35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Development of a Portable Bridge-to-Decision Blood Pump*

T. Yamane, K. Kitamura

Abstract— **We are developing an axial-flow pump with a cylindrical-impeller without airfoils. In the mock experiments of HA02 model a pressure of 13.3 kPa was obtained at a rotational speed of 12500 rpm and flow of 5L/min. The obtained pressure with HA02 was almost double than an airfoil-type impeller. The 2D analysis of hydrodynamic bearings for the pump revealed that a section with 3 or more arcs is stable with respect to angular position, and a minimum bearing gap of 100μm can be attained at a design bearing gap of 150 μm and at a groove depth of 100μm.**

I. INTRODUCTION

Though more than 200 patients are nominated to a waiting list of heart transplantation, only 40 donors can be found annually in Japan. Those heart patients can afford recently implantable left ventricular assist devices (LVAD) such as EVAHEART, DuraHeart, or HeartMate II and can afford to go out-of-hospital. Many of them use bridge-to-decision pumps before the final implantation of LVADs. However, presently available bridge-to-decision pumps are not only heavy but also expensive. We are developing a light and inexpensive system using a disposable axial-flow pump with hydrodynamic bearings as shown in Fig. 1.

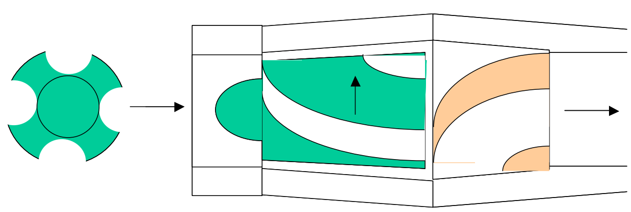

Fig. 1 System image of a portable bridge-to-decision pump

II. EXPERIMENTAL METHODS FOR AXIAL-FLOW PUMPS

From the stand of fluid dynamics, impellers of rotary pumps are requested to transmit the angular momentum to the fluid. Though usual axial-flow impellers use airfoils to convert directions of flow, we designed an impeller not with airfoils but with a grooved cylindrical shape. This intends to implement hydrodynamic bearings easily.

Based on rotary pump theory, the necessary torque, T, to increase the angular momentum can be written using flow Q, density ρ, circumferential velocity v, and radius r, as follows:

$$T=\rho Qrv$$

Using rotational speed ω and differential pressure ΔP, input power and output power of the fluid can be equated with hydrodynamic efficiency η, as

$$\Delta PQ=\eta\omega T$$

Therefore, the pressure head of the pump can be written as

$$\Delta P/\rho=\eta uv, \quad \text{where } u=r\omega$$

The above equation is valid for both centrifugal pumps and axial-flow pumps.

In our experience of an axial-flow impeller with airfoils (R=7.5mm) ΔP=13.3kPa and Q=5L/min was attained at

$$\omega=15000\text{rpm}=1570\text{rad/s};\ u=11.8\text{m/s}$$

This corresponds to $\eta=0.090$, assuming $u=v$. If we can assume $\Delta P/\rho=0.5u^2$ in the present design, the circumferential velocity becomes

$$u=5.03\text{m/s}$$

We have designed two impeller models as Fig. 2. When we assume a blockage of 67% for the model HA01,

Axial velocity: $w=1.42$ m/s

Inflow angle: $\alpha_1=16.2$ deg

When we assume a blockage of 50% for model HA02,

Axial velocity: $w=0.94$m/s

Inflow angle: $\alpha_1=10.8$deg

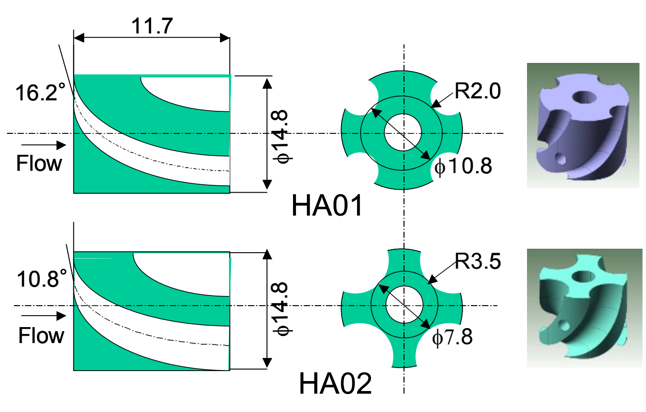

Fig.2 The newly designed impellers, HA01 and HA02

*T. Yamane, Professor, Mechanical Engineering Dept., Kobe University, Kobe, 657-8501 Japan (corresponding author, phone:/fax: +81-78-803-6146; e-mail: yamane@mech.kobe-u.ac.jp).

K.Kitamura,, Mechanical Engineering Dept., Kobe University, Kobe, 657-8501 Japan (e-mail: 0974530t@stu.kobe-u.ac.jp).

978-1-4577-0216-7/13/$26.00 ©2013 IEEE

III. EXPERIMENTAL RESULTS AND DISCUSSION

Two impeller models were newly manufactured with PEEK polymer and were driven with a DC motor. We constructed a circuit composed of a test pump, as Fig. 3, a soft reservoir, vinyl-chloride tubes, and a resistance. The flow rate and the upstream/downstream pressures were measured with an electromagnetic flow meter and two semiconductor pressure gages, while city-supply water was used as fluid.

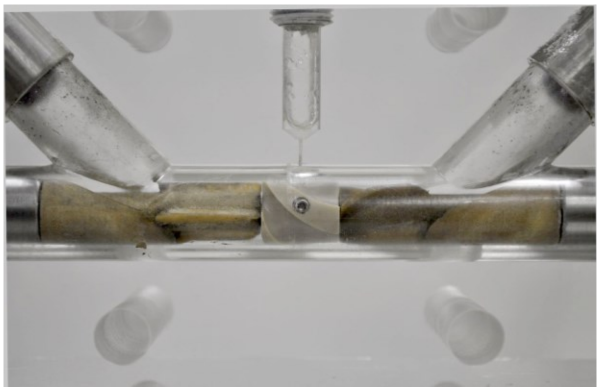

Fig.3 Experimental apparatus (Flow from left to right)

The obtained pressure-flow curves of the test pumps are shown as Fig. 4 to Fig. 6, corresponding to an airfoil impeller, HA01 impeller, HA02 impeller, respectively. Since the pressure values are for water, pressure values for blood can be obtained by multiplying 1.056 to the graph value. Fig. 4 shows usual right-side down curves as airfoil impellers since the angle of attack decreases as the flow increases. Fig. 5 shows very low maximum flows maybe because the fluid channel resistance of the impeller was small for HA01. Fig. 6 for HA02 impeller shows high pressures at the same flows compared to an airfoil impeller.

At a common rotational speed of 12500 rpm, as Fig. 7, an airfoil model generates 6kPa, model HA01 0kPa, while model HA02 generates13kPa, which is almost double of the airfoil model.

On the other hand, at a common pressure of 13.3kPa, an airfoil model needs 15000 rpm and HA02 needs 12500 rpm, which is 20% reduction in the rotational speed.

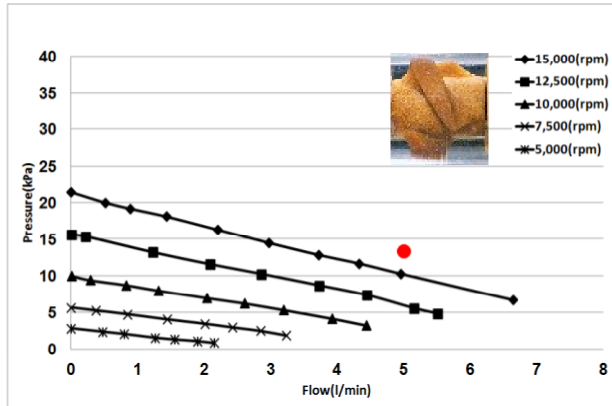

Fig. 4 Pressure/flow curve for an airfoil impeller

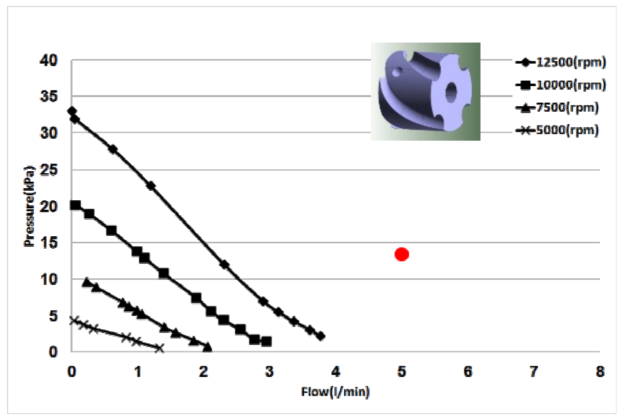

Fig. 5 Pressure/flow curve for HA01 impeller

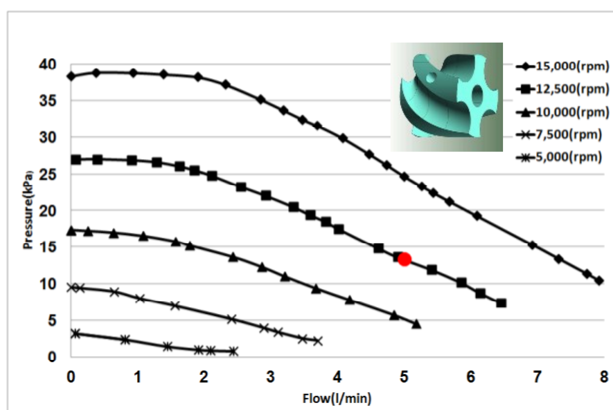

Fig. 6 Pressure/flow curve for HA02 impeller

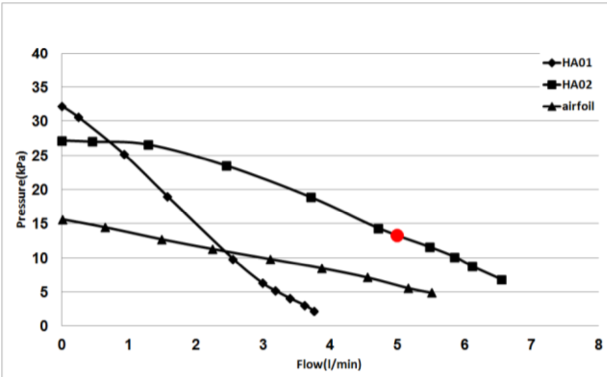

Fig. 7 Pressure/flow curves for 3 impellers at 12500 rpm

IV. 2D Analysis for Hydrodynamic Bearings

The hydrodynamic bearing on the surface of a cylindrical surface of the impeller was analyzed with 2D numerical model based on Reynolds Equation in lubrication. The section of the impeller is composed of inclined N arcs as Fig 8. The analysis was done for the region of 1/N and periodical boundary conditions were applied, while inlet side pressure was assumed 0 mmHg and outlet side pressure 100 mmHg. Investigated design parameters were the number of arcs, the mean bearing gaps, and the groove depth.

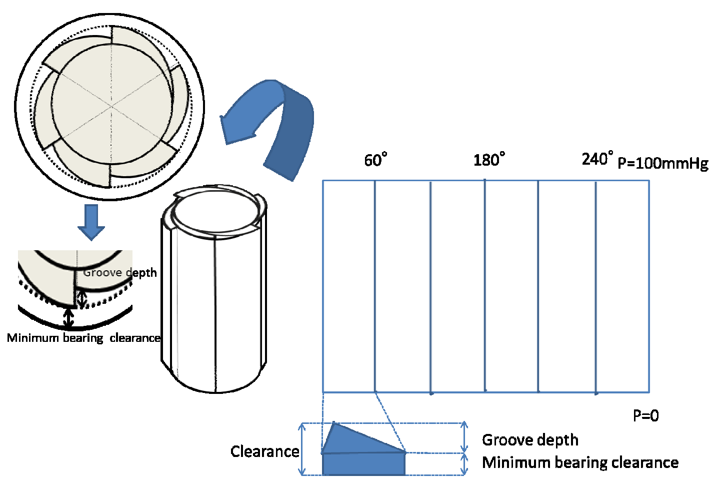

Fig. 8 Analytical model of Reynolds equation for a hydrodynamic radial bearing with multi-arcs

V. Analytical Results and Discussion

The variation of the pressure resultant were compared due to impeller angular position, in Fig. 9, for the cases of arc number of 2, 3, 4, 6. Since the results for variation for 2 arcs is not small, number of arcs for 3 or more were thought to be suitable.

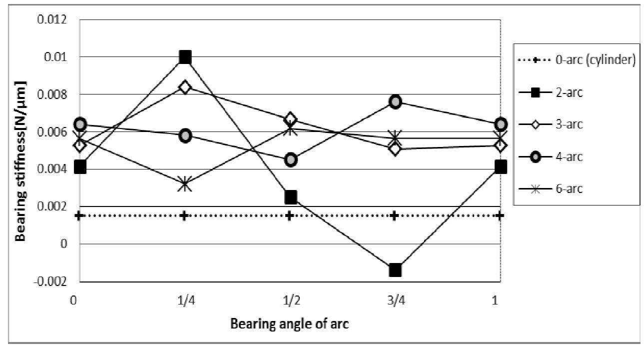

Fig. 9 Variation of pressure resultant with respect to impeller angular position (Number of arcs: 2, 3, 4, 6)

Pressure resultants were compared with respect to design bearing gap (mean clearance) for different groove depths, as shown in Fig. 10. Assuming the impeller weight to be 10 g, the equilibrium positions in the gap (Minimum clearance) were compared with respect to the designed gap (Mean clearance) as Fig. 11. The difference of ordinate and abscissa denotes the offset of the impeller. Then a design gap of 150 μm and a groove depth of 100μm were selected to attain a minimum bearing gap of 100 μm, which possibly leads to low hemolysis and low vWF damage.

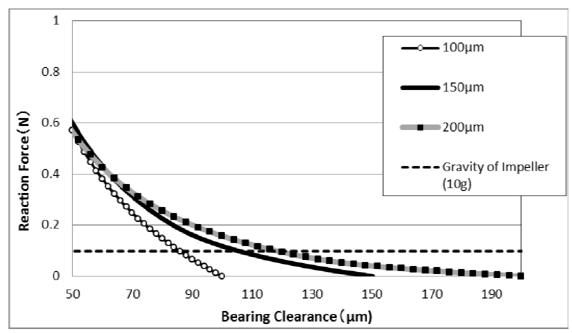

Fig. 10 Pressure resultants with respect to design clearances (Number of arc: 4)

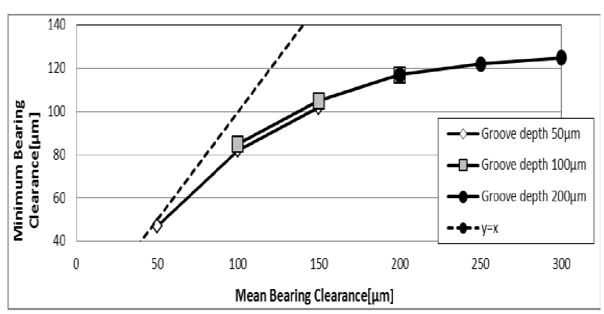

Fig. 11 Design bearing gap (Mean clearance) vs. equilibrium position in the gap (Minimum clearance) assuming impeller weight as 10g (Number of arc: 4)

VI. CONCLUSION

We have developed an axial-flow pump with a grooved cylindrical impeller without airfoils. In the mock experiments of HA02 impeller generated a pressure of 13.3 kPa at a rotational speed of 12500 rpm and a flow of 5L/min. The obtained pressure with HA02 was almost double than an airfoil-type impeller. The 2D analysis of hydrodynamic bearings for the pump revealed that a section with 3 or more arcs is stable against angular position, and a minimum bearing gap of 100μm can be attained at a design bearing gap of 150 μm and a groove depth of 100μm.

ACKNOWLEDGMENTS

The authors express their thanks to Mr. K. Yasui, Tokyo University of Science, and Mr. D. Mizota, Kobe University to their assistance to the hydrodynamic bearing analysis.

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