

Turbo Blower for 80 kW Proton Exchange Membrane Fuel Cell Vehicle

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Abstract: - Blower as an air supply system is one of the most important BOP (Balance of Plant) system for FCV(Fuel Cell Vehicle). For generating and blowing compressed air, the motor of air blower consume maximum 25% of net power. So, when the efficiency of whole FCV is to be considered, the optimal design of impeller and low friction lubrication of high speed rotor. Especially, for the purpose of reducing electrical power used by blower motor, oil-free air foil bearing is applied at the each side of brushless motor (BLDC) as journal bearings which diameter is 50mm. The normal power of driving motor has 2 kW with the 30,000 rpm operating range and the flow rate of air has maximum 163 SCFM. The impeller of blower was adopted mixed type of centrifugal and axial. So, it has several advantages for variable operating condition.

The performance of smart blower and parameters of air foil bearings was investigated analytically. Pressure sensor installed at the each side of blower, flow-meter was located at the front of blower for measuring of flow rate.

Key-Words:- Mixed Flow Impeller , Air Foil Bearing, BLDC Motor

1. Introduction

Air supply system, such as blower and compressor, is one of the importance things in BOP(Balance of Plant) of a fuel cell system. When we consider the consuming power of air supply system is 15% up to 25% of the full power generation of the PEM FC, the research of air system of the PEM FC is related with overall efficiency, directly[1].

The most significant criteria for choosing a suitable air supply system are pressure ratio, today pressures between 300 and 400 kPa atm of the mobile PEM FC, temperature rise (efficiency), size, weight, turn-down ratio, durability, noise, vibration and harshness (NVH) behavior, power consume, etc..

Tasks for air supply system of a fuel cell system are
1) air cleaning (particles, chemical substances, etc.);
2) air transportation as required from idle up to full load (turn down ratio);
3) pressurization from slightly above atmospheric pressure up to 2~4 bar;

4) humidification for PEM fuel cells: typically a dew point of about 50 °C (or 50% at 80 °C) is desired.

So, following major requirements, targets and boundary conditions have to be fulfilled[2]:

- good efficiency: especially in the partial load, energy recovery at high pressure levels;
- inlet temperature requirement of the fuel stack has to be met (e.g. typical PEM fuel cell: $T_{inlet} < 80\text{--}90^\circ\text{C}$).
- low noise emission;
- low weight, volume and costs;
- durability (approximately 6000 h for mobile).
- no particles or oil in the stack inlet air mass flow.
- good transient response.

Regarding above mentioned tasks, many companies and research institute group have developed several types of blower and compressor/expander.

Honeywell has developed motor driven centrifugal compressor/expander supported with air bearing for 50 kW PEM FC. It has good efficiency because expander is

2. Mixed Flow Blower

2.1 Meanline Design

An aerodynamic design of a small turbo blower for the fuel cell application with a specification following in the below was performed. A reliable meanline design program of RCOM1DR™, developed by MEEREX, is applied to first suggest a preliminary blower system layout for an electric motor design part and a structural design part. The program uses a conventional design in public as an initial design guess, and then performs an iterative analysis using reliable empirical loss models in every element in the centrifugal or mixed-flow compressor. Meridional view of turbo blower design is shown at Fig. 3. Specific speed at the design point is found about 134 which comes in some higher level for a conventional centrifugal blower. A mixed-flow impeller is therefore selected for an optimum efficiency. Meanline performance at the design point is predicted as 80.3% of isentropic blower efficiency at 1.101 of total-to-total pressure ratio and 0.0975 kg/s of mass flow rate. For a wide operating range, the vaneless diffuser is intentionally chosen, and the axial deswirler is also required to remove the exit swirl.

Combined compressor/expander machine(CEM) is consist of one scroll compressor which supply air to the cathode of fuel cell and turbo-compressor/expander. It is not easy to make a high pressure ratio using by turbo-compressor. For the optimal design of air supply system, we have to choose other type compressor, such as positive displacement compressors. Turbo-compressor of the CEM has conventional grease lubricated ball bearings.

Reformer air blower of R&D Dynamics is designed to run up to 140,000 rpm with air journal bearings. High speed rotor makes a windage loss and heat and high speed motor and controller diffuse amount of heat from coil and magnets. The solution of these problems is the key to success.

Another air supply system, PADT(Phoenix Analysis and Design Technologies) developed mixed type turbo blower which is driven by BLDC motor with the ball bearing support. It runs up to 30,000 rpm with the low pressure ratio. In the lubrication for the high turbomachinery, Operating speed and life time of the ball bearing has limit relatively. Also, conventional air bearing has lower stiffness value and low load carrying capacity. In the future, air foil bearing as a smart bearing with higher stiffness and structural damping force will be applied to the air supply system of the PEM FC[3,4].

In this present, the impeller of blower was adopted mixed type of centrifugal and axial. So, it has several advantages for variable operating condition. Especially, for the purpose of reducing electrical power used by blower motor, oil-free air foil bearing is applied at the each side of brushless motor (BLDC) as journal bearings which diameter is 50mm. The maximum power of driving motor has 2 kW with the 30,000 rpm operating range and the flow rate of air has maximum 163 SCFM.

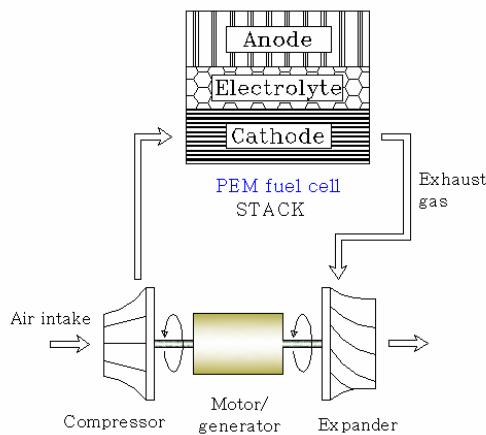


Fig. 1 Turbo-Expander of PEM Fuel cell system [2]

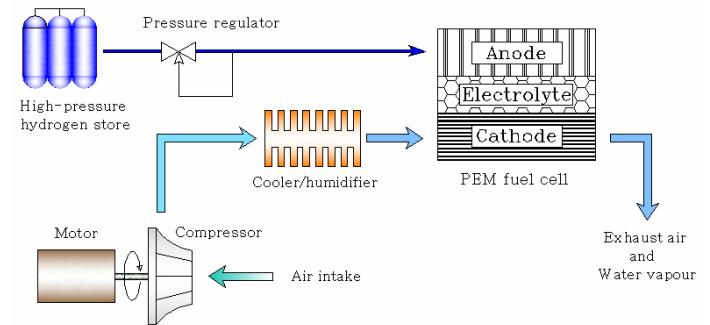


Fig. 2 BLDC Motor driven air blower and PEM Fuel cell

Table 1 Design specification of Mixed Type Air Blower

Parameter	Unit	Value
Gas	-	Air
Pressure Ratio (T-T)	-	1.1
Flow Rate	m³/min	5.14 (= 163 scfm)
Isentropic Efficiency (T-T)	-	More than 62%
Rotational Speed	rpm	30,000
Inlet flow conditions	-	Standard atmosphere
Flange exit diameter	mm	147.32

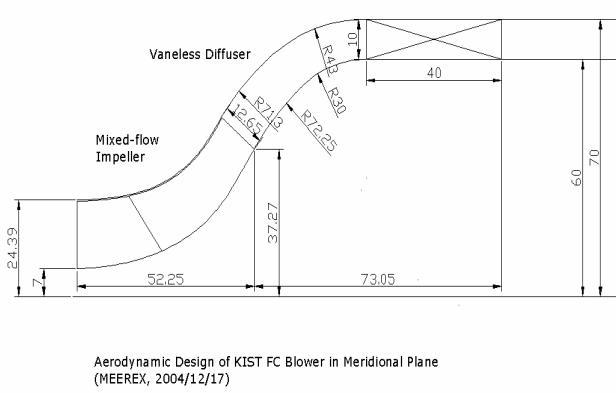


Fig. 3 Meridional view of turbo blower design

2.2 Meanline Performance Map Prediction

In order to find the validity of the meanline design results, the off-design performance from surge to choke flow when rotational speeds are changed is to be predicted. Flow loss and performance modelings for the impeller, vaneless diffuser and axial deswirler vanes are developed using various empirical loss models. As shown in Fig.4, Fig.5 and Fig. 6, a good margin of surge and choke is found for the present design.

2.3 Impeller 3D Profile Design

The mixed-flow impeller profile is designed using 6-point Bezier polynomial curves for hub/shroud contours and blade camberline angle distributions. Quasi-3D mean hub-to-shroud stream surface is effectively analyzed using the finite element method, and the rapid loading analysis is applied for blade-to-blade loading check. Fig.7 shows a final result of the mixed-flow impeller 3D profile design

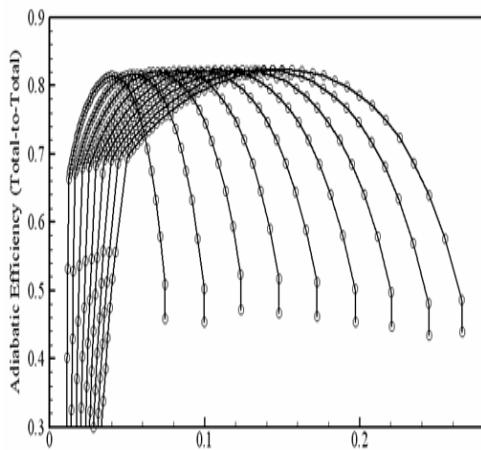


Fig. 4 Off-design performance map of turbo blower

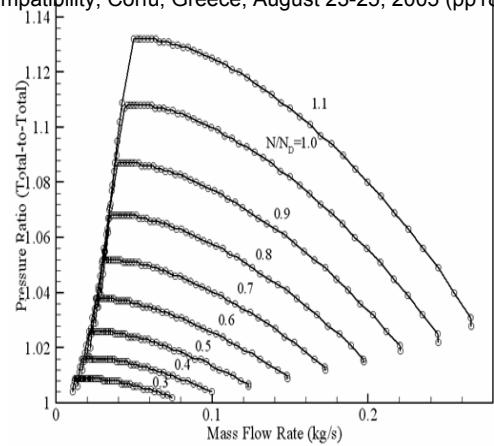


Fig. 5 Off-design performance map of turbo blower

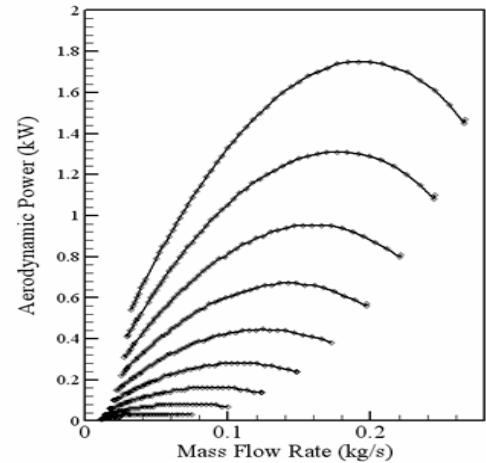


Fig. 6 Off-design performance map of turbo blower

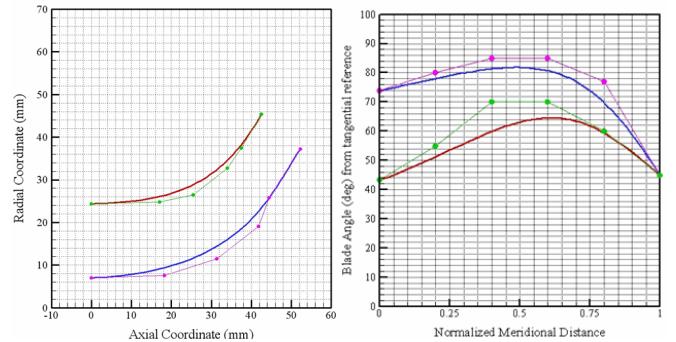


Fig. 7 Mixed-flow impeller 3D profile design

in geometrical view, where the meridional hub and shroud contours, the blade camberline angles.

Fig. 8 is the aerodynamic loading distributions along the blade for the selected geometry. A favorable decreasing distribution of relative Mach number along the blade is found with a reasonable limit of blade loadings. Many iterations between the geometry design and the

Fig. 9 shows some results of the quasi-3D mean hub-to-shroud stream surface at design flow, obtained from the same program, representing a favorable distributions of some critical design parameters. From the total pressure contours the acceptance of the impeller design can be made considering the pressure duty designated in the meanline design process. Favorable distributions of pressure contours are found to give a relatively higher efficiency estimation. A full three-dimensional turbulent CFD is to be performed to finalize the aerodynamic design of the blower.

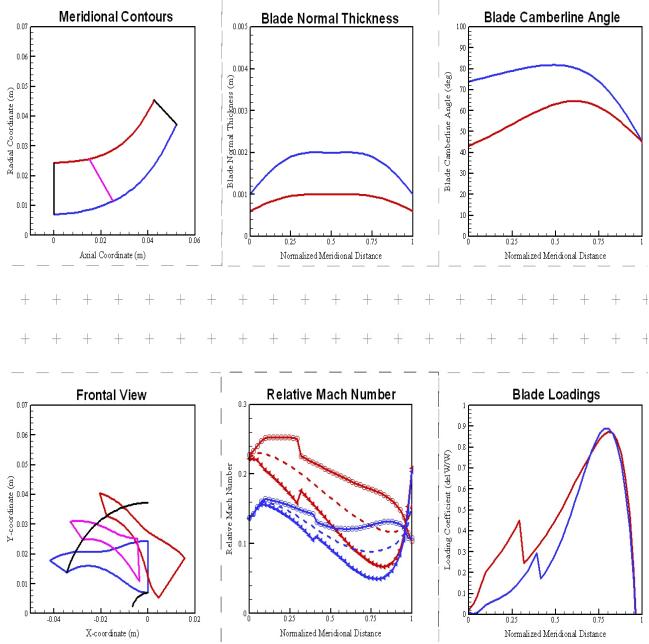


Fig. 8 Mixed-flow impeller 3D profile design with blade loading check

3. Design of Air Foil Bearing and Rotor-dynamic Analysis for Fuel Cell Blower

3.1 Compliance Air Foil Bearing

With the increasing need for the operating speed of turbomachinery, foil bearings have been considered as an alternative to traditional bearings. Since the foil bearing surface is compliant, it has certain advantages over traditional rigid bearings, including higher load capacity for a given minimum film thickness and less power loss. The compliance of foil bearings also makes them more tolerant of misalignment and centrifugal/thermal growth, since compliant foils can accommodate these changes in shaft diameter and bearing clearance.

On account of the above mentioned merits of foil bearings, many investigators have analyzed their

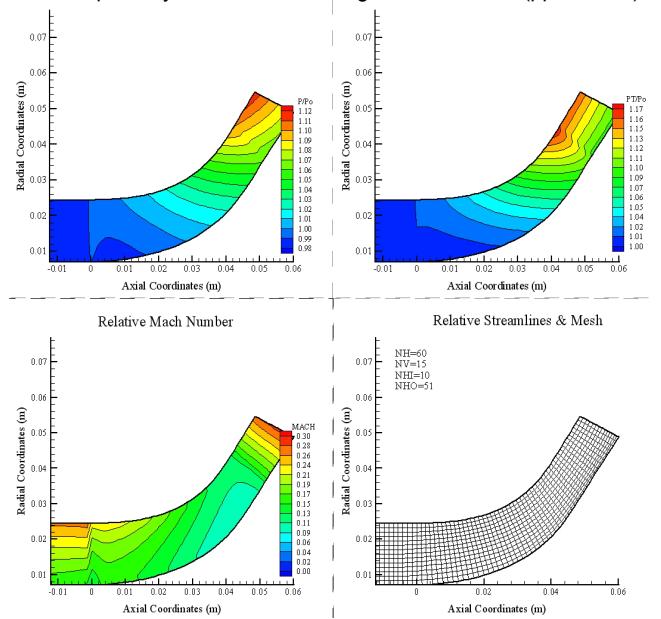


Fig. 9 Quasi-3D mean hub-to-shroud stream surface flows

performance since Heshmat, et. al.,[5] first presented a detailed analysis of their static performance. Peng and Carpino[6,7] presented dynamic stiffness and damping coefficients for foil bearings using the perturbation method. The effects of the elastic foundation, the foil membrane/bending stresses, journal misalignment, and sub-foil Coulomb friction have also been analyzed in detail. Lee [8,9] suggested viscoelastic foil bearings to enhance the damping capacity of foil bearings. He showed that a viscoelastic foil bearing can efficiently suppress subsynchronous vibration due to the surge in a two-stage compressor.

Fig. 10 shows that a conventional bump foil bearing consists of a smooth top foil and a bump foil. The hydrodynamic film pressure builds up in the small gap between the rotating shaft and the smooth top foil. The top foil provides a smooth bearing surface and is often supported by a series of bump foils that act as springs to make the foil bearings compliant.

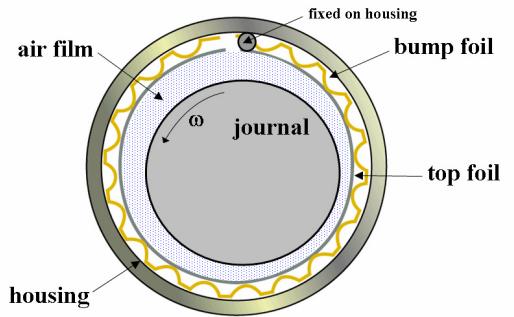


Fig. 10 Configuration of Air Foil Bearing

Bearing length, mm	22.0
Bearing diameter, mm	50.0
Approximate running diameteral clearance, mm	0.05 ~ 0.07
No. of pad	1
<i>Top foil :</i>	
Foil thickness, mm	0.12
Foil material	SUS301
Foil coating	MoS ₂
<i>Bump foil :</i>	
Bump pitch, mm	3.1
Bump length, mm	2.6
Bump height, mm	0.45
No. of bumps	1
Foil thickness, mm	0.1
Foil material	SUS301

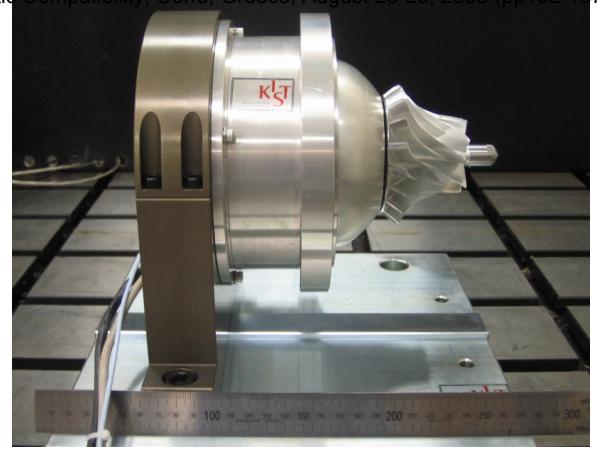


Fig. 12 Turbo Blower for Fuel Cell with BLDC Motor

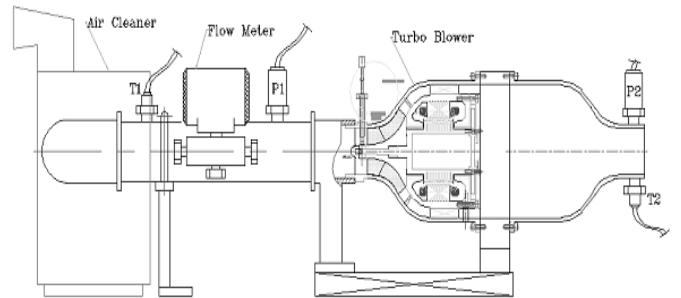


Fig. 13 Turbo Blower for Fuel Cell with BLDC Motor

4. Conclusion

In the paper, the performance of smart blower and parameters of air foil bearings was investigated analytically. The maximum power of driving motor has 2 kW with the 30,000 rpm operating range and the flow rate of air has maximum 163 SCFM. The impeller of blower was adopted mixed type of centrifugal and axial.

Especially, air foil bearing will contribute reduction for the loss of power due to the bearing friction and noise. So, it will be running up high speed range.

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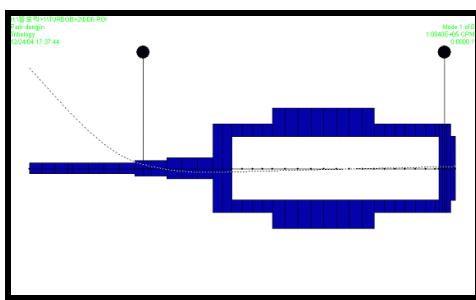


Fig. 11 Critical speed analysis supported without air foil bearing

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