

Aug. 13, 1946.

C. E. McMANUS ET AL

2,405,662

COATING

Filed Aug. 30, 1941

5 Sheets-Sheet 1

Fig. 1.

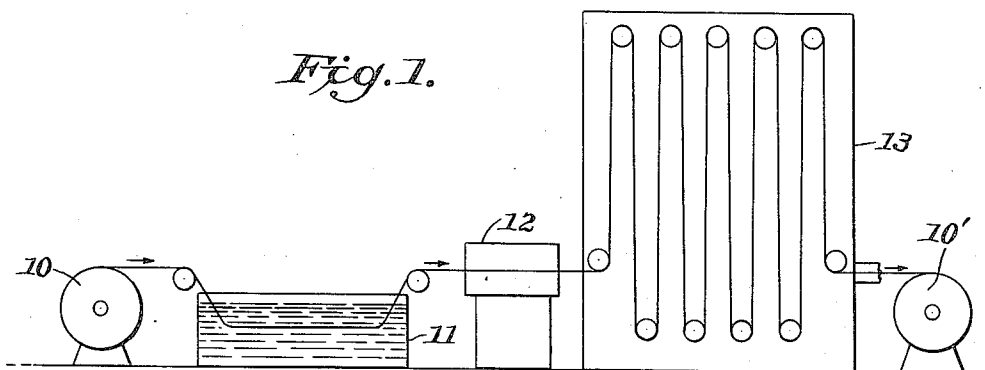


Fig. 3.

Fig. 2.

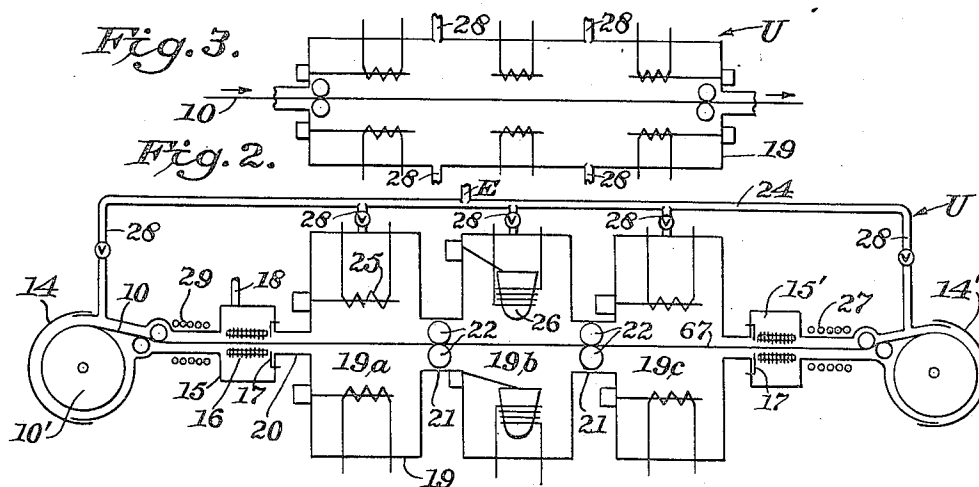
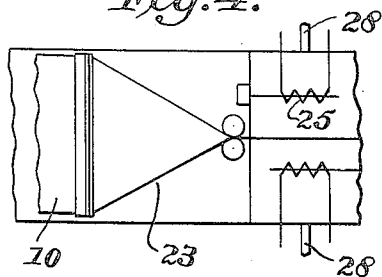


Fig. 4.



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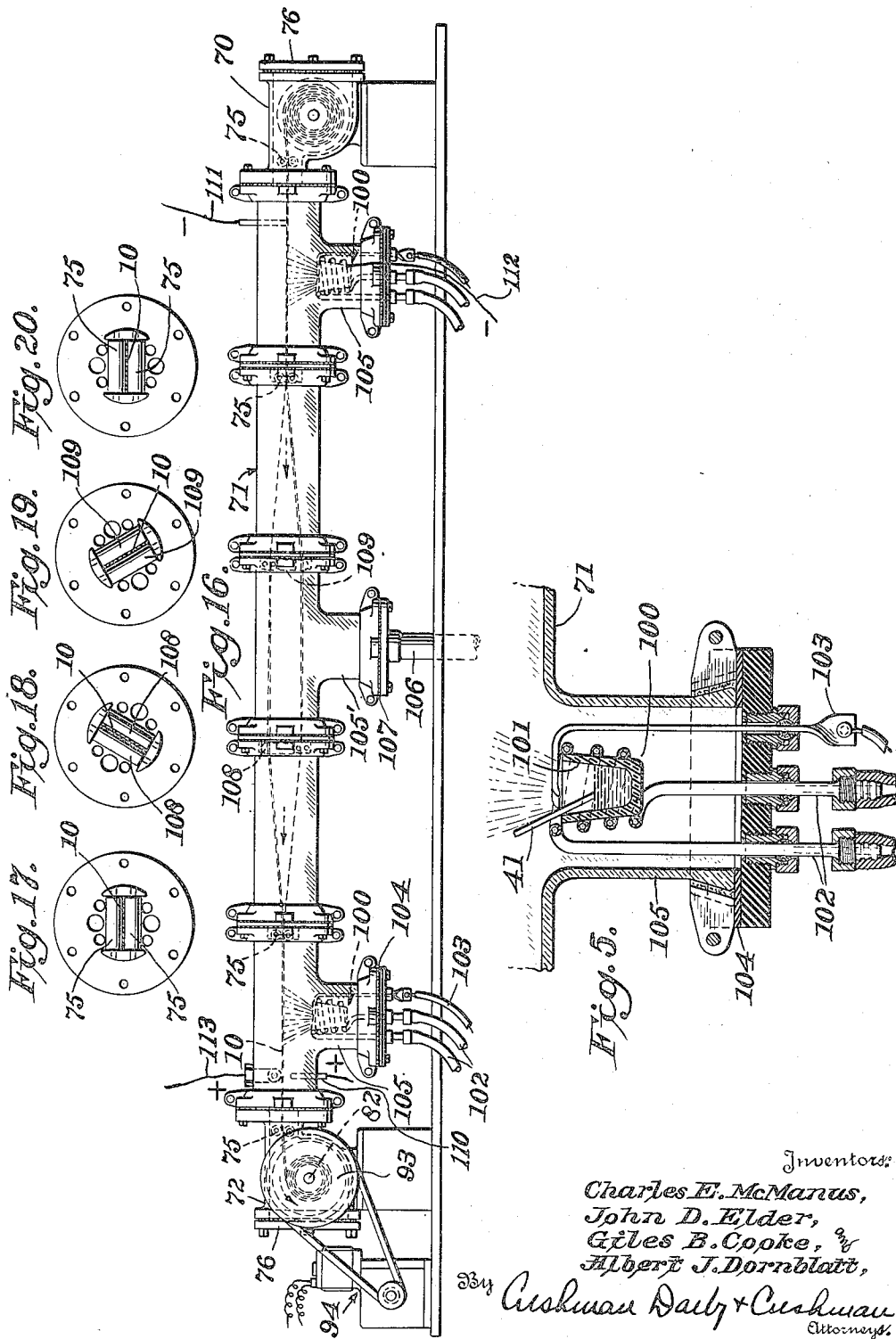
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Fig. 8.

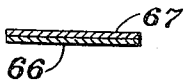


Fig. 9.

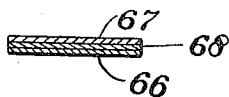


Fig. 6.

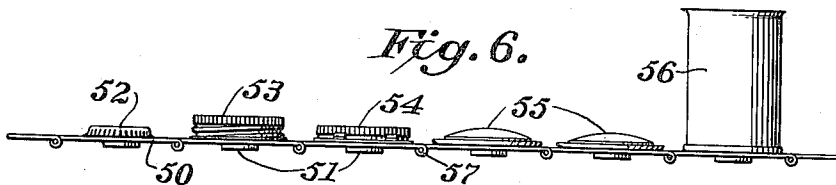
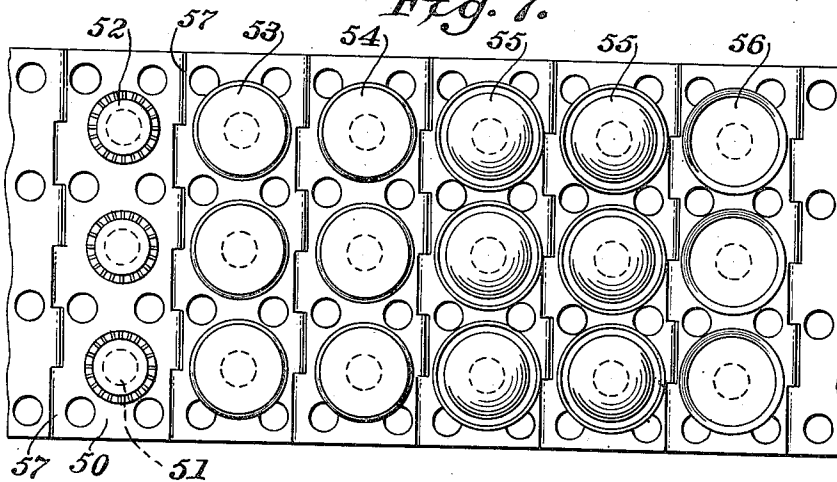


Fig. 7.



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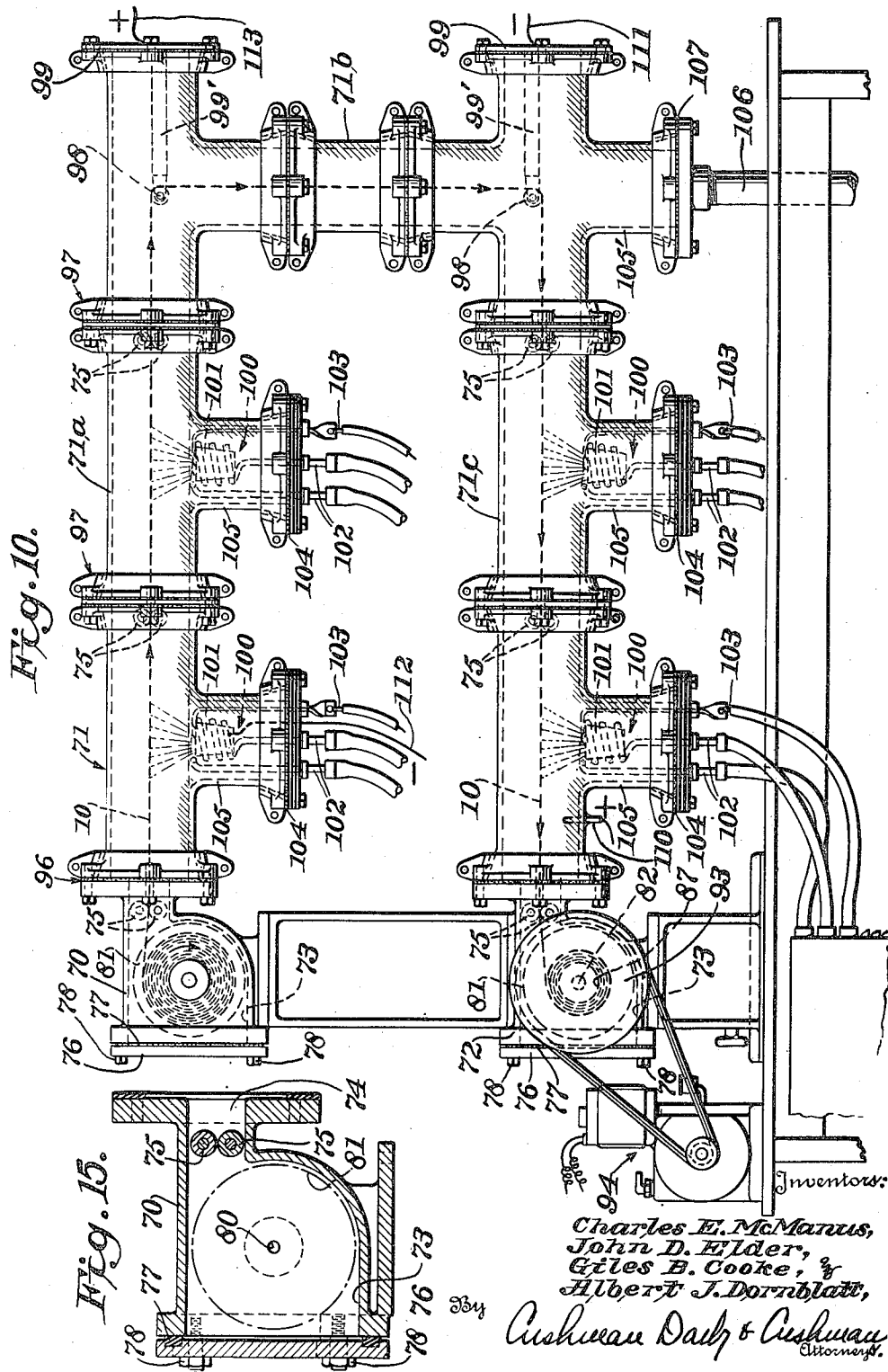
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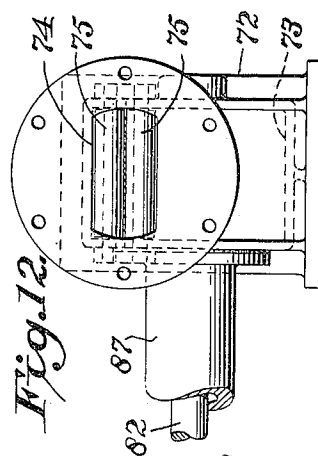
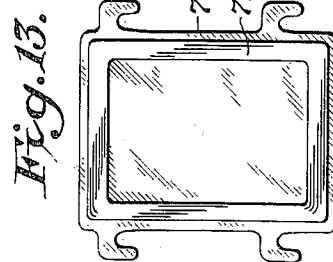
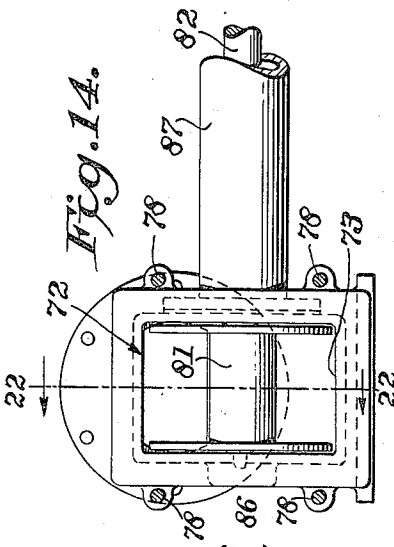
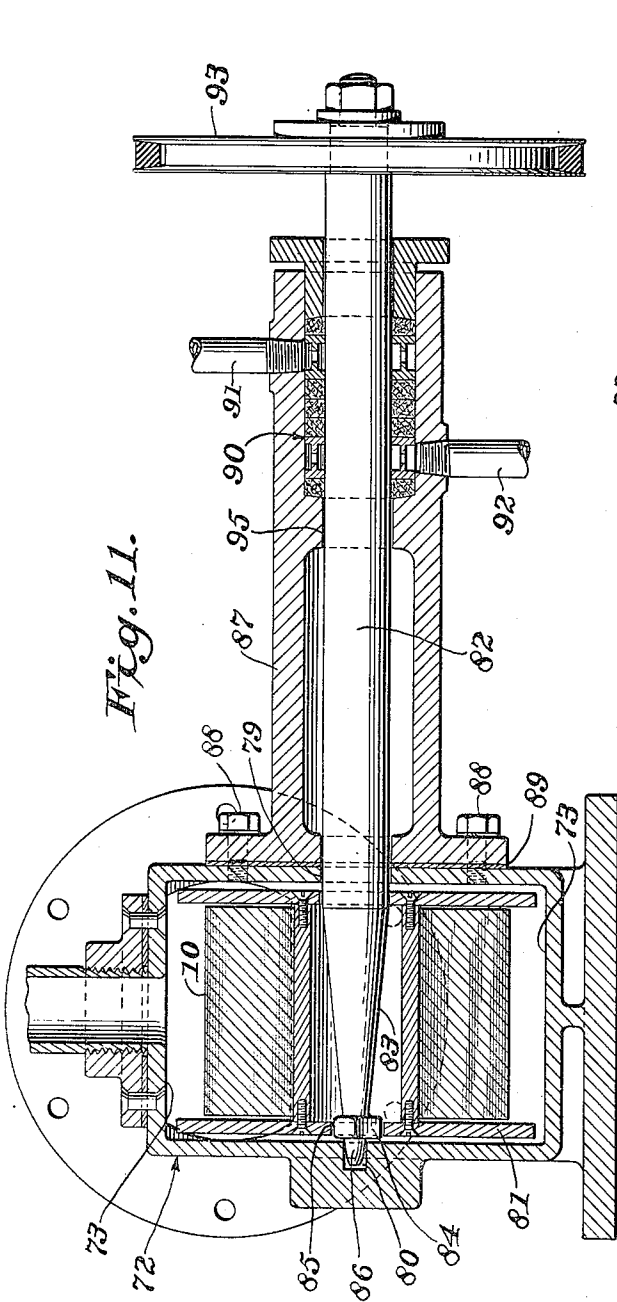
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COATING

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5 Sheets-Sheet 5



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UNITED STATES PATENT OFFICE

2,405,662

COATING

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Application August 30, 1941, Serial No. 409,090

5 Claims. (Cl. 204—192)

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The present invention relates to a method of coating with metallic vapors, and is particularly concerned with a novel product such as steel sheet or black iron having a coating of aluminum bonded thereto and articles formed therefrom.

The method of the invention includes the coating of a base which may be a continuous strip or length of material, as well as preformed articles, to produce on the base a permanently adherent surface film which is deposited or precipitated from an atmosphere of the vaporized coating metal. This coating can be determined as being produced from the metallic vapor by metallographic examination and X-ray diffraction studies.

The resultant laminated product exhibits characteristics which enable the coated metal to be formed and shaped, for example, (a) stamped into closure caps, particularly those of the skirted type such as crown, screw and lug caps, (b) pressed or drawn for use in the making of containers, and (c) spun to form articles which are best prepared by such operation, namely, bottles, reflectors, and goblets. In fact, the coated metal prepared in accordance with this invention is useful in a wide variety of applications where the base metal, if not protected, would ultimately present an objectionable appearance and in the case of containers, might affect the quality of the contents.

The aluminum coating produced from the vaporized metal is characterized by having a purity greater than that of customary aluminum coatings; in fact, the distillation of the aluminum enhances the purity of the coating so that it is substantially pure.

The coating of a base such as steel, in accordance with this invention, does not result in any impairment of the properties of the steel, i. e., the advantageous properties of the base are substantially unaffected by the coating film. In fact, the coating of the steel with vaporized metal is accomplished without substantially raising the temperature of the metal or otherwise heating it in a manner which might objectionably affect its desired properties. In other words, not only are the temperature conditions such that the properties of the steel are not affected, but the laminated product does not have a brittle intermediate zone or constituent, i. e., is substantially free of brittle intermetallic iron-aluminum compounds such as are frequently present where steel is coated by dipping in molten aluminum. Hence, the composite product has all the ductility of uncoated steel and is substantially free of brittleness.

This allows the coated metal to be employed for many forming operations. For example, in the production of crown caps, as by stamping, there is no evidence of cracking of the coating or the base metal. This is particularly advantageous, for example, in coating cold rolled strip where it is desired to preserve the stiffness and high polish of the skin-passed steel strip. Furthermore, the flexibility, rigidity and tensile strength of the base metal are not sacrificed and the resulting product possesses the advantageous properties of both the steel and of the metal coating.

A very important characteristic of the coated metal is its corrosion resistance. Not only does the aluminum coating protect the iron from corrosion, but it inherently possesses resistance to corrosion and is therefore suitable for many situations where corrosive influences would deleteriously affect the metal base.

Another characteristic of the laminated product or coated metal is the galvanic protection afforded by the direct coating of the vaporized metal such as aluminum upon the base metal such as steel or black iron. The steel is rendered rust-proof and is prevented from discoloring and may be employed in containers for foods and beverages.

Further attributes of the coated metal are the pleasing brightness and high reflectivity for radiant energy. These qualities of the coated metal make it available for walls in low-cost housing and for various applications where heat and/or light reflectivity is desirable.

The abrasion resistance of the coated metal is satisfactory but the coating may be oxidized and hardened to give enhanced abrasion resistance for certain purposes.

Another important characteristic of the laminated product is the strong and permanent adhesion or bonding of the aluminum coating to the metal base which makes the product suitable for the metal working processes as above described. In this connection, in some cases, by regulated heating of the coated metal, alloying of the two constituents can be controlled, i. e., the diffusion between the atoms of the steel base and the coating, and a substantially integral bond is thereby produced without embrittlement.

The aluminum coated metal may be suitably decorated, printed, dyed, or otherwise colored. It may also be subjected to well-known processes of the type used for oxidizing pure aluminum or relatively high aluminum content alloys. By such means an oxidized film is formed on the aluminum which readily permits impregnation by various

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dyes and offers an excellent base upon which organic finishes may be applied. The oxidized film may be produced under conditions which give it an extraordinary degree of hardness.

It will be appreciated that the aforesaid properties, whereby the coated metal may be worked and possesses the desired resistant qualities and receptivity for decoration, make it ideal for the manufacture of screw caps, crown caps, and other skirted closures. Likewise, the coated metal is useful for making containers and numerous other fabricated products. In other words, this aluminum coated steel, for example, forms a satisfactory substitute for the customarily employed tin plate prepared by usual practice and at less cost for the coating metal due to the thinness of the coating which is commercially satisfactory.

Another embodiment of the invention consists in applying an organic film such as lacquer, varnish or enamel or an inorganic vitreous enamel to the metal surface, e. g., steel either of a preformed article or a continuous strip, whereby any irregularities or pores therein are effectively sealed and a smooth surface for receiving the vaporized metal coat is provided. Brittle enamels should not be used on continuous sheet metal which is wound in coils. The adherent vaporized coating metal is applied, for example, to the organic coating and adheres thereto and forms a film bonded to the base which is characterized by remarkable brilliance due to the uniformity, continuity and smoothness resulting from the presence of the intermediate coating. This improved lustrous or mirror-like finish is comparable to a coating produced directly upon highly polished steel sheet when vaporized aluminum is deposited thereon as a film. For all usual purposes, the product above described, in which the vaporized aluminum is directly deposited upon the steel, is quite satisfactory, and in either the case of the aluminum coated steel or the aluminum coated presurfaced steel, the properties of the steel are not sacrificed and the properties of aluminum are made available. Should there be any pores or other lack of continuity in the intermediate coating film, the metallic film will afford the desired galvanic and corrosion protection.

In connection with the foregoing, suitable films are produced from the vaporized metal upon steel which has been subjected to such processing as "Parkerizing," "Bonderizing," and other methods in which the iron at the surface has been chemically modified to produce iron reaction products. Also, the metal coating from vaporized metals may be produced on surfaces on which have been previously applied a coating of finely flaked mica in a suitable vehicle.

A further product made in accordance with this invention is a foil which may be either of pure aluminum, or comprise thin backings of iron or steel of sufficient softness and flexibility, paper, plastics such as Vinylite or other synthetic resins, chlorinated rubber, zinc foil, etc. coated with a deposit of vaporized aluminum. In some cases where the laminated foil is produced, the thin metal strip is first coated with an intermediate film such as an organic film of varnish or lacquer upon which the thin aluminum coating or layer is deposited. The pure aluminum foil may also be produced by depositing the coating upon a suitable non-retentive surface, e. g., steel coated with "Apiezon" oil or stearic acid, wherefrom the foil may be readily stripped off by any suitable means. In general, substances used to make the surface non-retentive must not excessively dilute the

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metal atmosphere with their own vapors. Foils produced in accordance with this invention are suitable for cap spotting purposes, heat insulation and for electrical condenser foils.

In this connection also, aluminum powder and flakes may be satisfactorily produced in accordance with this invention for use as pigments, in pyrotechnics and other applications, by depositing the vaporized aluminum upon a non-retentive surface such as stearic acid, or in a non-adherent form under controlled conditions, i. e., at a reduced pressure representing a less highly exhausted state than that which is required to produce an adherent and continuous film and/or at a temperature of the metal base conducive to production of a spongy or powdery deposit, whereby a discontinuous film or otherwise powdery deposit is formed which may be readily removed. In some cases the deposit so recovered will have the necessary fineness or in any case where a greater degree of fineness is desired, the size of the particles may be reduced in any suitable manner.

In connection with the formation of foils and powder, we also accomplish this by placing strips or sheets of aluminum or other material having non-retentive surfaces on the walls of the coating chamber, whereby excess vaporized metal which would normally adhere to the wall of the chamber is caused to be collected upon the sheets or strips and may be suitably removed and the foil or powder recovered. If it is not desired to use separate sheets or strips, the walls of the coating chamber itself may be rendered non-retentive if necessary, so that the aluminum coating may be readily stripped or removed therefrom.

A further embodiment of the invention consists in producing metal coated materials having flexible strip material backings of paper, plastics such as Vinylite or other synthetic resins, chlorinated rubber, zinc foil, etc., by a transfer process in which the coating metal such as an aluminum film is first deposited from the vapor state upon a non-retentive surface either as a continuous film of foil thickness or as a thin discontinuous film. Thereafter, the flexible backing material to be coated having a suitably adhesive surface is passed over the coating with its adhesive surface in contact with the same so as to pick up and transfer either a continuous film of aluminum to the new backing or a discontinuous film as the case may be. Such laminated materials may be of foil thickness or be of greater thickness as desired. The metallized laminated product or foils produced by direct coating as above described or by the transfer process just mentioned may be used as foils for cap spotting purposes, packaging, insulating walls, as well as decorative purposes.

As will be appreciated, the products obtained in accordance with the present invention are highly valuable and their production is accomplished by novel methods which are commercially feasible.

An important object of the invention is to provide a method in which a permanent, uniform and coextensive adhesion between the coating and the base layer is assured which persists when the metal is worked, i. e., there is no evidence of peeling, nor cracking of the laminated product, and there is an absence of any objectionable brittled condition. We have discovered that there are several critical considerations which govern the obtaining of the integrally bonded laminated sheet. For example, it is of particular importance that the metal surface, e. g., of steel, be presented to the metal coating atmos-

phere in a thoroughly cleaned condition. That is to say, the metal surface should be free not only of extraneous or foreign material, but likewise of rust film. Another critical consideration which we have discovered is that for reliable adherency, the metal should be substantially free of occluded gases, and it is highly important that before the metal sheet or strip is subjected to the coating atmosphere, it be first not only physically and chemically cleaned, but degassed as completely as possible.

Equally important, with the foregoing, is the provision of a chamber for accomplishing the coating operation which will permit continuous movement of a continuous strip or sheet to be coated through the same and which will be thoroughly sealed whereby a substantially constant reduced pressure or vacuum is maintained and the vaporized metal in the chamber is prevented from being excessively diluted, or polluted in a manner such as would adversely affect the color or adherence of the film. It may not be objectionable to have, for example, a trace of air, but the presence of an appreciable amount of certain vapors as for instance grease hydrocarbons, may cause the deposit to be blackened and be loosely adherent, whereas a silvery white or bright metallic film is desired.

We use a single chamber or a plurality of interconnected chambers. The connections between the series of chambers are such that the material to be coated may be continuously travelled through the same while maintained under reduced pressure. The conditions in each chamber regarding the vacuum and the density of the vaporized metal may be modified in accordance with the product required.

As will be appreciated, the relative temperatures of the metal base and the metal vapor source within the coating chamber are maintained under conditions to promote rapid precipitation of the metal upon the base strip moving through the chamber to form the coating film, and while in many cases preheating or subsequent heating of the metal will be unnecessary, there are conditions where it may be desirable to either heat or cool the metal under vacuum to a satisfactory operating temperature before deposition.

The method provides for suitably heating the strip under vacuum for the purpose of removing any surface accumulations and occluded gases prior to its entrance into the coating chamber, and also for assuring in certain cases, i. e., aluminum upon steel, that a more adherent coating is obtained, and one which affords an optimum coverage of the base metal. In this connection, in some cases, the temperature of the metal is raised where necessary after the coating operation to further assure the maximum adherency and/or to improve the continuity of the deposited coating. These heating steps may be accomplished in a protective atmosphere, but are preferably carried out under vacuum.

In actual operation it has been found possible to obtain very adherent coatings of aluminum on steel strip over a sustained period of operation without the strip having been at any time heated to a temperature much in excess of room temperature. In fact, the continual introduction of the uncoated strip at normal room temperature into the coating chamber acts to provide a continuous means of condensing the hot vapors of aluminum and prevent an excessive accumulation of vapor concentration in

the chamber. Because of the relatively rapid rate at which the strip being coated passes adjacent to the incandescent vapor source there is insufficient opportunity for heat from the vaporizing source or the vapors to produce any excessive temperature rise of the strip. A particularly advantageous consequence of this method is the effect of introducing relatively cool metal so as to prevent the accumulation of too high a concentration of aluminum vapor which it has been found will produce a dark and non-adherent coating. In other words, if the aluminum vapor concentration becomes excessive there is a rise in pressure within the chamber which adversely influences the physical character of the deposit, e. g., thickness, adherency, brightness, uniformity, etc. We have found it possible by our invention to so regulate the temperature of the strip, the rate of travel of the strip, the rate of power input to the metal vapor source and the rate of exhaustion of the chamber by the pump system, to maintain an optimum condition with respect to metal vapor concentration and pressure whereby a thin, uniform, adherent and bright metallic deposit may be continually obtained.

It may be advantageous to operate the system at a pressure, for example, somewhat higher than that which will give the desired degree of adherency of the coating deposit and subsequently increase the adhesion of this deposit by heating the laminated product where, by virtue of alloying diffusion, an integral adherent bond is established. While we are not entirely sure, it appears that this heating step also has the effect of relieving stress resident in the aluminum coating under such conditions so that the tendency to peel is eliminated. Such stress, and in the peeling direction, may be due to the fact that the hot vapor is deposited upon the relatively cooler steel base and stresses arise owing to the coefficient of expansion differential between the aluminum and the steel. Substantially similar procedures may be employed in coating vaporized metal such as aluminum, silver or tin upon papers, e. g., varnish drab express paper to make a laminated product useful for cap spotting purposes.

With respect to the critical conditions for obtaining an optimum deposit, it has been found that, other conditions being constant, the adhesion tends to improve (a) with increasing metal source temperature; and (b) with reduced pressure. The effect of an increased rate of travel of the strip is in the direction of reducing the system pressure because of the more rapid condensation of vapor thereby obtained. We have found that while the strip is traveling through the vaporizing chamber that the pressure is reduced as compared to the pressure existing before the strip has been set in motion and after the movement of the strip has been discontinued. The effect of increasing the strip temperature is partly to reduce the rate of condensation because of the lesser temperature differential, but on the other hand, also to improve the adhesion because of the stress relieving and alloying tendencies. By virtue of the continual introduction into the system over the vaporizing sources of relatively cool metal at no time does the temperature of the metal rise to an extent which would adversely affect the desirable physical properties of the metal strip such as, for example, those imparted by a skin-pass. The effect of reducing the pressure, other conditions being constant, is to per-

mit improved adhesion because the opportunity for collision of the vapor particles with other gaseous molecules is reduced and in the ideal case where the distance between the vapor source and the strip is less than the mean free path of the vapor molecules under the prevailing conditions, no interfering collisions can occur and the vapor particles impinge on the metal base with maximum energy, thus promoting adhesion.

We have found that while a filament coated with the metal to be vaporized emanates the metal vapor in all directions substantially uniformly, that the emanation of vapor from an incandescent crucible is in the general form of an expanding cone-shaped beam of small angle with respect to the axis of the beam. For example, a crucible heated by induction placed beneath a steel strip will deposit a layer of the incandescent metal vapor in a circular pattern substantially directly above the vertical axis of the crucible. The diameter of this pattern increases with the distance of the crucible from the strip. While it is desirable to have the distance between the strip to be coated and the metal vapor source less than the mean free path of the metal vapor atoms or particles, this is not essential. We have found that commercially satisfactory adherent deposits can be obtained when the distance just referred to is greater by a limited extent than the mean free path.

It may be advantageous, in some cases, in order to promote a better adhesion and continuity, to subject the laminated material to elevated temperature for a predetermined time period and in a non-oxidizing atmosphere preferably under vacuum, followed by a cooling step in a non-oxidizing atmosphere or preferably under vacuum to eliminate the possibility of oxidation.

Also, after the coating has been deposited, if the temperature of the laminated metal strip or sheet is so high that it would result in rapid oxidation or discoloration when introduced to the air, it is preferable to cool the coated metal preferably under vacuum, or non-oxidizing influences before it is introduced to the air.

The invention includes a method in which while under vacuum or reduced pressure, in a suitable chamber, the metal strip, for example, of steel is continuously discharged from a roll and passed continuously through various instrumentalities, including the coating chamber. In this connection, in some cases before being introduced to the vacuum chamber, it is preferred to anneal the strip and a continuous annealer may be incorporated in the line, and in addition to accomplishing its accepted function, this heating step will have the further effect of de-gassing the metal herein above mentioned as one of the important preliminary treatments. Likewise, before the strip is introduced as a roll to the vacuum chamber, the cleaning and pickling operations may take place and may precede the annealing operation, if necessary, and, in some cases, a further cleaning and/or pickling may be resorted to after the anneal, if required, and before the rolls are placed in the vacuum chamber. With relation to the cleaning step, the strip metal may be subjected while under reduced pressure in the vacuum chamber to a glow discharge just before it is presented to the vaporized metal for the purpose of removing the last traces of any physical or chemical contamination. By a "glow discharge," we mean the application of a high difference of potential between the sheet to be coated as one

electrode and any suitable type of second electrode such as carbon pencil type. The use of the glow discharge requires a relatively low pressure which is greater than about one micron.

Where the glow discharge method is employed for cleaning, we use somewhat higher pressures in the system than are required if the deposition is to take place at a vacuum sufficient to make the mean free path of the metal vapor atoms greater than the distance between the source and the base to be coated. Where it is desired to use this method for cleaning, the operation can be carried out in a fore-chamber maintained at a suitable pressure which may be somewhat higher than that maintained in the vaporizing chamber.

In the practical operation of the invention using a high frequency induction-heated crucible type of metal source, it has been observed that the metal vapor is itself ionized as indicated by the development of a luminescent glow, e. g., for aluminum a characteristic vivid or electric blue luminescence and for tin an apple green luminescence and that under these conditions when such luminescence or glow appears, it is accompanied by an immediate further drop in the pressure within the vaporizing chamber. This indicates that the metal vapor is itself acting as a cleaning agent combining, for example, with oxygen and nitrogen, and probably also hydrocarbons which might be present.

If desired, according to our invention, means may be provided for travelling the strip in either direction through the system. Using such means, we may operate the system at a pressure suitable for the use of the glow discharge as a means of conditioning the metal base and subsequently, by reversing the direction of the strip, metallizing it under suitable conditions of vacuum while using a metal vapor source of any of the types covered by this invention. Alternatively, we may accomplish the glow discharge cleaning in one portion of the system while following this immediately by metallization in a successive portion of the system. Metallization can be accomplished at the same pressure or lower pressures than used for effecting the glow discharge.

As explained above, the coating chamber may comprise a single chamber or a plurality of interconnected chambers all of which are maintained under a reduced pressure including the connections between any series of chambers. In any given chamber, the metal vapor source or a group of metal vapor sources may be disposed transversely to the direction of travel of the strip in order to produce a uniform coating of the given thickness and may also be disposed in groups arranged in the direction of travel of the strip so that successive deposits may be obtained to build up the coating to any desired thickness. A different set of conditions may be maintained in any one chamber or in each chamber of a series which will enable the formation of multiple coatings upon the metal base, i. e., a built-up coating of any desired thickness, as well as afford increased flexibility of operation. By "flexibility of operation," we mean a method adaptable for meeting the numerous conditions which will be encountered for the successful high production of a continuous strip coated with vaporized metal. For example, one chamber or the individual chambers of a series may all be maintained under the same conditions so that a strip fed therethrough at constant speed will be provided with a coating of predetermined required thickness. In other cases where a thicker coating is required, the speed of

travel of the strip may be retarded with the other conditions maintained constant, or successive groups of metal sources transversely arranged in parallel may be used to successively increase the thickness of deposit; or other conditions being constant, the rate of evaporation of the metal vapor may be increased by increasing the power supply to the incandescent source, so as to assure that the particular predetermined thickness will be uniformly attained. In other cases, the temperature attained by the coated metal strip traveling through one chamber may not be suitable for proper deposition in a succeeding chamber, and, hence, the temperature in the said succeeding chamber may be controlled or intermediate cooling means may be introduced. This intermediate cooling means may be of a positive character, as for example, suitable chilling rolls or cooling coils through which the strip passes from one chamber to the next, or the passage between the chambers may be so constructed that the sheet necessarily undergoes a drop in temperature during its travel by loss of heat through radiation to the walls of the intermediate connection from which the heat may be removed in any suitable manner. In other words, the flexibility afforded by a multiplicity of inter-communicating coating chambers or provided by a single chamber having transverse and/or successively grouped transverse series of vaporizing sources, precludes the necessity for repeated coating steps in a single chamber of predetermined size. The present method preferably embodies individual inter-communicating chambers and allows coating of a continuously moving strip.

In addition to the aforesaid advantages accruing from the flexibility of the process, there is the further desirable factor that different metals may be vaporized in the several chambers or from succeeding groups of vaporizing sources in a single chamber, and, therefore, built-up coatings of different compositions may be produced on the base metal. For example, aluminum, silver, copper or tin may constitute the first coat upon a base of steel or other material followed by a deposition of a different metal or metals either selected from those just mentioned or any other metal which it may be desired to use. By subsequent heating of such built-up coatings, a surface layer composed of a true alloy, e. g., aluminum-silver, aluminum-copper or copper-tin and many other combinations may be produced with resultant advantageous properties such as increased hardness, resistance to wear or corrosion.

It is apparent that by alternating adjacent transversely grouped metal vapor sources so that the groups, for example, contain different metals, parallel deposits of dissimilar metals may be applied to the surface of the strip. For instance, we may alternate stripes of aluminum with stripes of copper or we may deposit stripes of vaporized aluminum on a copper strip or a strip having a vaporized copper coating or vice versa. This is particularly useful in the case of foils; the method may be carried out with any combination of metals. Laminated products produced by this method are suitable for various decorative applications. Designs may be applied to the traveling strip by the use of an endless belt suitably perforated and disposed in close proximity to one side of the travelling strip between the strip and the vapor source. The suitably perforated endless belt or stencil travelling at the same rate of speed as the strip being coated permits the continuous marking of the strip with designs in ac-

cordance with the nature of the perforations in the stencil. In a similar fashion, designs may be continuously applied to formed objects, for example, cans and caps mounted on a saddle-like endless conveyor having the saddle perforated in accordance with the stencil design to be applied. The object so decorated can be removed through suitable air locks from one end of the system or stored in an evacuated chamber connected to the system. The objects may be fed to the conveyor from a hopper in communication with the system through suitable air locks. Conventional methods of metal coloring may, of course, be used to enhance the decorative effect. For example, by controlled heating of a decorated film in an oxidizing atmosphere comprising at least in part vaporized copper, the copper coated portions can be made to take on any desired color in a series ranging from copper red to an iridescent purple or black. Similarly, a jet black can be produced by heating such a coating in an atmosphere containing sulfur gases or by immersion in a solution of polysulfides. Furthermore, a vaporized metal coating, such as copper, may be colored by electrochemical means, as, for example, the production of oxide films of controlled thickness which in turn give the copper various and controllable interference colors. This is accomplished by immersion in a bath, a suitable electrolyte under controlled conditions in accordance with established practice. The various decorating methods are particularly useful for forming labels, multicolored patterns and designs on caps, cans and other articles.

In addition to the foregoing features of the invention, we provide heating units which embody means for assuring that the metal to be vaporized will be constantly supplied and constantly vaporized at a substantially uniform and controllable rate. This is advantageous in that it enables constant conditions to be maintained in the coating chamber or chambers and assures the deposition of a continuous uniform film upon the traveling metal strip. Of particular importance, the provision of a continuous supply of the metal to be vaporized is accomplished automatically and, therefore, in such a manner as to not necessitate any loss or interruption of vacuum. Automatic vaporizable metal replenishing means are suitable for carrying out the invention, e. g., crucibles containing a surplus of metal will serve to automatically maintain a constant supply or continual supply of metal vapor or mechanical devices for automatically feeding predetermined amounts of metal are employed.

A further embodiment of the invention comprises the use of electrostatic means within the coating chamber for directing the gaseous metal positively and definitely during the deposition of the same as a film upon the backing. In this connection, equipment such as is embodied in the "Cottrell" precipitator may be advantageously used for this purpose, with the metal backing strip acting as the electrode upon which precipitation occurs. For example, we have found that the metal vapor produced by our energizing source is ionized at least in part as a consequence of thermal and/or electrical ionization and the positively charged aluminum atoms can be made to travel with great velocity and directness toward the strip or base to be coated. Where the base is non-conductive, the aluminum atoms are directed toward a negatively charged electrode or plate on the far side of the non-conductive strip; where the base is conductive, the same method may be

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applied or, alternatively, the strip itself may be made negative with respect to the charged aluminum vapor and thus constitute a moving electrode, directing the deposition of the coating upon itself. On the other hand, the use of such positive directional means is unnecessary in those cases where the energizing source and the container for the molten metal are placed below and open toward the surface of the strip material to be coated, which is a preferred method.

Furthermore, the vaporizing means can be used to produce an atmosphere of metal vapor under conditions permitting its diffusion in all directions.

While the metal coating film in many cases will present a satisfactory highly polished surface, the lustre of any coating formed in accordance with this invention which is not of maximum brilliance may be improved by passing the same through mirror-finish rolls such as tungsten carbide rolls. On the other hand, it has been found that steel can be coated with aluminum by our process to produce either a bright-finished product very closely resembling hot-dipped tin plate or a satin-finished product having a silver-white matter appearance resembling tin plate in which the tin coating is electro-deposited. The bright-finished aluminum coated product is obtained by vapolytically depositing aluminum on steel strip which has been given a mirror-finish by means of, for example, tungsten carbide rolls. The satin-finished product is similarly produced by depositing the aluminum upon steel rolled in conventional manner using cold rolls which have been ground but not polished to a mirror-finish.

In the drawings,

Figure 1 is a diagrammatic sectional elevation showing the initial portion of a line or system for continuously coating metal in accordance with this invention;

Figure 2 is a diagrammatic view of one of the vacuum chamber units;

Figure 3 is a view similar to Figure 2 in which a single chamber is employed as distinguished from a plurality of interconnected chambers as shown in Figure 2;

Figure 4 is a view similar to Figure 2 in which the material to be coated is travelled through the coating chamber or chambers in a vertical plane as distinguished from a horizontal plane as shown in Figures 2 and 3;

Figure 5 is a detail view partly in section showing the crucible and associated parts for heating the coating metal by means of high frequency current;

Figure 6 is a side view showing the manner in which preformed articles, e. g., closures, container bottoms and containers are supported while being carried through the coating system;

Figure 7 is a top view of the conveyor and articles thereon to be coated as shown in Figure 6;

Figure 8 is a sectional view showing the base metal such as steel directly coated with an adherent film of coating metal such as aluminum, deposited from aluminum vapor;

Figure 9 is a sectional view showing a base material such as steel coated with an adherent film of material such as lacquer, varnish or enamel over which is deposited directly a coating of metal such as aluminum deposited from aluminum vapor;

Figure 10 is a side elevation of another form of apparatus for carrying out the invention

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whereby continuous strip material is coated upon both sides;

Figure 11 is a detail sectional view of one of the housings from which the coiled strip is fed to the apparatus of Figure 10, the rewinding housing being of substantially similar construction; this view further shows the shaft upon which the coil supporting reel is mounted and the means whereby the same may be rotated while maintaining a vacuum-tight seal in the housing;

Figure 12 is an end elevation of the housing showing the strip guide rolls;

Figure 13 is a detail elevational view showing the door of the housing and the sealing gasket associated therewith;

Figure 14 is an end elevation of the housing with the door of Figure 13 removed and showing an empty reel in position;

Figure 15 is a longitudinal vertical sectional view of one of the housings, taken on line 22—22 of Figure 14;

Figure 16 is a side elevation of another form of apparatus in which the strip is coated on both sides while travelling and wherein the strip is rotated through 180° about its longitudinal axis after coating on one side to place the other side in proper coating position; and

Figure 17 to 20 are elevational views of the spaced rolls for rotating or turning the strip to 180° to carry out the operation of Figure 16.

While the invention will be described in connection with the coating of vaporized aluminum upon a steel strip or sheet, it is to be understood that other vaporizable metals may be used exemplified by magnesium, silver, tin, zinc, chromium, nickel, etc. Moreover, alloys of which those composed of aluminum and silver, silver and zinc, aluminum and manganese, nickel and chromium are examples, may be employed. In referring to a "pure metallic coating," and "vaporized metal," we intend to include by these and similar expressions, elements as well as alloys.

With respect to the use of metal alloys for the coating atmosphere, in some cases we employ separate sources for the elements which are to make up the alloy, so situated that their vapors intermingle, and control the heating so that each vaporizes at the desired rate to properly proportion the vapor mixture and hence deposit as an alloy of any desired composition upon the base. The sources are, of course, situated in the same coating chamber.

One method of lining the cans is to melt and vaporize the aluminum by means of an electrically heated filament centrally located in the can body in a high vacuum. Tungsten wire is the most suitable material for the filament. Wire varying in diameter from 0.015 to 0.045 inch may be used, but 0.035 inch is a preferred diameter although 0.025 inch has been satisfactorily used. We have used 12 to 20 amperes, 6 to 10 volts. The pressure used was quite low, being at least as low as 20 microns, and in many cases, as low as 0.1 micron. For some purposes, two or more coatings of aluminum may be built up to form a lining of desired thickness. In some cases, the aluminum coating is partially oxidized to render the lining more chemically or physically resistant, i. e., the lining is rendered harder. In those cases where the contents of the container will attack the aluminum lining, the lining may be suitably protected by a film of wax, chlorinated rubber or polyvinyl acetal resin. As will be appreciated, the galvanic protection afforded by the

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aluminum lining is substantial, and moreover increases the corrosion resistance. Small percentages of silver, i. e., 5% silver by weight in aluminum give a hard and adherent film. Rapid production is accomplished in the apparatus herein disclosed in Figures 6 and 7.

Referring to Figure 1, the numeral 10 indicates a coil of suitable backing or base material which may be steel or black iron, paper, textile fabrics, or some synthetic resinous material such as chlorinated rubber, "Vinylite" resin, polyvinyl acetate resin, cellulose acetate or other organic strip material as well as glass cloth or glass ribbon and such strip is preferably directly coated, but in some cases may be provided with an intermediate film. The invention as stated is particularly concerned and will be described in connection with strip steel or black iron. The steel band is led from the roll 10 through a suitable cleaning instrumentality 11 in the form of a bath, for example, a pickling bath to remove surface accumulations and scale, and the strip is conducted thence, through a suitable drier 12 to evaporate any liquid or moisture which may have been retained upon the surfaces. Thereafter, the steel band is continued through a bright annealing furnace 13 if annealing is required, and as heretofore stated, this heating step will serve to reduce the amount of occluded gases in the metal. From the annealing apparatus 13, the strip is preferably coiled as at 10'.

Referring to Figure 2, a coil 10' of uncoated strip material is placed in the housing 14 at the feed end of the vacuum coating unit indicated as a whole at U, carried through the unit and coated, and then recoiled in the housing 14' at the delivery end of the unit. Both the housings at the feed and delivery ends of the unit are under vacuum and are closed by a suitable hinged door, gasketed to insure a tight seal when the chamber is under reduced pressure, but which will allow the doors to be opened when the vacuum is broken so as to permit a coated coil to be removed and an uncoated coil to be supplied. The coil 10' may be mounted on a suitable feeding shaft wholly supported within the unit and the recoiling mechanism at the delivery end for drawing the strip through the unit may include a shaft operated by a suitable motor within the unit or from outside of the unit, the shaft in the latter case being suitably packed to afford a thorough seal.

The housing 14 opens into a closed conduit of reduced cross-section through which the strip is led as shown to the heating chamber 15 having suitable electrical heating means 16 therein and which chamber is under vacuum. In this heating chamber, the heating is carried out upon the continuously travelling strip to remove any occluded gases in the metal strip and also to vaporize any traces of volatile matter or surface accumulations. By this treatment and through the provision of a glow discharge means having electrodes 17, a perfectly clean metal surface is presented to the coating chamber and the heating chamber 15 is provided with means such as an exhaust pump 18 for positively exhausting any gases driven off in that chamber so that there is no possibility of polluting the metal atmosphere in the coating chamber. From the heating or outgassing chamber 15, the metal is continuously travelled to the coating chamber 19. Between the chamber 15 and the chamber 19, cooling means are provided in the restricted passage 20 if required. In some cases, the restricted pas-

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sage itself having external walls exposed to the atmosphere, will act to dissipate the heat sufficiently so that no positive cooling means is required. This connection 20 between the chambers may be elongated so that the metal to be coated enters the coating chamber at any desired temperature, for example, in the case of steel to be coated with aluminum, in the neighborhood of about room temperature. As explained, above, if the metal enters the chamber at a more elevated temperature, this is not necessarily objectionable, and in some cases promotes adherency and continuity of the deposited film.

In the construction shown in Figure 2, the coating chamber is shown as comprising a series of chambers 19a, 19b and 19c, and any desired number of chambers may be employed. The chambers are connected by restricted passages 21 which may be provided with positive cooling means in the form of chilling rolls 22 or may be lined with suitable cooling coils. As heretofore explained, these restricted passage-ways whose exterior surfaces are exposed to the atmosphere may be elongated if desired in order to effect cooling of the strip as it passes from one chamber to the other where this is found preferable to the provision of positive cooling means. It is believed that the provision of intermediate cooling means between the respective coating chambers of the series is conducive to good results, but a single coating chamber 19 such as shown in Figure 3 has been employed satisfactorily in lieu of the series of chambers shown in Figure 2.

The single chamber shown in Figure 3 is connected with the housings 14 and 14' and associated construction as described above in connection with Figure 2. In Figures 2 and 3, we have shown the metal as passing through the coating chamber or chambers in a horizontal plane while in Figure 4, we have shown the metal as being coated while travelling in a vertical plane, and for this purpose, after the metal leaves the coiled roll 10', it is turned 90° through any suitable turning guides (not shown) disposed at 23. This turning operation takes place at any convenient time or place in the line after the strip 10 leaves the roll and is conducted under vacuum. Instead of the turning mechanism, the feed and recoil shafts and the roll may be vertically disposed.

The unit including the coating chambers 19 and housings 14 and 14' are exhausted or maintained at a suitably reduced pressure by a vacuum pump or combination of pumps of any suitable construction connected to the exhaust manifold pipe 24 having leads to the individual chambers as shown in Figure 2 or to the single chamber as shown in Figure 3. Within the coating chambers are disposed suitable vaporizing means which may be in the form of filaments as shown at 25 or electrical resistance or induction heated crucibles as shown at 26 or aluminum cathodes for sputtering.

By reason of the vaporizing devices, a constant supply of the gaseous coating metal is maintained in the chamber 19, and as will be later explained, automatic means are provided to insure that the supply of metal to be vaporized is continuously replenished as needed. In lieu of such automatic means, a predetermined amount of metal to be vaporized is disposed at the energizing sources according to the area of strip to be coated and the coating thickness desired. Such a predetermined amount of coating metal will be preferably employed where electrically heated crucibles are used to contain the coating metal or cathode

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sputtering is utilized. We prefer to use an amount of coating metal slightly in excess of predetermined coating requirements. After the metal strip has travelled through the coating chamber, it is continuously led while maintained under vacuum through a cooling zone or vapor trap formed by the cooling coils 27 which surround the closed conduit leading from chamber 19c and which serve to trap any vapors which are discharged from the chamber 19c. This cooling means 27 likewise serves to lower the temperature of the travelling strip material. A similar trap 29 may be disposed at the other housing end, but this condition is generally taken care of in the chamber 15 where any objectionable vapors are continuously removed.

The coated material is drawn through the apparatus and after coating is rewound on a suitable reel in the housing 14'. Where it is desired to heat the coated strip before it is rewound, a heating means 15' similar to the heating chamber 15 is interposed before the cooling means 27. As will be noted, the heating and cooling in each case takes place under a vacuum.

Referring to Figure 2, it will be observed that separate exhaust connections 28 having adjustable valves are provided for each chamber of the series. This permits selective variation of the reduced pressures maintained in each chamber so that the coating operation is rendered flexible.

One of the advantages of the method shown in Figures 2 to 4 is the ability to bring the coating chamber 19 to the best or most desired condition for coating by vaporization with a minimum of pumping effort, and therefore at a more rapid rate. That is, a greater vacuum is required in the chambers 19a, 19b and 19c than is required in the remainder of the apparatus, namely, the housings and the chambers 15 and 15', and there are cases, for example, where a greater vacuum is desirable in one or two of the chambers 19a, 19b and 19c. Our method enables advantage to be taken of the law relating to the diffusion of gases at reduced pressure, in that we are able, with a minimum of pumping effort, to rapidly bring the chambers 19a, 19b and 19c to the required reduced pressure, and at the same time produce a reduced pressure in the other chambers which is sufficient for their respective particular purposes. In other words, in our apparatus we are able to operate with a pressure gradient existing in the system with a minimum pressure or the highest vacuum existing in the vaporization chamber 19.

This method and the advantageous results thereof may be achieved in several ways. For instance, the passages from the housings 14 and 14' and from the respective chambers 15 and 15' and 19a, 19b and 19c are restricted and, for example, in the case of strip metal, are of a thinness or narrow cross section such as will just allow the metal to freely travel in order that diffusion between the housings and the respective chambers may be reduced to a minimum. Where chilling means, heating means, or supporting or conveying means are interposed in such restricted passages, they so occupy the passage as to likewise reduce the possibility of any substantial diffusion. Again, as shown in Figure 2, the manifold 24 is exhausted by a single line E to the exhausting means and therefore the admittance speed or evacuation speed will be greatest in the chambers 19a, 19b and 19c which are closest to the exhaust pipe leading to the exhaust means,

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whereas the housings 14 and 14' and the chambers 15 and 15' will exhibit a pressure gradient with respect to the chambers 19, that is, will be less exhausted. Under such conditions, operation of the exhausting apparatus will rapidly bring all of the coating chambers 19 or any one or two of them to the desired reduced pressure, and the other chambers and housings to a satisfactory reduced pressure, and by reason of the restricted passages, between the housings and the various chambers, the amount of diffusion will be negligible in the coating operations.

While we have illustrated in Figure 2 a single exhaust line E connected to the manifold, there may be several such lines connecting to a single exhaust means or to independent means. In such cases, the restricted passages between the housings and respective chambers will likewise act to preclude any substantial diffusion and the valves in the lines leading from the housings 14-14' or the housings and chambers 15 and 15' to the manifold (where the latter are connected to the manifold), for example, may be closed when a suitable vacuum has been established therein so that all of the further exhausting may be accomplished with respect to the coating chambers 19 or any one or two of them where a higher degree of vacuum is required.

Furthermore, we provide in some cases a separate exhausting means for each of the housings and chambers. With this method and construction the restricted passages between the housings and chambers again act to prevent any substantial diffusion, and the exhausting means may be discontinued when a reduced pressure has been established in any housing or any chamber in the required degree.

In the methods just described above, less pumping effort is necessary, and the coating chambers are brought to the desired reduced pressure in a minimum of time.

In referring to exhausting means we mean, preferably, some multi-stage type using a suitable fore-pump for the preliminary exhaustion and higher vacuum pumps for subsequent stage or stages.

By reason of the restricted passages, the possibility of any substantial diffusion occurring is so reduced to a minimum that the method will operate satisfactorily, notwithstanding there may be slight leaks, for example, in the housings 14 or 14'.

In this connection, and as herein explained, where articles of greater dimension than steel strip are being coated, the passages likewise will be of a cross-sectional dimension to just clear such articles, and suitable baffles, e. g. flexible, may be disposed therein, if necessary, in order to reduce the possibility of diffusion.

In the construction shown in Figures 2, 3, 4, 10 and 16, provision is made for applying a film to each side of the strip material 10, but, if desired, the positioning of the vaporizing devices may be such that a coating is produced only upon one side of the strip.

In the various apparatus illustrated, we have shown both filament and crucible vaporizing means within the chambers. It is to be understood that in any one single chamber, all of the devices should be the same. Where a series of chambers are used, however, each chamber may have a different type of energizing source.

Referring to Figure 10, we have illustrated a further form of apparatus and methods which have proved highly satisfactory. The numeral

70 indicates a sealed housing from which strip material is fed continuously to and through a chamber 71. The chamber 71 may be of any suitable materials such as glass, metals, alloys, etc. and may be of any suitable size and shape in cross-section. Preferably, the chamber 71 is tubular and elongated and has an upper horizontal leg 71a, a vertical leg 71b, and another horizontal leg 71c which leads to a sealed housing 72 in which the strip material coated during its passage through the tube 71 is recoiled.

Referring to Figure 11, the housing 70 and the housing 72 each comprises a closed box 73. This box is provided at one end with a strip passage 74 as shown in Figure 15 and in which is disposed a pair of guide rolls 75. At the opposite ends, the housing is closed by a door 76 which may be hinged or separate as shown in Figure 13. This door has a suitable packing or gasket 77 and is bolted to the housing as shown at 78 to seal the same.

At one side, the housing is provided with an enlarged opening 79, while at its opposite side, there is provided a recess 80 of smaller dimension than the opening 79 but concentric therewith. In each housing, there is disposed a reel 81 as shown in Figure 11 which is rotatable upon a shaft 82 in the case of the feed housing 70 and is positively rotated by the shaft 82 in the recoil housing 72 for withdrawing strip material from the coil in the housing 70 and continuously drawing the same through the tube 71. The shaft 82, it will be noted, has a tapered end 83 which is normally disposed within the housing and within the hub of the reel 81. At one end of the tapered portion, there is provided a squared projection 84 which engages in a similar opening 85 in the reel 81. From the projection 84 there extends longitudinally a projection 86 extending into the recess 80 which acts as a guide and in some cases as a support or bearing for the shaft 82. The shaft 82 is supported in a bearing 87 which is bolted at 88 to the wall of the housing in a manner to seal the same, there being provided a suitable packing 89 between the flange of the bearing 87 and the wall of the housing. The bearing 87 has a suitable packing consisting of lantern glands with stuffing indicated as a whole at 90, and the shaft may be suitably lubricated by lubricant supplied through the inlet 91 which may be removed by the outlet 92 normally maintained at the reduced pressure of the system. At its free end, the shaft carries a pulley 93 which is rotated by a suitable motor 94 as shown in Figure 10 for positively rotating the reel 81 in the housing 72 to draw the strip through the coating apparatus. In addition to its movement of rotation, the shaft 82 is movable laterally so as to withdraw the tapered portion 83 from engagement with the reel and outside of the housing a sufficient distance to clear the reel whereby the same may be removed and another reel containing a coil of strip material to be coated replaced within the housing. This lateral movement does not affect the sealed condition of the housing because the bearing 87 is of a length that when the shaft is withdrawn from the housing, no part of the tapered portion extends beyond the bearing surface 95. When a reel has been positioned in the housing, the shaft is moved in to the position shown in Figure 18, and the apparatus is ready to be operated. The housings are in all respects similar, the only exception being that the shaft 82 in the case of the housing 72 is

positively driven and, therefore, carries the pulley 93.

The tube 71 is connected to the housings by joints 96 which are preferably of the flanged type and assure complete freedom from leakage. At 97, we have shown flanged joints for connecting sections of the tube, but these may be eliminated by welding the ends of the sections together. The tube may be formed of "Pyrex" glass but is preferably formed of steel having a smooth interior. In some cases, this smoothness is obtained by a suitable coating, such as tin. A plurality of pairs of guide rolls 75 are disposed in the tube, and at the ends of the chambers 71a and 71c, guide rollers 98 are employed over which the continuous strip travels from the upper leg 71a to the lower reversely extending leg 71c. These rollers 98 are preferably supported by the end sealing members 99 by means of brackets 99', the sealing members 99, brackets 99' and rollers 98 being of conductive material in some cases for a purpose to be later described.

Disposed at suitable points along the length of the tube are the vaporizing means which may be of the character heretofore described and which are indicated as a whole at 100 in Figure 5. In the present instance, crucibles 101 are illustrated and are preferably heated by a high frequency current introduced through the line 102, the line being suitably water-cooled as well known. The line 103 is in the nature of a tuning tap. The tubular extension 105 opening into the tube 71 and in which is disposed a crucible 101 and its heating means is sealed by a leak-proof joint 104 which also carries suitable insulation. Instead of having the vaporizing means disposed in suitable extensions 105, they may be positioned within the tube below the undersurface of the moving strip to be coated, and they may be suitably connected so that by opening one of the ends 99, all of the vaporizing means may be removed for repair or replenishing with metal.

The operation is, of course, carried out under a suitably high vacuum which is produced by connecting the line 106 to an extension 105' of the tube by means of a leakproof joint 107, the line 106 being connected to a suitable vacuum pump. In this connection, vacuum pumps may be associated with each of the housings 70 and 72 in addition to the vacuum pump working through the line 106.

It will be observed that a strip of metal to be coated is withdrawn as a continuous length from the housing 70 and continuously travelled through the tube leg 71a in which first its undersurface is coated by means of the vaporizing device or devices 100 disposed below the undersurface of the strip, whereupon the strip is turned through 180° in the leg 71b and its opposite surface is presented to and similarly coated by the vaporizing means in the leg 71c whereupon the coated strip is recoiled in the housing 72.

The construction shown in Figure 16 embodies a single longitudinal tube 71 in which means are provided for turning the strip after the undersurface has been coated through an angle of 180° so that its opposite surface may be similarly coated. The means for accomplishing this is shown in Figures 17 to 20 and embodies guide rolls 75 and guide rolls 108 and 109 which are disposed at a suitable angle with respect to the guide rolls 75 to turn the strip as it travels through the tube 71. Otherwise, the construction is similar to that shown in Figure 10.

Where the crucible is used, it is located ap-

proximately three inches from the strip with the molten metal about four inches from the surface of the strip. This gives satisfactory results. However, the crucible or other heating means may be located at various distances, and we have found that the farther away the crucible is located, the greater the area of the strip which will be covered. Moreover, the lower the pressure in the tube 71, the greater the distance the crucible can be disposed away from the strip, and the thinner the coating which will be produced. Also, the lower the pressure which is maintained in the tube 71, the fewer the crucibles which need be employed.

In carrying out the invention with a strip three inches wide, we moved the strip at the rate of twenty-three feet per minute and maintained a pressure of one micron in the tube 71. Using aluminum as the coating metal, we obtained a satisfactorily coated strip having a coating of about seven millionths of an inch thick. The power employed depends on the width of the strip being covered.

The crucibles or resistance heating means may be disposed in various ways to obtain the desired coating, but it is preferable in the absence of any means for positively directing the vaporized metal toward the strip, to dispose the same below the travelling strip, since we find that under reduced pressure, the metal tends to diffuse upwardly and efficiently cover the lower exposed surface of the strip. In this connection, the vaporizing means may extend transversely of the path of movement of the strip so as to comprehend the entire transverse dimension thereof, or the vaporizing means may be disposed in staggered relation to insure complete coating. The important consideration is to obtain a uniform coating of desired thickness, and the position of the vaporizing means will, therefore, depend upon the area of the sheet to be covered.

Referring to Figure 10, we have indicated two optional means for directing the vapor in any of the methods herein set forth, one or the other of which may be satisfactorily employed. The numeral 110 indicates a suitably insulated electrode which is sealed into one of the legs of the system, and the numeral 111 indicates an electrical contact of opposite polarity made through the metal plate 99 and supporting bracket and roll 98 with the strip 10. Between the electrodes 110 and 111, a difference of potential of up to several thousand volts is established, in such manner that the electrode connected to the strip is of negative polarity. This difference of potential can be established by use of a step-up transformer in conjunction with a rectifier such as a kenotron or a mechanical rectifier operated by a synchronous motor. The vaporized aluminum ions have a positive charge and will be attracted to the negatively charged moving steel strip 10. The second method involves the use of electrodes 112 and 113 and would be utilized in that case where the metal is to be deposited on the strip by the cathode sputtering process. The electrode 112 is sealed through the crucible so as to make electrical contact with the molten metal inside. This electrode will be at a negative potential with respect to the strip which is connected to the positive side of a high voltage direct current source through the electrode or connection 113. The vapor directing means described with respect to the optional methods may be interposed in the system at any convenient point and have been illustrated in Figure 10 simply for convenience. Where the legs 71 etc. are metallic, to avoid directing the deposition of

metal vapor upon the metallic walls adjacent to the strip in the vicinity of the vapor source, these walls will be electrically insulated from the moving strip in any suitable manner as by winding and unwinding the strip upon non-conducting mandrels 81. In this connection, we may take advantage of this high voltage direct current to effect cleaning of the strip by means of a glow discharge.

It is to be understood that while we have illustrated a continuous strip of material being coated, individual strips of any desired length may be suitably fed through the coating system while carried flat upon a conveyor or suspended therefrom. In this connection, also, one or both sides of a flat material such as strips or sheets may be coated, depending upon the position of the metal vaporizing means. Likewise, where the metal is coated upon both sides and it is desired to use an intermediate organic film, this will be applied to both sides of the strip or sheet.

In some cases, instead of forming the metal into a coil 10', it is introduced directly from the drier 12 or the annealer 13 into the coating chamber continuously passing from these instrumentalities into the unit. Also, in such cases, we some times provide at the entrance and exit ends of the unit a liquid sealing leg preferably of substantially U-shape through which the continuous strip is travelled. The seal is established by means of a suitable liquid maintained in the leg such as water, mercury, molten lead and other satisfactory liquids.

Where liquid sealing legs are employed it may be necessary to provide special means for preventing contamination of the coating metal by contact with the sealing liquid or vapor therefrom. For example, mercury will alloy with freshly deposited aluminum. We overcome this objection in that the coated steel emerging from the vacuum coating apparatus is first led through a layer of oil of low vapor pressure floating on top of the mercury of the exit sealing leg, whereby the oil film thus applied to the aluminum coated sheet will prevent contact between the mercury and the aluminum coating.

In the event that objectionable amounts of mercury vapors from the sealing leg at the entrance to the evacuated system are not removed by the trap 29 or from the de-gassing chamber 15, or by means of refrigerating coils or condensing surfaces within the evacuated system adjacent to the end of the aforesaid sealing leg in advance of the coating chamber 19, then these traces of mercury vapor are removed by an agent having a strong affinity for mercury such as metallic sodium, potassium or other alkali metal disposed between the sealing leg and said coating chamber. Capsules containing the absorbing metal can be separately vaporized by induction heating so that a film will be deposited upon the walls of the system ahead of the aluminum coating chamber 19, and this operation will be performed after initial evacuation but before aluminizing commences.

As explained above, the use of liquid sealing legs affords a completely continuous operation, in that the strip material need not be coiled for inclusion in the housing 14, but may be led directly from the drier 12 or annealer 13 into the coating apparatus.

In Figures 6 and 7, we have illustrated a foraminous belt 50 upon which are supported caps, can bottoms and also containers which are to be coated in accordance with this invention. The

various articles are maintained in position on the belt 50 by permanent or temporary magnets 51, and the coating may be carried out in any of the apparatus described herein. At the conclusion of the final step of the coating operation, i. e., when the conveyor reaches housing 14', a suitable means is employed to remove the coated articles from the belt 50.

In Figures 6 and 7, we have illustrated crown caps at 52, screw caps at 53, lug caps at 54, can bottoms at 55 and containers at 56. These various articles as well as containers, may be coated interiorly or exteriorly, or both, in accordance with their positions on the belt. Thus the outside of an article may be coated during part of the movement of the belt whereupon the article, held in position by a temporary magnet is inverted by a suitable means (not shown) and the inside coated or lined during another period of the travel of the belt. It is to be noted that the belt 50 is provided with a multiplicity of openings to permit communication through the belt. It is preferably formed of stainless steel and the sections thereof may be hinged as shown at 57.

In the case where articles of greater dimension than relatively thin strip material are being coated in accordance with the apparatus and methods herein described, the apparatus will be suitably enlarged to permit the passage of such articles through the respective instrumentalities of the unit. In this connection, where preformed articles are carried by the conveyor 50, they may be fed thereto at the feed end 14 of the unit from a suitable magazine maintained under air-tight or vacuum conditions, and discharged at the delivery end 14' of the unit into a suitable hopper or other collecting means, likewise maintained under vacuum or air-tight conditions. The magazine and hopper may be disposed within the unit or may be disposed outside of the unit and connected thereto through suitable air-tight connections. This will be particularly the case where caps, can bottoms and containers are being coated.

Referring to Figure 8, we have shown at 66 a base of any suitable material, such as steel or black iron, paper or film of organic material, directly coated with a coextensive film of aluminum 67 deposited from aluminum vapor.

In Figure 9, we have shown a similar base 66 provided with a coextensive intermediate film 68, such as lacquer, varnish or enamel upon which is deposited a coextensive coating 67 of aluminum deposited from aluminum vapor.

As explained above, the base 66 may be formed of paper or other flexible material, such as synthetic resins and cellulose derivatives, as well as chlorinated rubber or metal foils, i. e., of steel. In this manner, suitable materials are provided which are useful for providing center spots and overall facings for caps and closures. As understood, the backing or base in the case of spotting materials is provided with a suitable adhesive coating for securing the spot or overall facing to the cushion liner of the closure.

Foils of this character, of course, may be used for their insulative qualities and decorating characteristics.

Also, in the case of two-part caps, particularly those of the screw cap type, the inner member may be produced in accordance with this invention by coating the steel with a coextensive film of aluminum either inside or outside, or both. Likewise, the outer threaded member may be similarly coated.

Wherever desirable, the aluminum coating prepared in accordance with this invention, whether for spotting materials or as for linings for closures and containers, may be provided with a coating of suitable lacquer or varnish. Such organic coatings are useful where chemical action between the contents and the lining or foil might be set up.

While we have referred herein to steel band or strip, the invention is equally applicable to the coating of other material in continuous lengths, for example, wire and wire screening.

When the vacuum is broken with any of the methods described herein, as by cutting off the pump and allowing air to enter the system, we prefer that such air be dehydrated before it enters the system. This we find substantially reduces the time required to pump down the system to the desired reduced pressure for the next operation.

Also in the various methods recited, we prefer to introduce to the crucibles or other vaporizing means sufficient metal to be vaporized as will coat a predetermined length and width of strip. For example, for coating 5,000 feet of thirty inch wide strip on both sides with sufficient aluminum to give commercially serviceable rust resistance, approximately six pounds of aluminum will be sufficient and where several crucibles are used as in Figure 10, the total amount required is preferably equally divided among the crucibles at the start of each run, i. e., one and a half pounds in each crucible.

With further reference to the making of metal powder in accordance with this invention, it has been found that vapolytic aluminum films produced on steel, particularly relatively thick coatings ranging from about 0.1 mil to 1 mil in thickness, while initially continuous and relatively adherent will separate from the steel and be readily detached as thin irregular flakes or lamellar particles when the steel is made to bend sharply. Such flakes can be ball-milled to give a more uniform and smaller sized particle with or without further substantial reduction in thickness, i. e., converted to a form suitable for use in aluminum paint.

The power required to vaporize a pound of aluminum is so small, i. e. theoretically, it is only about 2.1 kw.-hours and with power at 1 cent per kw.-hour, it is apparent that the vapolytic method offers a much cheaper method for producing aluminum powder than the present method involving a cost of about 23 cents per pound to reduce sheet aluminum to powder, excluding metal cost. Furthermore, this is the only method that is explosion-proof and that can produce aluminum powder practically free from oxide. All present methods involve powdering the aluminum under conditions where oxygen is present, and oxide and explosions may be produced. We produce aluminum powder by condensing aluminum vapor on an endless belt, or by using a strip which can be operated first in one direction and then another, much as is the method followed in the vapolytic unit disclosed in Figure 10, except that the speed of travel of the belt will be so slow that a relatively heavy aluminum film will be formed and means will be provided for detaching this film by sharply bending the steel belt or strip or by a suitable "doctor" blade for example. The fragmented aluminum flakes thus obtained are ultimately withdrawn from the vacuum system and ball-milled and screened to give aluminum

powder suitable for paint, etc. We may ball-mill in vacuum or according to conventional practice; in the latter case, a substantial part of the time normally required to produce the desired fineness is saved, and the explosion hazard, while not eliminated, has been somewhat reduced. Alternatively, we carry out the ball-milling operation under an inert atmosphere, and have an aluminum powder lower in oxide content than conventionally produced.

In connection with the operations shown in Figures 10 and 16, both surfaces of the travelling strip 10 are simultaneously and successively coated. Also, referring to Figures 10 and 16, it is to be understood that as with other forms of the invention, the vapolytic means 100 may be disposed in each leg 71a and 71b upon opposite sides of the strip travelling therethrough so as to simultaneously coat opposite sides of the strip 10 as it travels through the respective legs of the chamber 11.

No claim is made in this application to the subject-matter which is the joint invention of the inventors in copending application Serial No. 349,646, filed August 2, 1940, now U. S. Patent 2,382,432, granted August 14, 1945.

We claim:

1. A method of coating a metal sheet with a vaporized metal comprising introducing the metal to be coated, prior to coating into a feeding zone and maintaining the same under reduced pressure therein, continuously advancing the metal sheet from said feeding zone in a substantially horizontal plane, while maintaining the metal sheet under reduced pressure, into a coating zone with the metal sheet at a temperature below that of the vaporized metal, maintaining that coating zone also under reduced pressure twisting the metal sheet through an angle of substantially 180° in the coating zone as it travels through the same, vaporizing the coating metal in said coating zone continuously as the metal sheet travels therethrough, maintaining a difference in potential between the continuously traveling metal sheet and the vaporized metal ions to thereby direct the vaporized metal to the metal sheet and to deposit the vaporized metal upon successively exposed longitudinally

spaced opposite surfaces of the continuously traveling metal sheet presented by said twisting while the metal sheet is moving through the coating zone, and continuously collecting the coated metal sheet from said coating zone in a zone maintained under reduced pressure.

2. A method of coating a metal base with a vaporized metal comprising introducing the metal to be coated, prior to coating into a feeding zone and maintaining the same under reduced pressure therein, continuously introducing the metal from said feeding zone, while maintaining the metal under reduced pressure, into a coating zone with the metal at a temperature below that of the vaporized metal, maintaining the coating zone also under reduced pressure, coating the metal surface on one side as it travels through said zone by vaporizing the coating metal in said coating zone continuously as the metal base travels therethrough and by maintaining a difference in potential between the continuously traveling metal base and the vaporized metal ions to thereby direct the vaporized metal to the metal base and to deposit the vaporized metal upon said side, coating another side of said metal base as it continuously travels from said first zone through a second zone and in the same manner as in said first zone, the second coating zone also being maintained under reduced pressure, and continuously collecting the coated metal from said second coating zone in a zone maintained under reduced pressure.

3. The method according to claim 1 wherein the metal base is steel and the vaporized metal for producing the coating on the steel is aluminum.

4. The method in accordance with claim 2 wherein the metal base is steel and the vaporized metal for producing the coating on the steel is aluminum.

5. The method in accordance with claim 2 wherein the metal being coated is sheet metal and the same is continuously advanced from the feeding zone in a substantially horizontal plane.

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