고속 사진기와 영상처리 기법을 이용한 인공판막의 흐름 분석.

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Flow Pattern Analysis of Artificial Valves Using High Speed Camera and Image Processing Technique

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Abstract

Artificial Heart Valve is the one of the most important artificial organ which has been implanted to many patients. The most important problems related to the artificial heart valve prosthesis are thrombosis and hemolysis. Usual method to test against this problem *In vivo* experiment, which is complex and hard work. Nowadays the request for *In vitro* Artificial Heart Valve testing system is increasing. Several papers has announced us flow pattern of Artificial Heart Valve is highly correlated with thrombosis and hemolysis. They usually get flow pattern by LDA, it is also hard work and has narrow measuring region. In this reason we have determined to develop PTV(Particle Tracking Velocimetry). By using High-speed camera and image processing technique, flow pattern could be relatively easily obtained. Parachute and Bileaflet Artificial Heart Valve designed by SNU were testified.

keywords: Artificial Heart Valve, flow pattern, PTV

Introduction

Most of artificial organs, in particular circulation organ, have rheological characteristic. The flow pattern analysis has been used to develop artificial heart and ventricular assist device. The rheological characteristics of an Artificial Heart Valve is an important factors determining the performances of Artificial Heart Valve in clinical application. There are several ways to test the performance of Artificial Heart Valve *in vitro*. Hydraulic dynamics test informs us regurgitation, pressure drop, energy loss and effect valve orifice area(EVOA). Flow pattern analysis is another way which can give us velocity profile, shear stress, Reynolds number, flow separation, turbulence intensity. Cavitation and leaflet motion analysis are also valuable test. An important achievement of modern experimental fluid mechanics is the invention and development of techniques for the measurement of whole, instantaneous field of scalars and vectors. One of the most popular method of these techniques is PIV(particle image velocimetry) or PTV(particle tracking velocimetry). It is a member of LSV(laser speckle velocimetry), which uses plane laser beam to make a object plane.[2] Laser sheeted image frames captured by camera are used to find out velocity. Movement of particles informs velocity direction and magnitude. There are several method in PIV depending on the number of frames and pulses; single frame/ single pulse, single frame/ double pulse, single frame/ multi-pulse, multi-frame/ single pulse, multi-frame/ double pulse, multi-frame/ multi-pulse.[3] Previously we have used single frame/ single pulse technique.[9] Processing procedure are as follows. 1) Image capture with CCD camera in video tape. 2) Image storing in computer memory. 3) Image enhancing with low pass filtering to wipeout noise. 4) Image matching by shifting frames to reference point. 5) Binarized image. 6) Median filtering to remove zebra effect which occurs owing to NTSC video signal characteristic. 7) Thinning to get a center line. 8) Normalize the line and get velocity vectors. 9) Accumulate velocities at same phases. 10) Define vector grid and calculate interpolated velocities at these grid points. Single frame/ single pulse method is the most simple and cheap one to capture an image. But its very difficult to detect the direction of velocity. A multi-frame processing method can be applied. To get velocity direction, double pulse or multiple pulse PIV is also available. But multi-pulse laser is very expensive and hard to set as we like. A technique to make multi-pulse speckle using non-pulse laser are developed, submitting low resolution. There is a fundamental limit in video recording PTV. High speed flow motion could not be detected. Max speed of image frames of video is 30 frames per second. If we reasonably assume that max tracking length is 1cm, than the upper bound of measurable velocity is 30cm/sec. $v = l f$ v: max measurable velocity l: max tracking length f: frame speed. However in our testing object, usual speed is above 2-3m/s and max tracking length is smaller than 1cm. If we assume again that max tracking length is 0.5cm and max measurable velocity is 300cm/sec, than we must take pictures 600 frames per second. This speed problem can be solved by using high speed camera.

Methods & Materials

In this experiment multi-frame/ single pulse PTV was used. Estimated max flow speed was 500cm/sec and max tracking length was determined as 1cm. So frame speed of high speed camera is 1000 frames per second. We processed continuous 12 frames at once. In this method, intersecting path line problem could be solved. When a path line between two frame is exist, it can be one of two types; one is real path on the laser sheeted plane, the other is a slopped line which pass through the plane. Second path is a intersecting path which cannot remain as multi-path line. It may disappear as one or two times connected path line. By eliminating this lines relatively good result could be obtained. The mock circulation system which designed to simulate the human physiological circulation. Schematics of the image capturing system shown in Fig.1. 33% glycerin and destined water was used as a blood analogue solution. Light source is He-Ne laser(30Watt, 6.5A, 2.45-3.20KV DC) and optical slit was used to get a plane beam. Amberlite particle (diameter about 0.4mm) was used for its similarity of specific gravity with blood analogue solution. Pulse-type flow was generated by VAD(ventricular assist device) actuator which has been developed by SNU BME. High-speed camera, shutter speed: 100-10000 frames per second (made by Holland-Photonics) was used. Kodak RAR 2497 film was used (ASA: 500, length: 125ft). The distance between the camera and the objective was 40cm. Image processing board which had multi-frame memory was necessary. MATROX image processing board which had four independent 1M byte memory frames was used. In this processing, frame size was 480pixels*480pixels. Each pixel had 8 bits resolution, 256 gray levels.

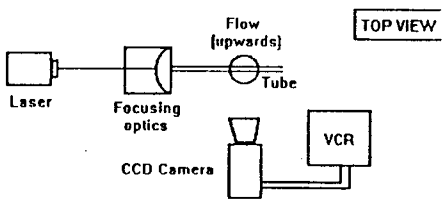

Fig.1. Valve Flow Visualization System

Results

We have tested the parachute valve & bileaflet valve which were developed in SNU BME. About 40 bpm pulsed flow was generated by VAD actuator. Film speed was 1000 frames per second. Pictures were taken about 5 seconds for each valve. Films were developed by Holland's film developer. Images are displayed on the screen by film projector. By using COHU CCD camera and Matrox Image processing board, image frames were digitized in IBM 386 computer memory. Image processing procedure from raw frame image to velocity profile is as follows. 1) To remove digitizing noise, each frames were low pass filtered. 2) By using histogram, segmentation levels were determined. 3) Frame images were binarized to get particle position information. 4) Centroid of each particle was found. 5) Each particle was tracked from one frame to next frame. 6) Invalid path lines were eliminated. 7) Path lines are normalized to velocity vectors. 8) Vector grid was defined. 9) Velocity vectors were interpolated to a velocity profile.1) 2) 3) 4) steps are well known image processing technique. The technique used to track the particle is as flows. For detailed description of this technique see [4],[9]. At the first tracking, a particle of the next frame is searched in a determined circular tracking region of which center is a particle position of first frame. The closest particle is selected to made a path line. After all path lines from first to second frame had been searched, there may be two or three to one mapping, which is impossible in real situation. So only the shortest path was selected, and other paths were eliminated. From second tracking, another modification is needed. A particle path cannot change its direction much in the next plane. In this reason, the searching area is modified from circle to fan shape. The direction of fan-shape searching region is determined by the direction of the previous connected path. The angle of fan shape must be selected reasonably. The tracking algorithm described above is represented schematically in Fig.2. As a result of above procedure a velocity profile and a flow pattern could be obtained for each valve. For each valve, selected 12 10 frames among 5000 frames which were corresponding to 1 roll film were processed. Flow patterns in the beginning of diastole and systole could have been obtained. The difference of two flow patterns of valves were clear.

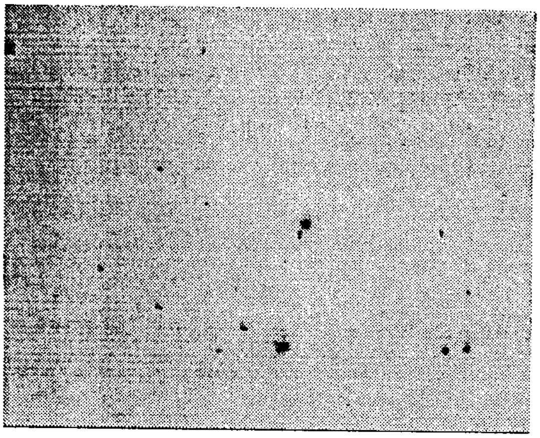

Fig.2.1 Original Image

Fig.2.2 Binarized Image

Fig.2.3 Centrorized Image

Fig.2.4 Tracked Image between two frames

Fig.2.5 Connected image with three tracked image

Fig.2.6 Connected image with eleven tracked image

Discussion

Velocity profile and flow pattern could be relatively easily obtained. This technique have overcome some defects which other flow visualization methods[1][5][9] have. With this information, we can calculate various parameters for valve performance *in vitro*. With this result, shear stress at particular position can be obtained. Turbulence intensity profile can be acquired using some much data at the same phase.

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