22nd International Conference
ENGINEERING MECHANICS 2016
Svratka, Czech Republic, 9 – 12 May 2016

FLOW PARAMETERS SIMULATION TECHNIQUE IN ANNULAR TURBINE CASCADE INLET

T. Jelínek*, M. Němec*, V. Uruba**

Abstract: *This article summarizes the concept of equipment which produces the required flow parameters at the inlet of annular turbine cascade. The investigation of inlet flow parameters - i) the boundary layer on hub and tip inlet channel end-walls and ii) the inlet flow turbulence – are part of a project intent on a flow in multistage steam turbine arrangement. This variable inlet can produce the laminar or turbulent boundary layer, respectively the laminar or fully turbulent velocity profile in the inlet channel. The change of inlet turbulence level is controlled by the grid. The detailed measurement of inlet flow: the turbulence and the total pressure distribution across the height of inlet channel were performed by HWA (hot wire anemometry) probe and by total pressure probe, respectively. The measurement results characterize the inlet flow for several inlet channel arrangements and are used for the experimental investigation of the flow field inside the stage and as the inlet parameters for CFD simulations.*

Keywords: Turbulence, Boundary layer, Annular inlet flow, Grid, Axial turbine stage.

1. Introduction

The flow in axial turbine stage is a very complex phenomenon. The outlet flow field behind the turbine stage is also depending on the parameters of inlet flow. The character of inlet flow can influence the transition in boundary layer and the production of secondary structures. These are strongly depending on the inlet turbulence and the character of boundary layer. Both play significant role in secondary structures production (Seeverding, 1985, Lampart, 2009).

Many authors attend to the influence of turbine blade inlet flow characteristics by simulation of increasing the inlet flow turbulence level on outlet flow characteristics. Lot of work was done on linear blade cascades and the authors show the influence of inlet turbulence intensity on the transition in boundary layer, the formation of wake vortexes consequently (e.g. Michálek, 2015). Gregory-Smith brings the investigation of the high inlet turbulence influence to the secondary structures production in linear blade cascade. The secondary structures may change the outlet flow angles from turbine vanes. Even small vane outlet angle deviation may evoke the change in rotor work efficiency.

The understanding of the inlet flow characteristics and its accurate setting is important when the CFD (Computational fluid dynamics) simulations are performed. The accurate setting of inlet flow parameters has a strong impact on the boundary layer transition, secondary structures production and may affect the outlet flow parameters.

To study this phenomenon on the annular turbine stage the appropriate device was necessary to propose and design. The device must make change the inlet turbulence level and the thickness of boundary layer on both, the hub and tip channel wall, resp. the velocity profile in the inlet channel.

2. Concept of the inlet channel

* Ing. Tomáš Jelínek, Ing. Martin Němec, PhD.: Výzkumný a zkušební letecký ústav, a.s., Beranových 130; 199 05, Prague - Letňany; CZ, jelinek@vzlu.cz

** Prof. Ing. Václav Uruba, CSc.: Institute of Thermomechanics AS CR, v.v.i, Dolejškova 1402/5 182 00 Prgue; CZ, uruba@it.cas.cz

The device (scheme in Fig. 1) consists of four concentric circular parts of inner and outer body, forms together the turbine stage inlet channel of height *h*. Forming the different inlet channel length *l* it makes the different boundary layer thickness δ, resp. forming different inlet velocity gradient *u(y)*. Inlet turbulence level is produced by the grid which is located in proper distance l_g in front of vane leading edge. The distance l_g can be variably set to change the level of inlet turbulence. The additional parts of the turbine stage disable mounting the traversing device just in front of the vane leading edge as it should require to now the parameters of the flow just in front of the vane. The measurement plane 0 had to be placed 46 mm in front of the vane leading edge. As the parameters can be well prediction analytically it is believed that they will be just verified in the plane 0 position. The measurement plane 1 was placed 5mm behind the vane trailing edge.

The total pressure probe of 0.6 mm in diameter was used for the total pressure measurement in plane 0 and the 4-hole probe to evaluate the total and static pressure and flow angle behind the vane was used in plane 0.

In both planes the HW probes were used to evaluate the turbulence. In front of the vane the 21 points were taken across the channel height, behind the vane 21 points across the vane channel in *h/2*. The DANTEC 55P02 and 55R02 probes with straight prongs and with the sensor at an angle of 45° to probe axis was used for the turbulence measurement in both planes.

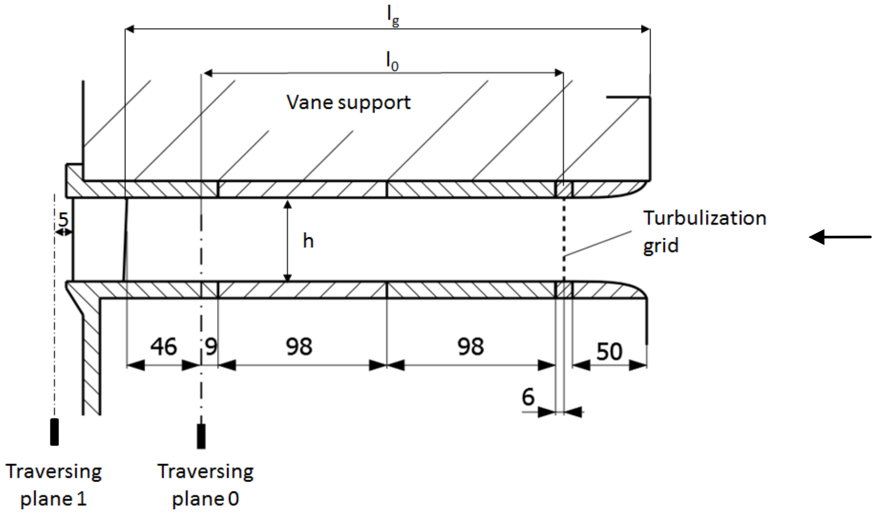

Fig. 1: Scheme of the inlet channel allows changing the inlet flow parameters.

2.1. Velocity profile

The assessment of the inlet channel length was based on the requirements to have the maximum boundary layer thickness in the position of vane leading edge δ = ¼*h*. As the flow in the channel is not considered as the channel flow defined (by Pope, 2000): $h = 2\delta$; $l/\delta >> 1$, the assessment of the maximum channel length was based on the equation for turbulent boundary layer thickness on a flat-plate (Schlichting, 2004):

$$\delta = 0{,}382 \frac{x}{\mathrm{Re}_x^{1/5}} \ . \tag{1}$$

To ensure that the transition to turbulent boundary layer starts at a very beginning the turbulization strip was used at the channel inlet. The strip is realized by send roughness of 40 and the width is 5mm.

For the case of the shorter channel which could produce very low thickness laminar boundary layer the Blasius law was used to predict the boundary layer thickness:

$$\delta = 4{,}91 \frac{x}{\sqrt{\mathrm{Re}_x}} \ . \tag{2}$$

2.2. Turbulence production

The most useful method how to generate nearly isotropic turbulence is by means of grid. The grid are mostly used to reduce the turbulence and for elimination of pressure non-uniformities. The grids of relatively large dimensions placed normal to a uniform upstream flow can be used to increase the isotropic turbulence of inlet probe. Roach (1987) in his paper summarizes the proposal of the grid based on many experiments and mention the equation for the turbulence:

$$Tu = C.\left(\frac{x}{d}\right)^{-5/7}, \tag{3}$$

where C is a constant which is considered for the case of uniform grid with circular wire 0.8; x is the displacement from the grid and d is the wire diameter. The exponent represents the turbulence decay. This relation is displayed in Fig.2.

The preliminary requirements on investigation of inlet flow parameters on the flow in axial turbine stage defined, that the required inlet turbulence should be in range of 8-2%. Based on this requirement the grid was defined: wire diameter d = 2mm, mesh length m = 7mm, that means the porosity of the grid $\beta = (1-2/m)^2 = 0.51$.

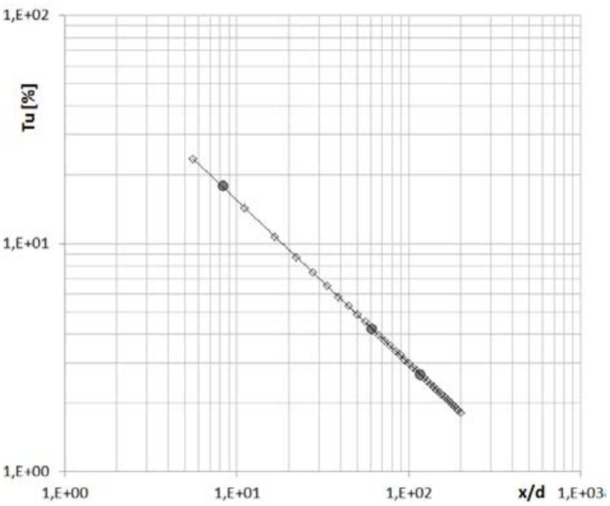

Fig. 2: The relation of turbulence on x/d: ◊ theory after Roach, • Measured values in centerline.

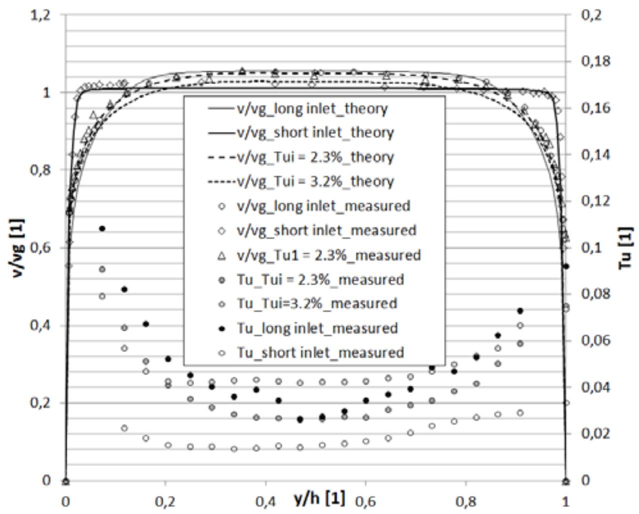

Fig. 3: Velocity and turbulence profile in plane 0 for different inlet channel configurations.

3. Velocity profile and turbulence measurement

The turbulence was measured and evaluated based on the methodology of Institute of Thermomechanics AS CR. The mean turbulence value on the channel center are displayed in Tab. 1 and also in Fig. 2 where there are compared with the theory after Roach. It is clearly visible that the measured turbulence meets the theory and thus the turbulence in the plane at the vane leading edge can be determined.

In Fig. 3 the measured velocity and turbulence profiles are shown for different inlet configurations. It is seen that the measured velocity distribution is in good accordance with the theory for both cases the laminar and turbulent boundary layer. For the cases when the grid is placed in the channel, the velocity distribution is in accordance as well. Slightly higher velocity can be observed in the lower part of the channel (y/H < 0.5) for some cases. This can be taken into consideration when the kinetic energy loss of vane is evaluated.

The effect of the inlet turbulence on the outlet stator flow field is seen in Fig. 4. The change of inlet turbulence has very minor impact on the generation of secondary flow inside the vane channel in hub and tip corners. The small changes in the secondary structures have a small effect on the outlet angle from vane as well. It is important for the rotor work efficiency, however the effect of the vane outlet parameters changes on the stage overall performance was negligible and the measured performance changes were lower than the measurement uncertainty.

Tab. 1: The measured values of three different grid positions.

Configuration No.		**006**	**004**	**005**
Length (from grid to plane 0) l_0	[mm]	15	113	211
Length (from grid to vane LE) l_g	[mm]	61	159	257
Turbulence measured (plane 0) Tu_0	[%]	(17,9)	4,23	2,66
Turbulence theory (plane 0) Tu_{0t}	[%]	17,59	4,24	2,67
Turbulence (vane LE) Tu_i	[%]	6,54	3,24	2,29

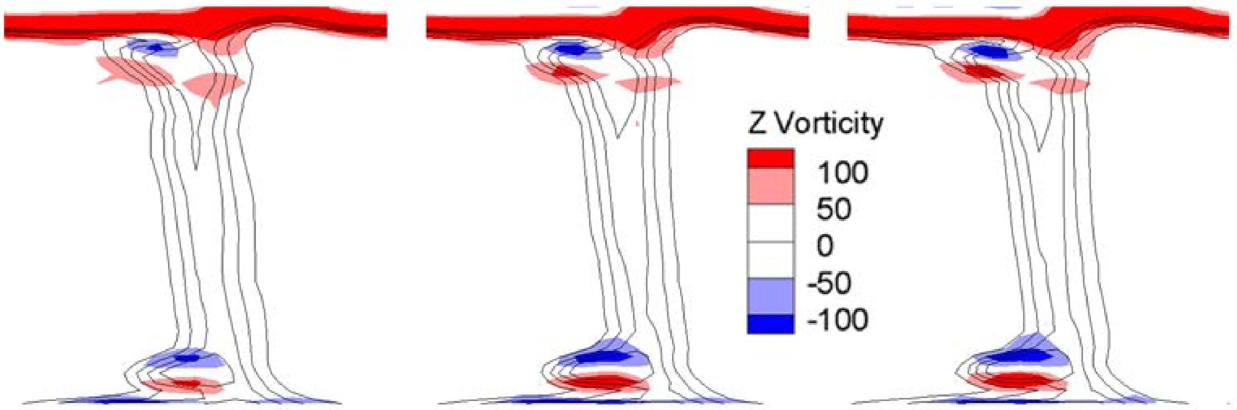

Fig. 4: The vorticity in the plane behind the vane trailing edge. Tu_i = 6.54% (left), Tu_i = 3.24% (in the middle) Tu_i = 2.29% (right)

4. Conclusions

The variable inlet channel to generate the different velocity profile and different level of turbulence in the inlet of turbine stage was design and the characteristics of inlet flow were verified by measurement using pressure probes and HW probes. The assessment of the grid produced the nearly isotropic turbulence was verified even for the application in annular channel flow.

The insight into the inlet flow parameters and the knowledge of exact values of inlet flow parameters are necessary as inputs for CFD calculations when the flow simulation can be done to analyze the flow filed in the turbine stage.

Acknowledgement

The work was performed with kindly financial support of TACR on the project TA04020129 “Investigation of flows in a multi-stage axial turbine stages arrangement”.

References

Gregory-Smith, D.G.: Secondary Flow Measurement in a Turbine Cascade with Figh Inlet Turbulence, ASME, 1990, 90-GT-20

Lampart P., “Investigation of Endwall Flows and Losses in Axial Turbines, Part I. Formation of Endwall Flows and Losses,” Journal of Theoretical and Applied Mechanics, Vol. 47, No. 2, 2009, pp. 321-342.,

Michálek J., Straka P.: Experimental investigation and steady/unsteady RANS modelling of the wake decay behind a low pressure turbine cascade, Proceedings of the 12th ISAIF 2015, Genova, Italy

Pope, S.B.: Turbulent Flows, Cambridge University Press, The Edinburgh Buiding, Cambridge, CB2 2RU, UK, 2000

Roach P.E., The Generation of Nearly Isotropic Turbulence by Means of Grids, Heat and Fluid Flow, June 87, 8 (2), pp. 82-92, June 1987

Schlichting H., K. Gersten, Boundary layer Tudory (8th edd.), Springer-Verlag 2004, ISBN 81-8128-121-7

Sieverding C.H.: Recent progress in the understanding of basic aspects of secondary flow in turbine blades passage, ASME, J. Eng. For Gas Turbine and Power, 1985, Vol. 107, pp 248-257