International Journal on Recent and Innovation Trends in Computing and Communication
Volume: 5 Issue: 9
ISSN: 2321-8169
23 – 26

Design and Simulation of Power Turbine for Micro Organic Rankine Cycle Thermoelectric System

Xinyu Li
Key Laboratory of Modern Electromechanical Equipment Technology
Tianjin Polytechnic University
Tianjin, China
e-mail: 43188940@qq.com

Ruiliang Yang
Key Laboratory of Modern Electromechanical Equipment Technology
Tianjin Polytechnic University
Tianjin, China
e-mail: yangruiliang2001@sina.com

Abstract— A miniature power turbine for the micro Organic Rankine Cycle (ORC) system is designed in this paper. In order to judge the aerodynamic performance of the power turbine system, the PROE software is used to model the main components of the turbine, and the TURBO tool of ANSYS GAMBIT is used to carry out the finite element meshing, and the thermal performance of refrigerant is written by UDF of FLUENT 6.3 software, then aerodynamic simulation is carried by FLUENT 6.3 software. The results show that the designed aerodynamic performance is good, and the kinetic energy efficiency is 73.86% under the stable condition.

Keywords *miniature power turbine; Organic Rankine Cycle (ORC)s; refrigerant; aerodynamic simulation*

*****

I. INTRODUCTION

Turbine is the core equipment for organic system of Organic Rankine Cycle (ORC) system, and its performance directly affects thermal efficiency of the overall system. Although the ORC system has been successfully applied to a large number of large plant operations, some scholars have begun to focus on the study of the small ORC system [1-6]. Due to great advantage of small ORC system for the thermoelectric conversion, a miniature power turbine for the miniature micro ORC system is designed in this paper. In order to judge the aerodynamic performance of the power turbine system, the PROE software, TURBO tool of ANSYS GAMBIT, FLUENT 6.3 software are used to numerically simulate its performance.

The miniature ORC thermoelectric system consists mainly of evaporator, condenser, working fluid pump, storage tank and miniature power turbine (see Fig.1).

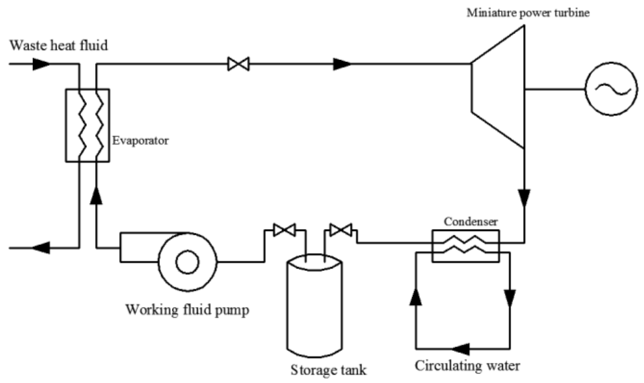

Figure1. ORC thermoelectric system cycle diagram

In the evaporator, the organic working fluid with low boiling point transfers heat from waste heat fluid, then evaporates into steam with high temperature and high pressure. Part of energy from the expansion of the steam converts to mechanical energy through turbine spindle. Refrigerant comes to condenser after the turbine, then condenses into liquid, stores in the tank, and then pumps to evaporator by the working fluid pump, completing a cycle.

II. DESIGN OF POWER TURBINE FOR MICRO ORGANIC RANKINE CYCLE THERMOELECTRIC SYSTEM

A. Selecting refrigerant

The temperature entropy diagram for ORC system is shown in Fig.2, which shows the working cycle of refrigerant in Fig. 1.

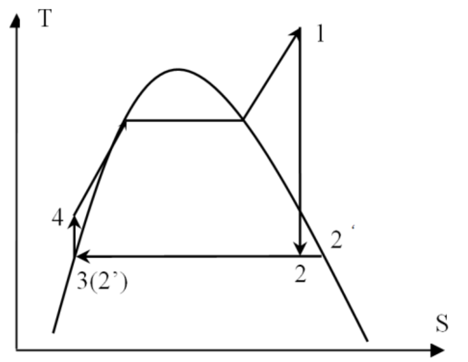

Figure 2. Temperature entropy diagram for ORC system

Taking into account the environmental performance, chemical stability, industrial safety, the critical parameters of working fluid, the project initially selects R134a, R123, R245fa and R227ea these four organic refrigerants.

To choose the most suitable refrigerant, four kinds of refrigerant are compared. The initial conditions for comparison are unified as follows: the mass flow 28kg / h, car exhaust gas with the temperature of 200 ^{0}C evenly through the heat exchanger, the temperature 95 ^{0}C after heat exchange. In the

ISSN: 2321-8169
23 – 26

condenser, the initial cooling temperature 15 ° C, the mass flow rate 0.5 kg / s, flow rate 0.1 kg / s.

The results are shown in Table I. It can be seen from the Table I that R134a is the most efficient refrigerant in the four refrigerants under given system cycle conditions, thus R134a is chosen as the cyclic refrigerant of the vehicle ORC system in this paper.

TABLE I. VARIOUS PARAMETERS OF ORGANIC REFRIGERANTS

Refrigerant	Net power (kJ)	Shaft power（kJ）	System thermal efficiency	Evaporator heat transfer (kJ)	Condenser heat transfer (kJ)
R134a	0.93	0.34	4.92%	18.88	17.31
R123	0.106	0.016	1.78%	5.94	5.79
R245fa	0.153	0.016	1.91%	8.01	7.80
R227ea	0.262	0.003	3.28%	7.97	7.65

B. Design of power turbine

The total mass of the refrigerant required in the system circulation is 6.8kg, the heat source temperature of the vehicle exhaust gas is 200 ℃, and the wind speed of the air side fan fins through the heat exchanger is 120m / s. So the initial design parameters of the power turbine are shown in Table II.

TABLE II. INITIAL DESIGN PARAMETERS OF THE POWER TURBINE

Parameter	Symbol	Value	Unit
Inlet pressure	p_0	3.0	MPa
Inlet temperature	t_0	73.8	℃
Enthalpy of ingress	h_0	2282.64	kJ/kg
Entropy	s_0	6.5812	kJ/(kg.K)
Into the steam density	ρ_0	3.035	kg/m^3
Exhaust pressure	p_2	1.88	MPa
Exhaust temperature	t_2	62	℃
Exhaust gas enthalpy	h_2	1981.39	kJ/kg
Exhaust steam entropy	s_2	5.9234	kJ/(kg.K)
Exhaust density	ρ_2	2.2637	kg/m^3
Isentropic enthalpy	$h_{s\bullet 02}^{*}$	1919.65	kJ/kg
Mass Flow	M	16.68	kg/h
Saturated vapor at standard atmospheric pressure	h'	2010.88	kJ/kg
Saturated water enthalpy at standard atmospheric pressure	h''	288.13	kJ/kg

From the point of view of the processing technology, the aerodynamic design parameters of the turbine are shown in Table III. The geometric dimensions of the turbine using the relevant thermodynamic calculations are shown in Table IV.

TABLE III. AERODYNAMIC DESIGN PARAMETERS

Parameter	Symbol	Value	Unit
Reaction level	Ω	0.6	—
Guide nozzle speed factor	φ	0.88	—
Turbine speed ratio	χ_a	0.2	—
Turbine diameter ratio	Y	0.48	—
Flow velocity coefficient	ψ	0.85	—

TABLE IV. SIZE PARAMETER OF TURBINE BLADE

Parameter	Symbol	Value	Unit
Blade center radius	r_c	50	mm
Blade radius	r_b	58	mm
Number of Blades	z_B	12	mm
Blade thickness	δ	1.5	mm
Inlet blade height	b_1	10	mm
Export blade height	b_2	20	mm
Entrance leaf clearance	Δz	1	mm
Export leaf gap	Δr	0.6	mm

III. SIMULATION OF POWER TURBINE FOR MICRO ORGANIC RANKINE CYCLE

A. Build model ofl the main components using the PROE software

ProE software is CAD / CAM / CAE software with a high reputation in the field of product design occupies an important position, and is widely used in automotive, aerospace, electronics, mold, toys, industrial design and machinery manufacturing and other industries. This paper builds model of the main components using the PROE software, as shown in Fig.2.

Figure 3. Miniature turbine 3D model using ProE software

ISSN: 2321-8169
23 – 26

B. Finite element meshing using ANSYS GAMBIT

Using the Boolean subtraction function in PROE environment, 3D model of the internal flow field of the turbine is built and saved as STP type, then TURBO tool of ANSYS GAMBIT is used to mesh the turbine model.

GAMBIT is a network generation software, its main function is for geometric modeling and grid generation, and can be directly used to mesh the model by the PROE software.

The trailing edge and the leading edge of the blade are the starting points of the area, and the intersection of the inlet and outlet boundaries is the dividing point. Fig. 4 is the finite element model of the single blade flow field, where the grid is divided into 277 452 tetrahedral meshes.

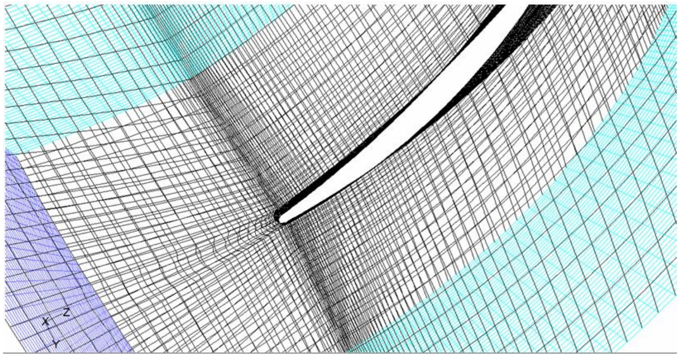

Figure 4. Meshing the model using the Ansys gambit

C. Set the boundary condition

After the three-dimensional grid is read in the Fluent 6.3 operating environment, the turbulence model is set to the standard $k-\varepsilon$ model. The turbulence viscosity coefficient is 0.05, and the near wall friction coefficient was 0.33. The flow field inlet is set to the pressure inlet and flow field under steady condition The outlet is set to the variable pressure outlet with variable parameters. The initial condition parameters are calculated according to the thermal cycle of the micro ORC system with large vehicle exhaust. The thermal performance of refrigerant is written by UDF of FLUENT 6.3 software, then aerodynamic simulation is carried by FLUENT 6.3 software.

In order to save the computation amount of FLUENT6.3 computing platform, the periodic boundary condition as shown in Fig. 5 is established. Relative to the ordinary dynamic grid, the use of periodic boundary conditions can reduce the time more than 90%.

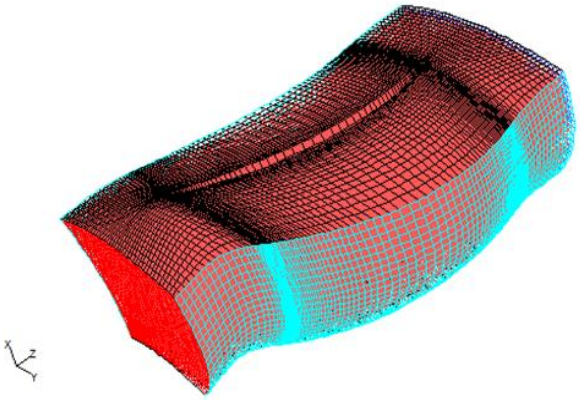

Figure 5. periodic boundary conditions of blade

D. Simulation results

The results are successfully converged using FLUENT 6.3 software. The theoretical value and simulation value of mass flow versus rotating speed are shown in Fig. 6. The difference between theoretical and simulation values is small, indicating that CFD simulation is very successful.

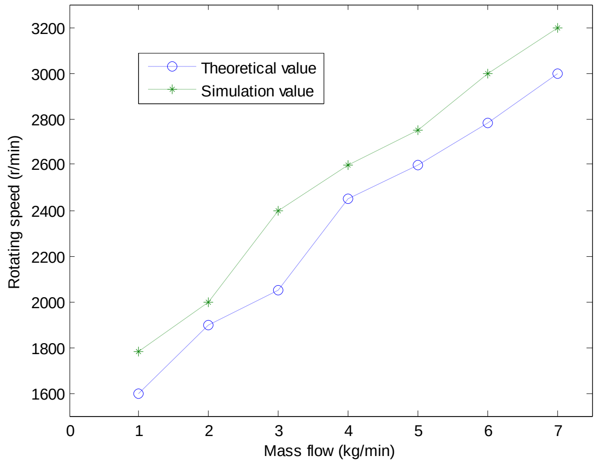

Figure 6. Mass flow versus rotating speed

Figure 7 shows the pressure distribution of the leaf surface. The distribution of the fluid on the pressure surface of the moving blade is proportional to the radial radius of curvature of the midline of the blade, especially at the leaf height of 53%. The pressure distribution is proportional to the curvature. The maximum value is 0.053 86 MPa from the maximum radius of curvature of 5.34 mm. From the pressure distribution formed by the gas molecules on the surface of the moving blades, it can be analyzed as follows: the working fluid has a certain impulse force on the blade pressure surface in the cascade channel, at the same time the airflow itself has different degree of rotation and downward rotation, and forms the vortex flow in the radial direction.

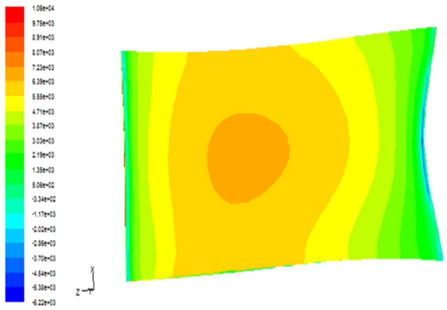

Figure 7. Pressure distribution of leaf pressure plane.

IV. DESIGN EFFECT ANALYSIS

Design effect is expressed by kinetic energy efficiency, which is defined as:

$$\eta = \frac{1-\left(\dfrac{p_2}{p_{w2}}\right)^{\frac{\kappa-1}{\kappa}}}{1-\left(\dfrac{p_2}{p_{w1}}\right)^{\frac{\kappa-1}{\kappa}}} \tag{1}$$

Where p_2 is static pressure of flow field outlet, p_{w2} is relative total pressure of flow field outlet, p_{w1} is relative total pressure of flow field inlet. Calculated kinetic energy efficiency is shown in Fig.8.

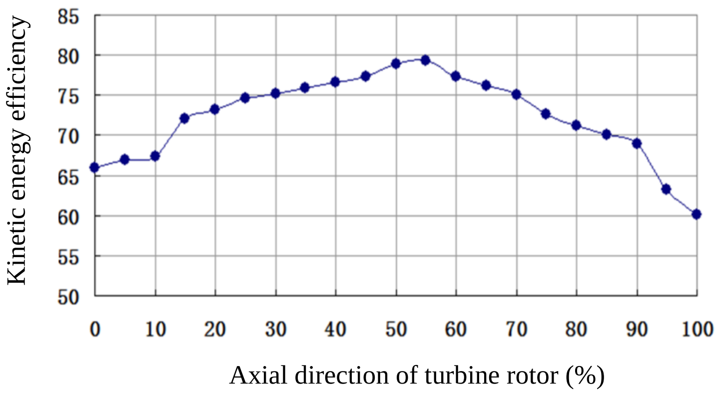

Figure 8. Kinetic energy efficiency of turbine rotor.

It can be seen from Fig.8 that the maximum kinetic energy efficiency of the turbine is 78.82% and the average kinetic energy efficiency is 73.86%, which is basically the same as the expected wheel cycle efficiency in the design process.

V. CONCLUSION

A miniature power turbine for the micro ORC system is designed in this paper. The PROE software, TURBO tool, and FLUENT 6.3 software were used to judge the aerodynamic performance of the power turbine system. The results show that the difference between theoretical and simulation values is small, indicating that CFD simulation is very successful. The maximum kinetic energy efficiency of the turbine is 78.82% and the average kinetic energy efficiency is 73.86%, which is basically the same as the expected wheel cycle efficiency in the design process.

ACKNOWLEDGMENT

This research is supported by Tianjin Natural Science Foundation (No. 16JCZDJC31400).

REFERENCES

[1] M. Imran; F. Haglind, M. Asim, and J. Z. Alvi, “Recent research trends in organic Rankine cycle technology: A bibliometric approach. Source,” Renewable and Sustainable Energy Reviews, vol. 81, pp 552-562, 2018.

[2] N. Chaiyat, Y. Wakaiyang, and X. Inthavideth, “Enhancement efficiency of organic Rankine cycle by using sorption system,” Applied Thermal Engineering, vol. 122, pp 368-379, 2017.

[3] H. Tian, X. Wang, G. Shu, M. Wu, N. Yan, and X. Ma, “A quantitative risk-assessment system (QR-AS) evaluating operation safety of Organic Rankine Cycle using flammable mixture working fluid,” Journal of Hazardous Materials, vol. 338, pp. 394-409, 2017.

[4] H. Xi, M. Li, Y. He, and Y. Zhang, “Economical evaluation and optimization of organic Rankine cycle with mixture working fluids using R245fa as flame retardant,” Applied Thermal Engineering, vol. 113, pp. 1056-1070, February 2017.

[5] V. R. Patil, V. I. Biradar, R. Shreyas, P. Garg, M. S. Orosz, and N. C. Thirumalai, “Techno-economic comparison of solar organic Rankine cycle (ORC) and photovoltaic (PV) systems with energy storage,” Renewable Energy, vol. 113, pp. 1250-1260, 2017.

[6] A. M. Pantaleo, S. M. Camporeale, A. Miliozzi, V. Russo, G. S. Mugnozza, C. N. Markides, and N. Shah, “Thermo-economic assessment of an externally fired hybrid CSP/biomass gas turbine and organic rankine combined cycle,” Energy Procedia, vol. 105, pp. 174-181, 2017.