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Simulation of Steady Flow Through Turbine System with Partial Admission Nozzle

Chang-Oug Hong*, Hyuck-Joon Namkoung** and Yoo-Cheol Woo***

부분흡입노즐방식의 터빈시스템에 대한 3차원 유동해석

홍 창욱* · 남궁 혁준** · 우 유철***

Key Words : *Turbine (터빈), Partial Admission (부분흡입), Nozzle (노즐), CFD 전산유체역학)*

Abstract

Numerical simulation using well-known commercial software Fine/Turbo is applied to the analysis of the aerodynamic performance for the supersonic turbine system with partial admission nozzle. Calculation was performed for coupled system of nozzle and blades using mixing plane method. In addition, calculations were also performed for the blades alone to investigate the effect of the performance variation with blade profile. These computational results are compared with the experiments. The agreement between the prediction and the experiment was found to be satisfactory..

1. Introduction

Pumps for liquid propellant rocket engine (LRE) are used to increase the pressure of the propellants. Theses pumps, one for each propellant (oxidizer and fuel), are on a single shaft and are powered by one turbine. Flow-field characteristic is a major factor in turbine performance (including life durability). This is particularly true if the turbine is a high work design, compact, supersonic and partial admission[2]. Specially turbine performance is mainly influenced with flow unsteadiness due to shock wave interaction that reduces efficiency and increases dynamic loading. To aid in the understanding flow-field characteristic, CFD analysis is generally used to support the aerodynamic performance assessments of turbine.[5]

In this study, steady aerodynamic characteristics has been analyzed. Calculation was performed for coupled system of nozzle and blades. In addition, calculations were performed for blades alone to investigate performance in variation with blade profile. These results are compared to those of experimental results using simulants.

2. Turbine Description[4]

Turbine has the characteristics of single stage, partial admission, impulse type, supersonic nozzle with exit guide vanes. The required performance for the turbine is 860 kW of power and 50,000 rpm of rotational speed. The nozzle is 8 converging-diverging type with circular cross sections and throat diameters of 6 mm. There are 80 impulse-type shrouded blades with heights of 14 mm, which is 21 percent larger than the minor axis of the nozzle exit ellipse. They have a mean diameter of 160 mm and axial chord of 8.4 mm. The blades are two-dimensional shape with identical airfoil sections from hub to tip. There are also 12 exit guide vanes. Axial spacing between nozzle and blades is 3 mm.

The turbine is driven by the hot gases with the ratio of specific heats, γ, of 1.17 and a specific heat at constant pressure, C_p, of a 3661 J/kg percent K. The gas enters the nozzles with a total pressure, P_{T0}, of a 6.8 MPa a total temperature, T_{T0}, of a 1000 K, and a mass flow rate of 1.4 kg/s. Mean line calculations predict the Mach number at the exit of the nozzle to be 2.15. The total to static pressure ratio, Pr_{t-s}, across the nozzle was designed to be 13.6.

3. Numerical Method of Analysis

The computations of the turbine flow-field were performed using commercial CFD code, Fine/Turbo. This code is used to solve the steady three-dimensional, Reynolds-averaged Navier-Stokes equations. The turbulent viscousity, μ_T, is calculated using the two layer Baldwin-Lomax algebraic turbulence model. In order to simplify and minimize the computational model, mixing plane method is applied to the interfaced plane between nozzle and blades[1]. The grid system is consist of the nozzle and mixing plane and blades. In order to catch the flow characteristics at blunt leading and trailing edge such as shock wave interaction, grid system is fined near the edges. The total number of grid point for each calculation was 486,189.

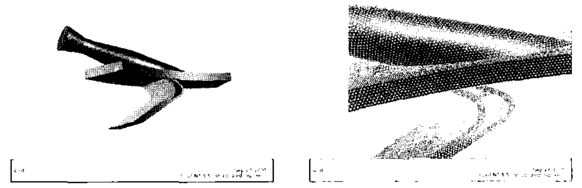

Figure 1. Computational geometry and grids

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* Hyundai MOBIS Co, cwhong@mobis.co.kr
** Hyundai MOBIS Co, nkhj@mobis.co.kr
*** Hyundai MOBIS Co, ycwoo@mobis.co.kr

4. Results and Discussion

4.1 Design Conditions

Turbine work per unit mass of gas is calculated by the following equation:

$$\Delta h = C_p(T_{T0} - T_{T2}) \tag{1}$$

Using the calculated performance for the turbine work is 655.3 kJ/kg. Thus the power is is calculated to be 820 kW. using the equations:

$$PW = m \times \Delta h \tag{2}$$

But in the above calculated power the power loss due to leakage through radial gap of blades is not included.

In case of considering the power loss, power and efficiency is decreased to 748.2 kW.

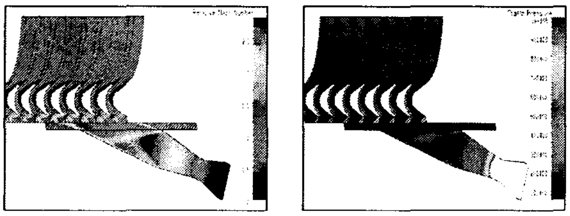

Figure 2. Mach number and pressure at mid span

Predicted Mach number and pressure contour at mid span are shown Fig. 2. In the nozzle the flow was accelerated with the expansion of the gas, thus in the exit of nozzle the flow becomes supersonic. A Mach disk is shown in the downstream of the throat. Shock waves form in the diverging section and reflect off the nozzle walls. The fluid expands as it leaves the nozzle. Supersonic flow enters the blade, and a leading edge shock is formed. The boundary layer separates from the suction surface of the blade due to interaction of the bow shock with the suction surface boundary layer. The separated region was expected as supersonic turbine blades generally generate large separated regions on the suction side of the blade at the design conditions.

4.2 Simulation for blade alone

In order to investigate the performance variation with blade profile of impulse turbine, calculations were conducted for blade alone as an inlet boundary condition imposing the results from exit of the nozzle.

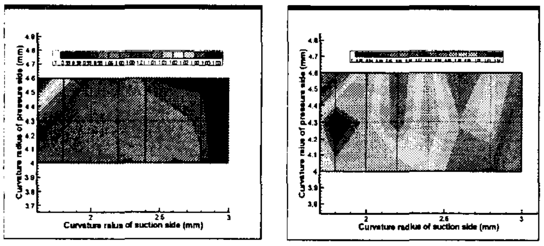

Figure 3. Efficiency and power in variation with blade profile

Calculated efficiency and power differences with blade profile are shown Fig. 3. As the curvature radius of suction side is decreased and that of pressure side is increased, efficiency and power have increased[3]. Because flow passage area is reduced than that of design case. The results show that the efficiency and power have difference within 3%.

4.3 Comparison of results with performance test

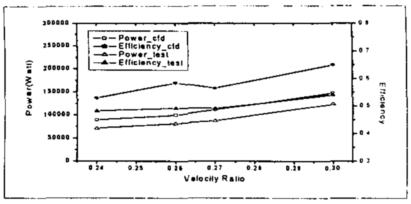

Figure 4. Difference of efficiency and power

The efficiency and power for the calculated results and experiments are shown in Fig. 4. The designed velocity ratio is 0.29. As velocity ratio is increased, efficiency and power is increased. Both of calculated efficiency and power are higher than those of test due to exclusion of leakage loss. In case of considering leakage loss, difference of power and efficiency is decreased till 7.8 % and 3.5 %.

5. Conclusions

A numerical study for the supersonic turbine system with partial admission nozzle was conducted. Calculation was performed for coupled system of nozzle and blades using mixing plane method was conducted. The calculation result at the design condition showed that the turbine produces higher power than required power. And in case of supersonic impulse turbine blade, variation of blade profile has very little influenced on performance of turbine. Simulation results are well agree with test results within 7.8 % and 3.5 % for the efficiency and the power, respectively.

Acknowledgement

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Refernece

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