

An Apparatus For Coating A Wire With A Silica based Coating And A Method Thereof

Technical Field

[0001] The present invention relates to an apparatus and a method for coating a wire. For example, an apparatus for coating a wire with a silica based coating and a method thereof. The apparatus and method of the present invention may be adapted to control the thickness of the coating on the wire.

Background

[0002] Copper, being a good electrical conductor, is commonly used to make wires, strips, which are used as electrical contacts in many electrical applications, e.g. power generation, power transmission, power distribution, telecommunications, electronics circuitry, etc.

[0003] The copper wires or strips are commonly insulated by a protective polymer layer, e.g. PVC (polyvinyl chloride) or rubber. For electromagnetic applications such as transformers, inductors, motors, speakers, hard disk head actuators, electromagnets, etc., the copper wires or strips therein are generally insulated (also known as enameled) using a thin polymer layer, e.g. polyvinyl formal (Formvar), polyurethane, polyamide, polyester, polyester-polyimide, polyamide-polyimide (or amide-imide), polyimide, etc. The coating methods commonly used for the wires or strips are coaxial extrusion, dipping and electro-statical deposition, etc.

[0004] To coat the wires or strips with a coating that comprises silica, the conventional methods mentioned above are not applicable. As the abovementioned polymer coatings are adhesive in nature and are able to stick to the wire when coated, the silica coating does not have the adhesive property and therefore does not adhere to the wire when used with the conventional methods. The formation of silica coating on the wire is established by molecular bonding, i.e. forming covalent bond, between the molecules of the coating and the wire. Therefore, due to the characteristics of the materials involved, the conventional coating methods above are not applicable for coating containing silica.

[0005] Further, as the silica based coating may be the thickness of the protective layer is critical for the performance of the wire as it affects the insulation characteristics and flexibility of the layer. However, it is difficult to control the thickness of the protective layer using the common coating method.

[0006] It is therefore necessary to provide a solution to the above mentioned problem.

Summary

[0007] According to various embodiments, an apparatus for coating a wire with a silica based coating is provided. The apparatus includes a tank adapted to contain a precursor solution comprising polysilazane, a conveyor adapted to convey the wire into and out of the tank through the precursor solution, such that the conveyor includes a plurality of conveying elements, such that each of the plurality of conveying elements is adapted to receive the wire in one direction and convey the wire to another direction, such that the one direction is different from the another direction, and such that the conveyor is adapted to control the speed of the wire through the precursor solution.

[0008] According to various embodiments, the plurality of conveying elements may be adapted to convey the wire into the tank in an entry direction and out of the tank in an exit direction, such that the plurality of conveying elements may include a proximal conveying element adapted to convey the wire into the tank in the entry direction, a distal conveying element adapted to convey the wire out of the tank in the exit direction, and one or more intermediate conveying elements disposed between the proximal conveying element and the distal conveying element, such that the one or more intermediate conveying elements may be adapted to convey the wire from the proximal conveying element to the distal conveying element.

[0009] According to various embodiments, the one or more intermediate conveying elements may be adapted to convey the wire in one or more directions that are not parallel to the entry direction and/or the exit direction.

[0010] According to various embodiments, the proximal conveying element and the distal conveying element may be adapted to rotate about a proximal axis and a distal axis respectively, such that the proximal axis and the distal axis are parallel to each other.

[0011] According to various embodiments, each of the plurality of intermediate conveying elements may be adapted to rotate about a rotational axis, such that the rotational axes of the plurality of intermediate conveying elements are parallel to each other.

[0012] According to various embodiments, the proximal axis and the distal axis may be perpendicular to the rotational axes of the plurality of intermediate conveying elements, such that the plurality of intermediate conveying elements may be adapted to convey the wire in directions that are perpendicular to the entry direction and/or the exit direction of the wire.

[0013] According to various embodiments, the proximal conveying element, the distal conveying element and the one or more intermediate conveying elements may be disposed along a plane, such that the wire when conveyed along the one or more intermediate conveying elements may be along the plane.

[0014] According to various embodiments, the proximal conveying element, the distal conveying element, and the one or more intermediate conveying elements may be disposed in a staggered arrangement, such that the wire when conveyed therethrough forms a zig-zag arrangement.

[0015] According to various embodiments, the proximal conveying element, the distal conveying element, and the one or more intermediate conveying elements may be arranged into two rows.

[0016] According to various embodiments, the conveyor may be adapted to convey the wire at varying speeds.

[0017] According to various embodiments, at least one of the number of plurality of conveying elements and distance between two adjacent conveying elements may be adjustable.

[0018] According to various embodiments, the plurality of conveying elements include a plurality of pulleys.

[0019] According to various embodiments, a method of coating a wire with a silica based coating is provided. The method includes conveying the wire into and out of a tank containing a precursor solution comprising polysilazane using a plurality of conveying elements, such that each of the plurality of conveying elements is adapted to receive the wire in one direction and convey the wire to another direction, such that the one direction is different from the another direction.

[0020] According to various embodiments, conveying the wire into and out of the tank may include conveying the wire into the tank in an entry direction via a proximal conveying element, conveying the wire out of the tank in the exit direction via a distal conveying element and conveying the wire from the proximal conveying element to the distal conveying element via a plurality of intermediate conveying elements disposed between the proximal conveying element and the distal conveying element.

[0021] According to various embodiments, conveying the wire via the plurality of intermediate conveying elements may include conveying the wire in one or more directions that are not parallel to the entry direction and/or the exit direction.

[0022] According to various embodiments, the method may further include conveying the wire via the plurality of intermediate conveying elements in direction that are perpendicular to the entry direction and/or exit direction.

[0023] According to various embodiments, the method may further include conveying the wire along a plane.

[0024] According to various embodiments, the method may further include conveying the wire at varying speeds.

[0025] According to various embodiments, the method may further include varying at least one of the number of plurality of conveying elements and distance between two adjacent conveying elements.

Brief Description of Drawings

[0026] Fig. 1 shows an exemplary embodiment of an apparatus for coating a wire with a silica based coating.

[0027] Fig. 2 shows an exemplary embodiment of the apparatus for coating the wire with the silica based coating.

[0028] Fig. 3 shows an exemplary method of coating a wire with a silica based coating.

[0029] Fig. 4 shows a graph depicting the relationship between the thickness of the silica based coating and the duration of the wires of various diameters that are submerged in the precursor solution.

Detailed Description

[0030] Fig. 1 shows an exemplary embodiment of an apparatus 100 for coating a wire 102 with a silica based coating. Apparatus 100 includes a tank 110 adapted to contain a precursor solution 112 comprising polysilazane, a conveyor 120 adapted to convey the wire 102 into and out of the tank 110. Conveyor 120 includes a plurality of conveying elements 122. Each of the plurality of conveying elements 122 is adapted to receive the wire 102 in one direction and convey the wire 102 to another direction such that the one direction is different from the another direction. Conveying element 122 may include a pivoting point, a rotatable element, e.g. a pulley, etc.

[0031] As shown in Fig. 1, the plurality of conveying elements 122 may be adapted to convey the wire 102 into the tank 110 in an entry direction 102E and out of the tank 110 in an exit direction 102X. Wire 102 may enter and exit the precursor solution 112 at an entry point and

exit point respectively. Plurality of conveying elements 122 may convey the wire 102 along a wire path, i.e. the path taken by the wire 102, having a path length. The path length may be the distance taken by the wire 102 from the entry point to the exit point. Plurality of conveying elements 122 may include a proximal conveying element 122P adapted to convey the wire 102 into the tank 110 in the entry direction 102E and a distal conveying element 122D adapted to convey the wire 102 out of the tank 110 in the exit direction 102X. Wire 102 may be conveyed in a different direction from the entry direction 102E and/or the exit direction 102X, e.g. in a lateral direction or perpendicular direction to the entry direction 102E and/or exit direction 102X. After the wire 102 enters the precursor solution 112 in the entry direction 102E, the proximal conveying element 122P changes the direction of the wire 102 to a lateral direction towards the distal conveying element 122D, which in turn changes the wire's direction to the exit direction 102X. Plurality of conveying elements 122 may be submerged in the precursor solution 112 when the apparatus 100 is in operation so that the wire 102 when conveyed through the plurality of conveying elements 122 is submerged in the precursor solution 112 for the coating to be coated onto the wire 102.

[0032] It may be necessary to coat the silica coating using a precursor solution 112. For example, to coat the wires or strips with silica (SiO_2), a precursor consisting of polysilazane may be required. Using the polysilazane solution as precursor, a thin silica film may be coated on the wire 102. The silica coating serves as protective film on the wire 102. The thickness of silica coating may typically be about 1-2 μm . For the wire 102 to be industrially applicable, the coating has to be hard and yet flexible. In addition, the coating has to provide electrical insulation to the wire 102. In order to achieve such properties, the thickness of the coating on the wire 102 is critical. Wire 102 may include a cable having a circular cross-section, a strip having a flat profile or any elongated and bendable element.

[0033] Fig. 2 shows an exemplary embodiment of the apparatus 200 for coating the wire 202 with the silica based coating. As shown in Fig. 2, the apparatus 200 includes the tank 210 adapted to contain the precursor solution (not shown in Fig. 2) comprising polysilazane and the conveyor 220 adapted to convey the wire 202 into and out of the tank 210. Conveyor 220 includes a plurality of conveying elements 222. Each of the plurality of conveying elements 222 is adapted to receive the wire 202 in one direction and convey the wire 202 to another

direction such that the one direction is different from the another direction. Plurality of conveying elements 222 may include the proximal conveying element 222P adapted to convey the wire 202 into the tank 210 in the entry direction 202E, the distal conveying element 222D adapted to convey the wire 202 out of the tank 210 in the exit direction 202X and one or more intermediate conveying elements 222M disposed between the proximal conveying element 222P and the distal conveying element 222D, such that the one or more intermediate conveying elements 222M may be adapted to convey the wire 202 from the proximal conveying element 222P to the distal conveying element 222D. Plurality of intermediate conveying elements 222M may be disposed along the wire path. As shown in Fig. 2, there may be four intermediate conveying elements 222M between the proximal conveying element 222P and the distal conveying element 222D. There can be any number of intermediate conveying elements 222M. Each of the one or more intermediate conveying elements 222M may be adapted to change the wire's conveyed direction therefrom. As each intermediate conveying element 222M changes the direction of the wire 202, the more intermediate conveying elements 222M used, the more turns the wire 202 makes along the wire path. In this way, the conveyor 220 is able to increase the length of wire 202 in the tank 210 without increasing the distance between the proximal conveying element 222P and the distal conveying element 222D. Hence, the conveyor 220 is able to lengthen or maximise the path length of the wire 202 in the tank 210 by increasing the number of intermediate conveying elements 222M or the distance between two adjacent intermediate conveying elements 222M. As shown, the apparatus 200 may be made more compact than a conventional dipping tank and/or allow a substantial longer path length of the wire 202 to be coated within the tank 210.

[0034] Referring to Fig. 2, the one or more intermediate conveying elements 222M may be adapted to convey the wire 202 in one or more directions that are not parallel to the entry direction 202E and/or the exit direction 202X. Entry direction 202E may a direction towards the tank 210 and may be perpendicular to the surface of the precursor solution. Exit direction 202X may be a direction away from the tank 210 and may be perpendicular to the surface of the precursor solution. The entry direction 202E of the wire 202 may be changed by the proximal conveying element 222P to another direction, e.g. a first direction 202D1. For example, the first direction 202D1 of wire 202 conveyed away from the proximal conveying element 222P by a first intermediate conveying element 222M1 may be perpendicular to the entry direction 202E. First direction 202D1 may be any direction away from the distal

conveying element 222D. As shown in Fig. 2, the first intermediate conveying element may change the wire 202 in the first direction 202D1 to a second direction 202D2 towards a second intermediate conveying element 222M2. Second direction 202D2 may be parallel to the first direction 202D1. However, the second direction 202D2 may be perpendicular to or in any direction away from the first direction 202D1. Accordingly, each additional intermediate conveying element may be adapted to change the direction of the wire 202. Ultimately, the wire 202 may be directed towards the distal conveying element 222D to be directed out of the tank 210 in the exit direction 202X.

[0035] For example, with reference to the tank 210, which has dimensions in the X, Y and Z axes, the entry direction 202E may be parallel to the Z axis, the first direction 202D1 may be parallel to the Y axis and the second direction 202D2 may also be parallel in the Y axis. However, the second direction 202D2 may be parallel to the X axis or Z axis. Finally, the wire 202 being conveyed to the distal conveying element 220D may be directed by the distal conveying element 220D in the exit direction 202X, which may be parallel to the Z axis. While the mentioned directions parallel or perpendicular to each other, it is possible that the angle between two adjacent directions be an obtuse or acute angle.

[0036] Referring to Fig. 2, the proximal conveying element 222P and the distal conveying element 222D may be adapted to rotate about a proximal axis 222PA and a distal axis 222DA respectively. Proximal axis 222PA and the distal axis 222DA may be parallel to each other. Depending on the orientation of the proximal conveying element 222P and the distal conveying element 222D, the proximal axis 222PA and the distal axis 222DA may not be parallel. Each of the plurality of intermediate conveying elements 222M may be adapted to rotate about a rotational axis 222MA. Rotational axes 222MA of the plurality of intermediate conveying elements 222M may be parallel to each other. Rotational axes 222MA of the plurality of intermediate conveying elements 222M may not be parallel to each other as the plurality of intermediate conveying elements 222M may be in different orientations. Proximal axis 222PA and the distal axis 222DA may be perpendicular to the rotational axes 222MA of the plurality of intermediate conveying elements 222M, such that the plurality of intermediate conveying elements 222M may be adapted to convey the wire 202 in directions that are perpendicular to the entry direction 202E and/or the exit direction 202X of the wire 202. Proximal conveying element 222P, the distal conveying element 222D and the one or more intermediate conveying

elements 222M may be disposed along a plane P, such that the wire 202 when conveyed along the one or more intermediate conveying elements 222M is along the plane P. The plurality of conveying elements 222 in plane P may form a layer of conveying elements. Proximal conveying element 222P, distal conveying element 222D and the plurality of intermediate conveying elements 222M may not be in the same plane and may be disposed anywhere in the tank 210 as long as the elements 222M are disposed along the wire path to convey the wire 202 into and out of the tank 210. Another layer of plurality of intermediate conveying elements 222M may be disposed in another plane (not shown in Fig. 2) parallel to the plane P to allow a longer length of wire 202 to be conveyed in the tank 210. Conveyor 220 may include a plurality of layers of conveying elements 222 in the tank 210. Proximal conveying element 222P, the distal conveying element 222D, and the one or more intermediate conveying elements 222M may be disposed in a staggered arrangement, such that the wire 202 when conveyed therethrough forms a zig-zag arrangement. Proximal conveying element 222P, the distal conveying element 222D, and the one or more intermediate conveying elements 222M may be arranged into two rows, such that the distance between two adjacent conveying elements may be the same. A spacing S between two conveying elements along one row may be varied. For example, as shown in Fig. 2, the plurality of conveying elements 222 in each row may be spaced such that the directions of the wire 202 when conveyed are parallel to each other. If the spacing between two conveying elements 222 are narrowed or widened, the directions of the wire 202 when conveyed may no longer be parallel. When the spacing between the two conveying elements are narrowed, the conveyor 220 may become more compact. Alternatively, it is possible to include more conveying elements in the arrangement to allow more length of wire 202 to be conveyed between the proximal conveying element 222P and the distal conveying element 222D.

[0037] Fig. 3 shows an exemplary method 1000 of coating a wire with a silica based coating. Method 1000 includes conveying the wire into and out of a tank 210 containing a precursor solution comprising polysilazane using a plurality of conveying elements 222, such that each of the plurality of conveying elements 222 is adapted to receive the wire in one direction and convey the wire to another direction, such that the one direction is different from the another direction.

[0038] In the following examples, reference will be made to the figures, in which identical features are designated with like numerals. The thickness of the coating on the wire 202 may be varied. The variables used to control the thickness of the silica based coating on the wire 202 may depend on the duration of the wire 202 being submerged in the precursor, i.e. the dipping time, and the composition of the precursor solution, e.g. the concentration of the solute, e.g. polysilazane, of the precursor solution. The duration may be the time taken from the time the wire 202 enters the precursor solution at the entry point to the time the wire 202 exits the precursor solution at the exit point. The duration may be affected by the conveying speed of the wire 202 through the precursor solution, i.e. the faster the conveying speed, the shorter the duration or dipping time and vice versa. The duration may be affected by the path length of the wire 202 in the precursor solution, i.e. the longer the path length, the longer the duration or dipping time and vice versa. Depending on the concentration of the solute, the speed of the wire 202 being conveyed by the conveyor 220 may be determined to achieve a pre-determined thickness of the coating on the wire 202.

[0039] Precursor solution may include a solvent and polysilazane in its composition. The composition of the precursor solution may be expressed as,

Compound	Weight Percentage
Polysilazane	X%
Solvent	(100-X)%

[0040] Precursor solution may further include perhydropolysilazane in its composition. The composition of the precursor solution may be expressed as,

Compound	Weight Percentage
Polysilazane	X%
Perhydropolysilazane	Y%
Solvent	(100-X-Y)%

[0041] Typically, the concentration of polysilazane and perhydropolysilazane, i.e. X+Y% may be less than 10%. The thickness of the coating after curing may vary with the travel speed. Due to the low weight concentration of the precursor solution, the variation may be insignificant. The formation of silica based coating using polysilazane as the precursor is a chemical reaction, which is the formation of covalent bonds between silica molecules and the wire 202.

[0042] Fig. 4 shows a graph 400 depicting the relationship between the thickness of the silica based coating on the wire 202 and the duration of the wires of various diameters that are submerged in the precursor solution, i.e. the dipping time, with a specific concentration. As mentioned above, the cured thickness of the coating may primarily be dependent on the duration the wire 202 is being submerged in the precursor, i.e. the dipping time, or in other words, the duration the wire 202 is exposed to the precursor solution. Other parameters affecting the coating thickness may include the dimension of the wire 202, e.g. diameter of the wire 202. As shown in Fig. 4, the thickness of the coating increases exponentially as the dipping time increases for a given diameter size of wire 202. Also, the thickness of the coating increases with increasing diameter of the wire 202 over the same duration or dipping time. The thickness of the coating may also increase with increasing concentration of the precursor solution. As established in Fig. 4, for a given concentration of precursor solution and wire diameter, the duration or dipping time is the controlling parameter for the cured thickness of the coating. The duration or dipping time may be in the range of several hundred seconds, e.g. 100-500 seconds. The duration may be in the range of 200-500 seconds or longer. Based on the duration or dipping time, the conveying speed of the wire 202 through the precursor solution may be determined. As shown above, the duration or dipping time may be determined by the number of conveying elements, the length of the wire path, i.e. the distance between each pair of conveying elements, and the conveying speed of the wire 202. The number of plurality of conveying elements 222 or distance between two adjacent conveying elements may be adjustable to increase the path length. The curing temperature may be at room temperature (about 25 degree), or at a higher temperature, e.g. up to 200oC. In other words, the curing temperature may be any temperature from 25oC to 200oC. The curing temperature may range from 25oC to 100oC. Although the apparatus 200 is used for a precursor solution, the apparatus 200 may be applicable for other coating solutions.

[0043] Conveyor 220 may include an actuator (not shown in Fig. 2) adapted to actuate the wire 202 along the plurality of conveying elements 222 or actuate one of the conveying elements to convey the wire 202. Actuator may include a motor coupled to at least one of the plurality of conveying elements 222 to convey the wire 202. Apparatus 200 may include a control unit adapted to control the operation of the conveyor 220. Actuator may be connected to the control unit adapted to control the actuator. Apparatus 200 may include one or more detectors for detecting the thickness of the coated wire 202 along the path of the wire 202 in the tank 210.

Detector may be connected to the control unit and adapted to send thickness signal to the control unit. Control unit may control the actuator to vary the conveying speed of the conveyor 220 depending on the thickness of the coating on the wire 202. If the thickness is not sufficient, the control unit may reduce the conveying speed to increase the dipping time of the wire 202 in the precursor solution so that the desired thickness is obtained. Apparatus 200 may include a concentration sensor adapted to measure the concentration of the precursor solution. Concentration sensor may be connected to the control unit and transmit a concentration signal to the control unit so that the concentration can be monitored and, if necessary, increased if the control unit detects that the concentration of the precursor solution is lower than a pre-determined level.

[0044] A skilled person would appreciate that the features described in one example may not be restricted to that example and may be combined with any one of the other examples.

[0045] The present invention relates to an apparatus for coating a wire with a silica based coating and a method thereof generally as herein described, with reference to and/or illustrated in the accompanying drawings.

Claim

1. An apparatus for coating a wire with a silica based coating, the apparatus comprising:
a tank adapted to contain a precursor solution comprising polysilazane,
a conveyor adapted to convey the wire into and out of the tank through the precursor solution, wherein the conveyor comprises a plurality of conveying elements, wherein each of the plurality of conveying elements is adapted to receive the wire in one direction and convey the wire to another direction, wherein the one direction is different from the another direction, and wherein the conveyor is adapted to control the speed of the wire through the precursor solution.
2. The apparatus according to claim 1, wherein the plurality of conveying elements are adapted to convey the wire into the tank in an entry direction and out of the tank in an exit direction, wherein the plurality of conveying elements comprises of a proximal conveying element adapted to convey the wire into the tank in the entry direction, a distal conveying element adapted to convey the wire out of the tank in the exit direction, and one or more intermediate conveying elements disposed between the proximal conveying element and the distal conveying element, wherein the one or more intermediate conveying elements are adapted to convey the wire from the proximal conveying element to the distal conveying element.
3. The apparatus according to claim 2, wherein the one or more intermediate conveying elements are adapted to convey the wire in one or more directions that are not parallel to the entry direction and/or the exit direction.
4. The apparatus according to claim 2 or 3, wherein the proximal conveying element and the distal conveying element are adapted to rotate about a proximal axis and a distal axis respectively, wherein the proximal axis and the distal axis are parallel to each other.
5. The apparatus according to any one of claims 2 to 4, wherein each of the plurality of intermediate conveying elements are adapted to rotate about a rotational axis, wherein the rotational axes of the plurality of intermediate conveying elements are parallel to each other.

6. The apparatus according to claim 5, wherein the proximal axis and the distal axis are perpendicular to the rotational axes of the plurality of intermediate conveying elements, wherein the plurality of intermediate conveying elements are adapted to convey the wire in directions that are perpendicular to the entry direction and/or the exit direction of the wire.
7. The apparatus according to any one of claims 2 to 6, wherein the proximal conveying element, the distal conveying element and the one or more intermediate conveying elements are disposed along a plane, wherein the wire when conveyed along the one or more intermediate conveying elements is along the plane.
8. The apparatus according to any one of claims 2 to 7, wherein the proximal conveying element, the distal conveying element, and the one or more intermediate conveying elements are disposed in a staggered arrangement, wherein the wire when conveyed therethrough forms a zig-zag arrangement.
9. The apparatus according to claim 8, wherein the proximal conveying element, the distal conveying element, and the one or more intermediate conveying elements are arranged into two rows.
10. The apparatus according to any one of claims 1 to 9, wherein the conveyor is adapted to convey the wire at varying speeds.
11. The apparatus according to any one of claims 1 to 10, wherein at least one of the number of plurality of conveying elements and distance between two adjacent conveying elements is adjustable.
12. The apparatus according to any one of claims 1 to 11, wherein the plurality of conveying elements include a plurality of pulleys.
13. A method of coating a wire with a silica based coating, the method comprising:
conveying the wire into and out of a tank containing a precursor solution comprising polysilazane using a plurality of conveying elements, wherein each of the plurality of conveying elements is adapted to receive the wire in one direction and

convey the wire to another direction, wherein the one direction is different from the another direction.

14. The method according to claim 13, wherein conveying the wire into and out of the tank comprises conveying the wire into the tank in an entry direction via a proximal conveying element, conveying the wire out of the tank in the exit direction via a distal conveying element and conveying the wire from the proximal conveying element to the distal conveying element via a plurality of intermediate conveying elements disposed between the proximal conveying element and the distal conveying element.

15. The method according to claim 14, wherein conveying the wire via the plurality of intermediate conveying elements comprises conveying the wire in one or more directions that are not parallel to the entry direction and/or the exit direction.

16. The method according to claim 14 or 15, further comprising conveying the wire via the plurality of intermediate conveying elements in direction that are perpendicular to the entry direction and/or exit direction.

17. The method according to any one of claims 14 to 16, further comprising conveying the wire along a plane.

18. The method according to any one of claims 14 to 17, further comprising conveying the wire at varying speeds.

19. The method according to any one of claims 14 to 18, further comprising varying at least one of the number of plurality of conveying elements and distance between two adjacent conveying elements.