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A Flexible Pressure Controller for a Portable Multi-Chamber Therapeutic Device

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Abstract

This note describes the design of a flexible pressure controller used in a multi-chamber portable therapeutic device. The device presents many novel features. There is a complete flexibility in setting the pressure profile for each of the chambers according to the needs of individual patients. The device is programmable via a personal computer and a USB interface. The design is optimised for power use and can be run on a battery for over a thousand cycles. The set pressure profile is tracked using a continuous pressure feedback and a proportional-derivative-integral controller. This paper also includes patient data to show the effectiveness of this multi-chamber device. The tests on the patients were conducted using a prototype built using the design described in this paper.

Keywords

Chronic Venous Disorder (CVD), Intermittent Pneumatic Compressor (IPC), Deep Vein Thrombosis (DVT), Feedback Control, Pressure Sensing

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1. Introduction

This paper presents the design of a multi-chamber therapeutic device that can be used to alleviate suffering of DVT patients. The device wraps around a patient's leg and air is pumped into individual chambers in a cyclic manner. The cycle and the pressure in each chamber is set depending on the medical condition of the patient. These setting may often change and vary from patient to patient. This calls for a flexible design that can reliably regulate the pressure in the chambers.

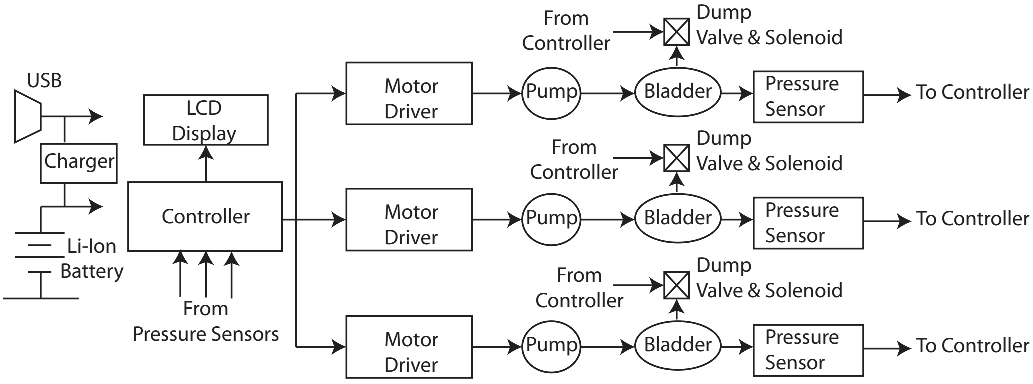

Figure 1. System Schematic.

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2. Multi-Chamber Therapeutic Device

The schematic for the device is shown in Figure 1. The device consists of a cuff with three chambers with a feature that each of the chambers can be independently inflated and deflated.

This provides extra flexibility to tune the cycle depending on the patient's needs. As shown in the schematic in Figure 1, there are three identical sets of a motor-driver, a motor, an air-pump, and a bladder. A digital controller provides signals to motor-drivers and the solenoids. The device is powered by a rechargeable battery that is charged from the USB.

The cycling schedule is input via a USB connection to a personal computer (PC). The PC has a very convenient user interface that accepts pressure profile for each bladder independently. The programming is normally done in a medical practitioner's office to make sure that the patient always operates within safe operating limits. The software is freely available and the user can program the device if the medical practitioner so advises.

The inflation and deflation is achieved by using a four-way H-bridge as shown in Figure 2. To pressurise the bladder, the solenoid is closed and the air is pumped from the "From Pump" port. To deflate the solenoid is opened (pump is switched off) and the bladder deflates from "To Dump Solenoid" port. A pressure sensor is connected to "To Pressure Sensor" port.

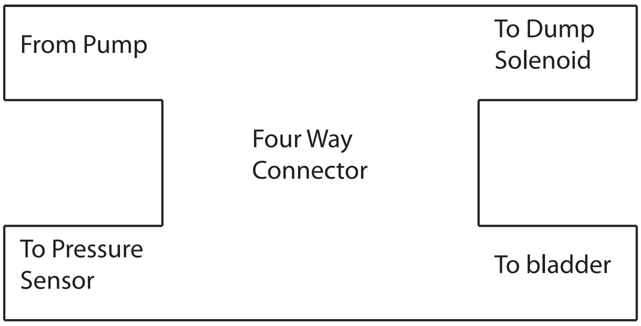

Figure 2. Four Way H-Bridge.

3. Feedback Control

The vital part of the device is a feedback controller in each of the three loops. The feedback controller is a proportional-derivative-integral (PID) controller [1, 2, 3, 4] as shown in the block diagram in Figure 3. The reference signal $R(s)$ in Figure 3 is the set reference pressure profile and $Y(s)$ is the measured sensor pressure. The set pressure and the measured pressure are compared in the summer block and the error is fed to the controller block. As is well-known the integral controller zeros the error but the tuning of the proportional, derivative, and the integral gains has to be done with care. The step-response of the open-loop system was used to tune the PID controller parameters. If the tuning is not done properly, the device may go into oscillations.

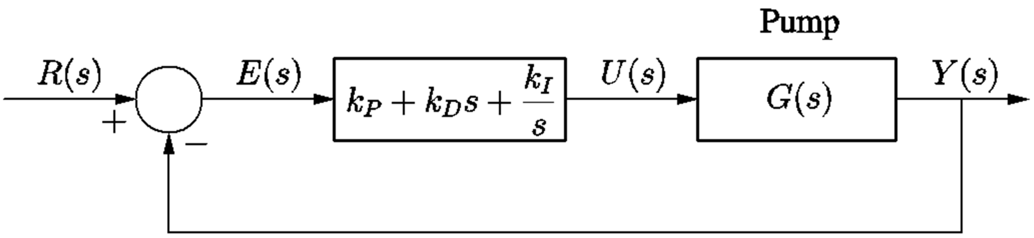

Figure 3. Feedback Block Diagram.

4. Discussion

Compression therapy is an important part of treatment for Chronic Venous Disorder (CVD) and hence the reduction in related complications [7]-[13]. Often patients do not comply with compression therapies, such as stockings, bandages, and non-mobile intermittent pneumatic compressor (IPC) units because of the difficulty with the use of these therapies [5]. The use of various IPC in patients with Deep Vein Thrombosis (DVT) or CVD has been discussed in a review of its application [6]. It was concluded by the author and further supported by relevant literature that the full potential of intermittent pneumatic compression has probably not yet been realised, and requires better quality research. System design must follow physiological evidence, and while complexity in that design may allow greater therapeutic flexibility, it may incur greater financial cost, difficulty in use, and in particular, may be unnecessary in the prevention of DVT [6]. Intermittent compression used in immobile patients is well established, and effective in the prevention of DVT and reduction of lymphoedema.

Our study has refined the use of an IPC that can be modified to an individual's needs that al- lows its use whilst being mobile, using a programmable sequential calf compression device (mo - bile SCCD) (Vekroosan®). Doppler ultrasonography has been used to study the effect of calf compression and also the use of sequential and individualised calf pressure changes to achieve excellent physiological outcomes. The peak femoral venous pressure measurements of pre and post calf compression in patients with a history of previous calf venous thrombosis has shown statistically significant improvements in peak femoral flow velocity as in shown Table 1.

The measured pre- and post-calf compression Peak Femoral Venous Flow Velocity (PFVFV) data for fifteen cases in Table 1 shows a remarkable improvement as a result of using the multi- chamber therapeutic device described in this paper. For the fifteen cases shown in Table 1 the mean PFVFV pre-compression is 26.4 cm s^{-1} and the mean PFVFV post-compression is 39.53 cm s^{-1}. The maximum increase in the PFVFV pre- and post-compression is 150 percent for Case 3 and the minimum increase is 2.16 percent for Case 7.

In some patients very little change in pressure increment is seen and the reason could be due to an abnormal venous reflux in patients with CVD and hence caudal blood flow in some patients may become significant enough rather than cranial flow, with the use of the calf compressors. In these patients, we need to individualise the pressure setting which is the biggest advantage with our design of Vekroosan® multi-chamber therapeutic device.

The use of such mobile calf compressors are clinically useful and patients would benefit with reduced leg swelling and hence pain. Further large study and multicentre trials may shed light on the full impact and usefulness of such devices.

Table 1. Pre and Post calf compression Peak Femoral Venous Flow Velocity (PFVFV).

Case No.	Pre-calf Compression	Post-calf Compression
1	39 cm s^{-1}	46 cm s^{-1}
2	5 cm s^{-1}	12 cm s^{-1}
3	22 cm s^{-1}	55 cm s^{-1}
4	59 cm s^{-1}	112 cm s^{-1}
5	28 cm s^{-1}	35 cm s^{-1}
6	13 cm s^{-1}	21 cm s^{-1}
7	46 cm s^{-1}	47 cm s^{-1}
8	24 cm s^{-1}	28 cm s^{-1}
9	26 cm s^{-1}	36 cm s^{-1}
10	25 cm s^{-1}	47 cm s^{-1}
11	18 cm s^{-1}	24 cm s^{-1}
12	25 cm s^{-1}	51 cm s^{-1}
13	39 cm s^{-1}	44 cm s^{-1}
14	15 cm s^{-1}	19 cm s^{-1}
15	12 cm s^{-1}	16 cm s^{-1}

5. Conclusions

The modular design of the pump hardware and the use of a feedback controller provides great flexibility and precision in controlling the pressure. This flexibility is being greatly utilised by medical practitioners in Australia to achieve encouraging results for DVT patients.

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