論文の内容の要旨

論文題目　Heat Transfer Effects in Small Wave Rotors
（小型ウェーブロータにおける熱伝達の影響）

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For small power source such as propulsion system of micro air vehicle and mobile electric generator, micro gas turbine is one of the promising candidates because of its high energy density. However, it is difficult for such small gas turbine to attain high performance. An attractive breakthrough may be found in employing a wave rotor that is expected to improve the gas turbine performance, owing to beneficial topping cycle arrangement (Fig.1). In a wave rotor, compression and expansion are performed by unsteady pressure wave propagations in tubes, instead of blade rotation in conventional turbo machines. According to previous studies, the benefit of wave rotor topping will be greater with smaller baseline engines. Therefore, drastic improvement is expected, in particular, for the micro gas turbine performance.

Basically, a wave rotor consists of a series of tubes arranged circumferentially around the rotation axis and several ports charging/discharging the fluid (Fig. 2). Pressure waves are generated and propagate in the tubes due to different pressures in the ports. The timings of port opening and closing should be set according to the arrival time of the waves at the tube ends (Fig. 3).

Although the wave rotor is expected to enhance the performance of micro and ultra-micro gas turbines, the device itself may be affected by downsizing. Apart from the immediate effect of viscosity on flow dynamics when size reduces, the effects of heat transfer on flow field rise at such small sizes.

Heat transfer and its effects of wave rotor, including but not limited to the small ones, are analyzed and presented in this work. Only limited prior work has been conducted to explain the effects of heat transfer since the influence of heat transfer on wave rotors of conventional sizes seems to be inconspicuous, although no evidence suggests whether heat transfer is influential or not at conventional sizes. Therefore, as a first step, the present work aims to settle the heat transfer problem of wave rotor cell, in which compression and expansion take place.

The current investigation focuses on heat transfer between internal flow passage and its surrounding wall of 3-D single cell of through-flow wave rotor. Conjugate heat transfer boundary treatment that simulates unsteady heat transfer across fluid-solid interface is employed to analyze heat transfer. To examine the capability of simulating possible internal flow dynamics and heat transfer phenomena in wave rotor cell, verifications are conducted for unsteady conduction problem, shock tube convective heat transfer problem, and internal flow dynamics and heat transfer associated with wave-rotor-like flow field that is designed to reflect essential characteristics of flow field in wave rotor cell and realized by experimental test run.

Wave rotor cells of five different sizes are investigates for comparison across size. The 69-mm-long cell of the micro wave rotor [1] is introduced as the 1X size. The remaining four sizes (10X, 3X, 1/3 and 1/10) are scaled geometrically. 10X size and 3X size correspond to the conventional size of wave rotor cell, in which heat transfer effects may be insignificant. 1X size, 1/3 size and 1/10 size are categorized as small wave rotor cells. Through comparing among the sizes from 10X to 1/10, the trend of heat transfer effects as size reduces can be obtained.

The situation that the whole cell is thermally insulated from outside is the major concern in this work. With the light shed by delving into heat flux distribution and by comparing adiabatic case and heat transfer case at conventional size and small size, this work presents investigations of causes of intense heat flux, as well as effects of heat transfer on internal flow field, charging processes and discharging processes for various sizes. High-speed inflows of hot gas and cold air, compressed gas and air, and shock waves are found to create noticeable heat flux at all sizes investigated. At small size, heat fluxes caused by primary shock wave propagating in air, expansion waves and compression wave becomes noticeable. The regions of intense heat flux at small size are marked in Fig. 4.

Regarding heat transfer effects on flow field, when heat transfer is taken into account, states of fluid in cell before compression process are affected, shock waves in compression process are weaker, and corresponding changes in the charging and discharging processes are observed as common phenomena at all sizes investigated. A unique phenomenon that arrival of reflected shock wave delayed owing to considerable heat transfer effects is discovered at the smallest size investigated. This delay demonstrates a necessity of port degree modification in wave rotor design. Besides, by conducting comparison across sizes, heat transfer effects on pressure, temperature and mass flow rate during charging and discharging are found to grow rapidly when reducing size from 1X size (exemplified by mass flow rate in Fig. 5). Moreover, it is indicated that with an appropriate temperature assigned to the lateral boundary as uniform wall temperature, isothermal boundary condition that costs less computation resource may be as acceptable for investigation of heat transfer problem related to through-flow wave rotor.

In addition, the elementary situation that the cell subjects to constant convective heat transfer at the external surface of shroud and hub walls is considered with external flow temperature of average temperature of ports. Since external flow temperature is close to wall temperature, heat transfer effects are similar to those in the situation when external surfaces of wall are adiabatic.

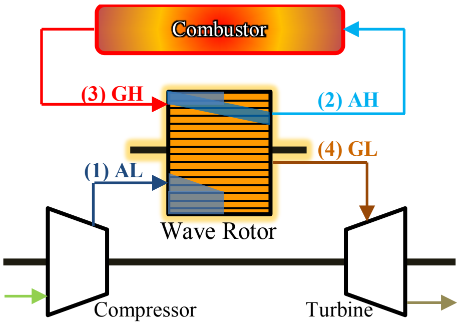

Fig. 1 Component schematic of wave rotor topped gas turbine

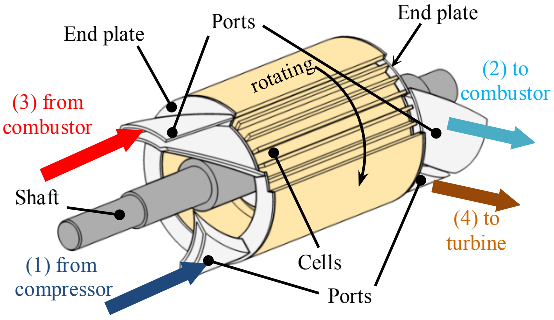

Fig. 2 Wave rotor schematic

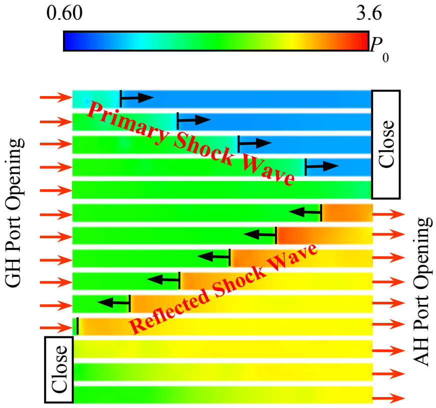

Fig. 3 Propagation of shock waves in tube (Total pressure normalized by 0.30 MPa)

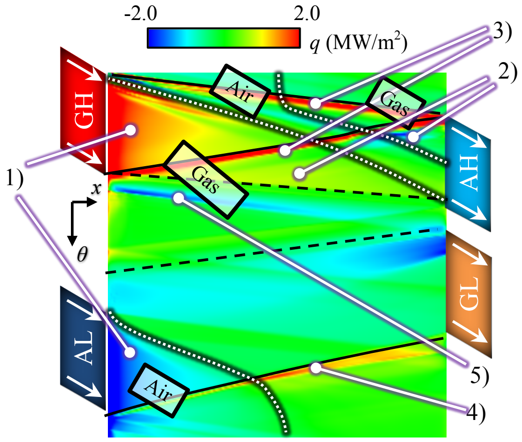

Fig. 4 Wave diagram colored in heat flux for heat transfer case of small size

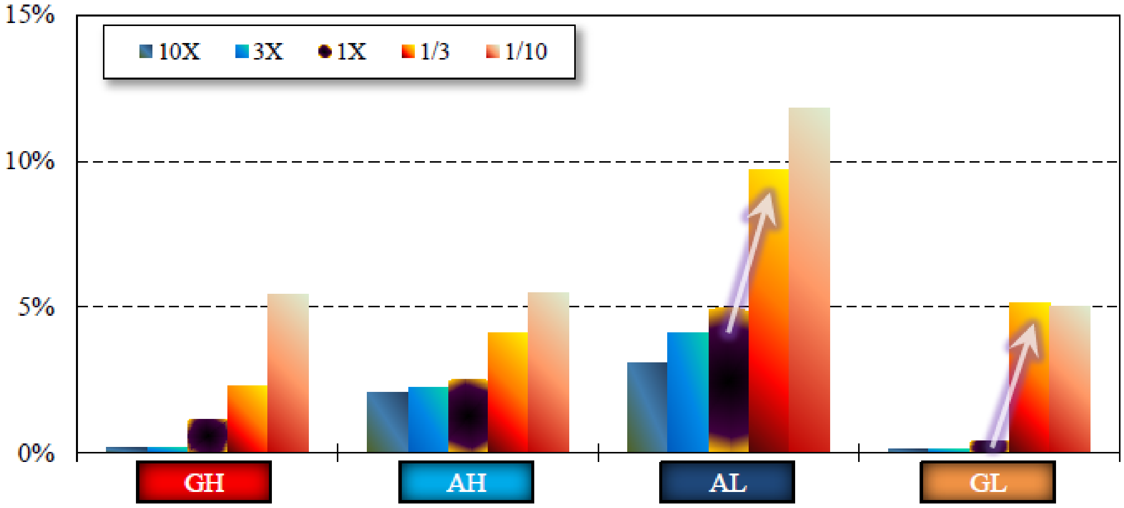

Fig. 5 Differences in mass flow rate when opening to ports for various sizes

[1] K. Okamoto and T. Nagashima, “Simple numerical modeling for gasdynamic design of wave rotors,” *Journal of propulsion and power*, vol. 23, no. 1, pp. 99–107, 2007.