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Simulation of Micro Partial Admission Impulse Turbine

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Abstract. For a micro partial admission impulse turbine design, the present study analyzed the variable working conditions by numerical methods. The results indicate that the impact loss on the blade cascades will increase under off-design rotational speeds; the influence of admission fraction on the inner efficiency is decreasing gradually with the nozzle number increasing, and the designed turbine can provide a large scale of output powers by changing the nozzle numbers.

Introduction

Micro partial admission impulse turbine has the characteristic of small size, low output power and high specific power. it is suitable for low speed and long range underwater vehicle, and it's a must to install nozzle on part of the arc[1].

Kiely et al.[2] designed pure impulse micro turbine whose disk diameter is about 25mm. Louisos et al.[3] studied the influence of expander angle on the performance of micro nozzle. Liu guangtao et al. [4] analyzed partial admission turbine engine with 30 times expansion ratio by numerical simulation. Han yongjun et al.[5] established the mathematical model of inner efficiency by combining theoretical analysis with empirical formula. Zhang fangfang et al.[6] established the model of energy loss of variable working conditions steam turbine nozzle, rotor cascade and turbine stage.

From the current public literatures, the research on the partial admission turbine engine in china is basically aimed at the conventional torpedo turbine engine. For micro turbine engine, the flow state in the nozzle and the cascade is different with conventional turbine. in this paper, the simulation calculation of micro turbine is explored and the research of the variable working conditions' characteristics of the turbine is carried out, which provides reference for the design and test of the micro turbine.

The Modeling of the Wholly Flow Field of Macro Turbine

Partial admission turbine engine consists of scarfed nozzle and rotor cascade, as shown in Fig 1. Scarfed nuzzle converts the internal energy of working medium with high temperature and high pressure into kinetic energy, and the high speed working medium blow towards the impeller at a certain angle and makes the impeller rotate at high speed, which achieves the transition from the kinetic energy of working medium to the rotating mechanical energy of impeller.

This paper will use the CFD method to test the rationality of the design approach. Firstly, given a set of design index. Then, the turbine in the literature [2] is carried out to test the CFD method. Finally, make the rationality validation of the designed turbine by the tested CFD method.

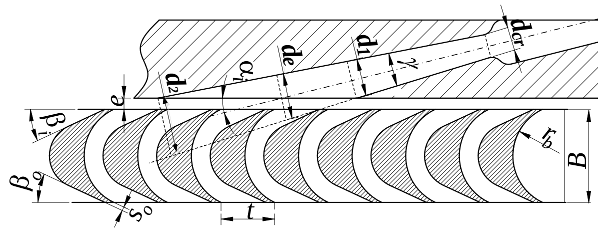

Fig. 1. Sketch of an impulse partial admission turbine

Design of Macro Turbine.

In order to validate the simulation calculation method, this paper references the turbine designed by Kiely et al.[2]. The design indexes of steam turbine are given in Table 1. The speed coefficient is 0.92, the radical leakage coefficient is 1.15, the friction loss coefficient is 0.4, the mechanical efficiency is 0.9.

Table 1. Design indexes of a turbine

Items	Values	Items	Values
turbine speed /r/min	150000	Intermediate diameter of turbine /mm	25
Chamber temperature /K	1000	Output power /kW	6.0
Chamber pressure /bar	40.0	Nozzle's scarfed angle	13°
Back pressure/bar	1.0	Nozzle's expander angle	8°

The three-dimensional grid of the turbine is divided by Gambit, and the number of the grids are 600 thousand, calculated by the multiple reference frame MRF model. The assembling axial clearance between the nozzle and the cascade is 0.2mm, the unilateral radical clearance between blades' top and the cartridge receive is 0.1mm. Finally, the total grid division and the set of the boundary conditions are shown in Fig 2.

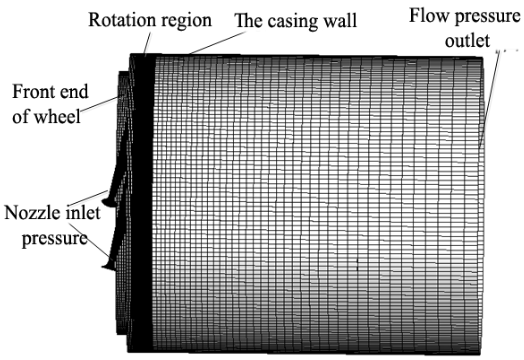

Fig. 2. Mesh model and boundary conditions of the 3D computational field

The Verification of the Numerical Model.

In order to validate the reliability of the simulation method, the simulation of the micro turbine designed by Kiely et al. is carried out in this paper. Because there is no date of radical clearance in the literature, the simulation model of 0, 0.1 and 0.2mm radical clearance are established in this paper.

From Table 2, we can know that the influence of radical clearance on the turbine inner efficiency is great, which can provide support to the amendment of the radical leakage loss in the design of the micro turbine mentioned above. When the radical clearance is 0.1mm, the corresponding turbine inner efficiency is basically consistent with the literature parameters, the error is less than 5%, which shows that the CFD simulation method is reliable.

Table 2. Comparisons of simulation results and experimental data

Contrast items	Radial clearance	Output torque	Output power	Inner efficiency
	mm	N m	kW	
Literature parameters	--	0.0439	2.000	0.629
Simulation result 01	0	0.0458	2.090	0.657
Simulation result 02	0.1	0.0420	1.912	0.602
Simulation result 03	0.2	0.0389	1.771	0.559

the working condition characteristics of the turbine well change by changing the inlet pressure, it is suitable to test the rationality of the design approach. Table 3 shows the Turbine performances with different inlet pressures.

Table 3. Turbine performances with different inlet pressures

Inlet pressure	Flow rate	Output efficiency	Available enthalpy drop	Inner efficiency
MPa	g/s	kW	kW	
5.0	20.5	7.28	26.6	0.274
4.0	16.2	6.46	20.5	0.315
3.0	12.3	4.23	17.2	0.246

Compared with the pressure of 5MPa and 3MPa of the turbine performance, it has the highest efficiency of the turbine when the pressure is 4MPa, and it's closer to the efficiency of the design. Therefore, the design approach of the micro partial intake impulse turbine is reasonable, and can meet the design requirements.

Performance of Variable Working Conditions

Varying the Back-pressure of Turbine.

The back pressure of the environment will change and the overall performance of the turbine will also be affected when the vehicle depth is variable. Now we find the effect of back pressure on the performance of the designed turbine though simulation.

Table 4. Turbine performances with different ambient pressures

Ambient back pressure	Output efficiency	Available enthalpy drop	Inner efficiency
Pa	kW	kW	
120000	6.17	20.0	0.308
100000	6.46	20.5	0.315
80000	6.62	21.2	0.311

Form table 4 we can find that the change of back pressure will lead the change of enthalpy drop and the drop of the turbine efficiency, and the turbine will not be able to provide the power required by the turbine under high back pressure. The reason is that the change of back pressure will cause the nozzle exit to generate shock wave or expansion wave, which will influence the stability of the nozzle flow and increase the aerodynamic loss of the turbine.

Varying the Rotational Speed of Turbine.

The speed of the turbine will change accordingly when the vehicle depth is variable. In order to observe the effect of rotating speed on the performance of the turbine, a simulation model of speed is 100, 150 and 200 thousand rpm is established. Simulation results are shown in Table 5.

Table 5. Turbine performances with different speeds

Speed	Moment	Output efficiency	Inner efficiency
$\times 10^4$rpm	N·m	kW	
20	0.298	6.25	0.305
15	0.411	6.46	0.315
10	0.548	5.74	0.281

The above table shows that the efficiency of the turbine will reduce if the speed changes. The reason is that with the change of the rotational speed, turbine wheel peripheral speed will change, it makes the relative speed direction of the cascade inlet direction deviate from the designed value, thereby increasing the flow of cascade impact, and increasing the energy losses.

Varying the Nozzle Number of Turbine.

Relative to the changes of the parameters of various turbines that cannot be easily changed, the control function of nozzle numbers is more convenient and practical. To explore the relationship between the partial admission ratio, the efficiency of the turbine and inner efficiency, this paper established a model with the number of turbine nozzle from1 to 10. The relationship of partial admission ratio and efficiency is shown in Fig3.

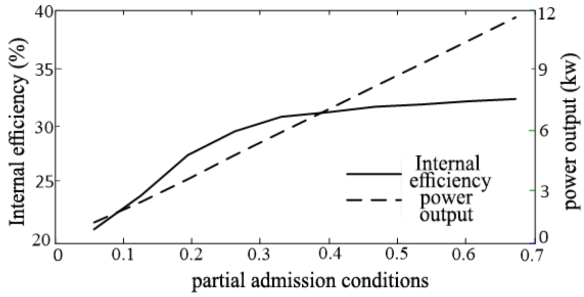

Fig. 3. Relations of the admission fraction and the inner efficiency and output power

From Fig3 we know that the power output shows a linear rise and its output efficiency has large adjustable range with the increase in the bearing part. However the rate of increase in the efficiency of the turbine becomes slow gradually. When the nozzle number is 2, the rate of inner efficiency reaches the critical value, and the output power of the turbine is about 6.5kW.

Conclusions

In order to make up the deficiency of the design theory of micro partial admission turbine, we make the simulation calculation of the turbine and study the characteristics of the design under variable back pressure, variable speed and variable nozzle numbers. This paper has the following conclusions.

(1) Present a simulation calculation method for a micro partial admission turbine and verify it by referencing the design by Kiely et al. The result shows that the method can predict the performance of the turbine accurately.

(2) The turbine cascade and casing can effectively prevent the separation of the flow of the nozzle exit under high back pressure; the turbine shock loss will increase without designed speed, resulting in the decline in efficiency. Effect of partial admission on the turbine inner efficiency becomes smaller, and the demand of output efficiency can be met by adjusting the number of nozzles.

(3) This paper can provide guidance for the design and experiment of micro turbine in the future from the exploration of the partial admission turbine.

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