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P11-1

Vibration Characteristics of PZT Actuator by Fluid Flow in Intravascular Oxygenator

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1. Introduction

Acute respiratory distress syndrome (ARDS) is a form of acute respiratory failure caused by extensive lung injury following a variety of catastrophic events such as severe infection and shock. Intravascular, as well as extracorporeal, artificial lungs need to be effective in transferring both oxygen and carbon dioxide. Membrane oxygenators are used during cardiopulmonary bypass procedures for cardiac surgery, for patients having chronic respiratory problems, and for premature infants with insufficiently developed lungs [1-4].

Membrane oxygenator performance is limited by the mass-transfer resistance on the side of the blood. The most successful techniques thus far for enhancing oxygenator performance have employed liquid-side pressure pulsations. Hattler and Federspiel, et al [5]. developed an intravascular hollow fiber membrane (HFM) lung assist device, the Hattler Respiratory Support Catheter of Hattler Catheter (HC) that began with an early prototype design and animal testing [6,7]. However, this HC can be disadvantageous since it can cause blood trauma: moreover, it achieves the least relative motion near the membrane boundary where the mass-transfer resistance of blood phase is confined.

We explore the use axial vibrations of a membrane tube bundle to increase oxygen transfer to the intralumenal liquid flow. A novel vibrating intravascular lung assist device (VIVLAD) has been designed that permits vibrating a parallel membrane hollow fiber bundle without directly pulsing the intralumenal liquid flow. The characteristics of oxygen transfer in the modules using a PZT actuator and a PVDF sensor is investigated.

In this paper, we tried to grasp correlation with vibrator and oxygen transfer.

2. Experiment

The experimental set-up of vibrating modules in the artificial lung device was shown in Figure 1. The PVDF sensor, LDT1-028K (AMP Co.), was 28 μm thickness. The piezoceramic material used for the test module is a multi-layer bender PZT actuator which is PL-128.255 Lead Zirconate Titanate (PZT) of the Digtal ECHO company. The dimensions are 40×10×0.45mm. The PZT actuator and PVDF sensor were bonded to the vibrating beam with araldite adhesive, and the electrical leads were soldered to the electrode of piezo-elements, and then covered by elastic rubber for waterproofing.

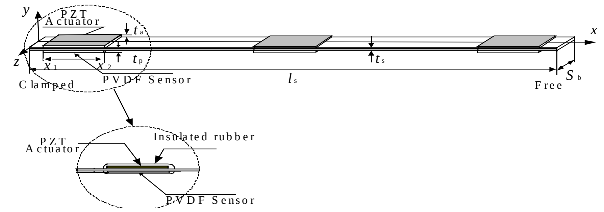


Fig. 1. Configuration of a PZT vibrator.

Figure 2 shows the experimental set-up of the testing equipment for vibration measurement of oxygen transfer. The test section was a cylinder duct with an axial length of 60 mm, and an inner diameter of 30 mm. The VIVLAD was prepared with a number of hollow fibers in the acryl cylindrical pipe. Table 1 shows the dimension of hollow fiber modules. The distance between the hollow fibers in the cylinder was fixed. The VIVLAD was made of microporous polypropylene with an inner diameter of 380 μm and a membrane thickness of 50μm (Oxyphane, Enka, Co.), respectively.

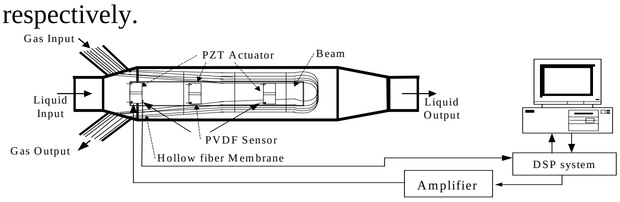


Fig. 2. Experimental set-up for the vibration measurements of test module VIVLAD.

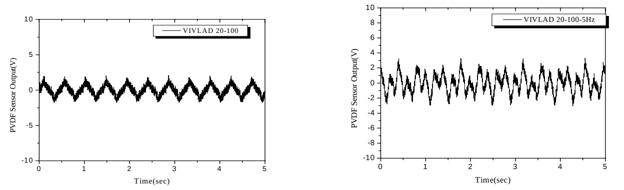
Table 1. Dimension of hollow fiber modules

	No. of Hollow fiber	Packing density	Void fraction	Hydraulic diameter (cm^2)	Frontal area (cm)
Type 1	37±1	37.0	36.8	37.2	6.84
Type 2	45±5	45.1	44.5	47.0	6.61
Type 3	0±5	1.1	1.8	2.7	6.39
Type 4	65±5	65.5	64.0	68.0	6.05
Type 5	12±1	12.0	11.6	12.5	5.54

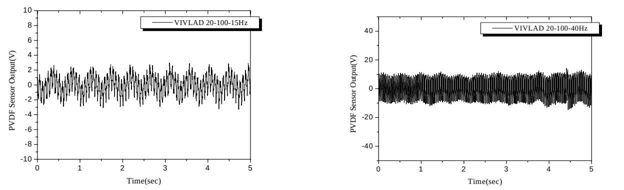
The experiments were performed at various frequencies, which were applied to the PZT actuator bonded with the flexible beam in the artificial lung device. The dynamic responses of the PVDF sensor were obtained by applying the dynamic input voltage with some varying frequencies of sinusoidal wave from 1 Hz to 50 Hz, the magnitude of the excited input voltage from 0 to 100V. The measuring system was discretized at every sampling interval of 1 ms.

3. Results and Discussions

Figure 3 shows the PVDF sensor response at VIVLAD module of type 1 that was excited by sinusoidal wave with varying frequencies from 5 Hz, 15 Hz, and 35 Hz. According to these figure, we shows that the VIVLAD designed with PZT actuator and PVDF sensor excited well and obtained a good performance for transferring the vibration of HFM.



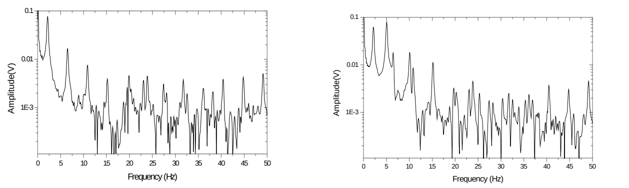
(a) No exciting (b) Exciting frequency; 5 Hz



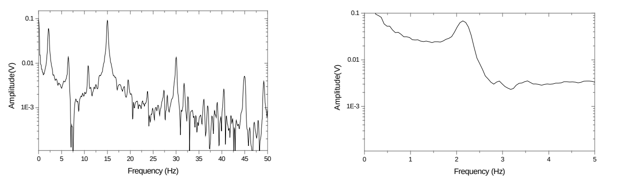
(c) Exciting frequency; 15 Hz (d) Exciting frequency; 35 Hz

Fig. 3. The PVDF sensor output at exciting VIVLAD module of system.

Figure 4 show the power-spectrum of the PVDF sensor at various frequencies of 5Hz, 15Hz, 25Hz, 35Hz and no exciting with the VIVLAD system. In these experiments, these modules have done well in exciting the HFM of VIVLAD, when the exciting frequency of the test module was varied, spanning from 0 to 50Hz (step 5Hz). From Fig. 6(d), effective response characteristics about the vibration amplitude can be achieved up to approximately 35Hz for module type 5, when the amplitude of the excited input voltage of sinusoidal wave is excited from 0 to 100V to PZT actuator.



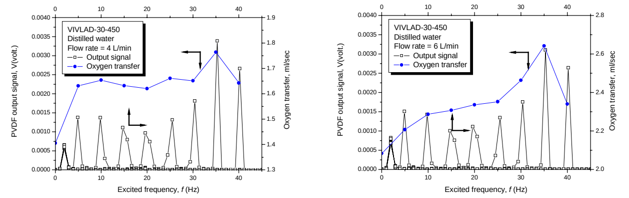
(a) No exciting (b) Exciting frequency; 5 Hz



(c) Exciting frequency; 15 Hz (d) Exciting frequency; 35 Hz

Fig. 4. Frequency response of the PVDF sensor at exciting various frequencies

Figure 5 shows the gas exchange performance for the VIVLAD when 4L/m and 6L/m flow rates each exited frequency in distilled water. The gas exchange results in a 30mm test section also showed that the gas exchange of vibrating types HFM performed substantially better than HFM when the VIVLAD module was in a static, various exciting modes.



(a) Flow rate: 4 L/m (b) Flow rate: 6 L/m

Fig. 5. Gas transfer performance of the VIVLAD in distilled water

4. Conclusions

One of the most important results of this study is the finding of the increase in the gas transfer rate resulting from the vibration of an intravascular lung assist device. We designed the oscillatory type artificial lung assist device attached with PVDF sensor and PZT actuator, and obtained the following conclusion for improving oxygen transfer rate of the VIVLAD.

The lung assist piezoelectric oscillatory device developed causes less of a pressure drop in the state of axial fluid flow, and the vibration transfer of HFM was reliable. We have shown that the efficiency of oxygen transfer of the VIVLAD consisting of HFM improves according to the approved sinusoidal wave at the PZT actuator in fluid flow. Therefore, the experiment results shown an effective performance for enhancing the gas transfer of the VIVLAD. The gas exchange efficiency for the VIVLAD was increased with the following design features: consistent and reproducible fiber geometry, and most importantly, an active means of enhancing convective mixing of blood around the hollow fiber membranes.

Acknowledgements

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