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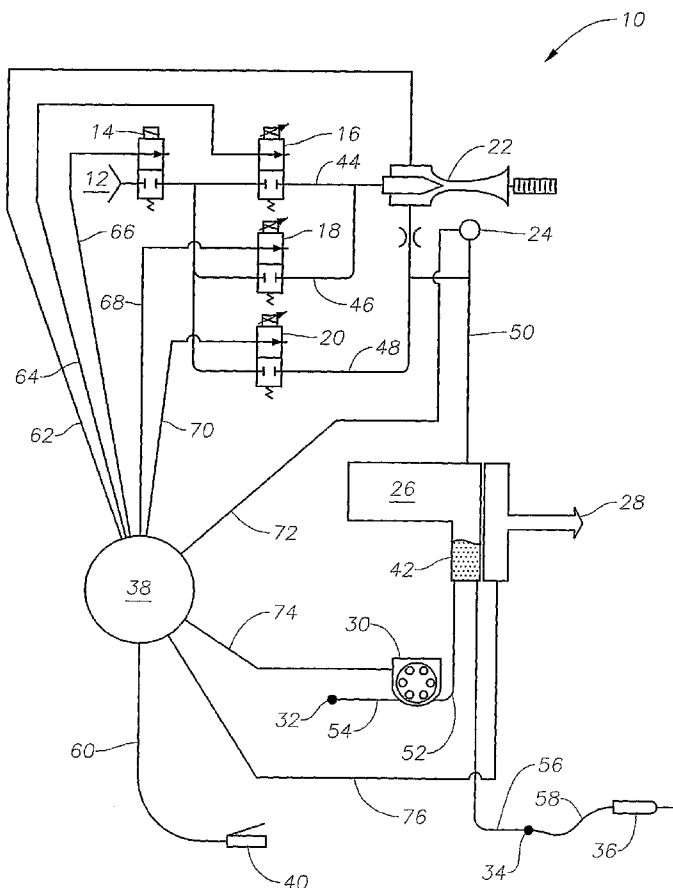
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(54) Title: ASPIRATION CONTROL



(57) Abstract: A micro-surgical system capable of controlling aspiration via a vacuum control mode, a suction control mode, or a flow control mode.

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## ASPIRATION CONTROL

### Field of the Invention

The present invention generally pertains to controlling aspiration in microsurgical systems and more particularly to controlling aspiration in ophthalmic microsurgical systems.

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### Description of the Related Art

During small incision surgery, and particularly during ophthalmic surgery, small probes are inserted into the operative site to cut, remove, or otherwise manipulate tissue. During these surgical procedures, fluid is typically infused into the eye, and the infusion fluid and tissue are aspirated from the surgical site. The types of aspiration systems used, prior to the present invention, were generally characterized as either flow controlled or vacuum controlled, depending upon the type of pump used in the system. Each type of system has certain advantages.

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Vacuum controlled aspiration systems are operated by setting a desired vacuum level, which the system seeks to maintain. Flow rate is dependent on intraocular pressure, vacuum level, and resistance to flow in the fluid path. Actual flow rate information is unavailable. Vacuum controlled aspiration systems typically use a venturi or diaphragm pump. Vacuum controlled aspiration systems offer the advantages of quick response times, control of decreasing vacuum levels, and good fluidic performance while aspirating air, such as during an air/fluid exchange procedure. Disadvantages of such

systems are the lack of flow information resulting in transient high flows during phacoemulsification or fragmentation coupled with a lack of occlusion detection.

Vacuum controlled systems are difficult to operate in a flow controlled mode because of the problems of non-invasively measuring flow in real time.

5           Flow controlled aspiration systems are operated by setting a desired aspiration flow rate for the system to maintain. Flow controlled aspiration systems typically use a peristaltic, scroll, or vane pump. Flow controlled aspiration systems offer the advantages of stable flow rates and automatically increasing vacuum levels under occlusion.

Disadvantages of such systems are relatively slow response times, undesired occlusion  
10 break responses when large compliant components are used, and vacuum can not be linearly decreased during tip occlusion. Flow controlled systems are difficult to operate in a vacuum controlled mode because time delays in measuring vacuum can cause instability in the control loop, reducing dynamic performance.

One currently available ophthalmic surgical system, the MILLENIUM system  
15 from Storz Instrument Company, contains both a vacuum controlled aspiration system (using a venturi pump) and a separate flow controlled aspiration system (using a scroll pump). The two pumps can not be used simultaneously, and each pump requires separate aspiration tubing and cassette.

Another currently available ophthalmic surgical system, the ACCURUS® system  
20 from Alcon Laboratories, Inc., contains both a venturi pump and a peristaltic pump that operate in series. The venturi pump aspirates material from the surgical site to a small collection chamber. The peristaltic pump pumps the aspirate from the small collection

chamber to a larger collection bag. The peristaltic pump does not provide aspiration vacuum to the surgical site. Thus, the system operates as a vacuum controlled system.

Accordingly, a need continues to exist for an improved method of controlling aspiration in a microsurgical system.

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### Summary of the Invention

The present invention provides a microsurgical system capable of controlling aspiration via a vacuum control mode, a suction control mode, or a flow control mode.

10 In a suction control mode of the present invention, a desired suction pressure is created in an aspiration chamber using a pressurized gas source and a vacuum generator. Fluid is aspirated from a surgical device into the aspiration chamber. An actual suction pressure is determined in the aspiration chamber. A pressure generated by the pressurized gas source and a vacuum generated by the vacuum generator are modified, in response to the actual suction pressure of the determining step, so as to maintain the actual suction  
15 pressure proximate the desired suction pressure.

In a flow control mode of the present invention, a desired suction flow rate is created in an aspiration chamber using a pressurized gas source, a vacuum generator, and a pump. Fluid is aspirated from a surgical device into the aspiration chamber. An actual level of fluid is determined in the aspiration chamber. A suction flow rate is calculated in  
20 response to the actual level of fluid of the determining step. A pressure generated by the pressurized gas source and a vacuum generated by the vacuum generator are modified to maintain the suction flow rate proximate the desired suction flow rate.

### Brief Description of the Drawings

For a more complete understanding of the present invention, and for further objects and advantages thereof, reference is made to the following description taken in conjunction with the accompanying drawing, in which Figure 1 is a schematic diagram illustrating aspiration control in a microsurgical system.

### Detailed Description of the Preferred Embodiments

The preferred embodiment of the present invention and its advantages is best understood by referring to Figure 1 of the drawings. Microsurgical system 10 includes a pressurized gas source 12, an isolation valve 14, a vacuum proportional valve 16, an optional second vacuum proportional valve 18, a pressure proportional valve 20, a vacuum generator 22, a pressure transducer 24, an aspiration chamber 26, a fluid level sensor 28, a pump 30, a collection bag 32, an aspiration port 34, a surgical device 36, a computer or microprocessor 38, and a proportional control device 40. The various components of system 10 are fluidly coupled via fluid lines 44, 46, 48, 50, 52, 54, 56, and 58. The various components of system 10 are electrically coupled via interfaces 60, 62, 64, 66, 68, 70, 72, 74, and 76. Valve 14 is preferably an "on/off" solenoid valve. Valves 16-20 are preferably proportional solenoid valves. Vacuum generator 22 may be any suitable device for generating vacuum but is preferably a vacuum chip or a venturi chip that generates vacuum when isolation valve 14 and vacuum proportional valves 16 and/or 18 are open and gas from pressurized gas source 12 is passed through vacuum generator 22. Pressure transducer 24 may be any suitable device for directly or indirectly measuring pressure and vacuum. Fluid level sensor 28 may be any suitable device for measuring the

level of a fluid 42 within aspiration chamber 26 but is preferably capable of measuring fluid levels in a continuous manner. Pump 30 may be any suitable device for generating vacuum but is preferably a peristaltic pump, a scroll pump, or a vane pump.

Microprocessor 38 is capable of implementing feedback control, and preferably PID control. Proportional controller 40 may be any suitable device for proportionally  
5 controlling system 10 and/or surgical device 36 but is preferably a PID controller.

System 10 preferably utilizes three distinct methods of controlling aspiration, vacuum control, suction control, and flow control. In vacuum control mode, microprocessor 38 activates isolation valve 14 via interface 66 and maintains pressure  
10 valve 20 in a closed state via interface 70. Proportional controller 40 and microprocessor 38 are used to proportionally open or close vacuum proportional valve 16 (and optionally vacuum proportional valve 18, for higher levels of vacuum) via interfaces 60, 64, and 68. A surgeon inputs a maximum vacuum level into microprocessor 38. Using proportional controller 40, the surgeon may then proportionally vary the desired vacuum provided to  
15 surgical device 36 and aspiration chamber 26 via vacuum generator 22 between zero and the maximum value. As aspiration chamber 26 fills with fluid 42 aspirated by surgical device 36, pressure transducer 24 measures the actual vacuum in aspiration chamber 26 and provides a corresponding signal to microprocessor 38 via interface 72.

Microprocessor 38 in turn provides feedback signals to valves 16 and 18 via interfaces 64  
20 and 68 to maintain the vacuum at the desired level indicated by proportional controller 40.

In the suction control mode, microprocessor 38 activates valves 14, 16, 18, and 20. System 10 is configured to provide a range of suction to surgical device 36 and

aspiration chamber 26 from a small positive value of pressure to a larger negative value of pressure (or vacuum). This range is preferably from about + 150 mm Hg to about – 650 mm Hg. Using proportional controller 40, a surgeon may proportionally vary the desired suction provided to surgical device 36 and aspiration chamber 26 via pressurized gas source 12 and vacuum generator 22 in this range. A signal corresponding to the desired suction is provided to microprocessor 38 via interface 60. Pressure transducer 24 provides a signal corresponding to the actual suction pressure in aspiration chamber 26 to microprocessor 38 via interface 72. Microprocessor 38 then provides feedback signals to any combination of valves 16, 18, and 20 via interfaces 64, 68, and 70, respectively, to maintain the suction within aspiration chamber 26 and surgical device 36 at the desired level. As one skilled in the art will appreciate, the suction control mode allows microprocessor 38 to close valves 16 and 18 and open valve 20 to create a pressure within aspiration chamber 26 equal to the intraocular pressure so as to prevent passive flow from the eye into surgical device 36 and aspiration chamber 26.

In the flow control mode, microprocessor 38 activates valves 14, 16, 18, and 20. System 10 is configured to provide a range of flow to surgical device 36 and aspiration chamber 26 from a value of zero flow to a maximum value of flow. Using proportional controller 40, a surgeon may proportionally vary the desired suction flow rate for surgical device 36 and aspiration chamber 26 in this range. Flow rate is calculated using the following equation:

$$Q_{\text{suction}} = Q_{\text{pump}}(N,P) + A \, dz/dt,$$

where  $Q_{\text{suction}}$  is the suction flow rate,  $Q_{\text{pump}}$  is the flow rate of pump 30,  $N$  is the speed of pump 30,  $P$  is the suction pressure measured by pressure transducer 24,  $A$  is the cross-



sectional area of aspiration chamber 26, and  $Z$  is the level of fluid 42 in aspiration chamber 26 measured via fluid level sensor 28. A signal corresponding to the desired  $Q_{\text{suction}}$  is provided to microprocessor 38 via interface 60. Microprocessor 38 provides a signal corresponding to pump speed  $N$  to pump 30 via interface 74 in response to the desired  $Q_{\text{suction}}$ . Fluid level sensor 28 provides a signal corresponding to the actual level of fluid within aspiration chamber 26 to microprocessor 38 via interface 76.

Microprocessor 38 uses the suction control mode, as described above, to maintain  $Q_{\text{suction}}$  at the desired level. More specifically, microprocessor 38 calculates  $Q_{\text{suction}}$  in response to the actual level of fluid within aspiration chamber 26 and provides feedback signals to any combination of valves 16, 18, and 20 via interfaces 64, 68, and 70, respectively, so as to maintain  $Q_{\text{suction}}$  at the desired level. As part of the suction control mode, pressure transducer 24 provides a signal corresponding to the actual suction pressure  $P$  in aspiration chamber 26 to microprocessor 38 via interface 72. As one skilled in the art will appreciate, the flow control mode allows microprocessor 38 to maintain a constant level of fluid 42 in aspiration chamber 26 ( $dz/dt = 0$ ) so as to maintain flow rate.

It is believed that the operation and construction of the present invention will be apparent from the foregoing description. While the apparatus and methods shown or described above have been characterized as being preferred, various changes and modifications may be made therein without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. Apparatus for controlling aspiration in a microsurgical system,

comprising:

a pressurized gas source;

5 a vacuum generator fluidly coupled to said pressurized gas source;

an aspiration chamber fluidly coupled to said pressurized gas source and said vacuum generator;

a vacuum proportional valve fluidly coupled between said pressurized gas source and said vacuum generator;

10 a pressure proportional valve fluidly coupled between said pressurized gas source and said aspiration chamber;

a pressure transducer fluidly coupled to said aspiration chamber;

a proportional controller; and

15 a computer electrically coupled to said vacuum proportional valve, said pressure proportional valve, said pressure transducer, and said proportional controller;

whereby upon the selection of a desired suction pressure for said aspiration chamber via said proportional controller, said pressure transducer determines an actual suction pressure in said aspiration chamber and provides a signal corresponding to said determined suction pressure to said computer, and said computer provides signals to said vacuum proportional valve and said pressure proportional valve to maintain said actual suction pressure proximate said desired suction pressure.

2. The apparatus of claim 1 further comprising a surgical device for aspirating tissue fluidly coupled to said aspiration chamber.

3. The apparatus of claim 1 wherein said vacuum generator is a vacuum chip.

4. The apparatus of claim 1 wherein said vacuum generator is a venturi chip.

5. The apparatus of claim 1 wherein said microsurgical system is an ophthalmic microsurgical system.

5 6. Apparatus for controlling aspiration in a microsurgical system, comprising:

a pressurized gas source;

a vacuum generator fluidly coupled to said pressurized gas source;

an aspiration chamber fluidly coupled to said pressurized gas source and said

10 vacuum generator;

a vacuum proportional valve fluidly coupled between said pressurized gas source and said vacuum generator;

a pressure proportional valve fluidly coupled between said pressurized gas source and said aspiration chamber;

15 a fluid level sensor operatively coupled to said aspiration chamber;

a pump fluidly coupled to said aspiration chamber;

a proportional controller; and

a computer electrically coupled to said vacuum proportional valve, said pressure proportional valve, said fluid level sensor, said pump, and said proportional controller;

20 whereby upon the selection of a desired suction flow rate for said aspiration chamber via said proportional controller, said fluid level sensor determines an actual fluid level in said aspiration chamber and provides a signal corresponding to said determined fluid level to said computer, and said computer calculates a suction flow rate in response

to said determined fluid level and provides signals to said vacuum proportional valve and said pressure proportional valve to maintain said suction flow rate proximate said desired suction flow rate.

7. The apparatus of claim 6 further comprising a surgical device for  
5 aspirating tissue fluidly coupled to said aspiration chamber.

8. The apparatus of claim 6 wherein said vacuum generator is a vacuum chip.

9. The apparatus of claim 6 wherein said vacuum generator is a venturi chip.

10. The apparatus of claim 6 wherein said microsurgical system is an  
ophthalmic microsurgical system.

10 11. The apparatus of claim 6 wherein said pump is a peristaltic pump.

12. A method of controlling aspiration in a microsurgical system, comprising  
the steps of:

creating a desired suction pressure in an aspiration chamber using a pressurized  
gas source and a vacuum generator;

15 aspirating fluid from a surgical device into said aspiration chamber;

determining an actual suction pressure in said aspiration chamber;

modifying, in response to said actual suction pressure of said determining step, a  
pressure generated by said pressurized gas source and a vacuum generated by said  
vacuum generator so as to maintain said actual suction pressure proximate said desired  
20 suction pressure.

13. A method of controlling aspiration in a microsurgical system, comprising  
the steps of:

creating a desired suction flow rate in an aspiration chamber using a pressurized gas source, a vacuum generator, and a pump;

aspirating fluid from a surgical device into said aspiration chamber;

determining an actual level of fluid in said aspiration chamber;

5 calculating a suction flow rate in response to said actual level of fluid of said determining step; and

modifying a pressure generated by said pressurized gas source and a vacuum generated by said vacuum generator so as to maintain said suction flow rate proximate said desired suction flow rate.

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