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Abstract

„ Research on the flow system of a partially admitted turbine with velocity compounding in a single rotor blade row"

Thermal turbines are widely used in various applications of conventional power production, distributed power generation, and in mobile drives. Particularly, the high-speed micro-scale technology is of special research interest due to its broad application in the mentioned distributed power generation. Research and developmental work in the field of turbine gas-dynamics focuses on two main aspects: continuous improvement of machine efficiency and increasing their power density. Especially in micro mobile drives, such as those used for powering pneumatic tools, power density plays a particularly significant role.

The practice of velocity compounding brings benefits in the form of reducing the dimensions of the machine (or reducing its rotational speed). Especially in the mentioned pneumatic drives, a challenge is the use of a low mass flow rate of the working fluid. In order to satisfy the low flow rate conditions, partial admission of the blade row is also utilized, which facilitates the manufacturing technology and reduces flow peripheral losses and tip leakage losses. However, this is associated with additional losses characteristic for partial admission of the blade row. A commonly used solution that utilizes both of the above-mentioned practices is the two-blade row Curtis stage. This paper discusses a theoretically competitive solution to the Curtis stage characterized by velocity compounding in a single rotor blade row. This allows achieving even greater compactness of the turbine stage and at the same time hypothetically reducing the pumping losses of the unadmitted part of the blade row.

In this dissertation, the method of designing such an unusual turbine stage using the 0D method and URANS CFD simulations with a 2D model was described. The process of

developing a prototype with a nominal power of 5 kW and a nominal rotational speed of 30000 rpm was detailed. The flow phenomena occurring in the flow at the nominal operating point were characterized.

The prototype was built and used to perform experimental studies with compressed air supply, which enabled the development of characteristics of the prototyped turbine stage. The designed construction allowed carrying out investigations in 3 different admission variants: in one sector, in two sectors, and in all three sectors. The experimental studies conducted enabled the validation of the computational model that utilized 2D geometry. The validation process showed that the 2D model can be successfully used to predict the performance of the turbine using velocity compounding in a single rotor blade row with partial admission using appropriate corrective practices. The obtained relative deviation of the experimental results from the values obtained through CFD simulations can be successfully linearized as a function of rotational speed, and in most of the examined ranges, this interpolation is approximately a constant function.

The validated model was used to carry out a series of analytical studies focusing on flow phenomena related to partial admission, but characteristic to the studied type of stage, in which the flow direction is reversed in each subsequent admission sector. The analyses showed deviations compared to the mechanisms of loss formation in classically partially admitted stages. The existence of an inter-sector leakage phenomenon, completely bypassing the main flow path after leaving the nozzle, and the effect of partial energy recovery at the entrance to the sector of the second velocity stage were indicated. The research highlighted how the intensity of these effects is particularly sensitive to various flow parameters, notably the pressures downstream of the nozzle, as well as to the geometrical features of the stage.

The work also determined the magnitude of partial admission losses in the studied prototype based on a developed hybrid method, combining experimental results achieved in three admission variants of the prototype with 3D CFD RANS simulation, where the simulation boundary conditions were supported by experimental results. The determined values of partial admission losses as a function of the velocity ratio, for the studied constant geometry of the stage, showed discrepancies compared to analytical models developed for classically partially admitted stages.