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CHARACTERISTICS OF FLUID DYNAMICS IN TUBES AND THE OUTFLOW TRACT OF AN ARTIFICIAL HEART, MEASURED WITH PULSED US DOPPLER TECHNIQUE

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Velocity profiles and turbulence intensities of steady flow in tubes were measured with a pulsed ultrasonic-Doppler instrument UDP 30. These results were compared with those of other flow measurement methods.

In a similar way such measurements were performed to study pulsatile flow in the inflow- and the outflow-tract of an artificial heart, developed by the Hospital of Internal Medicine, Wilhelm-Pieck-University, Rostock. The principles of signal acquisition and first results are presented.

1. Introduction

Interest in flow characteristics of artificial hearts – inside the ventricle and in the inflow and the outflow tract – is stimulated by the development of these implantable organs.

The knowledge of distributions of velocities in flowing blood and of the existence of so-called dead zones and regions with high degree turbulences is important. If the shear stresses exceed upper and lower borderline-values, blood cells and vessel walls may be damaged. Perhaps, these effects may contribute to thrombosis.

In vitro measurements of flow characteristics are made with laser Doppler anemometers, hot film anemometers and pulsed ultrasonic Doppler techniques. Furthermore, the flow behaviour can be watched by photographic or cinematographic methods. Flow patterns were studied in a model of circulation outside of artificial hearts by STEVENSON [1], REUL [2], CHANDRAN [3] and PELISSIER [4]. Their results are transferable to our system only with restric ions, because the flow characteristics are influenced strongly by the geometric forms of the ventricle and valves. Therefore, it is our aim to study the flow patterns inside and outside of the artificial heart.

2. Experimental methods and results

We used for flow velocity measurements the range-gated (ultrasonic) Doppler instrument, UDP 30, produced by Techpan, Warsaw. In order to test the aptitude of the Doppler unit to our purposes, the steady flow in tubes was studied by a simple set up, presented in Fig. 1.

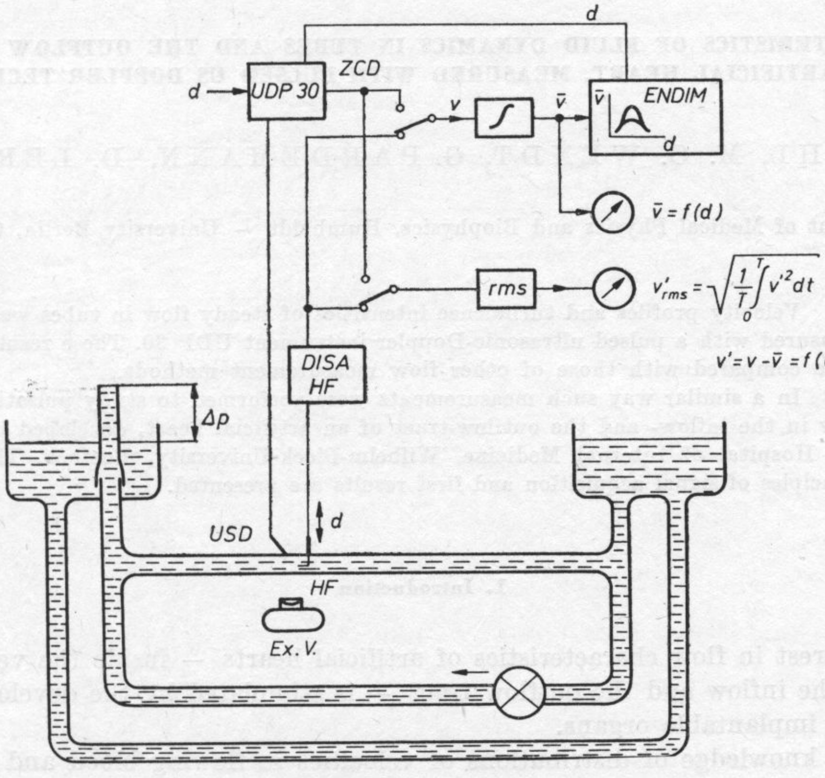

Fig. 1. Set up for steady flow measurements

We used as backscattering particles Callocryl in water, diameter 100 to 150 μm. Doppler measurements in circular tubes were compared with hot film flow measurements using a Disa electronic instrument (with physical parameters: entry length of 2 m; Reynolds numbers of 800 to 6000).

The results, shown in Fig. 2, demonstrate that UDP 30 is suitable for measurements of velocity profiles in such tubes, also in cases with non-laminar flow. The root mean square-values of velocity fluctuations are a useful measure of turbulence intensities, obtained with the UDP 30 and the hot film anemometer. The results of the measurements differ considerably near the wall, probably due to the limited resolution in depth of the UDP 30 instrument (1 to 2 mm).

The limited time resolution of the zero-crossing detector built in the UDP 30 is another reason for the observed differences. Furthermore, it should be stressed that from these measurements it is not possible to calculate the Reynolds shear-stresses. But these values would be very important in the sense of mechanical damage of blood cells (RBC and platelets) and vessel walls.

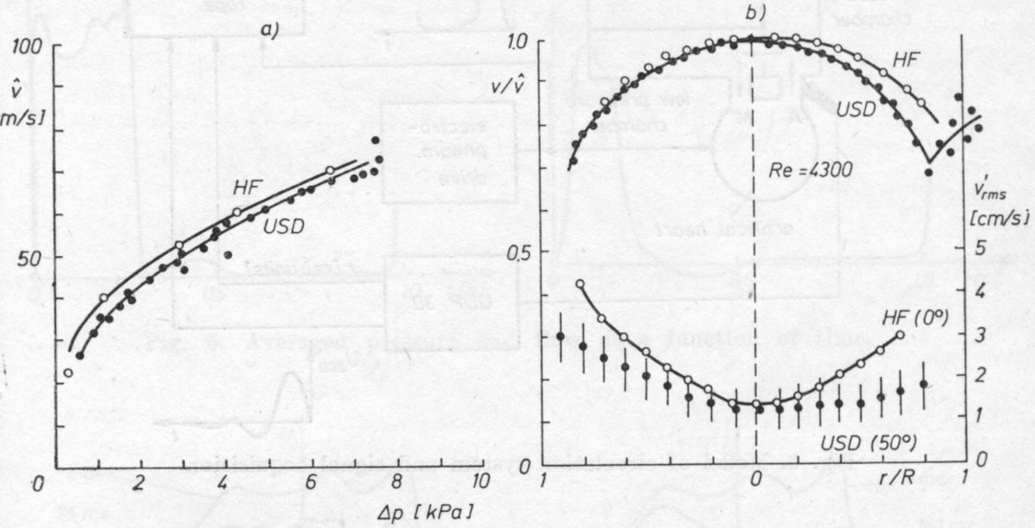

Fig. 2. Comparison between UDP 30 and hot film flow measurements: *a*. flow velocity maximum as a function of pressure, *b*. velocity profile and turbulence intensity for $Re = 4300$

In order to measure the inflow and outflow characteristics of the artificial heart, the ventricle is connected with a model of the circulation system, consisting of two pressure chambers, as depicted in Fig. 3. The high pressure chamber with a variable windkessel is connected with a low pressure chamber by an adjustable gap, simulating peripheral resistance. A pneumatic device drives the membrane of the ventricle. The beat frequency and systolic flow time can be adjusted. There are also shown the data processing, off-line registration on Thermionic magnetic tape and averaging in a DEC LINC 8 computer. An exact triggering signal was derived from the steepest ascent of the pressure curve.

Aortic flow curves are shown in Fig. 4, measured at a distance of 9 cm from the valve of Björk-Shiley type (*R*-flow near the wall, *Z*-central flow). These curves are not averaged. Here are clearly demonstrated the strong velocity fluctuations after the systolic flow period due to turbulent flow conditions.

The flow conditions in the inflow tract are similar, also measured at a distance of 9 cm from the mitral valve.

Fig. 5 presents pressure and flow as a function of time, measured in a selected volume element of the aorta. The curves are averaged over 32 cycles.

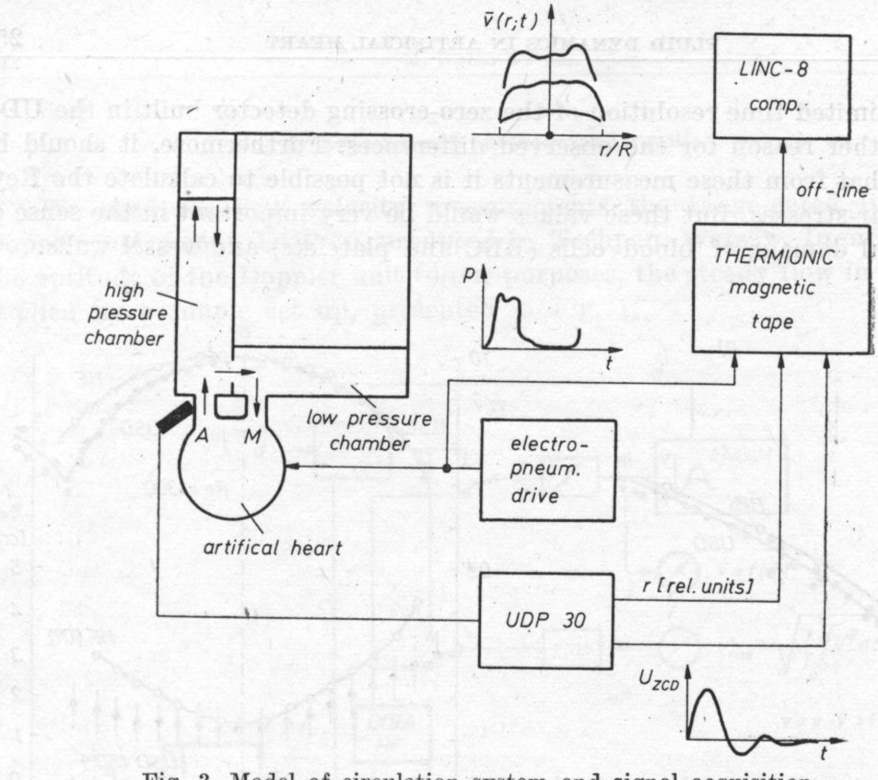

Fig. 3. Model of circulation system and signal acquisition

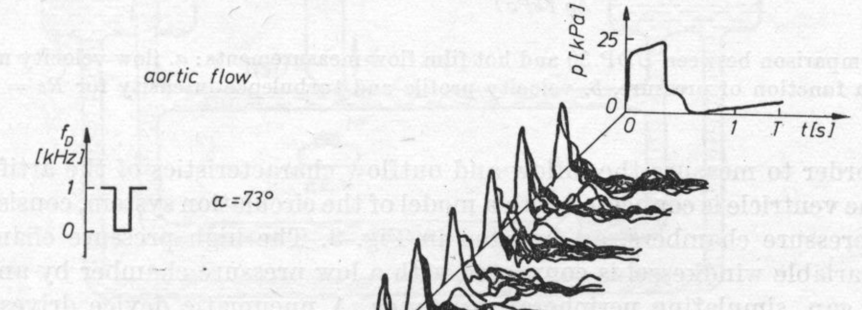

Fig. 4. Aortic flow curves (non-averaged) at different depth of tube

Velocity profiles are constructed from such curves for different times in the cardiac cycle (Fig. 6). From these, it is obvious that the velocity maximum depends on the time and radial position in the aorta. It should be noted that the flow behaviour in the aorta, especially the backflow after the systolic time, corresponds to theoretical predictions, given by WOMERSLEY [5].

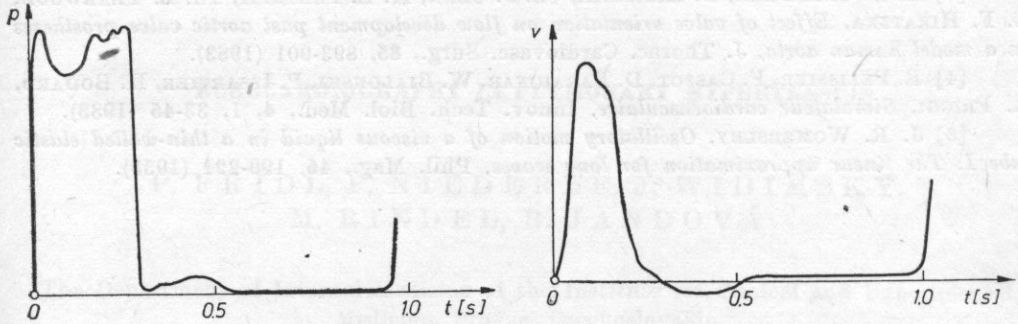

Fig. 5. Averaged pressure and flow as a function of time

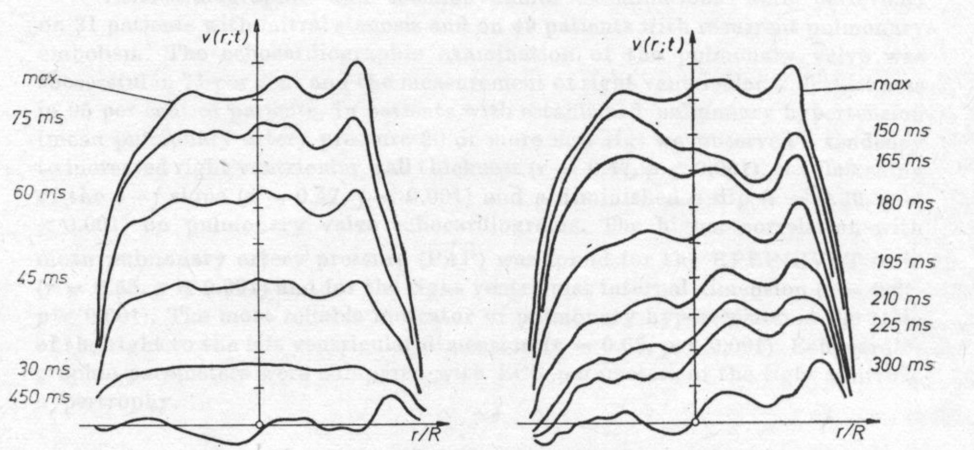

Fig. 6. Velocity profiles for different times in the cardiac cycle

3. Conclusions

The pulsed US Doppler technique is useful for measurement of velocity distributions in steady and pulsatile flow, results for turbulence intensities and shear stresses from zero-crossing signals are possible only to a limited extent.

Further measurements with combined *B*-mode/pulsed Doppler technique and FFT-spectral analysis in real time are in preparation.

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