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(54) **Title:** COMPACT ROBOTIC PAINTING BOOTH

(57) **Abstract:** A system for painting an article (12), such as an automotive vehicle body, includes a painting booth (16), a conveyor (14) for transporting articles (12) through the painting booth (16), a first rail (48) located beside and extending along the conveyor (14), a second rail (34) located beside and extending along the conveyor (14) at a lower elevation than an elevation of the first rail (48), a painting robot (26) including an articulating arm (40) mounted on the first rail (48) for displacement along the first rail (32), a panel opener robot (28) mounted on the second rail (34) for displacement along the second rail (34) such that the painting robot (26) and panel opener robot (28) can move past each other on the rails (34, 46) without interference, a paint applicator (200) carried by the painting robot (26), and a paint material system (300) for supplying paint to the applicator (200).

TITLE

COMPACT ROBOTIC PAINTING BOOTH

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U. S. Provisional Application Nos. 60/517,767, filed November 6, 2003, and 60/583,0789, filed June 25, 2004, the entire disclosures of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates generally to a robotic system for processing an article in serial high-volume production. More particularly, the invention pertains to minimizing the size of a painting booth containing a robotic system used to paint a motor vehicle body.

The safety zone is an area in a painting booth where people could be present while a robot, mounted for movement along a rail beside a conveyor, operates. Frequently people are present in the booth to view the robot in operation. It is conventional practice to use a limit switch, mounted on the rail, to stop the robot at a fixed location on the rail and prevent an articulating robot arm from entering the safety zone located at the end of the rail. If the robot travels too far down the rail, it will trip the limit switch and cause the robot to stop before the arm enters the safety zone.

Other techniques have been employed to guard against personal injury caused by a robot operating in a painting booth. For example, a light curtain, located at the boundary of the safety zone, stops the robot from entering the safety zone when the curtain is crossed by the end of the robot arm or tooling carried by the arm. The light curtain reduces the length of the rail and paint booth because it allows the robot to move to the end of the rail provided it does not cross the light curtain.

In an automotive paint booth, it is conventional to use a silhouette or cattle fence between the safety zone and the robot. The silhouette is a wall with a cutout slightly larger then the envelope of the vehicle body being process in the booth. The cattle fence is a railing that partially isolates the safety zone from the robot-painting zone. The cattle fence extends from the sidewall of the booth into the booth. There is an opening in the middle of the cattle fence that allows vehicle bodies to pass through the fence.

These devices are awareness barriers to remind people to stay out of the working range of the robot rather then a wall that is designed stop the robot. The light curtain typically extends from one side of the booth to the other side. But the light curtain must be disabled when the vehicle body is present because the vehicle body would otherwise break the light beam as the body passes along the conveyor path. Therefore, a control system is required to disable the light curtain, when the vehicle body passes through the light curtain. However, paint booth operators prefer that a safety emergency stop system operate independently of a control system, which, if operating correctly, would prevent the robot from entering the safety zone. Once the light curtain is disabled to allow the vehicle body to pass through the curtain boundary, booth occupants would not be protected from the robot if it went out of control and passed through the silhouette or cattle fence.

The limit switch wastes rail and booth line length. The light curtain must rely on a control system to disable the curtain when a vehicle body passes through the curtain boundary. When the light curtain is disabled to allow a vehicle body to pass, it doesn't offer any protection to a person in the safety zone. If control of the robot is lost while the curtain is disabled, the robot could pass through the silhouette or cattle fence undetected and enter the safety zone.

A technique is required that avoids wasted rail and booth length preferably by synchronizing the trip point of a limit switch based on the position of the rail and the angle of articulation of the robot the waist.

Other methods to reduce the size of a robotic paint booth and improve paint booth process throughput are required. For example, a painting robot, door opener robot, and a hood/deck opener robot, mounted on rails in the paint booth, would operate more efficiently if they could pass each other on the rails while performing their respective tasks.

Space in the paint booth that is required to accommodate direct charge atomizers could be saved by using a paint applicator, such as a rotary atomizer, that ionizes a stream of air directed onto the atomized paint produced by the atomizer.

A method to isolate a nonconductive paint component from a conductive component before mixing them is required when using a direct charge electrostatic application, in which the fluid stream is charged via direct contact with a high voltage probe.

Paint utility line failures are costly and time consuming to repair. It is necessary to support paint system utility lines connected across an articulating joint of a robot arm against failure induced by flexing the lines as the arm articulates. An arrangement of the utility lines that minimizes flexural displacement is required.

A goal of automatic painting equipment is to change rapidly from one paint color to another. Often the painting equipment includes a dump circuit, fluid passages used to carry cleaning solvent and waste paint from the system, as a means for venting existing air in the system before paint flow starts. It is preferable that a dump circuit for the solvent and waste paint land, and a vent circuit for venting air would be arranged for coordinated operation in order to expedite a cleaning operating, in which lines and operating components are cleaned and flushed of waste paint and solvent, and a color change operation, in which the system is filled with a new paint color.

SUMMARY OF THE INVENTION

The present invention concerns a robotic painting system for painting surfaces of a vehicle body including the interior surfaces of doors, hoods and decks. The system is located in a paint booth and includes a paint robot, a door opener robot, and a hood/deck opener robot mounted on rails that extend along a conveyor that carriers the body through the booth. The paint robot operates to paint the surfaces of the vehicle body using a bell cup applicator or the like. The door opener robot operates to move a vehicle door into a position so that the paint robot may paint its interior and exterior surfaces. Similarly, the hood/deck opener robot moves a hood and/or a deck lid of the vehicle body into a position so that the paint robot may paint its interior and exterior surfaces. Each of the robots can pass by the painting system, the other robots, and the vehicle body without interference while its doors, hood, and a deck lid are open.

Each opener robot can hand off an opened body panel to another opener robot. The door opener robot is positioned to minimize paint over- build-up. The system and method of this invention allow use of a compact indirect charge system for waterborne paint and direct charge fast color change systems for solvent and water-based materials.

A cam actuated limit switch assembly located at an articulating joint of a robot arm decreases the lengths of the rail and paint booth. A the arm becomes increasingly aligned with the axis of the rail, the limit switch is actuated to stop robot movement when the robot is at progressively greater distances from the end of the rail in order to prevent the end of the robot arm from entering the safety zone. But as the robot arm becomes increasingly articulated out of alignment with that axis, the limit switch is actuated when the robot is progressively closer to the end of the rail and before end of the robot arm enter the safety zone. Therefore, to the extent that the robot arm is extended laterally away from the rail and toward the article being processed in the paint booth, the rail's length and the paint booth's length are reduced by use of the limit switch assembly.

The system can operate in a reliable manner with similar maintenance intervals to those of other automotive class rotary atomizers. The benefits of the ionized air charging method and system are particularly useful for (a) continuous painting systems using conductive paints, such as waterborne fascia painting systems or automotive body exterior systems using batch painting methods; (b) painting systems using a combination of conductive and non-conductive paints; and (c) painting systems used to the interior compartments of automotive vehicles, where the non-incendiary benefits prevent electrostatic discharge, thus impeding ignition of the atomized paint cloud.

The paint utility line that supply electric power, paint, solvent, control system communications, etc. to the robot arm and paint system are protected against flexural failure as the arm articulates by securing them to the robot such that the lines are spaced in a wide, thin ribbon by a separator control bar located between a single bundle clamp and a staggered bundle clamp.

A paint system controller controls operation of a dump valve and vent valve, arranged in parallel with the dump valve, such that the vent valve is opened during a color change operation to vent air through narrow flow passages to a dump collector. The system opens the dump valve to the collector during a cleaning operation, which flushes solvent and waste paint from the supply lines and components of the painting system to the collector. This arrangement and control provides an advantage since the dump valve must be closed at precisely the right time in the process to gain the maximum benefit of venting all the air in the system, while preventing paint from being wasted through the dump passage. At the high flow rates desired for rapid color changing, inaccurate timing of even a fraction of a second can result in unacceptably high paint waste volumes. For example, in a conventional system, filling or priming at 1200 cc/min. will waste about 10 cc if the dump valve closes only 0.5 seconds too late.

DESCRIPTION OF THE DRAWINGS

The above, as well as other advantages of the present invention, will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment when considered in light of the accompanying drawings in which:

Figure 1 is a front elevation view of a painting system in accordance with the present invention, including a paint robot and opener robots shown in extended positions, in a paint booth containing a vehicle body;

Figure 2 is a perspective view of the painting system shown in Figure 1 with an alternate embodiment of hood/deck opener robot;

Figure 3 is a schematic top view of a limit switch arrangement for a robot supported on a rail;

Figure 4 is perspective view of a robot having multiple links;

Figure 5 is a schematic diagram of a robot mounted on a rail;

Figures 6-8 are schematic views showing the space saving effect of a limit switch assembly for a robot, whose arms are shown in extended and articulated positions;

Figure 9 is a schematic top view showing the effect of a limit switch arrangement installed on a robot supported on a rail in a paint booth;

Figures 10A-10D are alternate forms of a cam, cam follower, and limit switch assembly;

Figure 11 is a block diagram of an apparatus for isolating the conductive component of paint from the nonconductive component before mixing them;

Figure 12 is schematic diagram of a paint delivery circuit;

Figure 13 is a schematic diagram of a paint delivery circuit;

Figure 14 is perspective view of an apparatus for routing paint utility conduits across an articulating joint on a robot arm;

Figure 15 is a schematic view of a staggered clamp for the conduits of Figure 14;

Figure 16 is a perspective view of the staggered clamp shown in Figure 15;

Figure 17 is a perspective view of a lower clamp of Figure 14;

Figure 18 is a perspective view of the separator/control bar shown in Figure 14; and

Figure 19 is a schematic diagram of a paint delivery circuit including a dump valve and vent valve.

DESCRIPTION OF THE PREFERRED EMBODIMENT

1. Bypass Arrangement for Paint Booth Robots

Referring now to Figure 1, a robot bypass system in accordance with the present invention is indicated generally at **10**. The system **10** illustrated is a painting system for painting a vehicle body **12** moving along a track or conveyor **14** in a paint booth **16**. The paint booth **16** includes a roof **18** and a floor portion **20** connected by side walls **22** (only one is shown) to define an interior **24** thereof. The painting system **10** includes a paint robot **26**, a door opener robot **28**, and a hood/deck opener robot **30**. The paint robot **26**, door opener robot **28**, and hood/deck opener robot **30** are each shown in an extended or operating position in Figure 1. The paint robot **26** is mounted on an upper rail **32** attached to the sidewall **22** of the paint booth **16**, although the rail **32** may be supported, instead, on a frame above the floor **20**. The upper rail **32** is located near the roof **18** of the paint booth **16** and extends in a horizontal direction parallel to the conveyor **14**. The paint robot **26** is slidably mounted on the upper rail **26** to allow the paint robot to move relative to the vehicle body **12** during operation of the system **10**.

The door opener robot **28** and the hood/deck opener robot **30** are mounted on a lower rail **34** located near the floor **20** of the paint booth **16** and also attached to the side wall **22** or supported, instead, on a frame above the floor **20**. The lower rail **34** extends in a horizontal direction parallel to the conveyor **14**, and the door opener robot **28** and the hood/deck opener robot **30** are slidably mounted on the lower rail **34** to allow these robots to move relative to the vehicle body **12** during operation of the system **10**.

The paint robot **26** includes a base portion **36** slidably attached to the upper rail **32** and being rotatable about a vertical first axis. An inner arm portion **38** is pivotally attached to the base portion **36** for rotation about a horizontal second axis. An outer arm portion **40** is pivotally attached to the inner arm portion **38** for rotation about a horizontal third axis. A wrist **42** is attached a free end of the outer arm portion **40** and has fourth and fifth axes of rotation. A paint applicator **44** is attached to the wrist **42** and preferably includes a bell applicator or the like (not shown). The paint robot **26**, therefore, includes multiple (six including the sliding movement) degrees of freedom and is operable to articulate between an extended position, shown in Figure 1, and a retracted position, not shown. A plurality of supply lines **46** provides colors of paint, air and solvent to the robot **26** and a process control enclosure **48** is attached to the base **36** for housing control wiring and equipment (not shown) for controlling the operation of the paint robot **26**.

The door opener robot **28** includes a base portion **50** slidably attached to an upper portion of the lower rail **34** and a first arm portion **52** pivotally attached to the base portion **50** for rotation about a vertical first axis. A second arm portion **54** is pivotally attached to the first arm portion **52** for rotation about a vertical second axis. A door opener mechanism **56** is mounted at a free end of the second arm portion **54** for engaging and manipulating a front door **12a** and/or a rear door **12b** hinged to the vehicle body **12**. The mechanism **56** is operable to grasp the vehicle doors **12a** and/or **12b** such that robot **28** can move the door into a position so that an interior and/or exterior surface thereof may be painted by the paint robot **26**. The door opener robot **28** is operable to articulate between an extended position, shown in Figure 1, and a retracted position, not shown.

The hood/deck opener robot **30** includes a base portion **58** slidably attached to a lower portion of the lower rail **34,** and a first arm portion **60** pivotally attached to the base portion **58** for rotation about a vertical first axis. A second arm portion **62** is pivotally attached to the first arm portion **60** for rotation about a vertical second axis. A hood/deck manipulator **64** is mounted at a free end of the second arm portion **62** and has several movable arm portions operable to grasp a hood **12c** or deck lid (not shown) of the vehicle **12** to move the hood and/or deck into a position so that an interior and/or exterior surface thereof may be painted by the paint robot **26**. The hood/deck opener robot **30**, therefore, includes multiple degrees of freedom and is operable to articulate between an extended position, shown in Figure 1, and a retracted position, not shown.

The robotic painting system **10** shown in Figure 1 permits each of the robots **26, 28** and **30** to move past the other ones of these robots when necessary. In addition, when the robots **26, 28** and **30** are retracted toward the side wall **22**, the vehicle body **12** can be moved past the robots on the conveyor **14** while the doors **12a** and **12b**, hood **12c** and deck lid **12d** are open. Although not shown, a duplicate of the painting system **10** is provided on the opposite side of the conveyor **14** for painting the passenger side of the vehicle body **12**.

Referring now to Figure 2, an alternate embodiment painting system **10'** is shown with the paint robot **26**, the door opener robot **28**, and a hood/deck opener robot **66**. The robot **66** is similar to the robot **30** of Figure 1 except that it is slidably mounted on the same upper portion of the lower rail **34** as is the door opener robot **28** for painting operations where the **28** and **66** are not required to move past each other.

Although the system **10** is described in terms of a vehicle body painting system, it can be used to perform other operations wherein it is desirable for robots to bypass one another.

2. Painting Booth Safety Zone Limit Switching

Referring now to Figures 3 through 10D, a robot in accordance with the present invention is indicated schematically at **100**. The robot **100** is mounted on a base portion or carriage **102,** and it rotates on the carriage **102** about a waist axis. The robot **100** is adapted to be mounted on a longitudinal rail **106** located beside the conveyor **14** and is operable to move along axis **108,** which is substantially parallel to a longitudinal axis of the rail **106**. At least one robot arm **110** extends outwardly from the robot **100** and includes a robot wrist **112** and a tool **114**, such as a rotary paint atomizer or the like, on a free end of the arm. The robot **100** includes a cam **116**, formed on a radially outer edge and secured to the base of the robot for rotation on the carriage about the waist axis. The cam **116** engages a limit switch lever **118**, which pivot about a pivot support **120** as the cam and robot rotate. A spring **122** biases the lever into engagement with the cam **116**. A limit switch **124**, located adjacent the free end of the lever **118**, is connected to an electronic control system, which control operation of the robot **100** including control of a braking system that stops movement of the robot along the rail **108** and rotation about the waist axis.

The profile of the cam **116** on the robot **100** is such that when the robot **100** rotates counterclockwise about the waist axis, the cam **116** rotates counterclockwise about the axis, the lever **118** follows the cam and rotates counterclockwise about the point **120** compressing the spring **122** and engaging the limit switch **124**. The limit switch **124** is actuated to send a signal to the control system, which produces an output signal that stops translational and rotational displacement of the robot **100**. The profile of the cam **116** is selected such that the limit switch **124** is actuated by the lever **118** when an outer surface of the tool **114** enters an emergency stopping zone, indicated by an arrow **126** adjacent a safety zone, indicated by a line **128**. By stopping operation of the robot **100** when the tool **114** enters the emergency-stopping zone **126**, the tool will continue into the zone **126** but will decelerate to a stop before entering the safety zone **128**. Thus, the limit switch **124** stops operation of the robot **100** if the robot **100** is at the emergency-stopping zone **126**, regardless of the angular position of the robot. This arrangement allows the rail **106** and painting booth to be of a shorter overall length than would otherwise be required, thereby decreasing the cost of the rail **106** and booth. A stop bracket **130** prevents the carriage **102** from moving along axis **108** into either of the zones **126** or **128**.

As best seen in Figure 4, the robot **100** may include multiple rotary links: an inner arm **132** extending from and rotating on the carriage **102**, an outer arm **134** extending from and rotating on the inner arm **132**, a third arm **136** extending from and rotating on the outer arm **134**, and robot arm **110** extending from and rotating on the third arm **136**. The inner arm **132**, the outer arm **134**, and the third arm **136** each includes a cam **116**, lever 118 and limit switch **124**, which are organized in the form of an limit switch assembly **138** located at each articulating joint of the arm, as shown in Figure 3. The limit switch assemblies **138** are preferably connected in series, provide feedback to the control system, and stop operation of the robot **100** when either the inner arm **132**, the outer arm **134** or the third arm **136** enters the emergency stopping zone **126**. In addition, if the robot **100** includes any other type of links, those links also may include a limit switch assembly **138**. As is best seen in Figures 5-8, by incorporating feedback from the inner arm **132**, outer arm **134**, and third arm **136**, the effective length of the rail **106** may be decreased by a distance, indicated by the arrow **140** in Figures **7** and 8. The length of arrow **140** is equal to the difference between a distance **R2** and a distance **R1**. The distance **R2** is substantially equal to the range of motion of the arms **132**, **134**, **136**, and **110**, or any combination of robot arms.

Figure 5 illustrates robot arms **110**, **132** extended in alignment with the rail **106** to the limit of the robot's travel along the rail before entering the safety zone at **128**, but without use of a switch assembly **138**. The distance from the waist axis to the safety zone **128** is R2. The wasted rail and paint booth lengths are indicated.

Figure 6 illustrates arm **132** articulated about the waist axis on the carriage **102**, arm **110** aligned with the rail **106**, its tool located at the boundary of the safety zone **128**, with use of a switch assembly **138.** The distance from the waist axis to the safety zone **128** is R1, a shorter distance than R2.

Figures 7 and 8 illustrate the length of the reduced rail length and booth length **140** when the switch assemblies **138** are used for condition when the robot arm is reaching backward and reaching forward, respectively.

As Figure 9 shows, as the robot arm **110** becomes increasingly aligned with axis **108**, the limit switch **124** is actuated to stop robot movement when the robot is at progressively greater distances from the end of the rail **106** in order to prevent the end of the robot arm **110** from entering the safety zone at **128**. But as the robot arm **110** becomes increasingly articulated out of alignment with axis **108**, the limit switch **124** is actuated when the robot is progressively closer to the end of the rail **106** and before end of the robot arm **110** enter the safety zone at **128**. Therefore, to the extent that the robot arm is extended laterally away from the rail **106** and toward the article being processed in the paint booth, the rail's length and the paint booth's length can be reduced by using the limit switch assembly 138 of this invention.

Figure 9 further shows the robot **100** supported by carriage **102** on rail **106** for movement along axis **108**. The robot arm **110** is shown in various angular positions about the waist axis, where a controller **150** will have stopped operation of the robot when an outer surface of the tool **114** enters the emergency stopping zone **126** and before the tool enters the adjacent safety zone **128**. A robot position sensor **152** produces input signals at frequent, timed intervals to the controller **150** representing the current longitudinal position of the waist axis on axis **108** from a reference position and the angular position of arm **110** about the waist axis from a second reference angular position.

A control algorithm expressed in computer coded software, which is stored in electronic memory accessible to the controller **150**, is repeatedly executed by the controller **150** at frequent intervals using as input the signals produced by sensor **152.** Using this information, the controller determines the speed, direction of movement, acceleration, and current axial position of the tool **114** relative to the emergency stopping zone **126.** The algorithm produces an output signal **154**, which issues from the controller **100** as input to a robot braking system controller **156**, which stops operation of the robot **100** when an outer surface of the tool **114** enters the emergency stopping zone **126** and before the tool **114** enters the adjacent safety zone **128.**

Other means for engaging the limit switch **124** with the movement of the cam **116** will be appreciated by those skilled in the art while not departing from the scope of the present invention. For example, a straight connecting rod **160**, whose opposite ends contact the cam **116** and lever **118**, respectively, converts cam rotation to lever pivoting, thereby allowing the robot to be laterally spaced from the rail **106**. Or a **162** having a tapered surface **164** may contact and follow the cam **116**, transmitting cam movement to spaced rods **166**, **168**, which slide in guides **170**, **172** instead of pivoting a lever. Or a four bar linkage **174** may hold a follower **176** having a tapered surface **178** in contact with the cam **116** as the linkage pivots on two fixed, pivot centers **180**, **182** at the end of two of the bars **184**, **186** of the linkage **174**. The cam may be connected eccentric of its center of rotation to a link **190** that reciprocates as the cam **116** rotates, thereby converting cam rotation to lateral displacement of the link **190**, which is applied to the lever **118** causing it to pivot. These alternate arrangements are shown, respectively in Figures 10A-10D.

3. Delivering Multi-Component Conductive Paints to Electrostatic Applicator

Referring now to Figure 11, a system and a method for delivering conductive paints electrostatically is indicated in block diagram form at **300**. The system **300** includes a first paint component **302** and at least one second paint component **304**. The system **300** may also include additional paint components up to an "nth" paint component **306**. Preferably, the first paint component **302** is a conductive component, and the second paint component **304** through "nth" paint component **306** may be either conductive or nonconductive. The system **300** also includes a circulation system with a color change system **308**, a means for electrically isolating the circulation system **310**, a fluid delivery system **312**, and a diagnostic system **314**. The portion of the painting system **300** that includes the first paint component **302**, the second paint component

304, and the "nth" paint component 306 is in communication with a multi-component mixing system 316, which is in communication with the paint applicator and application method 318.

The apparatus for isolating the circulation system 310 the fluid delivery system 312 and diagnostic system 314 from the circulation system 308 is are described and shown in the U.S. Patent Application Serial No. 10/004,936, filed December 5, 2001, which is assigned to the Assignee of the present invention. The entire disclosure of U.S. Patent Application Serial No. 10/004,936 is incorporated herein by reference. The apparatus and method disclosed in the referenced patent application comprise a first embodiment of the present invention. The apparatus in that patent application can also be duplicated such that two painting systems are run in parallel, a second embodiment of the present invention. The first system is prepared for the next color while the second system is changing the current color. This will allow for a continuous or batch delivery of paint — virtually eliminating the time required either to refill a paint canister or to clean and fill the canister with a second color paint.

In Figure 12, there is shown a third embodiment of the present invention for isolating the conductive components. The circulation system **308,** which includes a color change system, is connected to a source of solvent **330** and a source of pressurized air **332.** The circulation system **308** communicates through an electrically isolated line **310'** to the component mixing system **316'**, which can be a static mixing tube or another device used in multi-component delivery systems. A canister isolation system is used for the nonconductive material, such as resin. If a non-conductive component is used for one of the materials, a more traditional means such as a gear pump or flowmeter **312'** can be used to deliver that fluid to the multi-component mixing system **316'**.

The mixed material can be applied by any direct charge electrostatic paint applicator **318'**, such as a rotary atomizer, where the paint and/or applicator is charged (electrostatics), or an electrostatic gun applicator.

Pressure transducers **314'**, which can be used for the diagnostic system as optional components, sense high and low pressure conditions in the system **300** and identify an off-ratio condition. There is no need to isolate from the circulation system. The diagnostic system **314'**, which senses high or low pressure conditions in the system **300**, or to identify an off-ratio condition, is an optional component of this system.

There is shown in Figure 13 a fourth embodiment of the present invention for isolating the waterborne or substantially conductive component when only the waterborne or substantially conductive material is provided and no second component is added. This is a batch painting system.

The paint circulation system **308** delivers paint to a color valve stack. Different colors of paint are supplied to a color changer **326,** which delivers the paint to a pair of paint valves **328**, one of which supplies paint to one of the canisters **320, 321**. A pair of canisters **320, 321** alternately supplies paint through an isolation manifold **322** to a robot-mounted applicator **324**. Canister **320** is shown in a filling position where paint is delivered to canister **320** through valve **328** at a docking station. Canister **321** is shown in its painting position. Each canister consists of a stainless steel canister sleeve, canister body, piston, ram, ball screw, motor, and drive frame. The painting canister **321** must be suitably undocked from the docking station to allow electrostatic isolation. This requires an additional pair of air cylinders and guides. When canister **321** undocks from its paint valve, it engages isolation manifold **322**, which carries paint to the robot and paint applicator **324**.

During painting, the applicator **324** and the paint line from the applicator **324** back to the painting canister **321** are charged. The painting canister **321** is isolated from its environment by air space, and from its drive mechanism by petticoats and seals. The charged paint line is an "isocore" or similar insulated line. The filling canister **320** is grounded and isolated from the painting system by air space.

To substitute a new canister containing the same color paint, the following procedure is used. The cycle starts with canister **320** in the docking station full of paint, and separated by an air gap from isolation manifold **322**. Canister 321, which has just completed supplying paint to applicator **324**, is essentially empty. Cascade powers down. A switching mechanism docks canister **321** and undocks canister **320**. Cascade powers up. Painting may begin as soon as the electrostatic system is energized. Canister **321** continues to fill while canister **320** is painting.

To substitute a new canister containing different color paint the following procedure is used. The cycle starts with canister **320** in the docking station full of paint. Canister **321** has just completed painting, and is essentially empty. Cascade powers down. A switching mechanism docks canister **321** and undocks canister **320**. Canister **321** executes a clean cycle by flushing the color changer **326**, fill line **340**, and the line from canister **321** to outboard valve **342** using solvent from color changer **326**. The flush path is through canister **321** and back through dump to a drain **344**. Meanwhile, cascade powers up and canister **320** dispenses paint. When canister **320** has completed painting, cascade powers down. The switching mechanism docks canister **320**, and canister **321** remains in dock. Canister **320** executes a clean cycle, as described above for canister **321**. Concurrently, the solvair valve **346** supplies solvent to the isolation manifold **322** and applicator supply lines, thereby flushing paint out through applicator **324.** When the clean cycle is complete, solvair blows its line dry and pressurizes the line for electric isolation. When the cleaning cycle at the docking station is complete, canister **321** fills with the new color paint. The switching mechanism undocks canister **321**, and painting begins as soon as the electrostatic system is energized. Canister **320** fills with the new color while canister **321** paints.

4. Supporting Painting Utility Lines on Articulating Robot Arm

Paint hose life is important to the performance and reliability of the paint system. Paint line failures are costly and time consuming to repair. This invention ensures proper life of the paint lines, uses a proven clamping technique, and employs low cost parts.

Referring now to -Figure 14-18, a robot in accordance with the present invention is indicated generally at **400**. The robot **400** includes a lower arm **402**, pivotally attached to a carriage portion **404**, and an upper arm **406**, pivotally attached to the lower arm **402**. A bundle **408** of elongated tubes, containing electric lines, hoses, tubes, and cables, is attached to the carriage portion **404** by a lower clamp member **410**.

The tube bundle **408** carries, for example, electrical power lines, paint lines, compressed air passages, and solvent lines to a tool attached at an end of the upper arm **406** of the robot. An upper clamp member **412** attaches the bundle **408** to the lower arm **402**. The bundle **408** is gathered and held in the form of a ribbon of tubes between the upper clamp member **412** and the lower clamp member **410** by a separator/control bar **414**. As Figure 18 shows, the bar **414** is formed with holes spaced along its length, each hole containing the threaded shank of an eyebolt **418**, whose eye or ring is fitted with a tube of the bundle **408,** thereby engaging each of the tubes of the bundle **408** and holding them in a single row along the length of the bar **414**.

As is best seen in Figure 14, the upper clamp member **412** is formed of a series of clamps **411** arranged in a stack of mechanically connected clamps, member **412** having a first end **416,** a second end **418,** and a plurality of apertures **420** through the thickness of the clamps **411** arranged in an upper row **422** and a lower row **424**. The apertures **420** in the lower row of the upper clamp member **412** are staggered by substantially one half pitch with respect to the apertures **420** in the upper row of the upper clamp member **412**. The upper and lower rows of the upper clamp member **412** reduce the width of the clamp member **412**. Figure 16 shows the tubes of the bundle **408** passing through the upper clamp member **412** in a staggered arrangement.

The separator/control bar **414** holds the tubes of the bundle **408** in a ribbon of tubes arranged side-by-side, thereby preventing the bundle **408** from "bird caging" (wherein the lines bow outwardly in different directions) and requiring the individual hoses, tubes, and cables of the bundle **408** to move as a unit, which stabilizes the bundle **408** and prevents erratic movements of the bundle **408**. The separator/control bar **414** causes the tubes of the bundle **408** to transition from the staggered rows at the upper clamp member **412** to a wider array of tubes at the separator/control bar **414**. This arrangement of tubes in the ribbon configuration allows the individual hoses, tubes, and cables of the bundle **408** to bend on the neutral axis.

As is best seen in Figure 17, the lower clamp member **410** is formed of a series of clamps **426** arranged in a stack of mechanically connected clamps, member **410** having a first end **428**, a second end **430**, and a plurality of apertures **432** through the thickness of the clamps **426**, the apertures **432** being arranged in a single row. The apertures **432** are preferably equally spaced and allow the tubes of the bundle **408** to extend laterally the full width of the ribbon.

The combination of the lower clamp member **410**, the separator/control bar **414**, and the upper clamp member **412** allows the hoses, tubes, and cables of the bundle **408** to flex more naturally during movement of the robot **400**, thereby increasing the life of each of the tubes of the bundle **408**.

Alternatively, the lower clamp member **410** may be replaced with the upper clamp member **412**, such that the tubes are in staggered rows also at the lower end of the bundle.

5. Priming a Painting Circuit for Automatic Painting Equipment

Some systems for priming a painting circuit of automatic equipment use a dump circuit, i.e., passages used to carry cleaning solvents and waste paint from the system, as a means for venting existing air. In such a system, the dump valve must he closed at precisely the right time in the process to gain the maximum benefit of venting all the air in the system, while keeping paint from being wasted through the dump passage. At the high flow rates desired for rapid color changing, inaccurate timing of even a fraction of a second can result in unacceptably high waste volumes of paint.

In the method disclosed here for priming a painting circuit of automatic equipment, the problem of precise timing is solved by adding a parallel, but somewhat restrictive circuit controlled by a second valve, the vent valve. This second passage is substantially smaller than the main passage of the dump circuit, perhaps 0.3 mm in diameter compared to the 6 or 7 mm diameter dump passage. Because of the viscosity difference between the air being vented and the paint being introduced into the system, the small vent line does not restrict the flow of air, but it greatly inhibits the flow of paint. Thus, paint can be introduced into the system rapidly, but its flow will suddenly be reduced when the paint reaches the very small paint line. In one example, a small 0.5 mm diameter line, 100 mm long would allow a paint flow of only 6-3 cc/mm when supply pressure is 140 psi. In this case, an unfavorable error in valve timing of 0.5 seconds would result in the waste of only 0.053 cc of paint

Referring now to Figure 19, a painting circuit for automatic equipment is indicated generally at **500**. The painting circuit **500** includes a paint source **502** in fluid communication with an inlet to a fluid pump **504**, preferably a gear pump. An outlet of the pump **504** is in fluid communication with a paint atomizer, indicated schematically at **506**. The paint supply **502** is also in fluid communication with an inlet of a dump valve **508**. An outlet of the dump valve **508** is in fluid communication with a dump collector **510**. The paint supply **502** is also in fluid communication with a vent valve **512**. An outlet of the vent valve **512** is also in fluid communication with the dump collector **510**. The dump valve **508** and the vent valve **512**, therefore, are connected in parallel between the paint supply **502** and the dump collection **510**. The paint pump **504**, the paint atomizer **506**, the dump valve **508**, and the vent valve **512** are in communication with an electronic controller **514**.

The passages through the vent valve **512** and associated fluid lines are of a substantially smaller diameter than the diameter of the dump valve **508** and its associated fluid lines. The dump valve **508** is opened during a cleaning operation and is used to carry cleaning solvents and waste paint away from the paint atomizer **506** and the associated lines of the painting circuit **500**.

The vent valve **512** is used during a paint color change operation after the paint atomizer **506** and the painting circuit **500** have been cleaned and the cleaning solvent and waste paint have been routed to the dump collection **510** through valve **508**. During a paint color change operation, the lines of the painting circuit **500** are filled with a paint of a new color, but trapped air in the painting circuit **500** must be vented before using of the paint atomizer **506**. This action ensures that the painting circuit **500** and the paint atomizer **506** are primed properly, which ensures proper operation of the painting circuit **500** and the paint atomizer **506**. During the paint color change operation, the controller verifies that the dump valve **508** is closed, and it opens the vent valve **512** to allow trapped air to escape from the painting circuit **500** and to be routed to the dump collection **510**. Because the vent valve **512** and its associated lines are of a substantially smaller diameter than the diameter of the dump valve **508** and its associated lines, the volume of paint that may be lost while priming of the painting circuit **500** is small. Upon completion of the paint color change operation, the controller closes the vent valve **512,** and the painting circuit **500** and paint atomizer **506** are operated normally.

The system is passive. Therefore, it requires no sensors or control logic other than timing, and it is well suited to automated painting where equipment must often operate in hazardous environments. Because the system includes the larger dump passage in parallel with the vent passage, the large, unrestrictive passage is available to carry waste solvent and paint from the system.

In accordance with the provisions of the patent statutes, the present invention has been described in what is considered to represent its preferred embodiment. However, it should be noted that the invention can be practiced otherwise than as specifically illustrated and described without departing from its spirit or scope.

WHAT IS CLAIMED IS:

1. A system for painting articles, such automotive vehicle bodies, comprising:

an enclosed painting booth **16**;

a conveyor **14** for transporting articles through the painting booth **16**;

a first rail **32** located beside and extending along the conveyor **14**;

a second rail **34** located beside and extending along the conveyor **14** at an elevation different from an elevation of the first rail **32**;

a painting robot **26** including an articulating arm **40**, mounted on the first rail **32** for displacement along the first rail **32**;

a panel opener robot **28**, **30** including an articulating arm **54**, **52**, mounted on the second rail **34** for displacement along the second rail **34** such that the painting robot **26** and panel opener robot **28**, **30** can move past each other on the first rail **32** and second rail **34**, respectively, without interference;

a paint applicator **200** carried by the painting robot **26**; and

a paint material system **300** for supplying paint to the paint applicator.

2. The system of claim 1, wherein the panel opener robot **28**, **30** comprises:

a door opener robot **28** mounted on a first track of the second rail **34**;

a hood/deck opening robot **30** mounted on a second track of the second rail **34**, such that the painting robot **26**, the door opener robot **28**, and the hood/deck opening robot **30** can move past each other on the first rail **32** and second rail **34**, respectively, without interference.

3. The system according to claim 2 wherein the painting robot 26 includes a base portion **36** supported on the first rail **32**, and articulating arms **38**, **40** supported on the base portion **36**.

4. The system according to claim 2 wherein said door opening robot **28** includes a base **50** supported on the second rail **34**, and articulating arms **52**, **54** supported on the base portion **50**.

5. The system according to claim 2 wherein the hood/deck opening robot **30** includes a base portion **58** supported on the lower rail **34**, and articulating arms **60, 62** supported on the base portion **58**.

6. The system of claim 1, further comprising:

a device **100** for limiting a side swing of the painting robot arm **110** such that the side swing narrows progressively as the paint robot arm **110** approaches a limit of its travel on the first rail **32**.

7. The system of claim 1, further comprising:

a carriage **102** moveable along one of the first rail and second rail **106**, and rotatably supporting a robot arm **110** thereon;

a cam **116** supported on the carriage **102** for rotation with the robot arm **110**;

a follower **118** engaging the cam **116**; and

a limit switch **124** actuated by the follower **118** in response to rotation of the robot arm **110** and displacement of the carriage **102** on the rail **106**, the limit switch **124** being operable to stop operation of the robot arm **110** when a portion of the robot arm **110** enters a predetermined area **126**.

8. The system according to claim 7 wherein the follower for engaging the cam **116** is a limit switch lever **118**.

9. The system according to claim 7, wherein the robot arm **110** includes at least one link **136** that includes a limit switch **138**.

10. The system according to claim 7, further comprising:

a robot position sensor **152** for producing input signals at frequent intervals representing the current longitudinal position of the robot arm **110** on the respective rail **106**, and the angular position of a robot arm **110** about a waist axis;

an electronic robot controller **150** communicating with the robot position sensor **152**, for repeatedly executing at frequent intervals a control algorithm expressed in computer coded software, using as input the signals produced by robot position sensor, and producing an output signal commanding the robot arm **110** to stop operation; and

a robot brake controller **156** for stopping movement of the robot arm **110** on the rail **106** in response to the output signal produced by the robot controller **150** such that the robot arm **110** is prevented from entering a safety zone **126**.

11. The system of claim 1, wherein the paint material flow system **300** for supplying paint to the paint applicator **318** further comprises:

a source **302** of a first electrically conductive component of the paint material;

a source **304** of a second component of the paint material;

a circulation system **308** for supplying paint having various colors including apparatus **326** for producing a change in paint color supplied by the circulation system **308**;

a multi-component mixing system **316** for mixing the first and second components **302, 304** of the paint material;

a fluid delivery system **318** for delivering the second component **304** to the multi-component mixing system **316**;

an electrically isolating fluid line **310** connecting the circulation system **308** and the mult-component mixing system **316**; and

a fluid line for carrying a mixture that includes the first and second components **302, 304** to the paint applicator **318**.

12. The system of claim 11 further comprising pressure transducers **314** for sensing high pressure and low pressure conditions in the paint material flow system **300**.

13. The system of claim 11 wherein the paint applicator **318** is a direct charge electrostatic paint applicator in which a stream of the paint mixture is charged by contact with a high voltage probe during application of the mixture on the article.

14. The system of claim 11 wherein the fluid delivery system is a fluid pump **312**.

15. The system of claim 11 wherein the multi-component mixing system is a static mixing tube **316**.

16. The system of claim 1, wherein the painting robot **26** includes a carriage **102** mounted on the first rail **32** and supporting the painting robot **26** for rotational displacement, the system further comprising:

a bundle of elongated tubes **408**;

a lower clamp member **410** attached to the carriage **102** for holding a portion of the bundle length therein;

an upper clamp member **412** attached to the articulating arm **402** of the robot **26** and spaced from the lower clamp member **410**, for receiving a second portion the bundle length therein; and

a separator/control bar **414** located along the bundle length between the upper clamp member **412** and lower clamp member **410**, for securing each tube **408** to the separator/control bar **414** at mutually spaced locations along a length of the separator/control bar **414**.

17. The system according to claim 16 wherein the upper clamp member **412** is a stack of connected clamps **411**, forming a first row of apertures **422**, and a second row of apertures **424** offset and staggered with respect to the first row, the tubes **408** being fitted into the apertures **422**, **424**.

18. The system according to claim 16 wherein the lower clamp member **410** is a stack of connected clamps **426**, forming a single row of apertures **432**, the tubes **408** being fitted into the apertures **432**.

19. The system according to claim 16 wherein the tubes **408** contain at least one of electric power supply, paint lines, pressurized air lines, and solvent lines.

20. The system of claim 1, wherein the paint material flow system for supplying paint to the paint atomizer further comprises:

a source of paint **503**;

a source of solvent **502**;

a dump collector **510**;

a fluid pump **504** in communication with the paint source **503**, the solvent source **502**, and the paint applicator **506**;

a fluid circuit portion of the paint material flow system that delivers paint and solvent to the paint applicator **506**;

a vent valve **512** in fluid communication with the dump collector **510** and said fluid circuit portion;

a controller **512** for controlling the vent valve **512** to open a flow connection between the dump collector **510** and said fluid circuit portion during a color change operation, thereby allowing trapped air to escape from said fluid circuit portion.

21. The system of claim 20 further comprising:

a dump valve in fluid communication with the dump collector and said fluid circuit portion, the dump valve being arranged in parallel with the vent valve between the dump collector and said fluid circuit portion.

22. The system of claim 20, further comprising:

a dump valve **508** in fluid communication with the dump collector **510** and said fluid circuit portion, the dump valve **508** being arranged in parallel with the vent valve **512** between the dump collector **510** and said fluid circuit portion; and wherein

the controller **512** further opens a flow connection through the dump valve **508** during a cleaning operation, whereby solvent and waste paint flow from the paint applicator **506** and said fluid circuit portion to the dump collector **510**.

23. The system of claim 21 wherein a cross sectional area of a flow passage in the vent valve **512** and a cross sectional area of a fluid line connecting the vent valve to the painting system are small relative to a cross sectional area of a flow passage in the dump valve **508**.

24. The system of claim 22, wherein the controller **512** further closes the dump valve **508** during the paint color change operation, and closes the vent valve **512** during the cleaning operation.

25. A system for controlling the range of movement of a robot arm **110** along a rail **106**, comprising:

a carriage **102** moveable along the rail **106**, and supporting the robot arm **110** for rotation about an axis;

a cam **116** that moves with the carriage **102** along the rail **106**, and that rotates with the robot arm **110** about the axis;

a follower **118** continually engaging the cam **116**; and

a limit switch **124** actuated by the follower **118** in response to rotation of the robot arm **110** about the axis and movement of the carriage **102** along the rail **106**, the limit switch **124** being operable to stop operation of the robot arm **110** when a portion of the robot arm **110** enters a predetermined area **126**.

26. The system according to claim 25, further comprising:

a spring **122** for urging the follower **118** into engagement with the cam **116**; and

wherein the follower **118** is a lever pivotably supported on the rail **106** near an end of the rail **106**.

27. The system according to claim 25, the system further comprising a spring **122** for urging the follower **118** into engagement with the cam **116**, and wherein:

the follower **118** is a lever pivotably supported on the rail **106** near an end of the rail **106**;

the cam **116** includes a cam surface that extends from the axis an increasingly greater distance as an angular displacement of the robot arm **110** about the axis approaches alignment with the rail **106** and as the robot arm **110** approaches the limit switch **124**; and

the limit switch **124** is actuated by the follower **118** when the robot arm **110** enters the predetermined area **126**.

28. A system for controlling the range of movement of a robot along a rail, comprising:

a carriage **102** moveable along the rail **106**, and supporting a robot arm **110** for rotation about an axis;

a cam **116** that moves with the carriage **102** along the rail **106** and that rotates with the robot about the axis;

a follower **118** continually engaging the cam **116**; and

a limit switch **124** actuated by the follower **118** in response to rotation of the robot arm **110** about the axis and movement of the carriage **102** along the rail **106**, such that as the robot arm **110** becomes increasingly aligned with the rail **106**, the limit switch **124** is actuated to stop robot arm movement when the robot is progressively further from an end of the rail **106**, and as the robot arm **110** becomes increasingly angularly displaced about the axis from alignment with the rail **106**, the limit switch **124** is actuated to stop robot arm movement when the robot is progressively closer to the end of the rail **106**, the limit switch **124** being operable to stop operation of the robot when a portion of the robot arm **110** enters a predetermined area **126**.

29. A system for controlling the range of movement of a robot along a rail, comprising:

a carriage 102 moveable along the rail **106**, and supporting a robot arm **110** for rotation about an axis;

a robot position sensor **152** for producing input signals at frequent intervals representing the current longitudinal position of the robot arm **110** on the respective rail **106**, and the angular position of a robot arm **110** about a waist axis;

an electronic robot controller **150** communicating with the robot position sensor **152**, for repeatedly executing at frequent intervals a control algorithm expressed in computer coded software, using as input the signals produced by robot position sensor, and producing an output signal commanding the robot arm **110** to stop operation; and

a robot brake controller **156** for stopping movement of the robot arm **110** on the rail **106** in response to the output signal produced by the robot controller **150** such that the robot arm **110** is prevented from entering a safety zone **126**.

30. A system for supporting paint utility lines, comprising

a robot arm **402** supported for articulation about a joint;

a carriage **102** supporting the robot arm **402** for rotation about an axis;

a bundle of elongated tubes **408** containing the utility lines;

a lower clamp member **410** attached to the carriage **102** for holding a portion of the bundle length therein at one side of the articulating joint;

an upper clamp member **412** attached to the articulating robot arm **402** and spaced from the lower clamp member **410**, for receiving a second portion the bundle length therein at an opposite side of the articulating joint from the first side; and a separator/control bar **414** located along the bundle length between the upper clamp member **412** and lower clamp member **410**, for arranging the tubes **408** in a single row along a length of the separator/control bar **414**.

31. The system according to claim 30 wherein the upper clamp member **412** is a stack of connected clamps **411**, forming a first row of apertures **422**, and a second row of apertures **424** staggered with respect to the first row **424**, the tubes **408** being fitted into the apertures **422**, **424**.

32. The system according to claim 30 wherein the lower clamp member **410** is a stack of connected clamps **426**, forming a single row of apertures **432**, the tubes **408** being fitted into the apertures **432**.

32. The system according to claim 30 wherein the separator/control bar **414** is formed with a row of holes extending through the separator/control bar **414** at mutually spaced locations along a length of the separator/control bar **414**, the system further comprising:

an eyebolt **418** secured to the separator/control bar **414** at each hole and formed with a ring, each tube of the bundle **408** passing through a ring, thereby securing the tubes **408** to the separator/control bar **414**.

34. A system for priming a paint material flow system **500** for supplying paint to a paint atomizer **506**, further comprising:

a source of paint **503**;

a source of solvent **502**;

a dump collector **510**;

a fluid pump **504** in communication with the paint source **503**, the solvent source **502**, and the paint atomizer **506**;

a fluid circuit portion of the paint material flow system **500** that delivers paint and solvent to the atomizer **506**;

a vent valve **512** in fluid communication with the dump collector **510** and said fluid circuit portion;

a controller **512** for controlling the vent valve to open a flow connection between the dump collector and said fluid circuit portion **500** during a color change operation, thereby allowing trapped air to escape from said fluid circuit portion.

35. The system of claim 34 further comprising:

a dump valve **512** in fluid communication with the dump collector **510** and said fluid circuit portion, the dump valve **512** being arranged in parallel with the vent valve **512** between the dump collector **510** and said fluid circuit portion.

35. The system of claim 34, further comprising:

a dump valve **508** in fluid communication with the dump collector **510** and said fluid circuit portion, the dump valve **508** being arranged in parallel with the vent valve **512** between the dump collector **510** and said fluid circuit portion; and wherein

the controller **512** further opens a flow connection through the dump valve **508** during a cleaning operation, whereby solvent and waste paint flow from the paint atomizer **506** and said fluid circuit portion to the dump collector **510**.

37. The system of claim 35 wherein a cross sectional area of a flow passage in the vent valve **512** and a cross sectional area of a fluid line connecting the vent valve **512** to the painting system **500** are small relative a cross sectional area of a flow passage in the dump valve **508**.

38. The system of claim 36, wherein the controller **512** further closes the dump valve **508** during the paint color change operation, and closes the vent valve **512** during the cleaning operation.

39. A system for supplying paint to a paint applicator **318** for application on an article, comprising:

a source of a first electrically conductive component of the paint material;

a source of a second component of the paint material;

a circulation system **308** for supplying paint having various colors including apparatus for producing a change in paint color supplied by the circulation system;

a multi-component mixing system **316** for mixing the first and second components of the paint material;

a fluid delivery system **318** for delivering the second component to the multi-component mixing system **316**;

an electrically isolating fluid line **310** connecting the circulation system **308** and the mult-component mixing system **316**; and

a fluid line for carrying a mixture that includes the first and second components to the paint applicator **318**.

40. The system of claim 39 further comprising pressure transducers **314** for sensing high pressure and low pressure conditions in the paint material flow system.

41. The system of claim 39 wherein the paint applicator is a direct charge electrostatic paint applicator **318**, in which a stream of the mixture is charged by contact with a high voltage probe during application of the paint mixture on the article.

42. The system of claim 39 wherein the fluid delivery system is a fluid pump **312**.

43. The system of claim 39 wherein the multi-component mixing system is a static mixing tube **316**.

44. A method for minimizing the floor space of a robotic painting booth **16** in which an article **12**, such as automotive vehicle body, is painted, the painting booth **16** containing a conveyor **14** for transporting the article **12**, a painting robot **26** having an articulating arm **110**, alongside the conveyor **14**, a paint applicator **200**, a paint material flow system **300**, then method comprising any one of the following steps and any combination of the steps:

a) limiting a side swing of the painting robot arm **110** such that the side swing narrows progressively as the paint robot **26** approaches a limit of its travel in the painting booth **16**;

b) mounting the painting robot **26** on a first rail alongside the conveyor **14**, and mounting a panel opener robot **28** on a second rail **34** at different elevation than the elevation of the first rail **32**, such that the painting robot **26** and panel opener robot **28** move past each other on the respective rails **32**, **34** without interference;

c) providing the painting robot **26** with a tube-bundle **408** control arrangement that allows the robot arm **110** to articulate in opposite directions from a straight alignment of the robot arm **110**;

d) allowing a first panel opener robot **28** to hold a panel **12a** and to release the panel **12a** only after a second panel opener robot **30** engages and holds the panel **12a**;

f) ionizing an air stream **224** and directing the ionized air stream **224** into atomized paint produced by the paint applicator **200** when applying paint electrostatically;

g) reducing paint change cycle time by purging a leading portion of a paint line **340, 342** while painting from an end portion of the line **321**; and

h) using a parallel air venting line **512** to expedite priming of the paint lines during a paint color change operation.

45. The method of claim 44, wherein step (b) further comprises:

mounting a first panel opener robot **28** on a first track of a second rail **34**; and

mounting a second panel opener robot **30** on a second track of the second rail **34**, such that each panel opener robot **28, 30** can pass the other panel opener robot and the painting robot **26** without interference.

46. A method for batch painting an article **12** with electrically conductive paint using a system that includes first and second canisters **320, 321**, a paint applicator **324**, a docking station **328**, and a paint color changer **326**, comprising the steps of:

a) filling the first canister **320** with paint from the paint color changer **326** at the docking station **328**;

b) deenergizing an electrostatic charge on the paint applicator **324**;

c) moving the first canister **320** from the docking station **328**;

d) connecting first canister **320** to the paint applicator **324**;

e) installing the second canister **321** in the docking station **328**;

f) grounding the second canister **321** and electrically isolating the second canister **321** from the painting system **300**;

g) producing an electrostatic charge on the paint applicator **324** and first canister **320**;

h) filling the second canister **321** with paint from the paint color changer **326** at the docking station **328**; and

i) upplying paint from the first canister **320** to the paint applicator **324**.

47. A method for changing paint color in a painting system **300** that includes first and second canisters **320**, **321**, a paint applicator **324**, a docking station **328**, a paint color changer **326**, and a dump drain **344**, comprising the steps of:

a) filling the first canister **320** with paint from the paint color changer **326** at the docking station **328**;

b) deenergizing an electrostatic charge on the paint applicator **324**;

c) moving the first canister **320** from the docking station **328**;

d) installing the second canister **321** in the docking station **328**;

e) performing a cleaning operation by flushing solvent through the color changer **326** and the second canister **321** to the dump drain **344**;

f) connecting first canister **320** to the paint applicator **324**;

g) producing an electrostatic charge on the paint applicator **324** and first canister **320**;

h) supplying paint from the first canister **320** to the paint applicator **324**;

i) grounding the second canister **321** and electrically isolating the second canister **321** from the painting system **300**;

j) deenergizing the electrostatic charge on the paint applicator **324**;

k) installing the first canister **320** in the docking station **328**;

l) performing a cleaning operation by flushing solvent through the color changer **326** and the first canister **320** to the dump drain **344**;

m) flushing solvent through the paint supply lines to the paint applicator **324**, and the paint applicator **324**;

n) filling the second canister **321** with paint from the paint color changer **326** at the docking station **328**;

o) moving the second canister **321** from the docking station **328**;

p) producing an electrostatic charge on the paint applicator **324** and the second canister **321**;

q) supplying paint from the second canister **321** to the paint applicator **324**; and

r) filling the first canister **320** with paint from the paint color changer **326** at the docking station **328**.

1/12

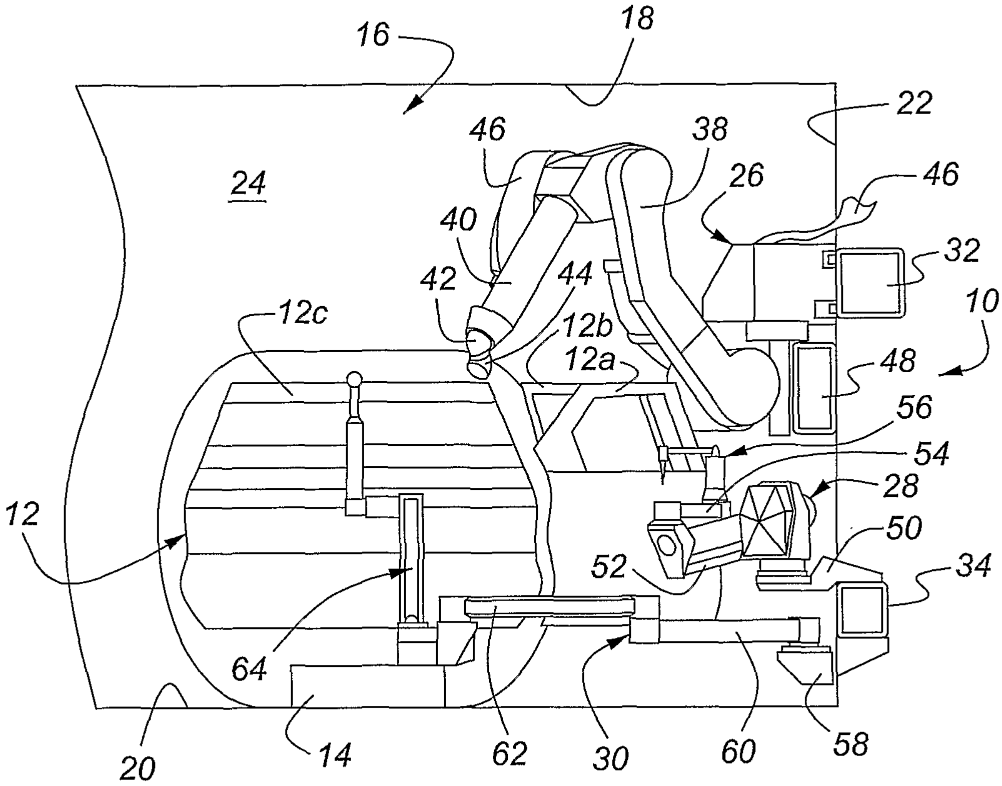
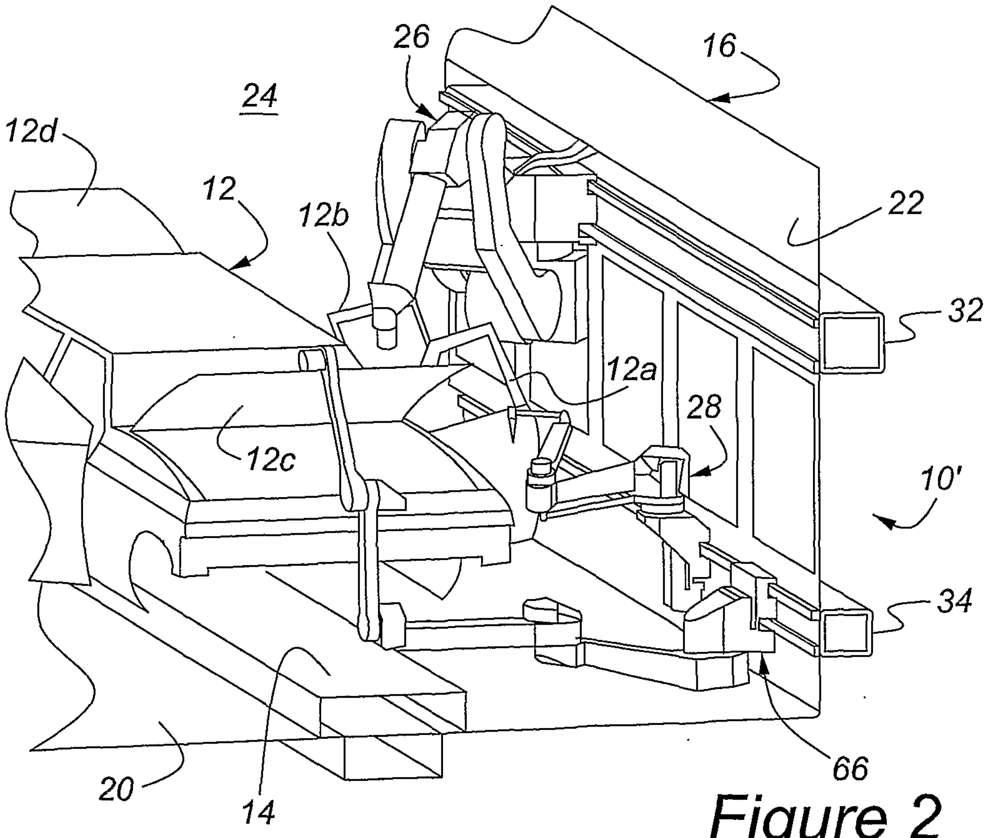


Figure 1



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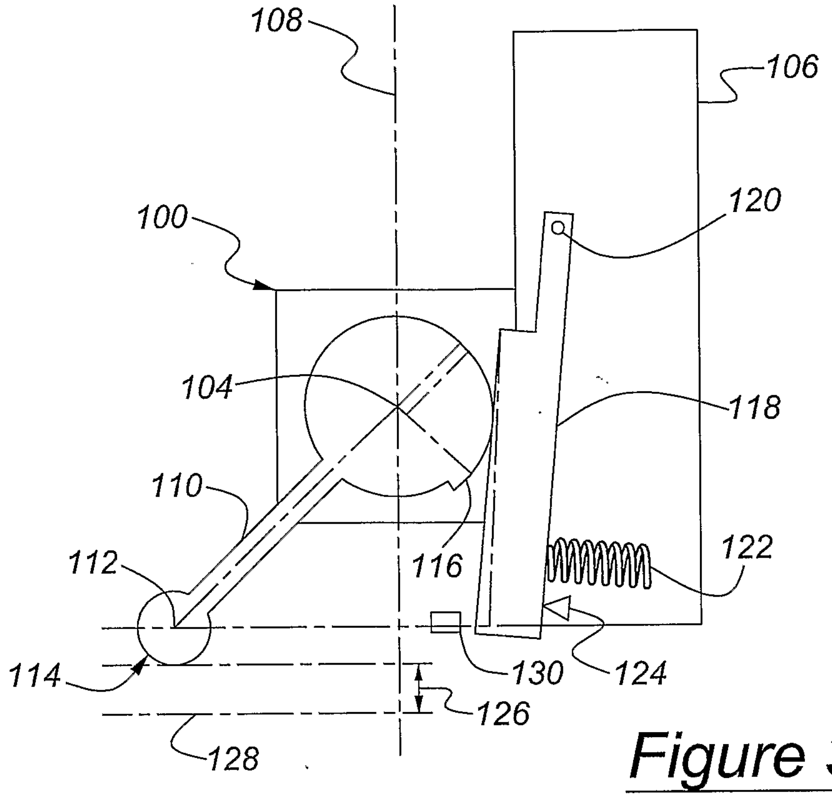

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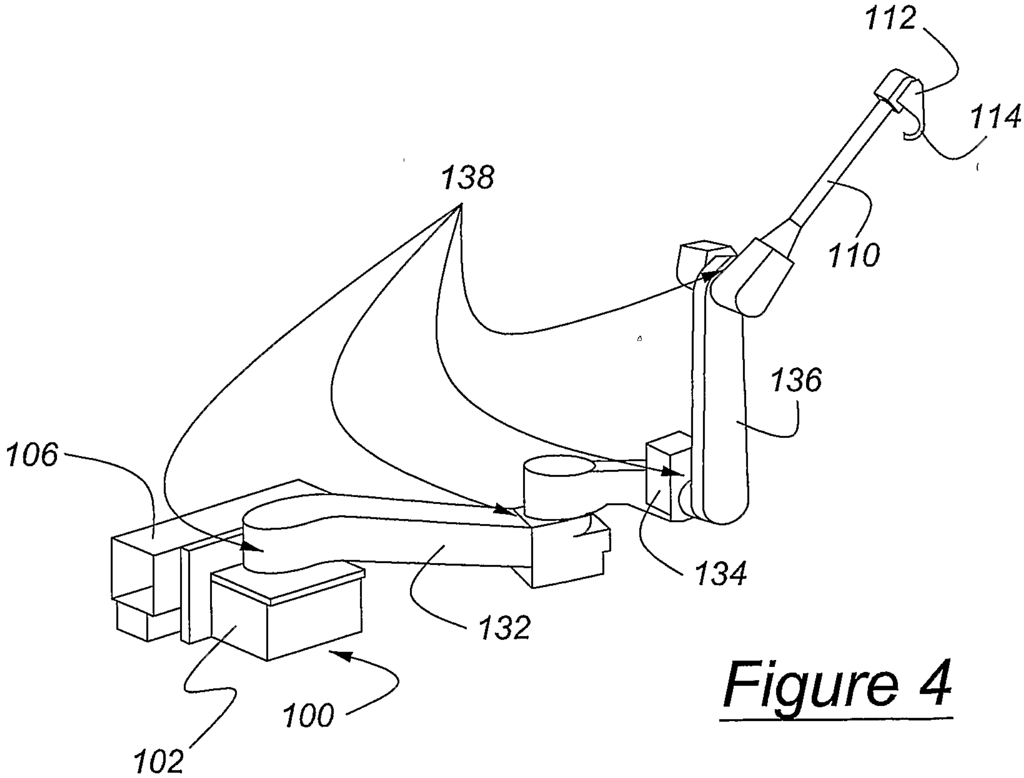

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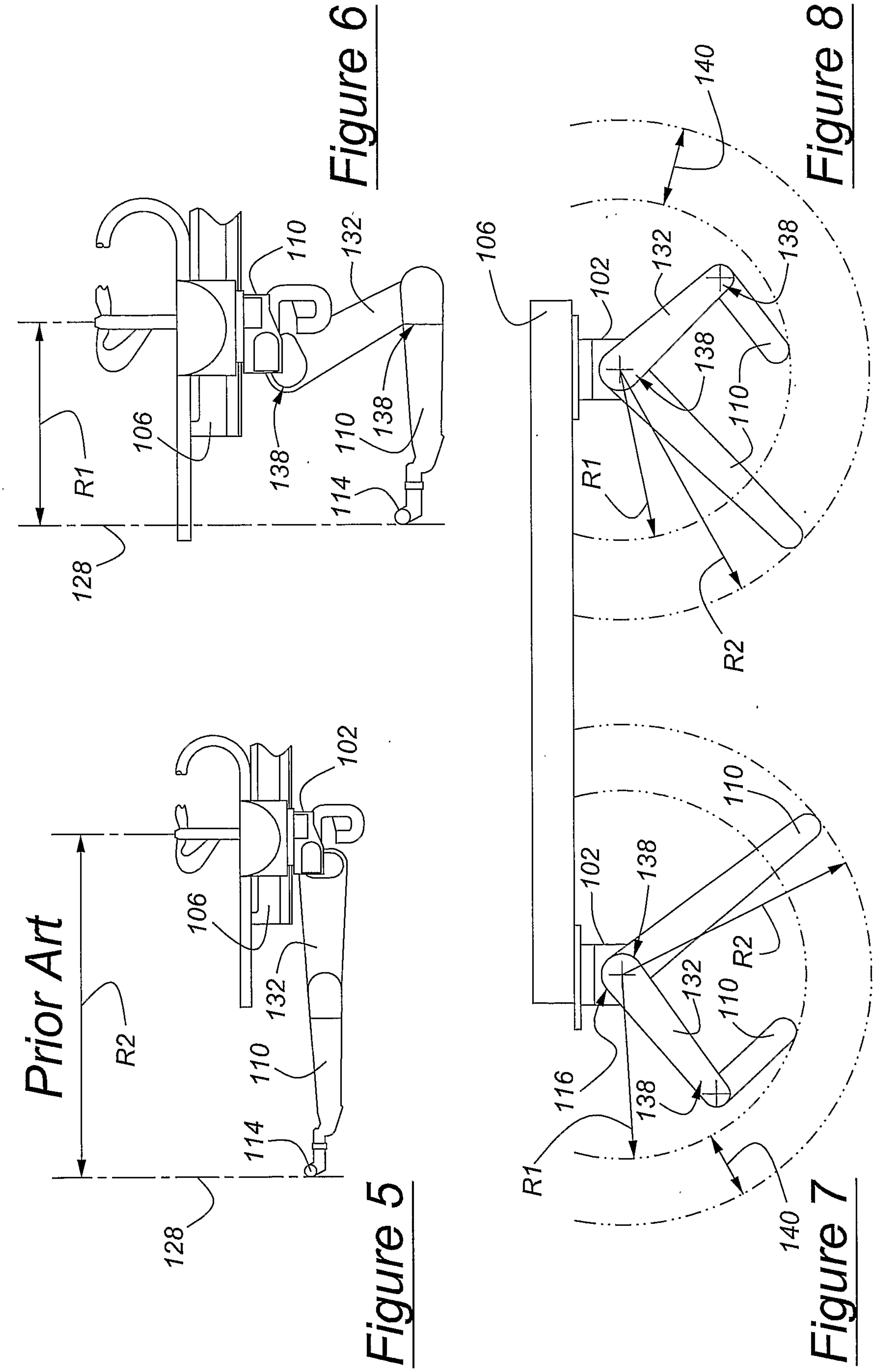


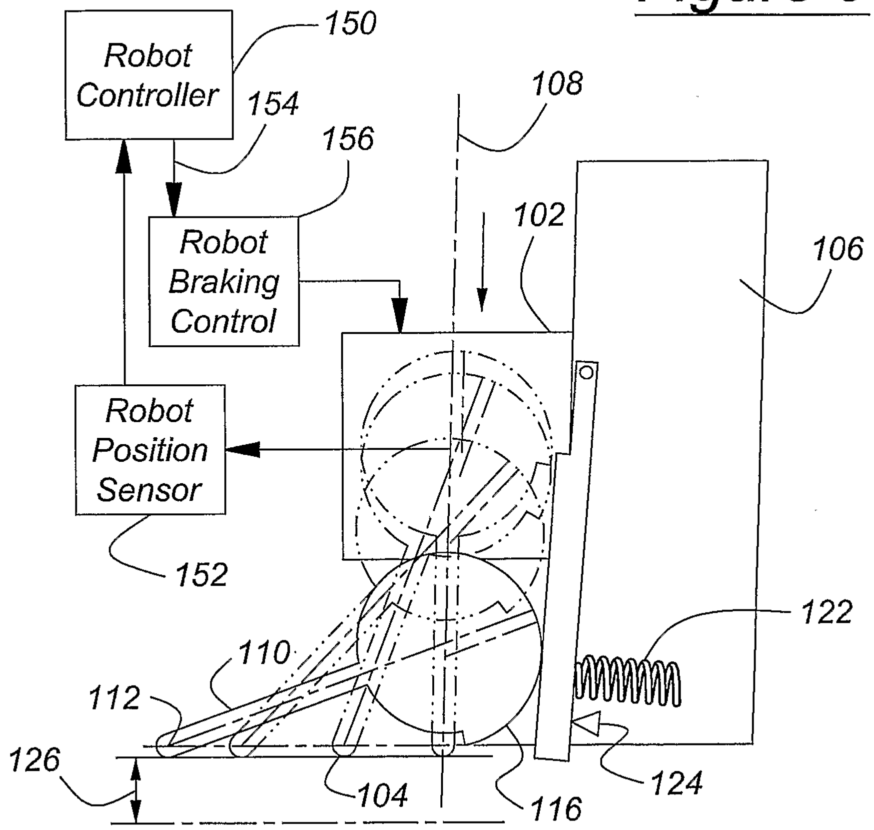
Figure 5

Figure 6

Figure 7

Figure 8

Figure 9


Robot Controller
150
154
156
Robot Braking Control
108
102
106
Robot Position Sensor
152
122
110
112
126
104
116
124

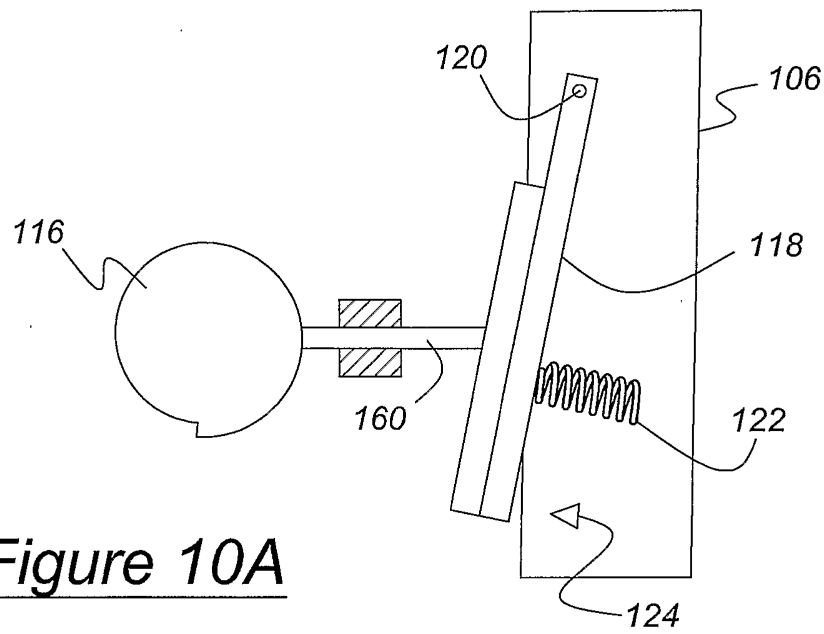


Figure 10A

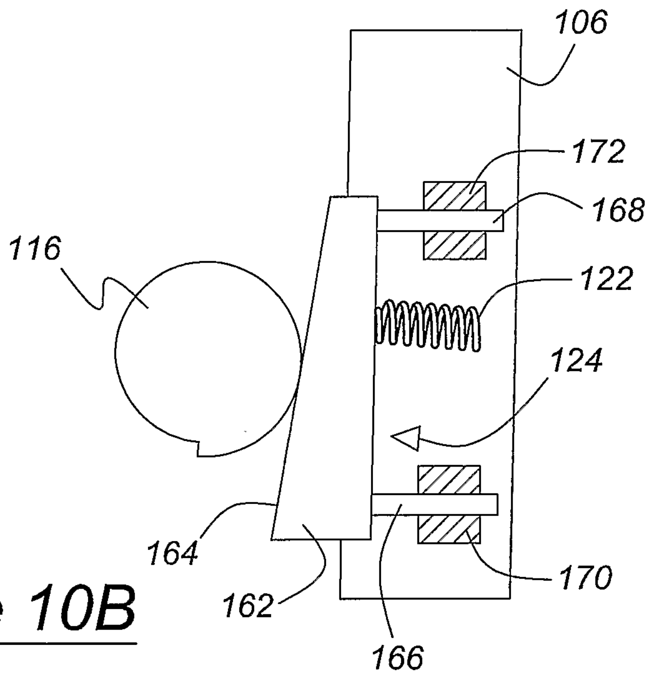


Figure 10B

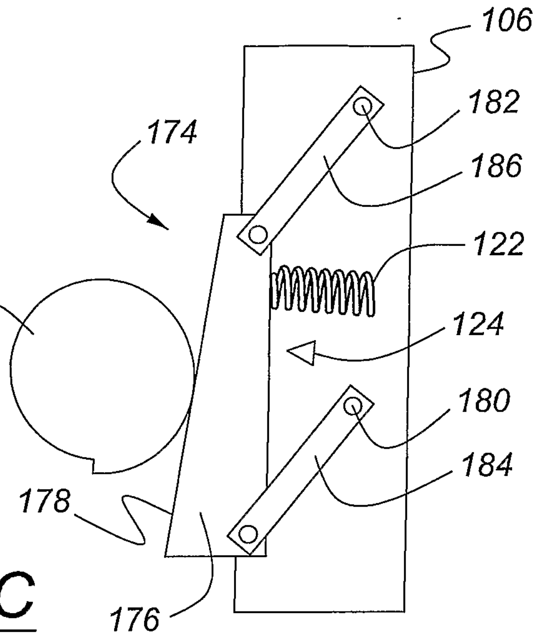


Figure 10C

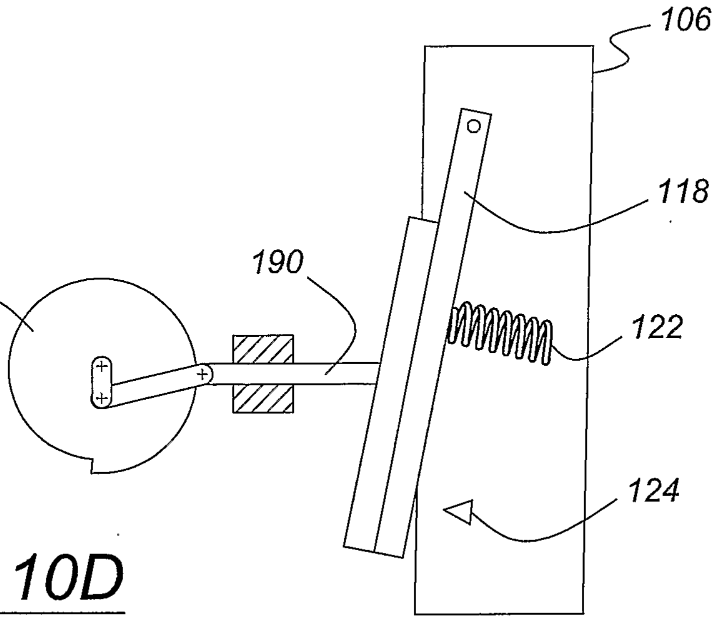


Figure 10D

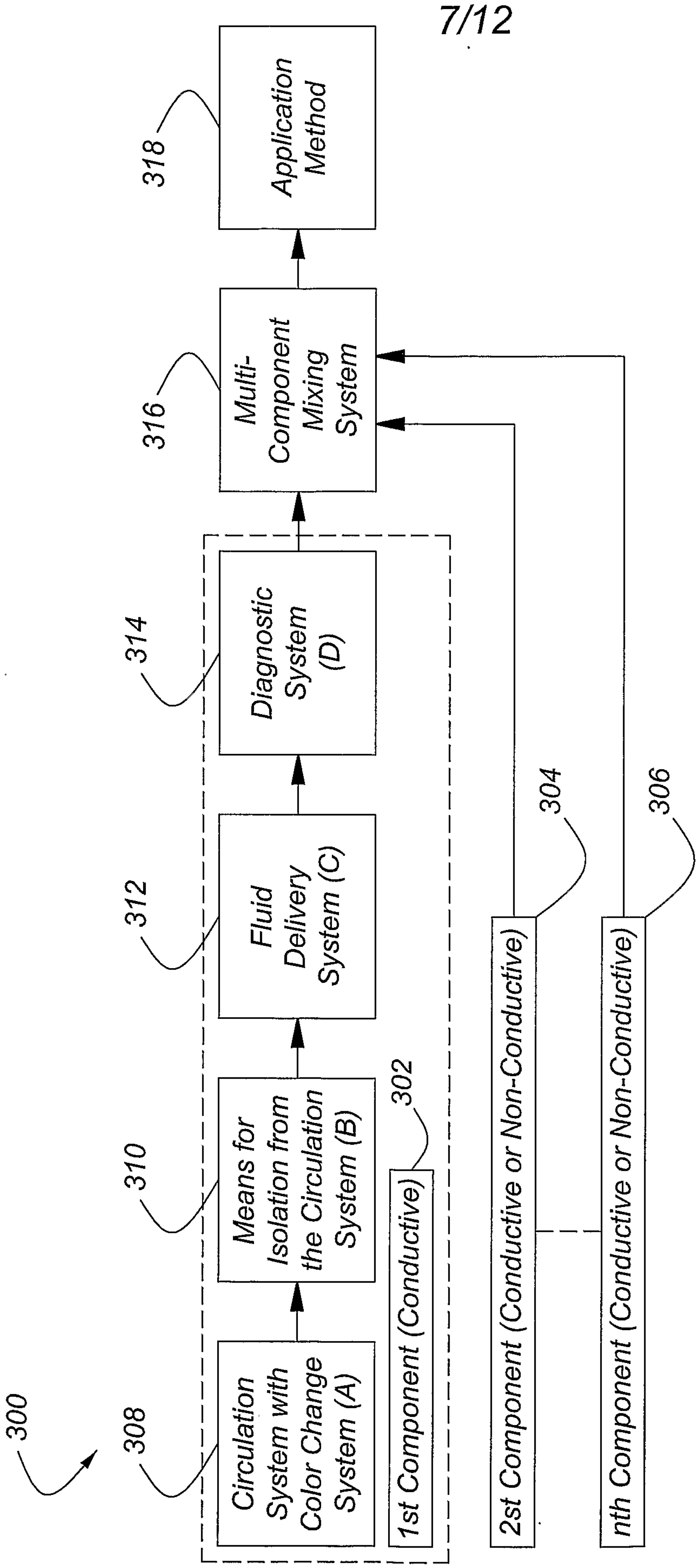

300
308
Circulation System with Color Change System (A)
310
Means for Isolation from the Circulation System (B)
312
Fluid Delivery System (C)
314
Diagnostic System (D)
316
Multi-Component Mixing System
318
Application Method
302
1st Component (Conductive)
304
2st Component (Conductive or Non-Conductive)
306
nth Component (Conductive or Non-Conductive)

Figure 11

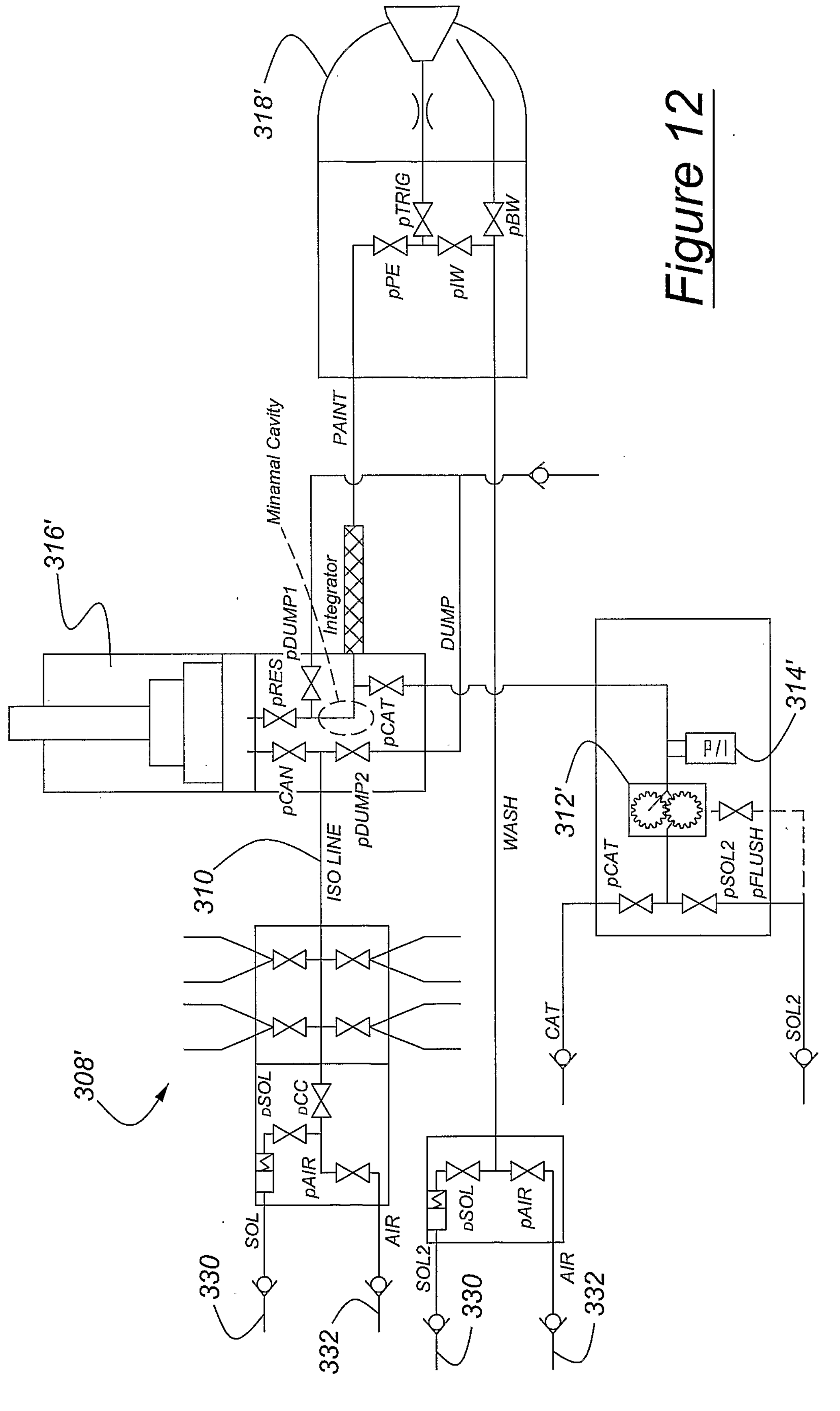

318'
pTRIG
pBW
pPE
pIW
PAINT
Minamal Cavity
316'
pDUMP1
Integrator
DUMP
pRES
pCAT
pCAN
pDUMP2
ISO LINE
310
WASH
312'
314'
P/I
pCAT
pSOL2
pFLUSH
CAT
SOL2
308'
pSOL
pCC
pAIR
SOL
AIR
330
332
SOL2
pSOL
pAIR
AIR
330
332

Figure 12

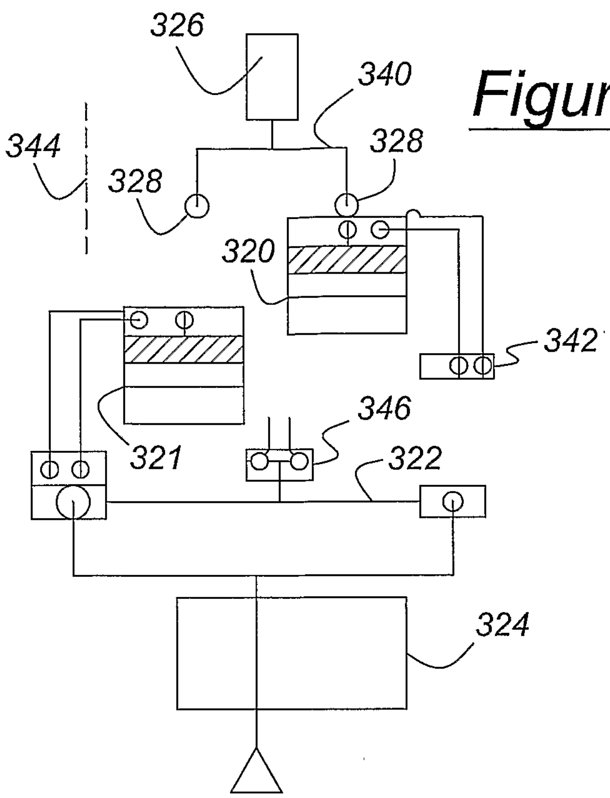


Figure 13

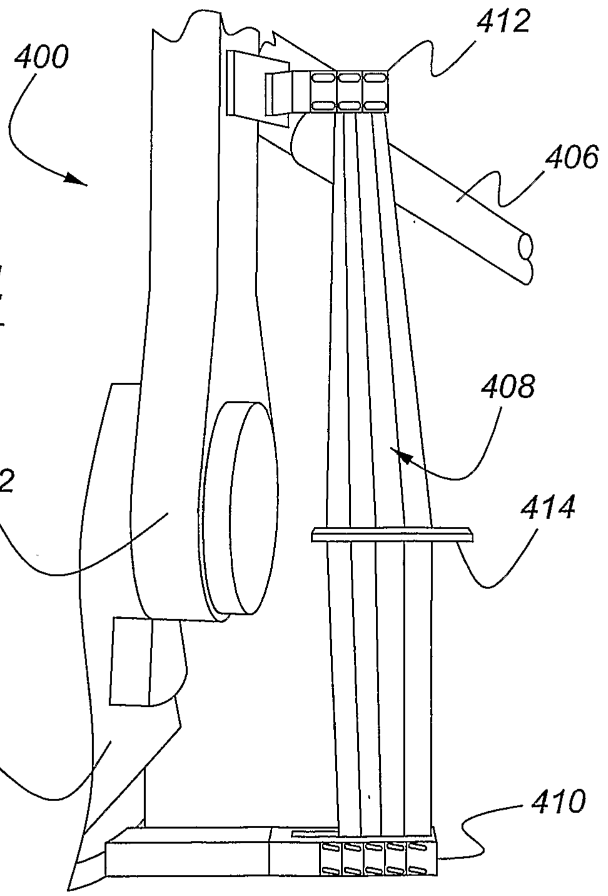


Figure 14

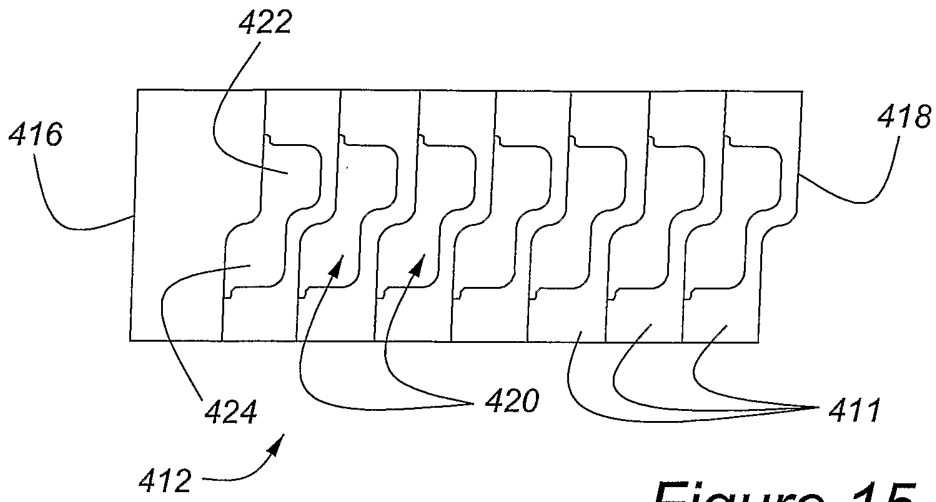


Figure 15

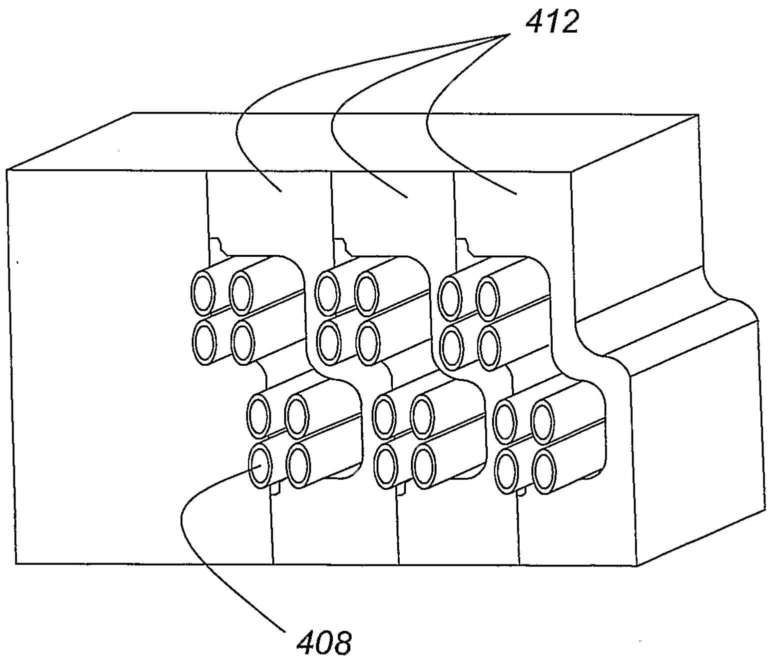


Figure 16

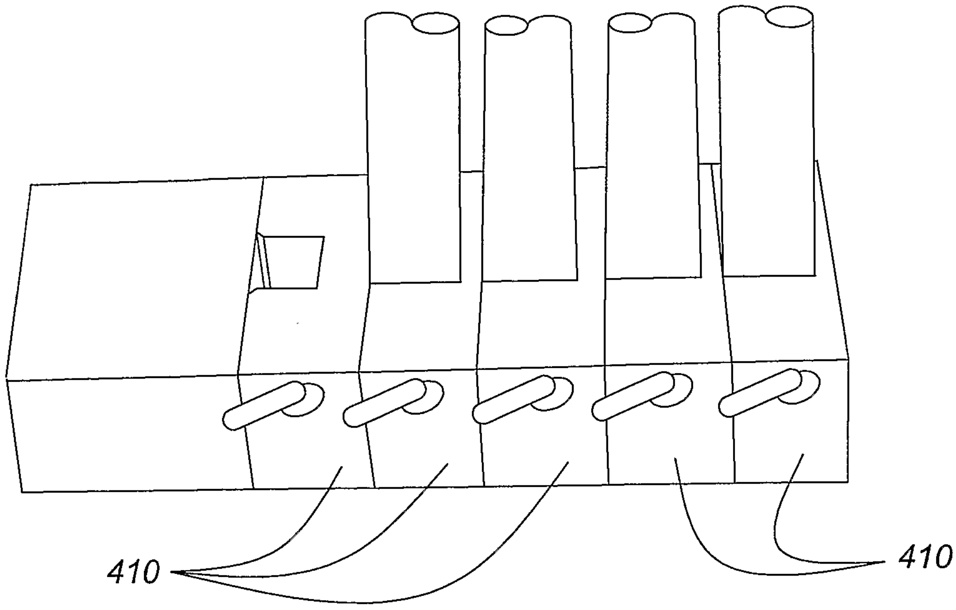


Figure 17

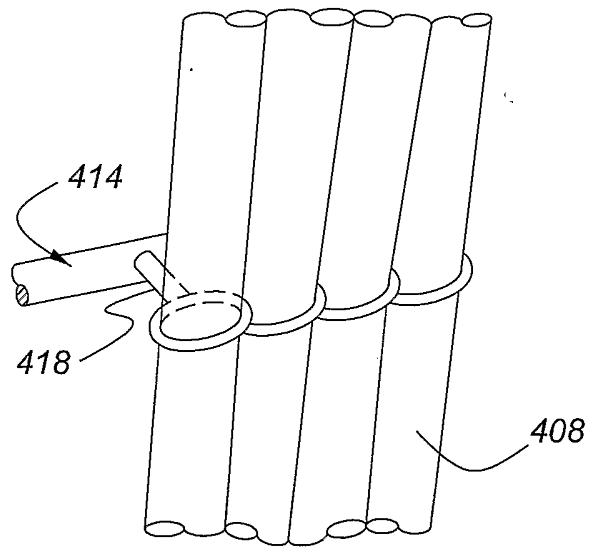


Figure 18

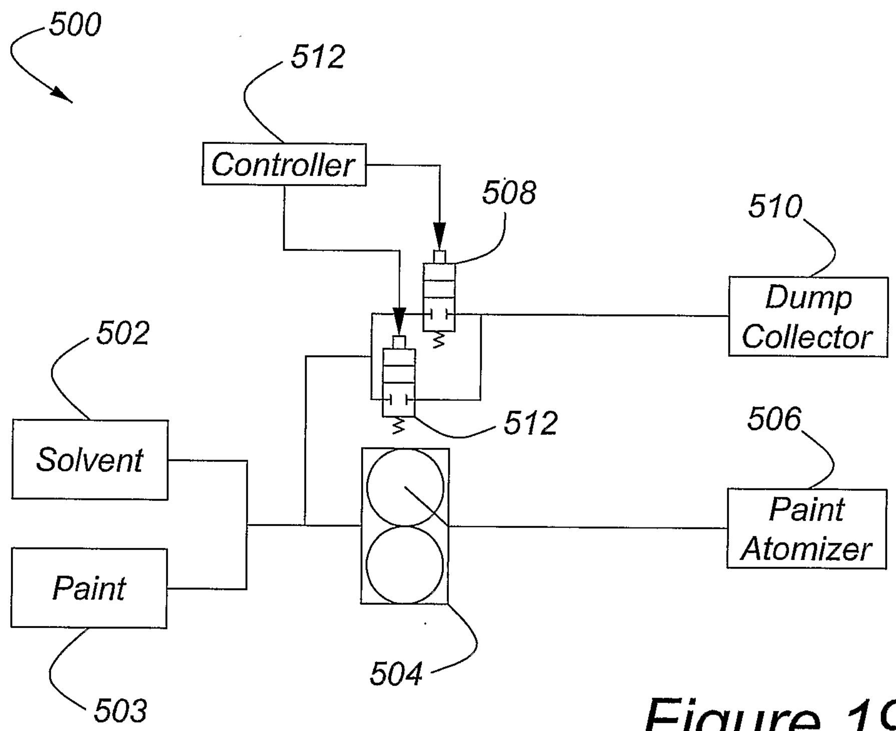

500
512
Controller
508
510
Dump Collector
502
512
Solvent
506
Paint Atomizer
Paint
504
503

Figure 19