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(54) **METHOD AND APPARATUS FOR WINDING THIN WALLED TUBING**

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(58) **Field of Search** 72/58, 61, 62, 72/135, 137, 146, 148, 370.01, 370.22, 371

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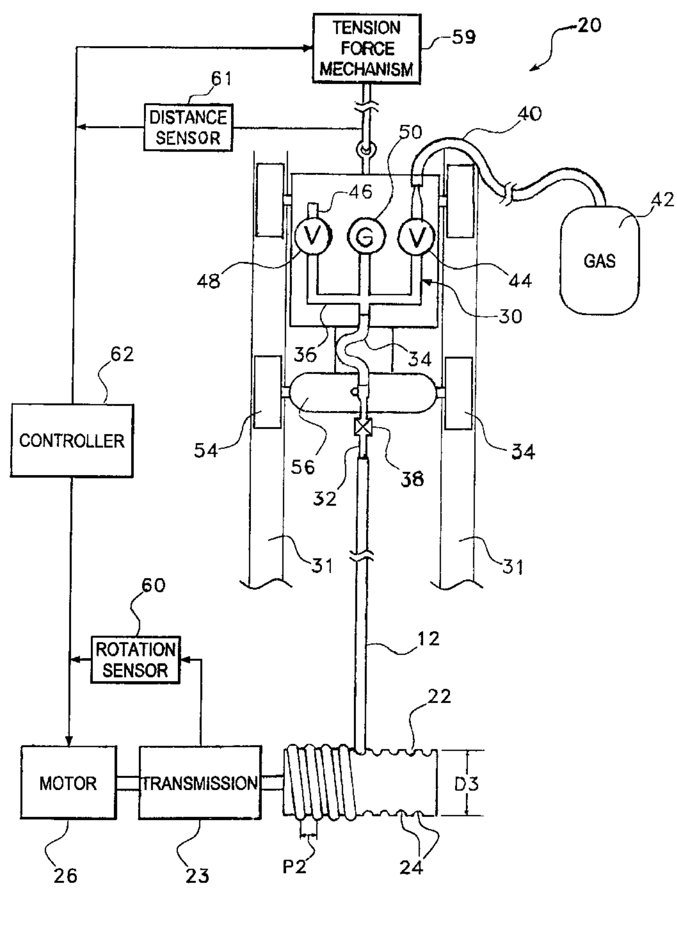
(57) **ABSTRACT**

A system and method of winding a length of tubing into a coil. The system uses a mandrel to wind a length of tubing into the form of a coil. The length of tubing is both internally pressurized and placed under tension prior to being wound around the mandrel. The tension experienced by the length of tubing causes the tubing to conform to the shape of the mandrel as the mandrel rotates. The internal pressurization of the tubing keeps the diameter of the tubing round as it is deformed around the mandrel. As such, the tubing is prevented from crushing or buckling as it winds around the mandrel.

16 Claims, 2 Drawing Sheets



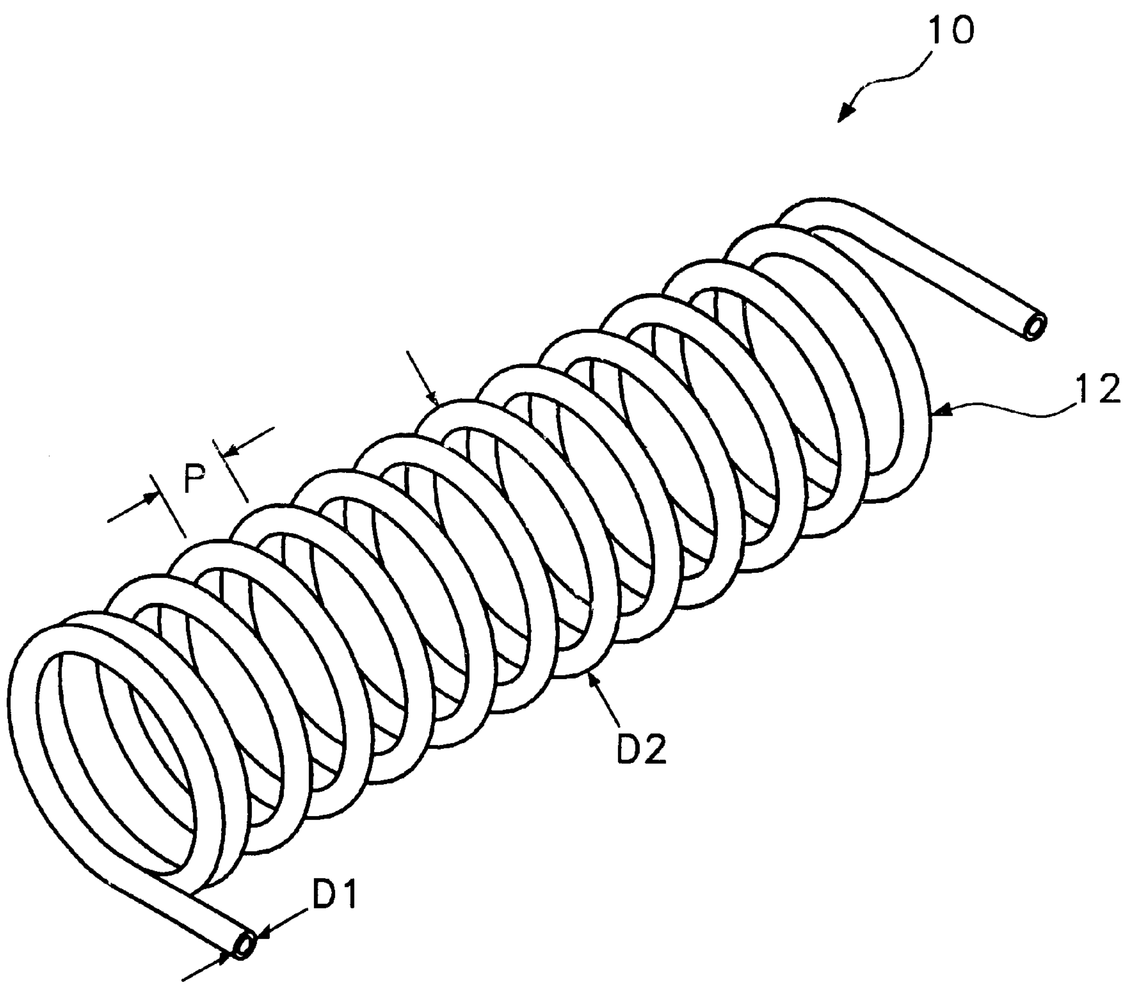


Fig. 1

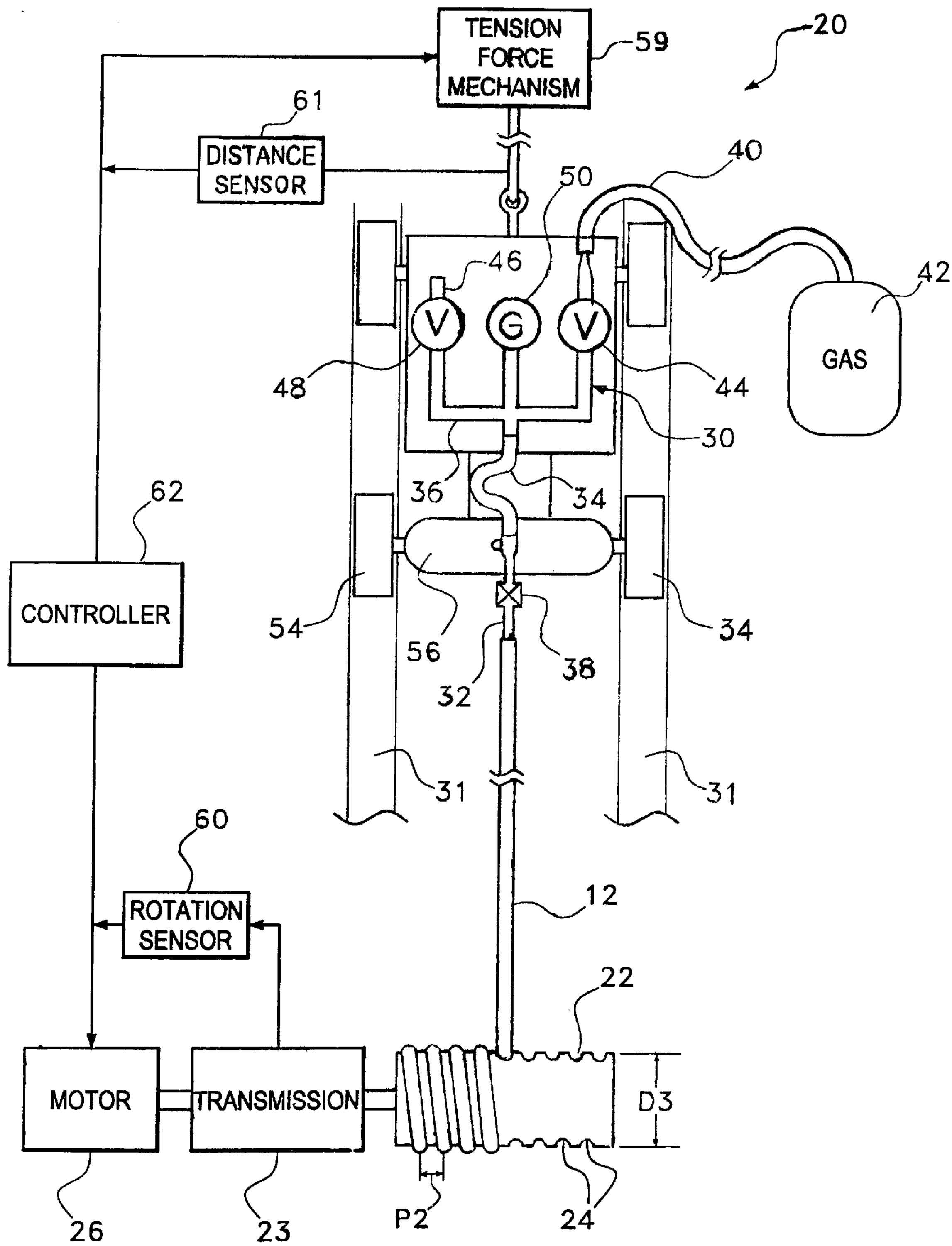

TENSION FORCE MECHANISM
59
20
61
DISTANCE SENSOR
50
40
46
42
GAS
V
G
V
48
44
30
36
34
62
CONTROLLER
54
56
34
38
32
31
31
60
ROTATION SENSOR
12
22
MOTOR
TRANSMISSION
D3
26
23
P2
24

Fig. 2

METHOD AND APPARATUS FOR WINDING THIN WALLED TUBING

REFERENCE TO DOCUMENT DISCLOSURE

The matter of this application corresponds to the matter contained in Disclosure Document 454,147, filed Apr. 1, 1999, wherein this application assumes the priority date of that document.

RELATED APPLICATIONS

This application is related to co-pending patent application Ser. No. 09/702,636, entitled HYDROGEN DIFFUSION CELL ASSEMBLY AND ITS METHOD OF MANUFACTURE.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to systems and methods of winding metal tubing into coils.

2. Description of the Prior Art

There are many different devices that contain coils made from hollow tubing. Such coils are commonplace in refrigerators, air conditioners, dehumidifiers and the like. When manufacturing such coils, a straight piece of metal tubing is connected at one end to a mandrel. The mandrel is then rotated, thereby cause the metal tubing to wind around the mandrel and create the desired coil. Such prior art coil production techniques work well for metal tubing that has thick walls. With such a thick walled tubing, the strength of the tubing itself prevents the tubing from crushing or buckling as it is wound around the mandrel. However, metal tube coils are made of many different materials and with many different wall thicknesses. In many applications, the strength of the tubing itself is insufficient to withstand a traditional winding procedure.

One application of a metal tube coil is described in co-pending patent application Ser. No. 09/702,636, entitled Hydrogen Diffusion Cell Assembly And Its Method Of Manufacture. In such an application, a coil is produced from palladium or a palladium alloy. Furthermore, the tubing is extremely thin walled, having an average wall thickness of between 0.001 inches and 0.005 inches. Such a thin walled tubing cannot be wound into a coil using prior art coil winding techniques. If such a thin walled tube were to be connected to a mandrel and wound in a traditional manner, the forces applied during the winding procedure would crush the tubing flat and/or cause the tubing to buckle.

A need therefore exists for a method and system that can be used to wind very thin walled tubing into coils. The need is met by the present invention as it is described and claimed below.

SUMMARY OF THE INVENTION

The present invention is a system and method of winding a length of tubing into a coil. The system uses a mandrel to wind a length of tubing into the form of a coil. However, prior to winding, the length of tubing is both internally pressurized and placed under tension prior to being wound around the mandrel. The tension experienced by the length of tubing causes the tubing to conform to the shape of the mandrel as the mandrel rotates. The internal pressurization of the tubing keeps the diameter of the tubing round as it is wound around the mandrel. As such, the tubing is prevented from crushing or bulking as it is wound around the mandrel.

The tension force applied to the length of tubing can be either constant or variable, depending upon the winding technique used. A constant tension force is used when the elongation of the length of tubing is left to chance. A variable tension force is used when the elongation of the length of tubing is monitored and controlled.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference is made to the following description of an exemplary embodiment thereof, considered in conjunction with the accompanying drawings, in which:

FIG. **1** is a perspective view of a tubing coil made utilizing the present invention system and method; and

FIG. **2** is a schematic illustrating the present invention system and its method of use.

DETAILED DESCRIPTION OF THE INVENTION

Although the present invention system and method can be used to produce coils from most any type of metal tubing, such as copper tubing, stainless steel tubing or the like, the present invention is especially well suited for winding thin walled, special metal tubing into coils. Consequently, by way of example, the present invention will be described in an application where it is used to wind palladium tubing having a wall thickness of only between 0.001 inches and 0.005 inches.

Referring to FIG. **1**, there is shown a coil **10** that has been fabricated using the present invention system and method. The coil **10** is made of metal tubing **12** that has been wound. In the shown embodiment, the metal tubing **12** being used is made of palladium or a palladium alloy. The tubing **12** has a diameter D1 of between 0.1 inches and 0.5 inches. The thickness of the wall of the tubing **12** can be as thin as 0.001 inches. The tubing **12** is wound into a coil having a coil diameter D2 and a winding pitch spacing P1 of at least as long as the diameter D1 of the tubing **12**.

Referring to FIG. **2**, a winding system **20** is shown for use in fabricating the wound coil **12** shown previously in FIG. **1**. The winding system **20** contains a winding mandrel **22**. The winding mandrel has an outer diameter D3 that corresponds to the coil diameter D2 (FIG. **1**) of the coil to be produced. The mandrel **22** has a helical groove **24** formed on its exterior surface. The helical groove **24** has a radius of curvature that corresponds to that of the tubing **12** being wound. The helical groove **24** in the mandrel **22** also has a winding pitch spacing P2 that corresponds to the winding pitch spacing P1 (FIG. **1**) of the coil being produced.

The mandrel **22** is turned by a motor **26**. An optional transmission **23** may be placed between the motor **26** and the mandrel **22** if the rotational speed of the motor **26** is different from what is practical for the winding procedure. A transmission **23** can also be used if the torque produced by the motor **26** is insufficient to directly wind the tubing **12**.

Prior to attaching the tubing **12** to the mandrel **22**, the first end of the tubing **12** is soldered closed to create a gas tight seal at the first end of the tubing **12**. The first end of the tubing **12** is then connected to the mandrel **22** at the beginning of the helical groove **24**. When the tubing **12** is first attached to the mandrel **22**, the tubing **12** is straight. The length of the straight section of tubing **12** is made to correspond to the length of tubing needed to complete the coil **10** (FIG. **1**).

The second end of the tubing **12** is connected to a wheeled cart assembly **30**. The wheeled cart assembly **30** has a front end and a rear end. At the front end of the wheeled cart **30** is a connection nipple **32**. The second end of the tubing **12** is soldered or otherwise interconnected to the connection nipple **32**. The connection nipple **32** is connected to a flexible hose **34** that leads to a gas supply manifold **36**. A gas flow restrictor **38** is positioned between the gas supply manifold **36** and the connection nipple **32** for a purpose which will later be explained.

The gas supply manifold **36** is connected to a supply hose **40** that connects the manifold **36** to a source of compressed gas **42**. Although many different types of gas can be used, the preferred gas is compressed nitrogen. A supply valve **44** is disposed between the manifold **36** and the supply hose **40** to selectively control the flow of compressed gas into the manifold **36** from the source of compressed gas **42**.

A vent port **46** is also connected to the gas supply manifold **36**. A venting valve **48** is disposed between the manifold **36** and the vent port **46** to selectively control the venting of gas from the gas supply manifold **36**. A pressure gauge **50** is also connected to the gas supply manifold **36** on the wheeled cart assembly **30**. The pressure gauge **50** measures the pressure in the gas supply manifold **36**.

When the second end of the tubing **12** is soldered to the connection nipple **32**, the interior of the tubing **12** becomes interconnected with the gas supply manifold **36**. Accordingly, as the source of compressed gas **42** pressurizes the gas supply manifold **36**, the interior of the tubing **12** also becomes pressurized. Consequently, the pressure gauge **50** that measures the pressure within the gas supply manifold **36** also measures the gas pressure that exists inside the tubing **12**. The flow restrictor **38** is used as a safety feature to prevent the tubing **12** from whipping around should the tubing **12** ever break or become severed while under pressure.

The pressure supplied to the tubing **12** depends upon the material and wall thickness of the tubing **12**. Preferably, the tubing **12** is pressurized to a pressure between one tenth and one half its designed rupture pressure.

The wheels **54** at the front end of the cart assembly **30** are attached to a front axle assembly **56** that is free to pivot. As a result, as the tubing **12** is wound along the length of the mandrel **22**, the wheeled cart assembly **30** can turn laterally and track along the length of the mandrel **22** with the advancing tubing **12**. Although not required, the tracking of the wheeled cart assembly **30** can be improved by providing a set of tracks **31** on which the wheeled cart assembly **30** rides. The tracks **31** guide the wheeled cart assembly **30** so that the wheeled cart assembly **30** is always at the proper position with respect to the mandrel **22** as the tubing **12** is wound.

The wheeled cart assembly **30** is free rolling and supplies only limited resistance to the rotating mandrel **22**. To keep the tubing **12** taut during winding, a tether **58** is attached to the rear end of the wheeled cart assembly **30**. The tether **58** supplies the wheeled cart assembly **30** with an resistance force F that opposes the rotational pull of the mandrel **22**. The resistance force F supplied through the tether **58** is created by a tension force mechanism **59**. The tension force mechanism **59** be a series of weights and pulleys, a clutched motor, a variable inclined plane or any other mechanism capable of providing a resistance to a tether under tension. The magnitude of the resistance force is dependent upon the characteristics of the tubing **12** being wound.

To operate the present invention system **20**, a segment of straight tubing **12** is supplied. The first end of the tubing **12** is sealed and is attached to the mandrel **22**. The opposite end of the tubing **12** is soldered to the connection nipple **32** on the wheeled cart assembly **30**. An appropriate resistance force F is applied to the tether **58** at the end of the wheeled cart assembly **30**. The resistance force F is thus experienced by the tubing **12**. The tension in the tubing **12** keeps the tubing **12** straight and causes the tubing **12** to conform to the helical groove **24** in the mandrel **22** as the mandrel **22** is wound.

Prior to winding the tubing **12** around the mandrel **22**, the supply valve **44** is opened on the wheeled cart assembly **30**. The supply valve **44** connects the pressurized gas source **42** to the connection nipple **32** through the supply manifold **36**. The pressurized gas in the supply manifold **36** fills the inside of the tubing **12**. The pressure of the gas is brought to a predetermined level as measured by the pressure gauge **50** on the wheeled cart assembly **30**.

Once the tubing **12** is pressurized and is under tension, the mandrel **22** is rotated. The tension experienced by the tubing **12** causes the tubing **12** to conform to the helical groove **24** on the mandrel **22**. The pressure within the tubing **12** causes the tubing **12** to maintain its round cross-section while it is deformed around the mandrel **22**. As such, the tubing **12** does not crush or buckle as it is deformed into a coil.

Once the tubing **12** is fully wound around the mandrel **22**, the supply valve **44** on the wheeled cart assembly **30** is closed and the tension of the tether **58** is released. The pressurized gas within the wound tubing **12** is then released by opening the venting valve **48** on the wheeled cart assembly **30**. The two ends of the wound tubing **12** are then freed and the wound tubing **12** is removed from the mandrel **22**.

The described method of operation can be varied in two ways. In a first technique, the resistance force F applied to the tether **58** by the tension force mechanism **59** can be kept constant. In a second technique, the resistance force F applied to the tether **58** by the tension force mechanism **59** is varied.

As the tubing **12** is placed in tension between the mandrel **22** and the wheeled cart assembly **30**, the tubing elongates. Using the first technique of constant tension, the resistance force F supplied by the tension force mechanism **59** is calibrated to be just slightly greater than what is needed to cause the tubing **12** to conform to the helical groove **24** in the mandrel **22**. Under these conditions the degree to which the tubing **12** stretches is dependent upon the wall thickness of the tubing **12** and the annealing of the tubing **12**. The wall thickness and annealing of the tubing **12** vary along the length of the tubing **12**. As such, the tube does not stretch evenly. The result is that different sections of tubing **12** may increase in length by between one percent and six percent. The variability in elongation also corresponds to variability of wall thickness causes by the elongation. The result is a wound coil hat has thin spots at different points in the tubing **12**.

A second technique used when winding the tubing **12** is to vary the tension force F as a function of tube elongation. To utilize this technique, a rotation sensor **60** is attached to the mandrel **22**, the mandrel motor **26** or the transmission **23** between the motor **26** and the mandrel **22**. The rotation sensor **60** detects the number of degrees the mandrel **22** has turned in a given period of time. Furthermore, a distance sensor **61** is coupled either to the wheeled cart assembly **30** or the tether **58** extending to the wheeled cart assembly **30**. The distance sensor **61** detects how far the wheeled cart assembly **30** has moved in a given period of time.

The rotation sensor **60** and the distance sensor **61** are both coupled to a controller **62**. The controller **62** controls the tension force mechanism **59**. The controller **62** varies the tension force mechanism so that the amount of tubing **12** wound on the mandrel **22** in a predetermined period of time corresponds to a predetermined degree of movement of the wheeled cart assembly **30** in that same predetermined period of time. The result is that the degree of elongation experienced by the tubing **12** is kept relatively constant along its entire length.

There are many variations to the present invention system and method that can made. For instance, the wheeled cart assembly **30** can be substituted with a sled, a tracked vehicle or any other assembly capable of linear movement. Furthermore, there are many different types of gas supply manifolds that can be used and there are many different connectors that can be used to connect the tubing **12** to the supply manifold **36**. It will therefore be understood that a person skilled in the art can make numerous alterations and modifications to the shown embodiment utilizing functionally equivalent components to those shown and described. All such modifications are intended to be included within the scope of the present invention as defined by the appended claims.

What is claimed is:

1. A method of creating a coil from a length of tubing, comprising the steps of:

connecting one end of the length of tubing to a mandrel;

applying a tension to the length of tubing that biases the tubing away from the mandrel;

internally pressurizing said length of tubing;

rotating said mandrel, wherein the length of tubing winds around the mandrel and forms a coil;

monitoring the rotation of said mandrel in a period of time;

monitoring the movement of said length of tubing toward said mandrel in said period of time; and

varying said predetermined tension force as a function of the rotation of said mandrel and the movement of said length of tubing.

2. The method according to claim **1**, wherein said mandrel has a helical groove formed thereon and the length of tubing conforms to the helical groove when wound around the mandrel.

3. The method according to claim **1**, wherein said step of applying a tension to the length of tubing includes the substeps of:

providing a cart;

attaching one end of the length of tubing to the cart;

biasing the cart away from the mandrel with a predetermined tension force.

4. The method according to claim **3**, wherein said substep of biasing the cart includes attaching a tether to the cart and applying said tension force to said tether.

5. The method according to claim **1**, wherein said step of internally pressurizing the length of tubing includes connecting the length of tubing to a pressurized gas source.

6. The method according to claim **3**, wherein said cart supports a supply manifold coupled to a pressurized gas source.

7. The method according to claim **1**, further including the step of venting pressure from the tubing after the length of tubing is wound around the mandrel.

8. The method according to claim **1**, wherein said tubing is made from a material selected from a group consisting of palladium and palladium alloys.

9. The method according to claim **1**, wherein the length of tubing has a predetermined rupture pressure and the length of tubing is internally pressurized to a pressure between one tenth and one half said predetermined rupture pressure.

10. A system for forming a length of tubing into a coil, comprising:

a selectively rotatable mandrel capable of engaging a first end of the length of tubing;

a supply manifold having a supply valve, a vent valve and a connection port, wherein the connection port is connectable to a second end of the length of tubing;

a cart for supporting said supply manifold;

a tensioning mechanism for biasing said cart away from said mandrel with a tension force, wherein said tubing experiences elongation under said tension force and said tensioning mechanism selectively varies said tension force as a function of said elongation; and

a source of compressed gas connected to said supply manifold, wherein said source of compressed gas can be selectively interconnected with the length of tubing via said supply valve.

11. The system according to claim **10**, wherein said mandrel has a helical groove formed thereon, whereby the length of tubing follows the helical groove when wound around said mandrel.

12. A method of winding tubing into a coil, comprising the steps of:

pressurizing the interior of a length of tubing to a predetermined pressure above ambient pressure;

winding the length of tubing around a mandrel while the length of tubing is pressurized;

applying a tensioning force to said length of tubing as it wound around said mandrel, wherein said tensioning force creates elongation in said length of tubing;

monitoring the rotation of said mandrel in a period of time;

monitoring said elongation in said length of tubing in said period of time;

varying said tensioning force as a function of the rotation of said mandrel and said elongation;

venting the tubing to ambient pressure; and

removing the wound tubing from the mandrel.

13. The method according to claim **12**, wherein said mandrel has a helical groove formed thereon and the length of tubing conforms to the helical groove when wound around the mandrel.

14. The method according to claim **12**, wherein said step of applying a tension force to the length of tubing includes the substeps of:

providing a cart;

attaching one end of the length of tubing to the cart;

biasing the cart away from the mandrel with a said tensioning force.

15. The method according to claim **13**, wherein said substep of biasing the cart includes attaching a tether to the cart and applying said tensioning force to said tether.

16. The method according to claim **13**, wherein said step of pressurizing the length of tubing includes connecting the length of tubing to a pressurized gas source.

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