Miniaturization of an implantable pump for heart support

Sebastian Hallier, Jitendra Kumar, Frank-Hendrik Wurm, Institute of Turbomachinery, University of Rostock, Germany

Long Abstract

Introduction

Heart failure is a frequent chronic disease which is spread over 20 million people worldwide. About 1 million people worldwide need to receive a heart transplant because of their advanced heart failure. In contrast there are only 3000 people donating hearts each year. Therefore there is the clear intention to develop a technical solution as a substitute. Different concepts are pursued but all of them must distinguished themselves in: low blood damage (hemocompatibility), high efficiency, low noise radiation and small size. A Promising concept is the implantation of an axial flow pump. It has the advantage that the drive can be integrated into the pump easily and the most affected left ventricle [1] can optimally be supported by this concept. The axial flow pump consists of the hydraulic part of the pump and the drive where the rotor is placed within a magnetic bearing. These pumps are relatively heavy and placed below the heart as shown on the left side in Figure 1.

Miniaturization of implantable axial flow pump having axial inflow and outflow direction is the objective of current research work. The main target of the work is the miniaturization of the hydraulic part with respect to the above mentioned parameters, especially the hemocompatibility. The hydraulic part of the existing pump consists of an inlet guide vane, an impeller and an outlet guide vane. With a miniaturized hydraulic part it can be placed partially inside the left ventricle of the heart as shown on the right side in Figure 1. In this configuration however, a radial or tangential outflow graft seems to be more beneficial as it allows restriction for the needed space of the pump to the direct vicinity of the heart. This less invasive approach might lead to fewer postoperative complications and a lower morbidity rate.

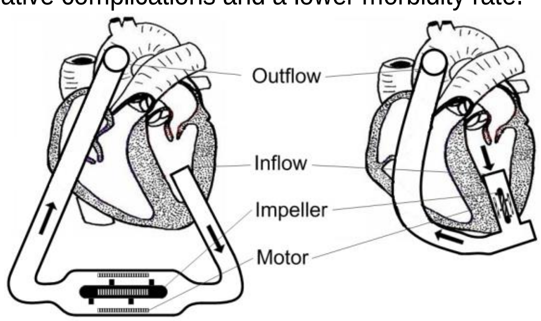

Figure 1. Placement of the existing design (left side) and the new design (right side)

1. Methods

Different methods are used within the project for the design of the impeller blades, e.g. a semi-empirical method with consideration of cascade effects and a method of singularities. For the design of the volute casing a method based on the principle of constant angular momentum was developed and used. The result is an asymmetric volute in which the specific angular momentum remains constant. The investigation and optimization of the flow field was done by using numerical methods. Three dimensional numerical models of the entire pump were created in order to perform URANSE simulations at different load conditions, using the SST turbulence model with curvature correction and the Gamma Transition Model. For spatial discretization a structured mesh, resolving the boundary layer of the flow, was used. A periodic boundary condition was used at the inlet in order to reproduce the time varying inflow caused by the remaining activity of the heart. The performance of the different designs was assessed by flow patterns at leading edge, static pressure head, efficiency and as main critical criteria the hemocompatibility. Latter criteria is evaluated using the modified index of hemolysis (MIH) which is defined in equation (1), where Q is the flow rate and τ the equivalent stress provided by the von Mises criterion.

$$MIH = 10^6 \left(\frac{1}{Q} \int_Q (3.62 \cdot 10^{-7} \tau^{2,416})^{\frac{1}{0,785}} dV \right)^{0.785} \quad (1)$$

The MIH allows to predict the global hemolysis of a blood pump and to compare it to other designs. Thus it is used in the design and optimization process of medical devices [2].

2. Results

The designed hydraulic part has a volume which is approximately 60% lower compared to the existing pump which is a big step forward for the application as heart support system. The efficiency of the new design is on the same level as efficiency of the existing pump despite the drastic reduction of the dimensions. The simulation results show that hemolysis in the existing pump has its minimum at the point of best efficiency and increases towards part and overload conditions as presented in Figure 2. For the new pump design hemolysis at point of best efficiency is at a similar level as in the reference pump. An increase of hemolysis towards part load can be observed, it is however lower than in the existing solution. Towards overload conditions hemolysis is even decreasing (Figure 2). In the inlet guide vane hemolysis rates are nearly negligible because of the yet undisturbed flow field with low velocities.

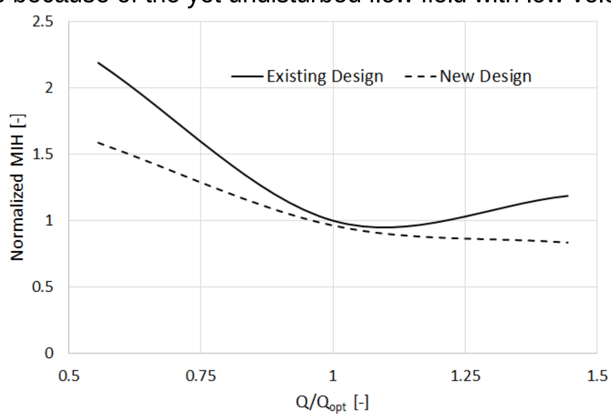

Figure 2. Normalized values of MIH in different load conditions

The simulation results show that highest shear stress in all operation points occurs in the impeller region, due to the very high rotational velocity of the impeller and the resulting velocity gradients at the leading edges and in the gap between impeller blades and the stationary casing.

At part load conditions the blood damage in both, the impeller and the volute, increase as a result of recirculation zones, which lead to relatively high shear stress and exposure time for blood particles. Additionally a separation zone within the first section of the volute behind the cutwater can be identified. At overload condition, regions of high stresses inside the new volute design are very small and restricted to the zone around the volute tongue. For this reason reduced hemolysis rates are observed in the new volute whereas the guide vanes of the existing pump cause increased hemolysis due to shear at the leading edge and separation.

The new designed hydraulic part fulfills all requirements on an implantable pump. The reached dimensions are small enough in order to implant it by minimal-invasive methods, which is a big step forward in the use of implantable heart supporting systems.

References

[1] N. Moazami et al. Axial and centrifugal continuous-flow rotary pumps: a translation from pump mechanics to clinical practice. *Journal of Heart Lung Transplant*. 2013;32:1–11, 2013

[2] A. Garon and M.-I. Farinas. Fast Three-dimensional Numerical Hemolysis Approximation. *Artificial Organs*, 28(11):1016–1025, 2004