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A semi-empirical procedure for the evaluation of multi-stage turbine performances

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Abstract. The available tools for the analysis of fluid-dynamic processes inside turbomachines are nowadays extremely powerful and versatile. Despite this, the use of simplified procedures, such as the 2D meridional approach, is still relevant, due to its great running simplicity and good accuracy. The full three-dimensional analysis, in fact, even if it could model thoroughly details the fluid-dynamic phenomena occurring in turbomachines, requires huge computational resources and longer computational times with respect to two-dimensional approaches, and this is justified only after a simplified preliminary study of the machine. Also management simplicity, consistence of the required data and usability of results are aspects that should not be ignored, above all for the possibility of creating tools easily available for turbomachines designers. A through flow method, formulated in terms of pressure rather than velocity, for the analysis of multistage axial turbines is presented. It is designed to provide reliable radial distributions of, circumferentially averaged values for the fundamental unknowns. The proposed form of the radial equilibrium equation can represent also sharp velocity gradients in radial direction and deal with very realistic situations as discussed in the applications presented. The code has been used for the analysis of both an experimental multistage gas turbine and an industrial steam turbine. The results obtained have been compared with the circumferentially averaged results of a viscous fully 3D commercial code.

Key words

Through-flow, Turbine, Correlations, Combined Cycle, Semi-empirical.

1. Introduction

The aim of this work is to realize a semi-empirical method able to predict the performances of a small steam turbine that can be employed in combined cycle power plants for ship propulsion. In fact, this kind of plants are put forward in order to improve the overall efficiency and thus reduce emissions. Throughflow calculations are widely employed in industrial applications due to the high stability of the procedure and to its accuracy in terms of results [1].
Moreover it is important that these procedures present high stability, robustness and quick convergence rate in order to create easily available tools for preliminary analysis of turbomachines.

These procedures are in most cases semi-empirical, since they employ experimental correlations both for losses and for row exit angle evaluation. Losses and angles are usually taken as distributed in a uniform way in span wise direction. These methods provide overall results in accordance with those obtained from 3D CFD calculations, but this agreement cannot be always obtained also for the local values of fundamental unknowns.

Several throughflow procedures which employ local (and not overall) correlations both for losses and flow angle evaluation have been proposed in the open literature. Despite this, in order to evaluate the spanwise distributions of thermodynamic unknowns, it is fundamental that the method has high stability and robustness in order to properly evaluate high spanwise gradients caused by secondary effects, which in turn provide high variations of basic unknowns close to both hub and shroud.

2. Calculation model

For the resolution of the analysis problem it is assumed that the whole geometrical parameters are given. In the general formulation, in order to get the flow conditions in each point of the machine, it is necessary to calculate two thermodynamic variables and the three components of the velocity vector. Thus, if no further simplifying hypothesis reduces the problem dimension, the fundamental unknowns are five, and so the fundamental equations, which enable to solve the problem, have to be five. The calculation model is based upon the fundamental assumption of steady flow, axisymmetric flow with axisymmetric flow surfaces and adiabatic