Performance Prediction of Volute Housing for A Rotodynamic Blood Pump

Wenfeng Lu, William A. Smith

Department of Biomedical Engineering

Cleveland Clinic Foundation

Cleveland, Ohio

1 Introduction

Despite the great achievements of modern medicine, cardiovascular disease continues to exact the greatest toll of human life, causing approximately 800,000 deaths each year in the United States [1]. Medications and heart surgeries are helpful for mild cardiovascular disorders. However, they are no longer effective for End-Stage-Heart-Failure (ESHF). Heart transplantation is an effective therapy for saving patients suffering from ESHF. Unfortunately, it is reported that there is about 2,200 donor hearts available each year in USA while at least 40,000 patients might be benefit from heart transplantation [1]. Therefore, a safe, reliable and durable device, i.e. ventricular assist devices (VAD) or total artificial hearts (TAH), could provide a satisfactory solution for a large number of patients with ESHF. It is estimated that as many as 100,000 people could be saved if VAD or TAH had been extensively used.

To design a blood pump used as a heart assist or replacement device has always been a hot topic. The discharge system is very important to overall pump performance. Volute, as a form of discharge system, can result in a significant pressure recovery, but can also cause radial forces and disturbed flow patterns. In case of high radial forces acting on the impeller, the shaft may broken thus the whole pump failed. Reliability of the blood pump is a life/death issue. The volute pressure distribution is a fundamental determinant of the radial forces that affect the reliability of the pump. There are many methods available in literature for the determination of volute pressure distribution for commercial pumps. Bloods pump are very different from commercial water pumps because blood is more viscous and blood cells are prone to damage by high shear stress. Any mechanical failure will be a fatal problem. However, no volute analysis methods have been approved to be effective for blood pumps.

Starting page #: 1085

2 Materials and Methods

In this work, four most frequently referenced analysis methods [2 5] used for commercial pumps are identified and compared for the conditions of use of a blood pump, which is based on a rotodynamic blood Pump developed by Cleveland Clinic Foundation. Theoretical calculation has shown that those four methods fail to agree with each other in predicting the volute pressure distribution. An experimental loop is set up to measure the volute pressure distribution as well as to visualize flow pattern inside the volute. Blood analog (mixture of water and glycerin) was used as the working fluid. This loop consists of two main circuits, i.e., the primary circuit for obtaining pump performance parameters and the secondary circuit for preparing testing liquid. The primary circuit contains the blood pump, flow meter, pressure transducers and a clamp for manual adjustment of flow through the test pump. The flow is measured by an ultrasonic flowmeter (T 110, Transonic Systems Inc.). The pressure rise is measured using a variable reluctance differential pressure sensor (Validyne Engineering Co.). All data signals were digitized and recorded using a PC with data acquisition board (AT-MIO-16XE, National Instruments Co.). The secondary circuit, used for heating, filtering, and sterilizing the test fluid. The fluid can be heated by an electrical heater (1000 W, Omega Inc.), which is controlled by an adjustable switching temperature controller (Omega CN 350, Omega Inc.). A circulation 200 W centrifugal pump (Little Giant Pump Co.) is employed to divert the flow from the secondary loop back to the primary loop.

3 Results

Preliminary experimental data showed that all the theoretical methods have over-predicted the volute pressure for the blood pump, indicating that an underling energy loss exists. Therefore, a model to determine the volute loss is proposed. With more pools of reliable and reproducible experimental data, an effective volute analysis method good for blood pump will be defined. Flow visualization experiments indicate that the pump is free of swirling or stagnation flow while results from hemolysis testing have shown that red blood cell damage caused by the pump well below an acceptable range. As a result of this work, a scientific basis will exist to design high performance blood pump volutes that minimize pump size and maximize efficiency without severe penalties respecting the fatal mechanical failure, blood cell damage or risk of thrombosis.

4 Reference

[1] DeVries, W.C., et al., 1984, "Clinical use of the Total Artificial Heart". New England Journal of Medicine, 310, pp.273-278.

[2] Stepanoff, A.J., 1986, Centrifugal and axial flow pumps: theory, design and application, John Wiley Sons, Inc., New York.

[3] Karassik, I.J., 1990, Pump Handbook, 2nd edition.

[4] Iversen, H.W., Rolling, R.E. and J.I Carlson., 1960, "Volute pressure distribution, radial force on the impeller, and volute mixing losses of a radial flow centrifugal pump", Transactions of ASME, April: pp.136-144.

[5] Lorett, J.A. and S. Gopalakrishnan, 1986, "Interaction between impeller and volute of pumps at off-design conditions, Transaction of ASME: Journal of Fluids Engineering, 108, pp.12-19.