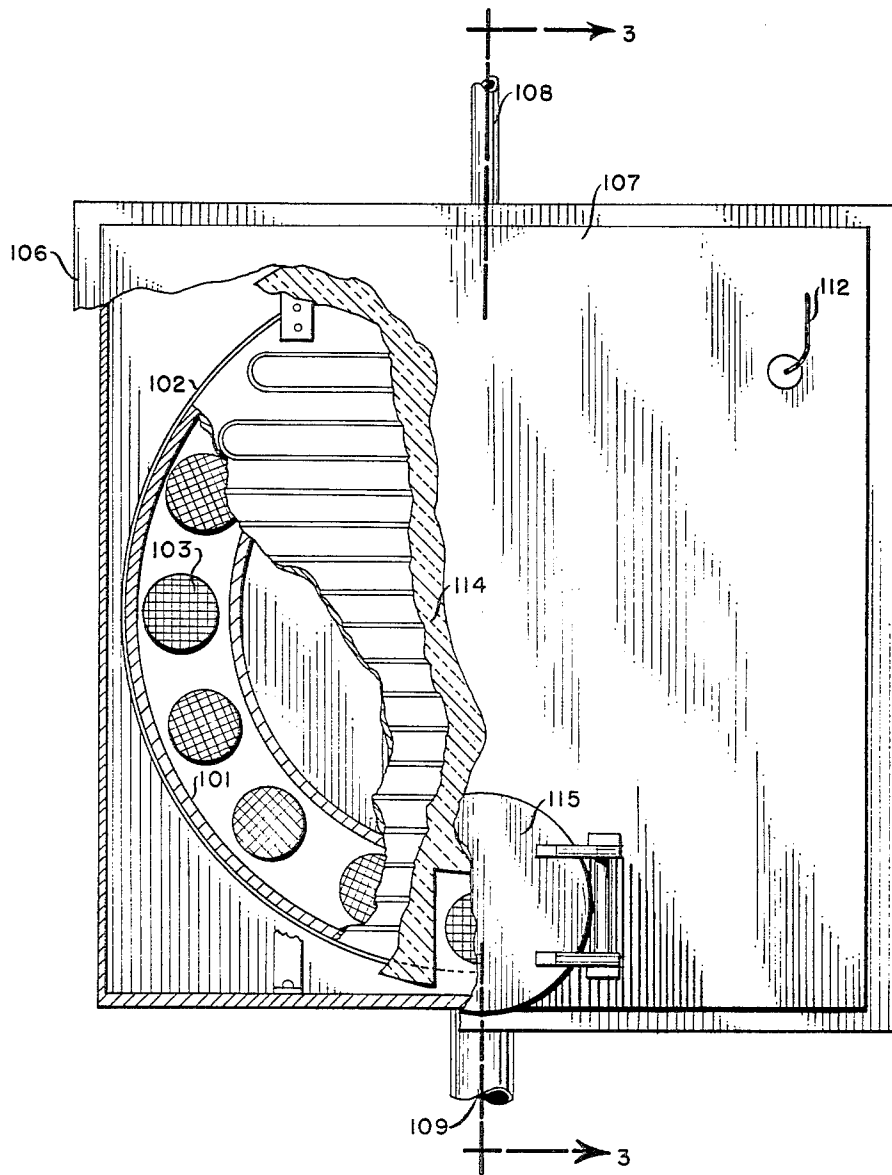


FIG. 5

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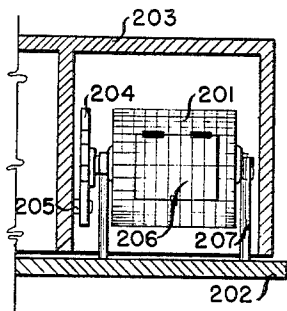


FIG. 7

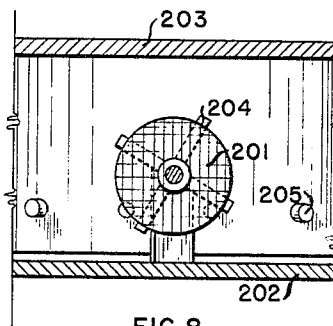


FIG. 8

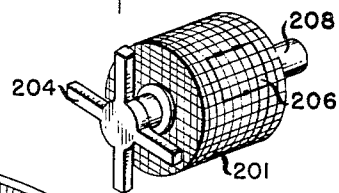


FIG. 9

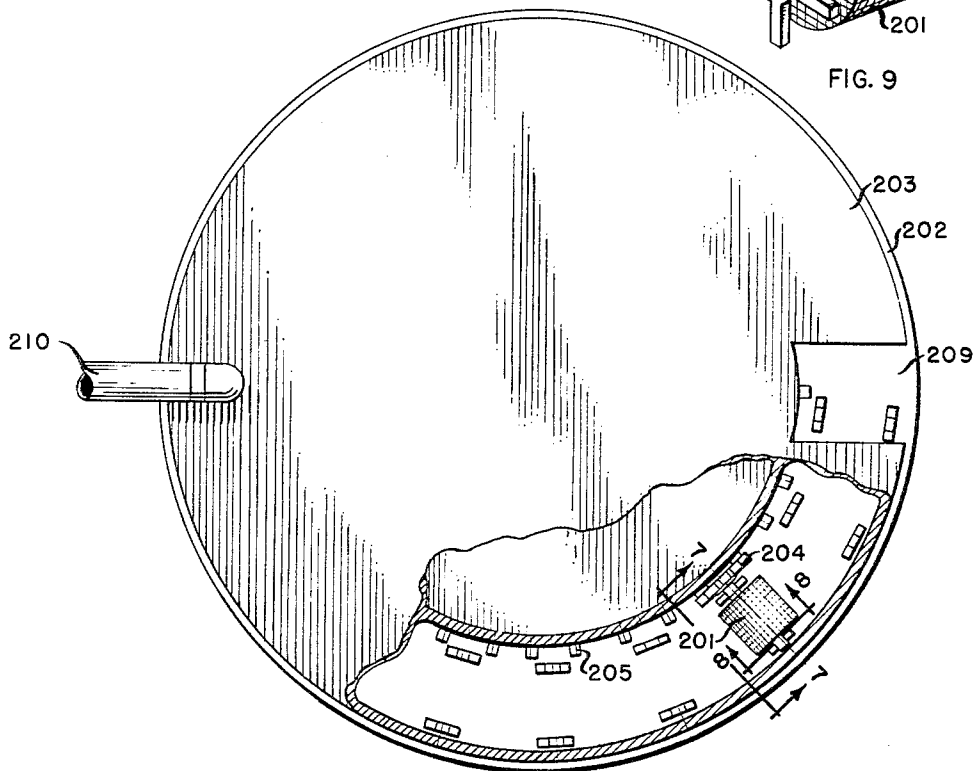


FIG. 6

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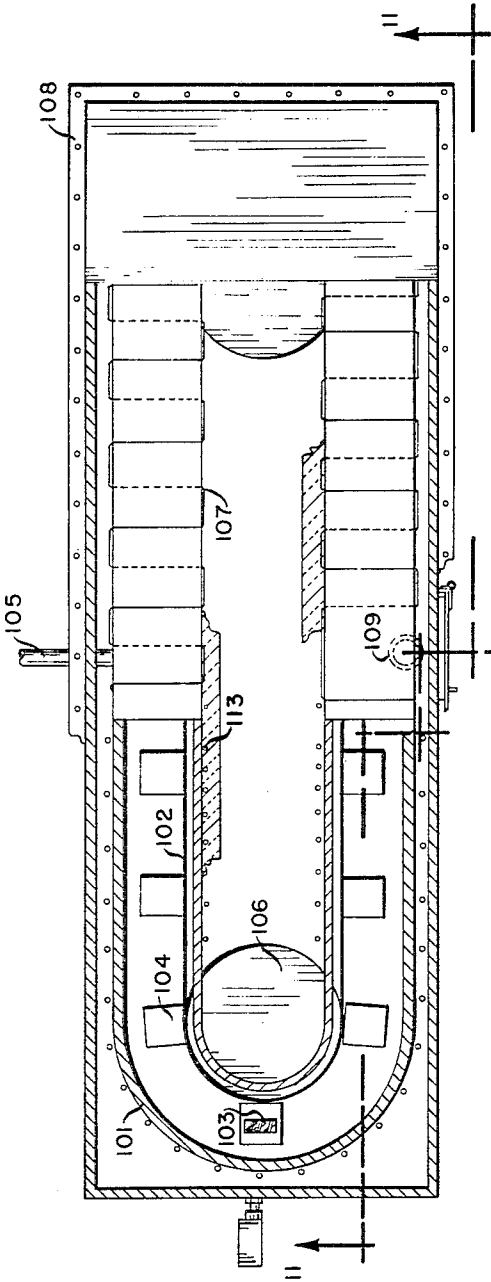


FIG. 10

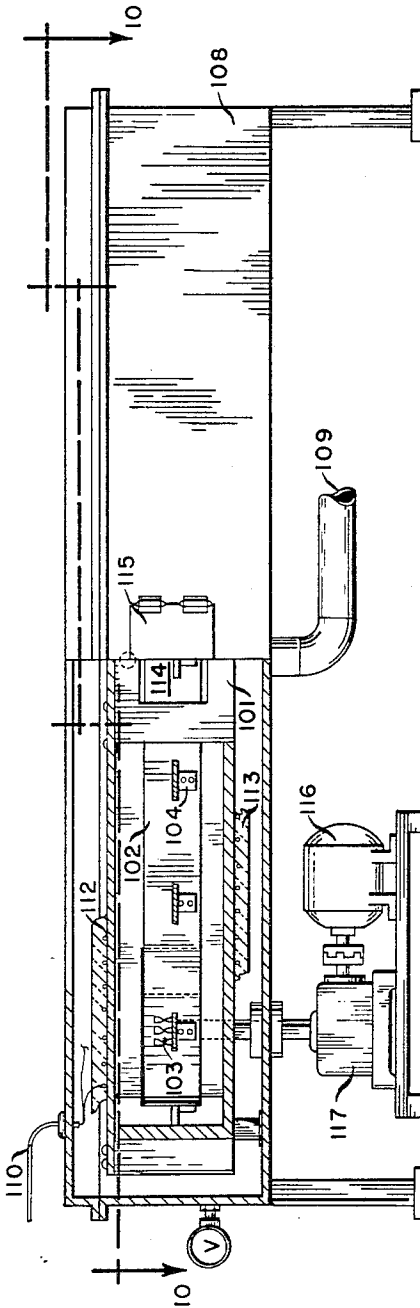


FIG. 11

1

2

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## METHOD AND APPARATUS FOR TUNNEL PLATING

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28 Claims

### ABSTRACT OF THE DISCLOSURE

A method and apparatus for depositing a metal coating upon parts by revolving the parts on an endless path enveloped by a closed loop tunnel and alternately contacting the parts on the endless path with concurrently flowing and countercurrently flowing pyrolytically decomposable vapor plating compound, thereby enabling the vapor plating compound as it contacts the parts to form a metal coating thereon.

Prior art techniques of vapor plating have had numerous disadvantages. Such techniques have failed to achieve uniformity of coating, and waste of vapor plating compound has been high. As a result, the articles produced using such techniques have proved both low in quality and high in cost.

In overcoming the deficiencies of the prior art certain objectives have been sought pursuant to this invention; (1) to maximize the ratio of area to be coated to volume of coating compound, (2) to lengthen the time of contact between the flowing coating vapors and the parts being coated, and (3) to efficiently and economically direct vapor flow against multiple sides of the parts being coated so as to achieve uniform coatings without shadow effects. Objectives (1) and (2) have been realized in the present invention and have dramatically increased efficiency as less vapor plating compound is wasted. Objective (3) has likewise been realized and remarkably uniform coatings have been achieved at a reduced cost.

Basically, the invention involves revolving heated parts to be coated in an endless tunnel which may be circular, elliptical or of other shape. In some embodiments incoming vapor plating compound is split in the tunnel and half of the stream flows countercurrently to the revolving parts and the other half of the stream flows concurrently with the revolving parts. Any part, upon making a full revolution or cycle in the tunnel, encounters both concurrent and countercurrent flow, each flow contacting the parts from an opposite direction and thereby achieving a uniform coating upon the parts. Such parts may be stationary with respect to the revolving means or free to tumble in containers while revolving.

In other embodiments the incoming vapor stream is not split. Instead, the stream flows in a complete closed loop formed by the tunnel until it reaches a port of exhaust adjacent to the port of entry of the incoming stream and is thereat withdrawn from the tunnel. So that the revolving parts may contact both countercurrent and concurrent vapor flow, the direction of revolution of the parts is periodically reversed.

The enclosed tunnel in all embodiments maximizes the ratio of area being coated to volume of coating vapor. Also, a circular or elliptical tunnel pathway lengthens the time of contact between the vapor stream and the parts being coated. These latter two features markedly decrease the amount of plating compound which is wasted.

Other objects and features of the present invention will now in part be obvious and will in part appear hereinafter.

For a fuller understanding of the nature and objects of

the present invention, reference should be had to the following detailed disclosure taken in connection with the accompanying drawings wherein:

FIGS. 1 and 2 show a first embodiment of the invention.

FIG. 1 is a cross section through the apparatus on the line 1—1 of FIG. 2, FIG. 1 showing a side view of the interior of the tunnel plater.

FIG. 2 is a top plan view with a partial cutaway section showing a top view of the interior of the tunnel plater.

FIGS. 3, 4 and 5 show a second embodiment of the invention.

FIG. 3 is a cross section of the apparatus on the line 3—3 of FIG. 5, FIG. 3 showing a side view of the interior of the tunnel plater.

FIG. 4 is a perspective view of the tunnel and rotatable table with a partial cutaway section showing the interior of the tunnel containing perforate containers.

FIG. 5 is a top plan view with a partial cutaway section showing a top view of the interior of the tunnel plater.

FIGS. 6, 7, 8 and 9 show a third embodiment of the invention.

FIG. 6 is a top plan view with a partial cutaway section showing a top view of the interior of the tunnel plater.

FIG. 7 is a cross section through the apparatus on the line 7—7 of FIG. 6, FIG. 7 showing the interior of the tunnel and a side view of a rotatable perforate container.

FIG. 8 is a cross section through the apparatus on the line 8—8 of FIG. 6, FIG. 8 showing the interior of the tunnel and an outside end view of a rotatable perforate container.

FIG. 9 is a perspective view of a rotatable perforate container.

FIGS. 10 and 11 show a fourth embodiment of the invention.

FIG. 10 is a top plan view with a partial cross section through the apparatus on the line 10—10 of FIG. 11 and showing the interior of an elliptical tunnel plater.

FIG. 11 is a side view with a partial cross section through the apparatus on the line 11—11 of FIG. 10 and showing a side view of the interior of the tunnel plater.

FIGS. 1 and 2 show a first embodiment of the invention. Element 1 is a circular tunnel (or annular chamber) which snugly abuts an underlying rotatable table 2. Within the tunnel and lying upon the table are holding means 3 which may take a variety of shapes. The ones shown are racks with slots in which parts to be coated such as element 4 may be inserted. The element 4 shown is a turbine blade. The parts to be coated can of course be all types and sizes of items, the scope of the invention here being virtually unlimited. Element 5 is a vacuum box within which the tunnel and rotatable table are located. Overlying the tunnel is insulation 6; heating coil 7 is within the insulation and directly adjacent to the tunnel. Vacuum box 5 has a hinged top 12 for easy access to the tunnel, table, heating coil, and insulation. Electrical leads 8 supply energy to heating coil 7. Plating compound enters into tunnel 1 through entry port 9 and is exhausted through exit port 10 by means of a vacuum which also exhausts vacuum box 5. The presence of oxygen and water vapor cause inferior, defective coatings upon the parts. Parts to be coated are inserted through loading port 11. Rotatable table 2 is attached to drive shaft 13 by bolts 15. Drive shaft 13 extends through bearings 14 located concentrically with the bottom of vacuum box 5.

In the operation of this first embodiment the articles to be vapor plated are placed in holding means; turbine blades are shown secured in racks. These are then located within the tunnel and upon the rotatable table until, preferably though not necessarily, the entire periphery of

the rotatable table is covered. Loading is carried out through loading port 11. Once the tunnel is filled with parts to be coated, heat is supplied through electrical leads 8 to heating coil 7, and the temperature of the tunnel, parts, and table is elevated to a desired constant. When the desired elevated temperature is reached, plating compound is fed into port 9. When the plating compound enters the tunnel, the flow splits and part goes in one direction through the tunnel and the other part flows in the opposite direction. Meanwhile the rotatable table is being rotated by drive shaft 13 and the parts thereon are being revolved. Thus, at any given time half of the parts being coated are moving concurrently with the flowing plating compound while the other half are moving countercurrently to the flowing plating compound. Therefore, for each cycle a part being coated is struck on one side by concurrently moving vapor and subsequently on the other side by counter-currently moving vapor. The alternation occurs when the part being coated moves past the plating compound feed port 9 and when the part moves past the exhaust port 10. As the vapor plating compound strikes the heated parts, it is pyrolytically decomposed and part of the vapor forms a thin metal coating upon the parts. The vapor plating compound is thus enabled to strike the parts from at least two different sides and thus eliminate the possibility of any shadow effect, thereby insuring a uniform coating upon the parts. It may be seen that completely filling the tunnel with parts maximizes the ratio of area being coated to the volume of coating compound. Also, since the tunnel is circular, it lengthens the time of contact between the flowing coating vapor and parts being coated. These two features spell increased efficiency in the use of vapor plating compound and, in fact, very little is wasted. Of course, of chief importance is the fact that the parts are remarkably uniformly coated. The remainder of the vapor plating stream which has entered at port 9 and has been split is reunited at exhaust port 10 and exhausted by means of a vacuum. The operation could be performed continuously although it is shown and described as a batch operation. It is further apparent that the rotatable table could be located at the top of the tunnel; then the table would not be rotatable; rather, the tunnel would now support the parts and be rotated. The plating compound would in this case be fed through the stationary table rather than through the rotating tunnel. The tunnel could of course have numerous different cross sections without departing from the scope of the invention and is manifestly not limited to a rectangular cross section.

FIGS. 3, 4 and 5 show a second embodiment of the invention. The apparatus herein is similar to the apparatus of FIGS. 1 and 2. If the apparatus of FIGS. 1 and 2 were turned on its side, then the similarity would be more pronounced. However, the means for holding the parts being coated is quite different from that of the first embodiment, and the parts being coated are, for that matter, quite different. It has been found extremely difficult in the vapor plating art to coat smaller parts such as nuts, bolts, rivets, screws, etc. In this embodiment of the invention such small parts are contained within perforate containers such as element 103. These perforate containers are attached to table 102 by means 105, e.g., a nut and bolt. The containers are located on the periphery of the rotatable table within the tunnel 101. The tunnel 101 and the rotatable table 102 are located within vacuum box 106. Vapor plating compound is fed to the tunnel through entry port 108 and exhausted through exit port 109. The rotatable table 102 is turned by a drive shaft 110. The parts to be coated are loaded through loading port 115.

In the operation of this second embodiment of the invention, first, all the parts to be coated are placed within perforate containers 103. These perforate containers preferably completely fill the tunnel and are at-

tached to the periphery of the rotatable table so as to be relatively immovable thereto. When the filling and loading operation is completed, then the tunnel, table, containers and parts are brought up to an elevated temperature by use of heating coils 113 connected to electrical leads 112. Heat is conserved within the unit by insulation 114. Once the apparatus has been brought to a constant elevated temperature, rotation is begun with drive shaft 110, and the parts and containers are revolved within the tunnel. Then plating compound is admitted through entry port 108 and the stream splits, part flowing concurrently with the revolving parts and the other parts of the vapor stream flowing countercurrently to the revolving parts. The vapor stream passes through the perforated containers and thereby contacts each of the individual parts. Rotation of the table causes the parts being coated within the perforate containers to be tumbled thus insuring a uniform coating as the vapor contacts all sides of the parts. For each revolution a container makes within the tunnel, gravity causes the parts being coated to tumble a complete revolution about the axis of the container which is immovable relative to the table. The vapor plating compound upon contacting the heated parts, pyrolytically decomposes and deposits a thin metal shell upon each of the parts. As explained concerning the first embodiment of the invention, when the parts pass through a full cycle they are contacted by both countercurrent and concurrent vapor flow. However this is not as important as in the first embodiment. The significant feature herein is the tumbling caused by revolving the perforate containers. Other advantages as described in relation to the first embodiment are reproduced, namely, the ratio of area to be coated to volume of coating compound is maximized, and the length of time of contact between the flowing coating vapor and the parts being coated is increased through use of a circular tunnel. Tumbling both assures uniformity of coating and dispenses with the laborious securing of each part in a holding means since the parts may be placed haphazardly into the perforate containers. Also, while a large number of parts may be tumbling, the parts fall only for short distances thus causing little or no damage to the coatings on the parts. This embodiment of the invention drastically reduces the amount of labor formerly required to coat small parts.

FIGS. 6-9 show a third embodiment of the invention. This embodiment combines features of both the first and second embodiments and adds other unique features. First, it is apparent that the table and tunnel in this embodiment are arranged horizontally as in the first embodiment and not on a side as in the second embodiment. But, the holding means are perforate containers as in the second embodiment rather than means for individually securing each part (such as racks) as in the first embodiment. Perhaps, the chief unique feature is that tumbling of the parts being coated is not caused in the same manner as in the second embodiment. Tumbling of the parts in the second embodiment is accomplished by simple utilization of gravity. Tumbling of the parts in this embodiment is accomplished through use of a gear and pin mechanism which rotates each of the perforate containers upon its own axis while it is also revolving about the axis of a rotatable table which forms the bottom of the tunnel.

This third embodiment necessitates only a few elements which are different from those of the first and second embodiments. Element 201 is the perforate container and is shown preferably to have a side loading port 206 although the invention is not limited to a side loading port. Perforate container 201 is secured to rotatable plate 202 by attachment means 207. Perforate container 201 is shown herein with a gearlike mechanism 204, here having four teeth though not limited to that number. These teeth contact pins 205 which are located on the inner side of tunnel 203 and thereby cause rotation of the perforate containers and tumbling of the parts as the containers

move along the path formed by the circular tunnel. Thus the perforate containers are rotating, each upon its own axis, and also revolving about the axis of the table. In FIG. 6 is shown port 210 through which plating compound is introduced to the tunnel and loading port 209 through which parts to be coated are loaded into the tunnel.

Operation of this embodiment is somewhat similar to that of the first embodiment in which the coating apparatus is horizontal. Also, there is some similarity to the second embodiment in which small parts are tumbled while being plated. First, as in all embodiments, the tunnel, table, containers and parts are brought up to a constant elevated temperature. Rotation is then begun, and vapor plating compound is introduced as in the first and second embodiments. The vapor plating compound splits, part flowing countercurrently to the perforate container and the other part flowing concurrently with the revolving perforate containers and parts located therein. As the rotatable table turns, thus causing the perforate containers and parts to turn with it in the path formed by the circular tunnel, the perforate containers are rotated each upon its own axis as gears 204 contact pins 205 located on the inner side of tunnel 203. The same beneficial results achieved in the second embodiment are likewise achieved here as the parts are tumbled and the vapor plating compound flows through the perforate containers and pyrolytically decomposes upon the parts, thereby depositing a thin uniform metal coating upon each. As explained in relation to the second embodiment, the concurrent and countercurrent flow is not so important here as it was in the first embodiment. The tumbling action is of primary importance in securing a uniform coating. Other advantages of the first embodiment are achieved as explained in relation to the second embodiment since the ratio of area to be coated to volume of plating compound is maximized through use of a circular tunnel. Also through use of a tunnel, the length of contact time between the flowing coating vapor and the parts being coated is maximized.

FIGS. 10 and 11 show a fourth embodiment of the invention. The primary departure here from the other three embodiments is that neither a circular tunnel nor a rotatable table is employed. The tunnel in this embodiment is elliptical in shape and the rotatable table is replaced by a flexible belt. Flexible belt 102 forms one wall of elliptical tunnel 101. Parts carriers 104 are attached to flexible belt 102 and parts 103 to be coated are located on parts carriers 104. The elliptical tunnel and flexible belt are, as in other embodiments, placed inside a vacuum box, here element 108. The elliptical tunnel, flexible belt, parts carriers and parts are heated by means of heating coils 112 which are connected to electrical leads 110. The entire apparatus within vacuum box 108 is insulated with insulation 113. Vapor plating gas is fed into tunnel 101 through entry port 105 and is exhausted through exhaust port 109. Loading ports constitute both an inner access port 114 and an outer access port 115. The flexible belt is driven by a wheel 106. This wheel is operatively connected to a gear box 117 which leads to an electric motor 116.

The operation of this embodiment is not markedly unlike that of the first embodiment. Perhaps the primary advantage of this embodiment is that one is able to lengthen the time of contact between the flowing coating vapor and the revolving parts being coated without the necessity of decreasing the r.p.m. of a rotatable table as in the first two embodiments or of using a larger apparatus with a tunnel of greater circumference. This embodiment is of course not limited to an elliptical shape but many other shapes are feasible. It is also apparent that the parts carrier is not critical to the invention since the parts to be coated may be attached directly to the belt. It is also conceivable that other appropriate containers may be used such as in the second and third embodiments. The appa-

ratus of this embodiment may be arranged in a vertical manner as in the second embodiment with perforate containers, or it might be arranged as in the third embodiment horizontally with perforate containers, and such containers may be rotated individually, each upon its own axis, as in the third embodiment. It is thus seen that this latter embodiment encompasses all the other embodiments with the only change being one primarily of shape of the tunnel and of being able to dispense with a rotatable table.

It is evident that in all of the above embodiments a closed cycle single vapor stream flow could be employed instead of the two streams resulting from splitting vapor flow. In each of the figures of the drawings, the port of vapor exhaust is shown to be diametrically opposite to the port of vapor entry; this is to allow for splitting and reuniting vapor flow. To have but a single stream vapor flow, it would be necessary in each embodiment to place the port of exhaust adjacent to the port of entry, rather than diametrically opposite thereto. By use of baffles at the port of entry, vapor flow could be directed either clockwise or counterclockwise through virtually the complete length of the endless tunnel to the port of exhaust adjacent the port of entry. In order to contact the revolving parts with both countercurrent and concurrent vapor flow, it would only be necessary to periodically reverse the direction of the revolving parts.

The operation of this apparatus is in part illustrated by the following example and experimental results:

EXAMPLE

A circular tunnel of the type shown in FIGS. 1 and 2 was employed. This tunnel measured 5 x 3 inches in the interior and had an outside diameter of 36 inches. The plating compound employed was trimethylaminealane (or trimethylamine aluminium hydride). It was found that the velocity of the plating compound in the tunnel could be varied from 0.5 ft./sec. to 100 ft./sec. although 2 ft./sec. to 10 ft./sec. produced best results. Temperature within the tunnel was varied over a wide range of 130 to 350° C. but best results occurred within a range of 160 to 190° C. A plating time of from 30 minutes to 2 hours was required to deposit 0.5 mil to 1 mil of aluminum. An average of about 30 to 40 percent of the aluminum feed was deposited upon the parts. Due to the short length of the tunnel, 30 to 40 percent of unreacted plating compound passed out the exit of the tunnel. About 30 percent of the aluminum was plated on the tunnel walls and holding means. Since the inner circumference of the tunnel represents a shorter travel distance than the outer circumference, a thinner coating was deposited on parts located on the inner circumference. The thickness obtained is proportional to the magnitude of the circumference.

| Parts                    | Avg. Coating Thickness, mils |                      |                     |
|--------------------------|------------------------------|----------------------|---------------------|
|                          | Inner circumference          | Middle circumference | Outer circumference |
| Turbine blades.....      | 0.68                         | 0.73                 | 0.77                |
| Calibration coupons..... | 0.67                         | 0.71                 | 0.83                |

Uniformity of coating was improved by loading the parts so that the areas to be plated were proportional to the magnitude of the circumferential circles within the tunnel. That is, more parts were placed on the outermost circumferences with the following results in coating large coupons:

| Radial distance            | Thickness of coating, mils |
|----------------------------|----------------------------|
| Inner circumference .....  | 0.64                       |
| Middle circumference ..... | 0.65                       |
| Outer circumference .....  | 0.63                       |

The uniformity of coating on individual parts was in the order of ±0.1 mil for a 0.7 mil coating with the exception of the point of attachment of the part in its holder. At this particular area, the coating was usually about 0.3

mil thinner than other areas because of the partial stagnation of vapor flow caused by the restriction of the holding device. A coating distribution on a 2¾ inch x ¾ inch coupon was as follows:

| Section of coupon | Thickness of coating, mils |    |
|-------------------|----------------------------|----|
| Top -----         | 0.8                        | 5  |
|                   | 0.8                        |    |
| Midpoint -----    | 0.85                       |    |
|                   | 0.8                        |    |
| Base -----        | 0.5                        | 10 |

The uniformity of coating on irregular surfaces was excellent. For example, a ½ inch diameter threaded Parker type tube fitting was given a coating thickness of 0.55 mil with a spread of only  $\pm 0.05$  mil, including the root of the threads.

The present invention is obviously not limited to the vapor plating compound of the above example. Other compounds well known and fully described in the art may be used. For example, metals to be deposited may be introduced as gaseous metal carbonyls or organometallic plating compounds, etc., or as vaporized solutions of certain of the metal carbonyls or organometallics, etc., in readily vaporizable solvents. Also exemplary are nitroxyl compounds, nitrosyl carbonyls, metal hydrides, metal alkyls, metal halides, and the like. Illustrative compounds of the carbonyl type are nickel, iron, chromium, molybdenum, tungsten, cobalt, and mixed carbonyls. Illustrative compounds of the other groups above listed are: nitroxyls such as copper nitroxyl; nitrosyl carbonyls such as cobalt nitrosyl carbonyl; hydrides such as antimony hydride or tin hydride; metal alkyls such as triisobutylaluminum, diisobutylaluminum hydride; and carbonyl halogens such as osmium carbonyl bromide, ruthenium carbonyl chloride, and the like.

What is claimed is:

1. A method for depositing a metal coating upon parts comprising:

(a) revolving said parts on an endless path enveloped and formed by a closed loop tunnel and

(b) sequentially contacting said parts along part of the path with concurrently flowing vapor plating compound and along the rest of the path with countercurrently flowing vapor plating compound, thereby enabling said vapor plating compound as it contacts said parts to form a metal coating thereon.

2. The method of claim 1 wherein said parts are heated and said vapor plating compound pyrolytically decomposes as it contacts the heated parts to form a metal coating thereon.

3. The method of claim 1 wherein the tunnel is circular.

4. The method of claim 1 wherein the tunnel is elliptical.

5. The method of claim 1 wherein said vapor plating compound is caused to enter the tunnel and upon entering said tunnel is split, part moving concurrently with revolving parts and the rest moving countercurrently to revolving parts.

6. The method of claim 5 wherein what remains of said vapor plating compound is reunited at a location spaced from a location of entry of said compound and exhausted.

7. The method of claim 6 wherein the location of entry is diametrically opposite to the location of exhaust.

8. The method of claim 1 wherein said parts revolve with revolving means.

9. The method of claim 8 wherein said revolving means is a flexible endless belt which forms a wall of the tunnel,

10. The method of claim 8 wherein said revolving means is a table which forms a wall of the tunnel.

11. The method of claim 10 wherein said wall is the bottom of said tunnel.

12. The method of claim 8 wherein said revolving means is the tunnel.

13. The method of claim 8 wherein said parts tumble while revolving.

14. The method of claim 13 wherein said parts are caused to tumble within at least one individual perforate container as said parts revolve with said container about said path enveloped by said tunnel.

15. The method of claim 14 wherein said tumbling is caused by the container being revolved about a second axis, the first axis coinciding with the axis of said revolving means.

16. An apparatus for depositing a metal coating upon parts comprising:

(a) a closed loop tunnel which envelopes and forms a path for said parts;

(b) means for introducing vapor plating compound into all of the tunnel;

(c) means for exhausting unused vapor plating compound and gases from decomposed vapor plating compound from said tunnel; and

(d) means for revolving said parts in said tunnel.

17. The apparatus of claim 16 wherein said means for revolving is a wall of said tunnel which is relatively revolvable to said tunnel.

18. The apparatus of claim 17 wherein said wall is a circular table on which said parts rest.

19. The apparatus of claim 17 wherein said wall is an endless flexible belt which revolves said parts.

20. The apparatus of claim 18 wherein said tunnel is circular.

21. The apparatus of claim 19 wherein said tunnel is elliptical.

22. The apparatus of claim 17 including at least one perforate container for holding said parts.

23. The apparatus of claim 22 including means for revolving each container upon its own axis.

24. The apparatus of claim 22 wherein each container is attached to said wall which is revolvable.

25. The apparatus of claim 22 wherein each container is attached to said tunnel which is revolvable.

26. The apparatus of claim 16 wherein said means for exhausting said vapor plating compound is a vacuum.

27. The apparatus of claim 26 wherein said exhausting means is diametrically opposite to said introducing means.

28. The apparatus of claim 26 including heating means for elevating the temperature of said parts.

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ANDREW G. GOLIAN, Primary Examiner

U.S. Cl. X.R.

117—107.2; 118—48