21st International Conference **ENGINEERING MECHANICS 2015**
Svratka, Czech Republic, May 11 –14, 2015
Paper **#137, pp. 122–123**

Aerodynamic Characteristics of Steam Turbine Prismatic Blade Section

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Keywords: prismatic blade cascade, high pressure nozzle, high-speed flow, Reynolds number effect, flow separation, RANS

Abstract: For the needs of high-performance steam turbines producer the data of a blade section measurement have been analyzed in detail by experimental and numerical approach. The blade section is used on prismatic blades in high and medium pressure steam turbine parts. The linear blade cascade was tested at four pitch/chord ratios at two different stagger angles. The blade cascade was tested under two levels of Reynolds number in the range of output izentropic Mach numbers from 0.4 to 0.9.

The inlet of the test section was measured pitch-wise by five-hole probe to determine the inlet flow angle. The free stream turbulence of inlet flow was determined of 2.5% what is very close to the operating conditions on first high pressure stages. Two-dimensional flow field at the center of the blades was traversed pitch-wise downstream the cascade by means of a five-hole needle pressure probe to find out the overall integral characteristics. The blade loading was measured throughout surface pressure taps at the blade center. An in-house code based on a system of Favre-averaged Navier-Stokes equation closed by non-linear two-equation EARSM k-ω turbulence model was adopted for the predictions. The code utilizes an algebraic model of bypass transition valid both for attached and for separated flows taking into account the effect of free-stream turbulence and pressure gradient. Results are presented by integral characteristic in means of kinetic energy loss coefficient and velocity or pressure distribution in the blade wakes or on the blade surface. In this article, the effect of investigated criteria and comparison of experimental and numerical approach are presented and discussed.

Introduction

The common procedure for the designers of turbine stages is to test experimentally the optimized blade sections during or after the optimization process to obtain the aerodynamic characteristics. It is also necessary for filling the databases which are used during subsequent design procedures. Therefore, the detailed testing in aerodynamic wind tunnel was performed on a blade section used for prismatic nozzle blades of a new reaction stage and several criteria on this blade section were investigated.

Although the blades in steam turbines of 40-300MW power operates mainly on Reynolds number (Re) in range of $1.10^6 – 1.10^7$ where the turbulent boundary layer occurs, it is important to study the flow in such levels of Re where the boundary layer transition emerge somewhere on the blade, because at this moment the aerodynamic efficiency starts decreasing [1]. For the investigated blade section model and the conditions in the non-pressurized wind tunnel the Re = 5.10^5 in overall Mach number range is maximum value. Therefore the two levels of Re ($2,5.10^5$ and 5.10^5) were chosen for investigation.

The purpose of testing the blade section on several pitch/chord ratios (t/c) and at two different stagger angles (γ) is based on the whole turbine stage design procedure: In the last steps of the stage design the stage nozzle is turned around the radial axes and the optimal turbine stage mass flow is set. Therefore the two utmost positions of γ were tested. The t/c ratio is also a sensitive criterion how to balance the losses of the stage [2].

For the numerical study of blade section characteristics the model by system of Reynolds-averaged Navier-Stokes equations enclosed by non-linear two-equation EARSM k-ω turbulence model was used. The turbulence model is supplemented by an algebraic bypass-transition model proposed by Straka and Příhoda [3].

Results and discussions

In Fig. 1 the overall results of kinetic energy loss versus Mach number obtained by experimental tests and CFD data are displayed for selected investigated criteria. In the article the data in selected regimes are supplemented by pressure distribution in wakes and blade loading.

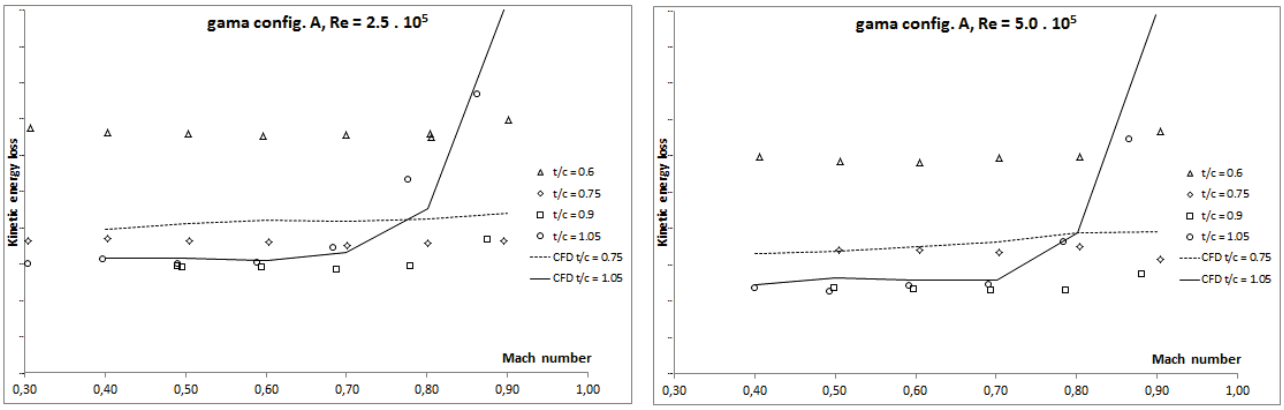

Fig. 1: Overall characteristics for selected criteria

1. Effects of investigated criteria (Re, t/c, γ). Common Re effect on the kinetic energy loss coefficient is that with decreasing the Re the loss coefficient increase. It is affected by boundary layer´s character in subsonic regimes. The laminar boundary layer (forming on lower Re) is wider and such the losses are higher. By transition to turbulent boundary layer the velocity in boundary layer increases and losses such decrease. Fig. 1 presents the comparison of overall level of kinetic energy loss coefficient for two Re levels and the definite influence of Re on the point where the losses begin to increase (due to boundary layer separation).

The results confirm that the optimum of t/c ratio is about 0.75. When the ratio further increase the kinetic energy loss coefficient still decrease but for higher Mach numbers (0.8-0.9) the boundary layer begins to separate and the loss coefficient increases.

2. Comparison of experimental and CFD data. The comparison of CFD and experimental data shows the same trends of the investigated criteria and very good comparison of integral characteristics. The CFD results predict little higher losses (approx. 5% higher as compared with exp.). The character of boundary layer is captured very well for t/c = 1.05. For lower values of t/c CFD results predict probably boundary layer translation later than it is happened physically during experiment. The trends character of kinetic energy loss coefficient matches the laminar boundary layer on the blade so therefore the losses are predicted litter higher. The more detailed analysis is given in the article.

Acknowledgement: The work was performed with help of long term institutional support kindly provided by Ministry of Industry and Trade of the Czech Republic.

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