CHARACTERIZATION OF A PUMP-CATHETHER SYSTEM FOR FLOW CONTROL IN AN INTRACORPOREAL MEMBRANE OXYGENATOR

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Introduction

Acute respiratory failure is a prevalent pathological state among patients worldwide. Treatment often requires mechanical ventilation, however, most respirators work with overpressure, thus they expose the lungs to non-physiologically high pressures and often injure them [1] increasing overall mortality. An alternative is to oxygenate the blood extracorporeally, but that means guiding large blood volumes out of the body, which inevitably increases the risk of thrombosis, embolism, hemorrhage, and infections [2].

A minimally invasive intracorporeal membrane oxygenator that overcomes most of the shortcomings of currently available devices is proposed as an alternative. A key limitation with intracorporeal oxygenators (IVOX [3], Hattler catheter [4]) is the lack of blood flow control. Thus issues such as thrombosis and vein occlusion often arise, leading to insufficient gas transfer and cardiovascular complications. In this work, a system characterization approach is proposed that enables pump flow estimation which can subsequently be utilized for sensorless flow control.

Methods

The motor equation is given by eq. (1), where, τ_M is the motor torque, K_M is the motor constant and I_M is the motor current. The equation of motion is given by eq. (2), where J_M and J_P are the moments of inertia of the motor and the pump respectively. The torque due to friction τ_F, can be measured when the pump is driven with no load through eq. (3). The load torque τ_L - can be expressed through eq. (4) as a function of the pressure difference Δp over the pump, the blood flow Q, the rotational speed ω and a hydraulic conversion efficiency constant η_H, which can be acquired from a lookup table [5]. Substituting in eq. (2) for the steady state results in a non-linear relation between I_M, ω, Q and Δp - eq. (5).

$$\tau_M = K_M \cdot I_M \tag{1}$$

$$\tau_M = (J_M + J_P) \cdot \dot{\omega} + \tau_F + \tau_L \tag{2}$$

$$\tau_F = K_M \cdot I_{noLoad} \tag{3}$$

$$\tau_L = \frac{Q \cdot \Delta p}{\omega \cdot \eta_H} \tag{4}$$

$$K_M \cdot I_M = K_M \cdot I_{noLoad} + \frac{Q \cdot \Delta p}{\omega \cdot \eta_H} \tag{5}$$

In order to reduce the variables in eq. (5), the system curve was acquired and a 2nd order polynomial was fit to the data, thus acquiring an expression for Δp as a function of Q i.e. the hydraulic resistance of the system, any deviations from which might signal for leakage or occlusion.The data were acquired during in-vitro testing of the CO_2 removal capacity of the membrane catheter. A centrifugal blood pump (BPX-80, Medtronic, Dublin, Ireland) was used for pumping driven by an DC motor (EC60, Maxon, Sachseln, Switzerland) and a membrane module with 600cm^2 area, 10cm fiber length and 1.5cm packing diameter.

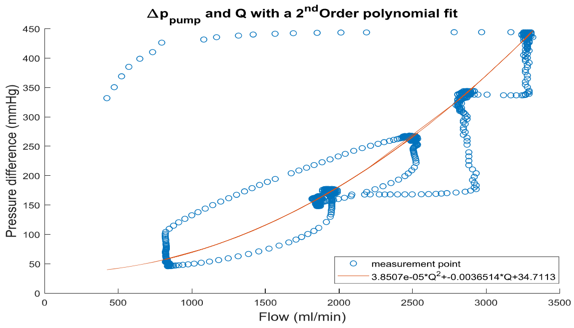

Figure 1: The pressure difference across the pump can be expressed as a 2nd order polynomial function of the flow at different rotational speeds.

Results

The system curve was acquired as a part of the pump-catheter system characterization process. The resulting curve is presented in Figure 1. A second order polynomial was fit to the data resulting in r^2=0.9847 correlation coefficient between the estimated and measured pressure.

Discussion

A high correlation coefficient was achieved, even though the non-steady state data points were not excluded. This suggests that the pressure can be omitted from eq. (5) and the flow through the pump can be estimated from I_M and ω – variables that are already known to the controller. In future research, a full characterization of the pump will be carried out thus acquiring a 3D surface of Q as function of I_M and ω.

References

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