Novel fluidic pump design for application in an eye surgery system

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Abstract

This work describes the design and performance tests of an innovative fluidic pump system which is applied in a novel anterior and posterior eye surgery system [1]. Traditionally such a pump system is either Venturi tube based, where the pressure response is rather quick and the steady state pressure is stable but the actual flow is hard to control, or use a peristaltic tube pump, where the actual flow can be controlled more accurately but the pressure response is slow and the steady state pressure has significant variations. The newly developed pump is a mechatronic system that interacts with a sterile disposable cartridge. The pump comprises a pressure sensor, a compensation piston (piston 1), an inlet valve (valve 1), a pump piston (piston 2) and an outlet valve (valve 2). All are actuated using direct drive motors in combination with flexible hinges. With this pump it is possible to control either the eye pressure or flow to (irrigation) or from (aspiration) the eye and maintain dynamic safety levels to prevent unwanted behaviour, even if the flow restriction suddenly changes. Measurements show that the response time of this novel pump system is much faster compared with traditional systems, especially in flow mode. Furthermore by properly tuning the movement cycle of the pistons and valves, the pressure stability in flow mode is superior to traditional tube pump systems. This enables eye surgeons to perform delicate operations requiring a very stable aspiration pressures, but without sacrifice of direct aspiration pressure response.

1. System design

Figure 1 shows the front view of the pump system, together with the disposable cartridge. By creating a vacuum pressure between the cartridge and pump front, the cartridge membrane is stiffly connected to the aspiration pistons and valves. In this way the volume displacement of the pistons and valves can be accurately transferred to the fluid chambers in the cartridge.

Figure 1: Overview pump with cartridge

During surgery it is important that especially the aspiration flow and pressure are very stable and do not fluctuate. Figure 2 shows that by properly tuning the position setpoints of the valves and pistons, in theory a very smooth aspiration flow can be realized. In the first step piston 2 moves outward and pushes the liquid in the waste bag, while piston 1 is responsible for realizing a smooth aspiration flow from the eye. Then valve 2 closes and valve 1 opens. In step 3 piston 1 is moved outward, while simulaneously piston 2 is moved inward with a higher speed than piston 1, resulting in a net volume flow that is equal to step 1. Finally valve 1 is closed again and valve 2 is opened. This sequence is then repeated.

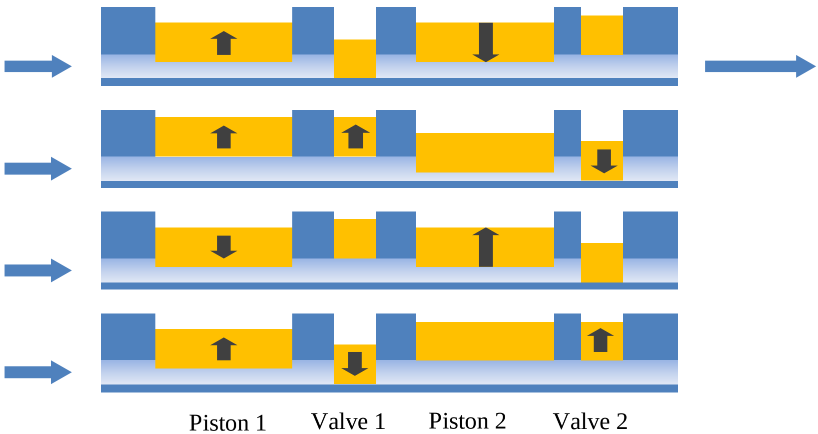

Figure 2: Pump sequence

In order to accurately control the aspiration pressure and flow, the position setpoint of the valves and pistons needs to be controlled very accurately. This was realized by using custom designed direct drive actuators with flexible hinges (see Figure 3 and 4). This ensures that the actuator has a very linear relation between motor current and displacement, has very low hysteresis and is very stiff.

Figure 3: The direct drive actuators of the two valves and two pistons

Figure 4: A detailed view of the drive train of one of the the pump valves

Especially during the valve movements and in the presence of gas bubbles in the aspiration line it is difficult to predict the exact volume change inside the cartridge. Therefore an iterative procedure has been used in which the pressure deviations recorded using a reference position profile of the valves and pistons are used to calculate an improved profile. This was repeated until the pressure variations where sufficiently small.

The use of direct drive actuators allows new pump behaviour upon requested as this can be implemented via software. Furthermore system safety is ensured by redundant pressure sensors. The pump and cartridge have been designed such that in case of a system failure (like a power outage) an inherently safe situation is guaranteed.

2. Performance tests

To determine the performance of the pump system, various tests were carried out. During these tests normal surgery tubings were connected to the cartridge. For the tests, an artificial eye with pressure sensors was used. Figure 6 shows the resulting aspiration pressure rise times measured in the eye that were realized with the pump operating in pressure mode. For reference a typical rise time curve for a tube pump system is shown as well. The figure shows that the novel pump has a much faster response time.

Figure 7 shows the aspiration pressure stability in the eye realized with the novel pump operating in flow mode. For reference a typical aspiration pressure curve for a tube pump is shown as well. The figure indicates that the stability of the aspiration pressure with the new pump is much higher than that of a tube pump system.

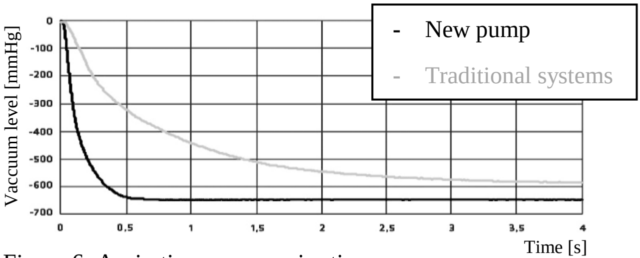

Figure 6: Aspiration pressure rise time

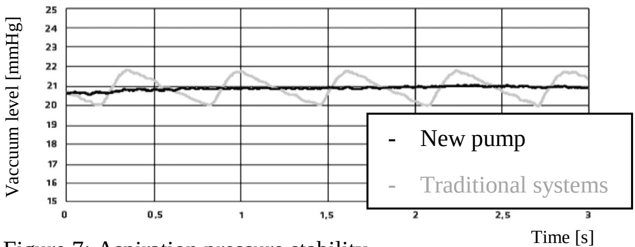

Figure 7: Aspiration pressure stability

References:

[1] EVA: A STATE-OF-THE-ART SURGICAL SYSTEM FOR PHACO-VITRECTOMY. Supplement to Retina Today, summer 2013. http://www.evabydorc.com/pdf/retina_today.pdf