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Development of a pneumatic driven left ventricular assistant device (LVAD) - preliminary results

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SUMMARY

This paper describes the design and preliminary testing of a pneumatically driven blood pump. In this micro device a turbine acting as the drive unit generates the power for the pump unit which assists the heart in unloading the left ventricle. In order to achieve hermetic separation of the two units torque transmission is done through a magnetic coupling in combination with a planetary gear. In experiments on a test rig the drive torque of the turbine at specific rotational speeds was determined. The results will be used to further optimize the design of the magnetic coupling and the planetary gear.

INTRODUCTION

After a heart attack or before/after heart surgery, critically ill patients need temporary circulatory assistance. Intra-aortic counter-pulsation and electrically driven heart-assist pumps are clinically used to increase cardiac output and support the failing heart temporarily. Both systems have limitations in regaining full recovery of myocardial jeopardy.

In order to overcome these limitations and to provide more effective heart assistance we developed a tiny pneumatically driven blood pump. In combination with counter-pulsation the device can simultaneously assist the heart in unloading the left ventricle and increase coronary circulation. For minimally invasive placement through the femoral artery into the left ventricle the maximum diameter of the heart pump is limited to 6 mm and its rigid length must be less than 45mm. One challenge of the development is the realization of a micro turbine that generates enough power for the pumping unit to perform as an effective heart assist device.

This study describes the development and testing of the drive unit on a scale of 2:1 (max. diameter 10mm) and the determination of the optimal transmission rate between turbine and pump unit.

METHODS

The development of the turbine as drive unit of the pump was done using 3D computational design and a computational fluid dynamics (CFD) simulation.

The working medium of the drive unit is Helium which is also used in the intra-aortic balloon pump. Due to a maximum allowed temperature difference of 13K between inlet and outlet of the turbine, mass flow rate is only 0.12 g/s and the design of a single stage reaction turbine with partial admission was chosen. With a mean rotor diameter of 7mm the turbine generates an estimated power of 2.1W at 265 000 rev/min. Due to the small size and in order to be able to realize and test different blade geometries, lithographic ceramic manufacturing technology was used. Different blade geometries were simulated in the CFD analysis. To verify the computationally estimated performance of the designed drive unit, an experimental setup was established. Due to the small torque and the high rotational speed it was not possible to use a generator to measure the power output. A test setup based on a viscometer [1,2,3], as shown in figure 1, was designed and used to experimentally determine the characteristics of the turbine.

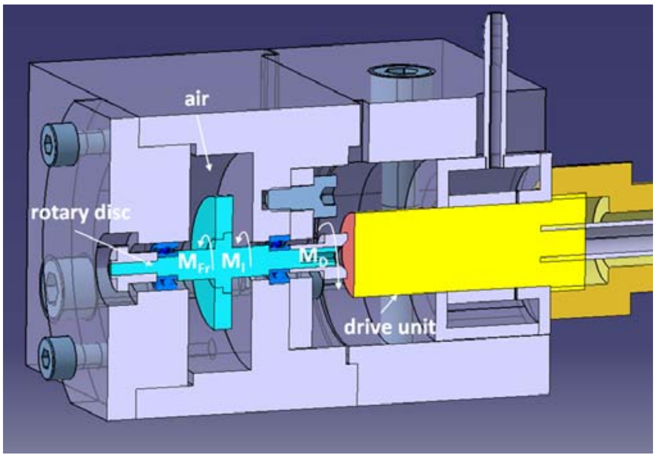

Figure 1: Torque test setup (Viscometer)

The setup consists of the drive unit connected to a rotating disc with a known moment of inertia M_I and wheel friction M_{Fr}. The drive torque M_D was predicted by calculating the equilibrium of angular momentum. From the measured torque at each specific rotational speed the power output was derived.

The preliminary fluid dynamics design of the pump unit was done at a flow rate of 9.8 L/min and differential pressure of 60 mmHg. To determine the optimal operating point of the pump unit, it was coupled to and driven by the turbine with different rotational speeds. At the optimal operating point the pump produces the highest flow rate against a defined differential pressure.

RESULTS AND DISCUSSION

In figure 2 the power output of the turbine over the rotational speed at different flow rates is displayed.

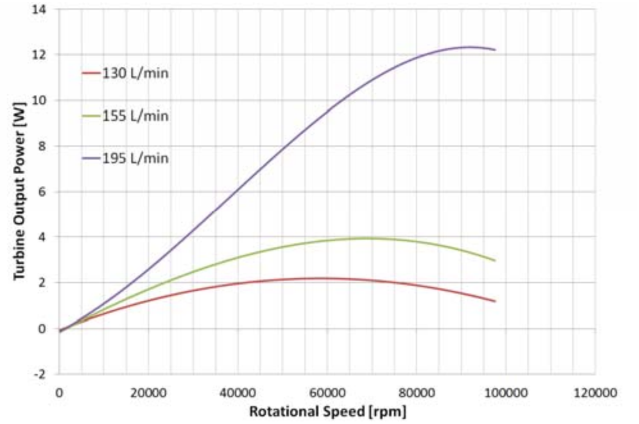

Figure 2: Turbine characteristics at different flow rates

For each instantaneous mass flow rate in the turbine, there is a specific rotational speed where the maximum active power is generated. For the given flow rate of 155 L/min maximum power is reached at about 70000 rpm of the turbine.

The pump's optimal working point is at 26100 rpm. Therefore, a reduction of the rotational speed from the turbine to the pump unit through a gearing is needed. For the first tests a commercial planetary gear with a transmission rate of 3.9 and an outer diameter of 6mm was selected that copes well with the high speeds of the blood pump. For optimal transmission and most effective transformation of the drive power from the turbine to the pump a customized planetary gear with a certain transmission rate will be developed.

The complete assembly of the blood pump (figure 3) was manufactured. The fabrication process which was used for building the ceramic parts has proven to be capable of handling small and complex geometries. First tests with the complete assembly showed promising results, although the magnetic coupling could not transmit the full torque generated by the drive unit.

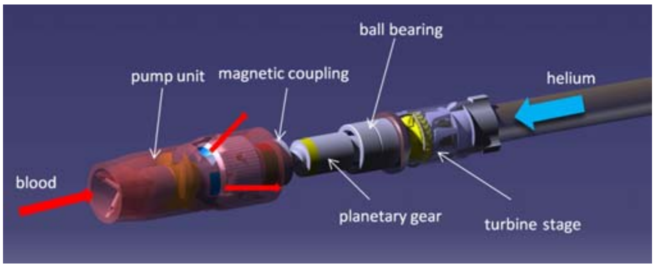

Figure 3: Assembly of a heart catheter pump

CONCLUSIONS

Characteristics of the pneumatic drive unit and the pump unit were computationally estimated and experimentally verified [4]. In the next step the gearing and the magnetic coupling between turbine and drive unit will be optimized in order to increase the efficiency of the LVAD.

A complete prototype of the heart pump on a scale of 2:1 was manufactured and showed promising results in first tests.

Further tests in a mock circulation will be done to prove the functionality of the micro pump as a heart assistant device before downscaling to the original size is done.

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