PROTOTYPE OF A PNEUMATICALLY OPERATED HEART CATHETER PUMP

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SUMMARY
Effective assistance of the cardiopulmonary system poses a particular technological challenge. In this work we describe an innovative system for temporary heart assistance in critically ill patients, which - though minimally invasive – is efficient for recovery of the heart. An Archimedic screw drive that transports the blood out of the left ventricle into the ascending aorta is coupled to a pneumatic drive unit by a contactless magnetic bearing. First tests with a prototype of the heart catheter pump on a scale of 2:1 have shown promising results and proven the feasibility of the concept based on a pneumatic drive. Additionally the pneumatically operated heart catheter pump can be combined with an intra-aortic balloon pump leading to even higher efficiency.

INTRODUCTION
According to the European Society of Cardiology, cardiovascular disease causes 42 per cent of all deaths in countries of the European Union. Effective assistance of the cardiopulmonary system poses a particular technological challenge. To assist the heart to pump blood out of the left ventricle into the aorta, electric heart-assist pumps that are minimally invasively inserted into the heart through the femoral artery can currently be used as temporary solution in critically ill patients recovering from a heart attack or awaiting a transplant [1]. Problems associated with the electric drive are the generated heat inside the body and hemolysis caused by damaged blood cells. In this study a prototype for a pneumatically operated heart catheter pump has been developed that could be used as a safer and more effective alternative to the electric heart pump.

METHODS
The functionality of the pneumatically operated heart catheter pump is based on the principle of an axial flow turbine. The pump is inserted into the ascending aorta via a catheter and the tip is inserted into the left ventricle through the cardiac valves so that blood is transported out of the left ventricle into the aorta. The pump is connected to the external devices through the femoral artery via a flexible tube for in- and outflow of the gas for the pneumatic drive.

For effectiveness in critically ill patients the pumping capacity has to be at least 2-2.5 l/min. The pump has to meet the following requirements: due to anatomical restrictions maximum diameter should be 5 mm and maximum length 45 mm; for safety reasons the maximum overpressure in the flexible tube for the pneumatic drive is restricted to 1,5 bar.

To test the feasibility of the pneumatically operated heart catheter pump a first prototype on a scale of 2:1 (figure 1) was developed, which is easier to manufacture and adapt than a device in the original size.

Figure 1: Prototype of the pump on a scale of 2:1, housing of pumping unit removed.

Basically, the pump consists of a pumping unit and a drive unit, which are connected via a contactless magnetic coupling based on Neodym magnets and hermetically separated to avoid contact of blood and gas.

The pumping unit contains the rotor, an Archimedean screw made of ceramic, which is bedded as a pendulum on a ball bearing in order to minimize friction and generation of heat. At sufficient rotational speed the rotor is additionally bedded on an axial hydrodynamic bearing between the rotor and the partition to the drive unit, enabling the rotor to rotate completely without contact. An emergency bearing at the tip of the pump ensures that the rotor stays in place in case of disturbances. The design of rotor and bearings was optimized in order to avoid dead spaces and consequently minimize hemolysis.

The drive unit is based on the principle of an axial-flow turbine. The drive rotor is supported in the housing in two sinter bearings. An additional freewheel ensures functionality at high rotational speeds. The gas for the drive unit is led in

and out of the pump through a flexible tube that is divided into two compartments for in- and outflow. Lines for measurement of the rotational speed are integrated into the wall of the tube (figure 2).

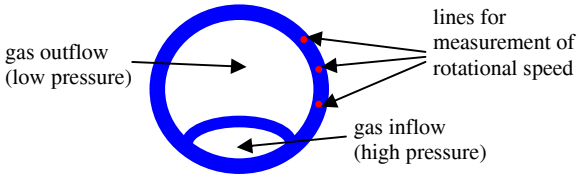

Figure 2: Cross section of the flexible tube for gas in- and outflow

The assembled prototype was tested in an experimental set-up. Tubes were connected to the outlets for the transported fluid (in the experiments water was used instead of blood) so that the delivery pressure could be determined via the delivery height. To measure the rotational speed a hall sensor was integrated in the housing that senses the oscillating magnetic field of the coupling magnets in the pumping unit (figure 3).

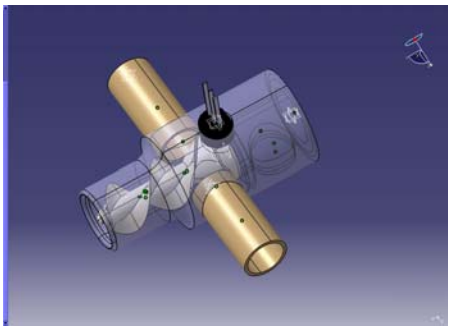

Figure 3: Drawing of the prototype with attached tubes and Hall sensor for the experimental set-up.

RESULTS AND DISCUSSION

First tests with the experimental set-up have shown that the idle-speed strongly varies with input pressure. At an input pressure of 3.5 bar the idle-speed is about 50000 rpm. In the loaded condition when the pump transports the fluid the rotational speed is about 14400 rpm, what corresponds to a pumping capacity of about 2.5 l/min. Looking at these results it has to be considered that due to inaccuracies in the manufacturing process the gap between rotor and housing was not constant, what led to an unsteady run of the rotor. For the prototype the rotor made of ceramic was produced by a rapid prototyping technique, which is a quick and cost-effective solution. For optimal accuracy either the manufacturing process has to be improved or the rotor has to be manufactured of a different material, e.g. titanium. Even small inaccuracies lead to reduced efficiency or instable transient behavior of the pump. To further increase the efficiency of the pump the optimal pitch of the Archimedean screw and the optimal parameters of the hydrodynamic bearing have to be determined in an iterative design process.

To manufacture the heart catheter pump in the requested size - maximum diameter 5 mm and maximum length 45 mm – further adaptations of the design will be necessary. The single magnets in the coupling will have to be replaced by one multiply poled magnet. Appropriate biocompatible materials for the final version of the device are titanium, carbon and ceramic. All friction couplings will finally be realized as ceramic/titanium pairings.

Finally, also a reduction of noise in the drive unit will be necessary.

CONCLUSIONS

First tests with the prototype of the heart catheter pump on a scale of 2:1 have shown promising results and proven the feasibility of the concept based on a pneumatic drive. Further optimizations and adaptations will be necessary in order to further miniaturize the device to the requested size for implantation into the human heart.

An additional advantage of the pneumatically operated heart catheter pump is that it can be combined with an intra-aortic balloon pump. This hybrid procedure combines active assistance of blood transport with pressure increase through the balloon catheter improving blood support of the heart.

ACKNOWLEDGEMENTS

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REFERENCES

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