HIGH SPEED MICRO TURBINE FOR SPECTROSCOPY APPLICATION

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In the present study, the flow dynamics of a high speed micro turbine system is investigated numerically utilizing CFD simulations with the tool OpenFOAM. This micro turbine system is applied in a device for chemical and biological analysis — the so-called Nuclear Magnetic Resonance (NMR) spectroscopy. NMR spectroscopy is a wide spread method in Biology and Chemistry for the investigation of liquid and solid samples. In particular for solid samples usually the Magic Angle Spinning (MAS) method, a special NMR technique is used. Herein, the MAS rotor containing NMR sample is rotated with a frequency in the range of spinning rates of $5\,kHz$ to $100\,kHz$. As driving fluid pressurized air at ambient temperature is used, which is jetted out through seven duct nozzles aligned on an intake spiral, as shown in Figure 1. The compressed gas is driving a Pelton type micro turbine that is mounted on the top end of the rotor. Recently, Wilhelm et al. [1] investigated the MAS turbine system showing that the efficiency factor is in the range of 20%. Three rotation frequencies of $23\,kHz$, $55\,kHz$ and $67\,kHz$, which are typically for the MAS system, are considered in our study. The micro turbine system is investigated by analyzing the influence of rotational frequency and geometrical parameters on the aerodynamic forces and torque and on the turbine efficiency.

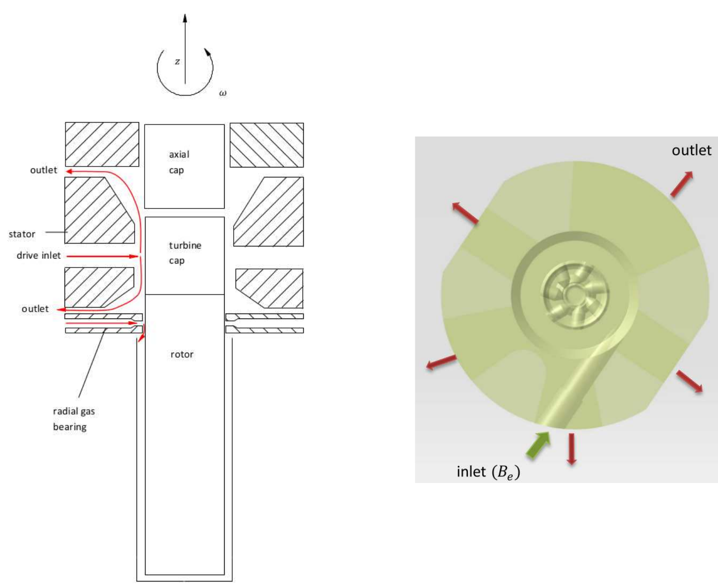

Figure 1: Sketch of MAS rotor system with turbine and radial bearing (left) and top view of the rotor and stator flow region (right). The drive gas is supplied from the inlet and afterwards distributed into the drive nozzles, then driving the turbine and leaving through the various outlet planes.

The investigated MAS system consists of two computational domains. The stationary domain, the stator, is formed by the housing and includes the port for the drive pressure (inlet) and the outlet regions where the air flow exits the system, see Figure 1. The rotating domain including the micro turbine and the rotor revolves with a certain angular velocity with respect to the systems vertical axis. First, initial studies of mesh type and refinement, of time influences of the solver, and of turbulence model settings were carried out to identify the most effective computational methodology. It was found that the steady-state MRF solver runs very efficient on the structured mesh that is locally refined in the rotor region. To cope for the time dependency and thus the resulting influence of the rotor position relatively to the nozzles, three positions were simulated individually and then the forces and the torque were averaged. The steady state results obtained with the MRF method were further validated with unsteady simulations performed with the OpenFOAM application rhoPimpleDyMFoam by using the sliding mesh approach.

The main optimization criteria of the MAS system is not primarily the efficiency, like in turbomachinery applications, but rather the achievement of a rotor high speed and secondly the turbine stability. In order to attain this criteria, a sensitivity study has been carried out in the frame of fabrication tolerances by variation of the nozzles diameter and the nozzle position relative to the rotor. The presented fluid dynamics study of the micro turbine system includes the analysis of local fluid flow values like velocity, Mach number (see Figure 2), temperature and pressure, as well as global quantities like forces and driven torque acting on the turbine. For all investigated cases it was found that the dominant force is directed in

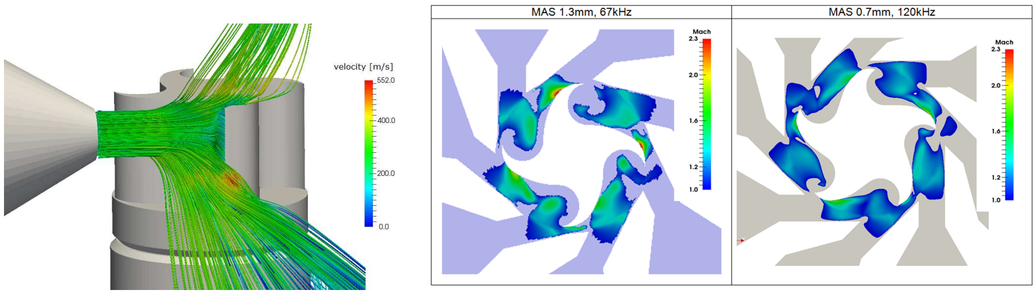

Figure 2: Stream tracer jetting out from a nozzle and impinging a blade (left); Mach number in radial section (right).

the downward vertical direction which is beneficial for the stability and fastening of the rotor. The non zero values of the horizontal pressure force components, which are of 3 to 4 orders of magnitude smaller than the vertical force component, indicate the occurrence of a pitching torque. Increasing the rotation frequency, the absolute value of the vertical force and of the driven torque also increase. Variation of the nozzle axis position relative to the turbine is influencing the flow fields distribution over the turbine blades and also the mass fraction of the jet air which flows down- or upwards after leaving the turbine, represented by stream tracers in Figure 2. For negative offsets much smaller driving torque values were found, due to larger mass fraction leaving the turbine through the downward part. By decreasing the ducts nozzle diameter the velocity leaving the nozzles increases exhibiting supersonic regions on the turbine blades, whereas the driven torque increases.

Comparisons with experimental measurements on the MAS system were given based on an efficiency factor defined as the bearing power acting on the shaft and the total power. The measured and simulated values of the efficiency factor agree very well especially for large downward positions of the nozzle axis relatively to the rotor, as shown in Figure 3. Concerning the efficiency factor dependency on the offset a small efficiency decreasing related to the downward movement

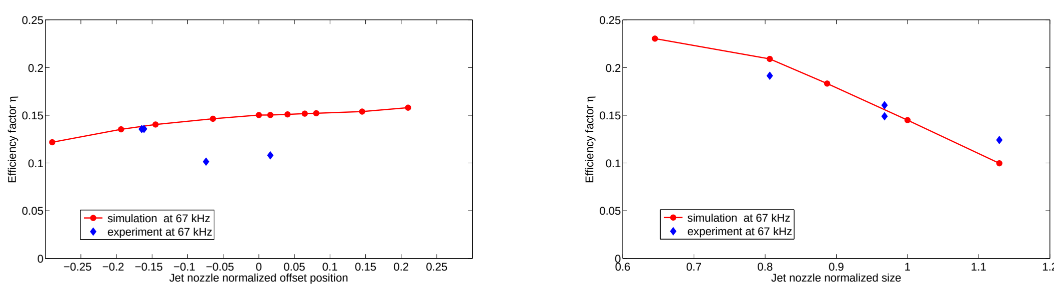

Figure 3: Efficiency factor as function of the normalized offset position (left) and as function of the normalised nozzle size (right) at maximal rotation frequency. Comparison between simulation and measurement data.

of the translation part is observed. Comparisons between simulation and measurement by variation of the nozzles diameter show also a very good agreement, the efficiency increases significantly by employing nozzle with smaller diameter. In further numerical and experimental studies the fluid dynamics investigation is intended for a smaller turbine diameter.

Acknowledgments

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References

[1] Wilhelm D., Purea A., Engelke F. (2015) Fluid flow dynamics in MAS systems, J. Magn. Resonance, 257, 51-63.