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No. 114, 2003, 3-4

Editorial

These Special Issues of the *Transactions of Fluid-Flow Machinery*, Nos. 113 and 114 contain selected papers from the International Conference on *Turbines of Large Output* devoted to commemorate 100$^{\text{th}}$ Birthday Anniversary of Prof. Robert Szewalski. The conference was held in Gdańsk, Poland on September 22-24, 2003.

The Conference is a continuation of previous conferences held at the Institute of Fluid-Flow Machinery PAS in former years dedicated to technology of steam turbines. Series of conferences bearing the same name took place in the years 1962, 1965, 1968, 1993. In 1997 organised has been a conference on steam turbines and related topics, but with a slightly amended title – *Problems of Fluid-Flow Machinery.* At present at the Institute of Fluid Flow Machinery there are conduced research of fundamental character encompassing both the issues related to steam turbines and fundamentals of power engineering.

Organisers of the present conference have returned to the traditional name, i.e. Conference on *Turbines of Large Output* to mark the respect to the memory of Professor Robert Szewalski (1903-1993), the founder and a director of the Institute of Fluid-Flow Machinery for several years, and initiator of the conference series devoted to the problems of steam turbines.

The Editors are very grateful to the referees of the papers presented in this issue of the *Transactions of Fluid-Flow Machinery*: J. Badur, W. Batko, E. S. Burka, J.T. Cieśliński, P. Doerffer, A. Gardzilewicz, B. Grochal, J. Kiciński, G. Kosman, T. Król, J. Krzyżanowski, J. Mikielewicz, A. Neyman, W. Ostachowicz, R. Puzyrewski, R Rządkowski, J. Świrydczuk, M. Trela, T. Uhl and Z. Walczyk.

We appreciate cordially the manifested authors interest in our conference. Special thanks are conveyed to Ms 'Maya' Bagińska, for her fruitful editorial help related to directing the papers to reviewers and correspondence with the authors of contributions.

Prof. Jarosław Mikielewicz
Editor-in-Chief

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TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 114, 2003, 191-200

V. G. SOLODOV* and YU. V. STARODUBTSEV

Numerical model of viscous turbulent flow in "inlet pipe – 1^{st} stage" compartment of power steam turbine

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Abstract

The paper describes 3D numerical model and some results of numerical simulation of viscous turbulent flow in "Inlet Pipe – 1st Stage" compartment of large power steam turbine.

Keywords: Viscous turbulent flow; Inlet pipe; Compartment; Steam turbine

1 Introduction

The experimental studies [1] of turbine inlet pipes point out on complicated spatial flow pattern, strong parameters nonuniformity and total pressure loss. Flow nonuniformity, created by the inlet pipe, depends on certain design and operational factors, adversely effects on flow through 1st stage. Discrete steam supply through tubes creates at the inlet of stage circular large scale nonuniformity of gasdynamical parameters comparatively with the nozzle pitch, therefore certain sectors of channels operate under off-design regimes and this diminishes the efficiency and safety of the whole turbine[1, 2].

The problem of simulation of viscous turbulent flow in the inlet pipe (or simply Inlet) meets certain difficulties because of its multiconnectivity and complexity of topology. Besides, in order to obtain the adequate solution the problem requires the simultaneous calculation of flow in all the channel of coupled stage. The pitch of every channel is the 2-order less then the character dimension of Inlet and total area of friction surface of blading essentially exceeds the internal

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surface area of Inlet collector.

One of the authors at the start of 90's had proposed the approach to modeling of aerodynamic interaction of the turbine stage and large scale joint device [3,4]. In present paper this approach is developed for numerical model of viscous turbulent flow through inlet compartment of axial turbine. The results of numerical analysis of LP inlet compartment of steam turbine presented, are based on two pipes Inlet and 1st stage. The geometry description, numerical analysis and postprocessing are realized with the use the *MTFSoftware* [5].

2 Formulation of the problem

The inlet compartment model is assembled of one part supply of Inlet and complete set of vanes and blading of 1^{st} stage (Fig. 1)

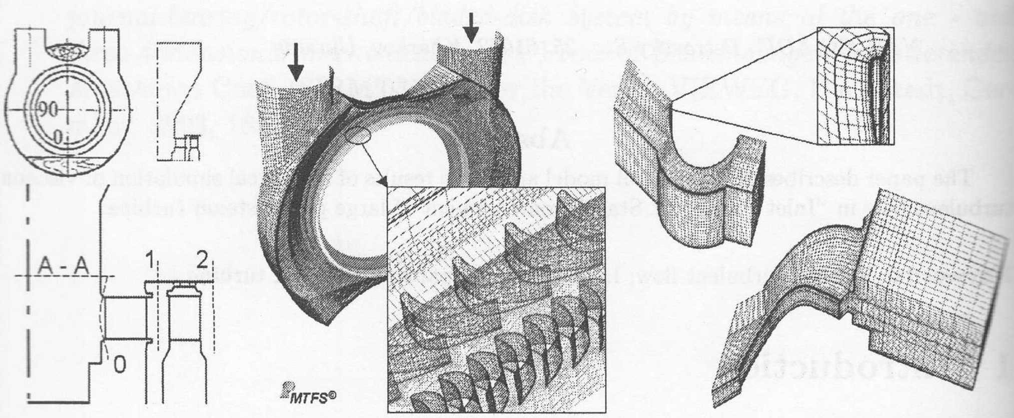

Figure 1. The scheme of calculation region and meshing.

The most general approach to gas dynamical flow modeling of compartment supposes the united calculation region, built up in Inlet and in all stage channels and marching procedure in whole compartment under uniform total parameters in supplying pipes and outlet flow rate or static pressure. Such a formulation is mathematically and physically valid, corresponds to experimental conditions[1, 2], but the realization of such approach requires non-realistic amount of calculation.

The way out could be seen in simplification of the problem taking in view the peculiarities of flow in the compartment. Namely, the velocity level at inlet plane of stage for operational flow regime is about 0.1-0.2 M. The difference in scales of Inlet and stage channel ensures sufficiently smooth character of circular distributions of flow parameters after the Inlet in comparison with pitch of nozzle

Therefore, every nozzle channel approximately could be supposed as operating under condition of quasi-uniform flow. This permits to split the problem of compartment flow into separate subregions: Inlet and stage with transfer through interface surface between them basing on averaging procedure and following interpolation of mass, momentum and energy. Thus we obtain the first essential simplification – the possibility to realize in Inlet the mesh in circular direction, sufficient for calculation of the flow in Inlet but essentially more coarse than the mesh in stage channels, namely with the cell dimension comparable to pitch of nozzle. This simplification is able to give the economy of computational resources for Inlet subregion not less than 80-100 times (Fig. 2).

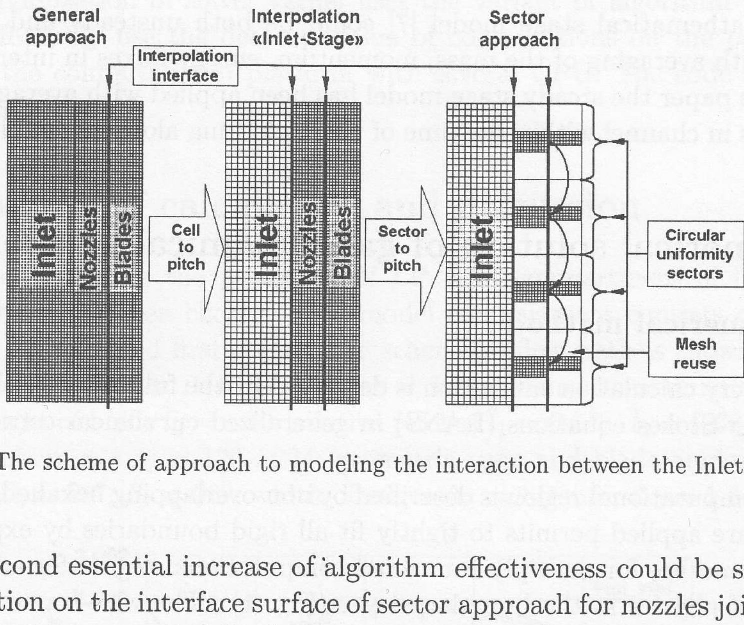

Figure 2. The scheme of approach to modeling the interaction between the Inlet and stage.

The second essential increase of algorithm effectiveness could be searched by the realization on the interface surface of sector approach for nozzles joining. This approach had been applied firstly in problem of stage – exhaust hood unsteady interaction [3, 4] in frame of inviscid gas model. Validation of sector approach is based on evaluation of velocity circular non-uniformity which is in limits of 5-15% per radian at the outlet section of typical Inlet [1, 2] with 1-4 supplying pipes. As it was already mentioned, the circular distributions of flow parameters have sufficiently smooth character. This is also confirmed by experimental data [2], by results of flow simulation through isolated Inlet [6], and this could be explained by large relative dimensions of Inlet, by smooth joint of pipes and collector, scroll design etc.

So, it is possible to approximate the circular distributions of gas dynamical parameters by piece wise constant functions on sectors of interface. It means that for group of nozzles, joined to certain sector, the same flow pattern is realized. The use of this fact is able to save the computer resources for joined stage about

5-10 times.

The consideration of Inlet symmetry relatively the plane in comparison with axial symmetry of joined stage permits to make calculations of flow in left and right half of compartment separately due to weak effect of disturbances from stage up stream into collector and this one is explained by confuser property of the Inlet.

The approach presented has generality, is applicable both for steam turbine compartments and for gas turbine units including the axial radial type and could be adapted for special cases. The angular sector size is regulated and is chosen during the calculation using the condition of minimal gradient values of parameters on sectors of interface.

The mathematical stage model [7] could be both unsteady and stationary one, i.e. with averaging of the mass, momentum, energy fluxes in inter-row spacing. In this paper the steady stage model has been applied with averaging of flow parameters in channel within the time of blade clocking along the pitch of nozzle.

3 Numerical solution of gas dynamical problem

3.1 Numerical method

The every calculation sub-region is described by the full Reynolds-Favre averaged Navier-Stokes equations (RANS) in generalized curvilinear coordinate system.

The computational region is described by non-overlapping hexahedral meshes. The software applied permits to tightly fit all rigid boundaries by exponentially condensed meshes for multiply connected computational region for adequate description of physics in the boundary layer (Fig. 1). The wire-frame model and meshing of flow region are based on solid modeling.

The CFD solver used for analysis is the commercial CFD code MTFS®v.3/03D [5]. This code uses the Godunov's type cell-centered ENO scheme [8, 9] that is spatially 2nd order accurate. The turbulent effects are introduced through the one-equation Spalart-Allmaras differential turbulence model [10] based on the Boussinesq hypothesis. The implementation of S-A turbulence model was discussed in [11].

Flow is supposed to be fully turbulent which could be determined by inlet boundary conditions, so S-A trip function was not used in this study. The model [10], among the modern turbulence models, shows high efficiency, robustness and high quality of simulation for complex turbulent flows. This transport equation is basically of similar form as RANS and is solved by the same difference scheme and technique.

3.2 Boundary conditions

For inlet part of boundaries the total pressure, total temperature and direction of velocity vector are formulated. For outlet one the constant static pressure is formulated. For turbulence model equation the inlet part of boundaries requires the pseudoviscosity value as the initial value of turbulence, which is a part of laminar viscosity. At the vicinity of outlet part of boundaries the pseudoviscosity is a constant. At the rigid boundaries the usual non-slip condition is used.

3.3 Parallelization

The organization of solver kernel uses the variant of algorithm [12], which permits effectively use the decomposition of computations on the parallel processes for the computational platform with several CPU. The code testing has been published in [11].

4 Example of calculation and discussion

For model testing the prototype of LP Inlet compartment of large power steam turbine has been chosen. The model compartment consists of two pipe variant of Inlet [1] and first stage. The scheme of flow path is shown in Fig. 1. The Inlet areas ratio is $A_{INLET}/A_{EXIT} = 1.75$. Main characteristics of stage: relative height of blade $\bar{l}_2 = 1.19$; relative pitches $\bar{t}_1 = 0.648$, $\bar{t}_2 = 0.68$; vanes and blades numbers $z_1 : z_2 = 120 : 224$; geometric vane and blade angles $\alpha_0 = 90^o$, $\alpha_1 = 22^o$, $\beta_0 = 28^o$, $\beta_1 = 36^o$, width of edges $\Delta_1 = 1.0$ mm, $\Delta_2 = 1.5$ mm.

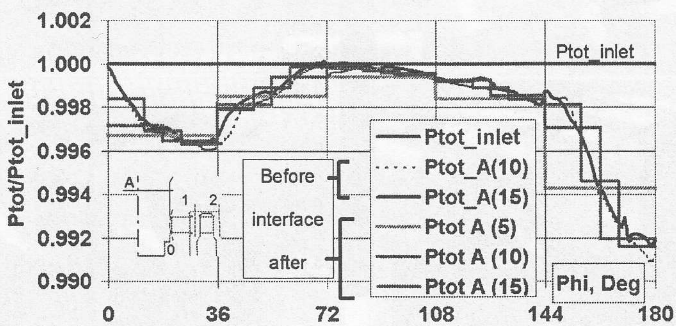

Figure 3. The convergence of sector approach: 10, 20, 30 sectors circular total pressure distributions near interface surface .

Calculation was made under compartment pressure drop $P_{exit}/P_{tot} = 0.63$. Numerical model of one quarter of Inlet without pipes contains about 0.5e+6 cells that yields $y^+ \leq 7.8$; the model stage have the cylindric flow path without seals and shroud model; every channel contains about 1.0e+5 cells that yields $y^+ \leq 3.5$ for stage. The interface surface was chosen in section A-A, where the gradients of flow parameters are relatively small. The calculations were made for 10, 20, 30 sectors of interface surface for algorithm convergence testing. The results of convergence of sector approach are given in Fig. 3.

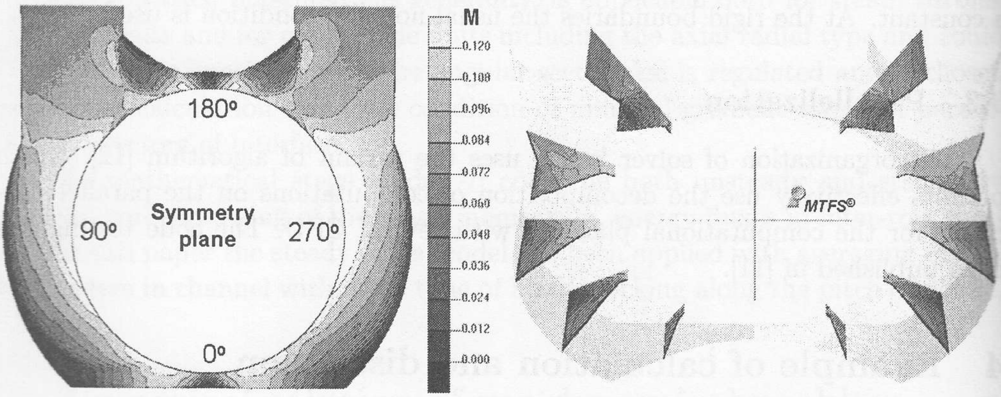

Figure 4. Flow pattern in Inlet.

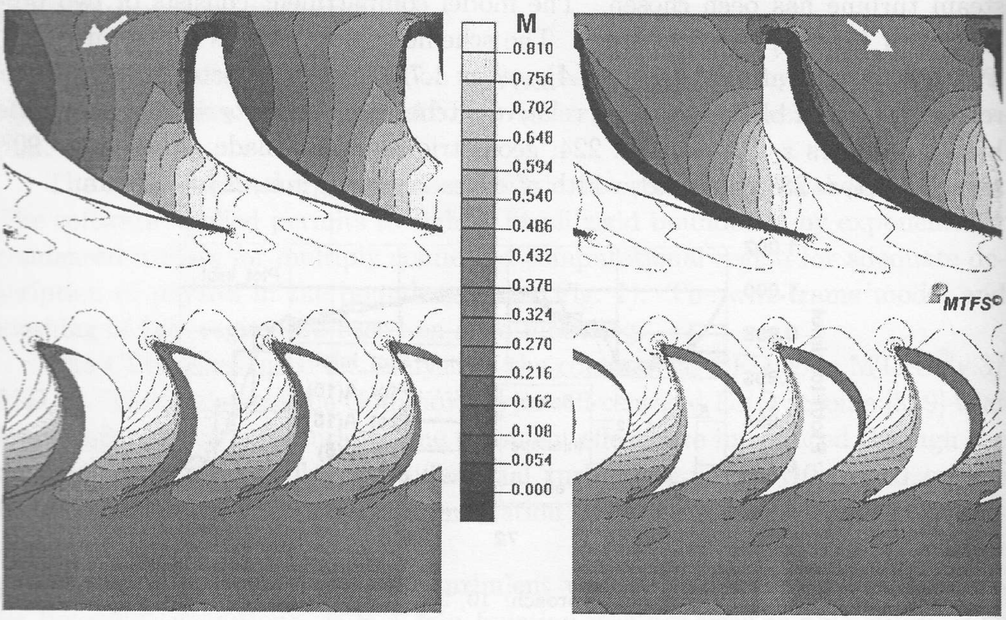

Figure 5. Velocity fields in absolute movement for sectors $\varphi = 90°$, $\varphi = 180°$.

Some results of analysis are presented briefly in Fig. 4-9. In the case of presented regime the velocity level at the Inlet doesn't exceed 0.15 M, Reynolds numbers for Inlet interface surface about 2.2e+6/m; weak violation of flow symmetry is observed because of nonaxial symmetric resistance of stage (Fig. 4). The same reason leads to distinction of flow patterns in stage channels of different sectors (Fig. 5). The incidence angles of vanes reach 50°, which corresponds well to the results of experiment [2], provokes the development of secondary flows in channels of stator and rotor (Fig. 6).

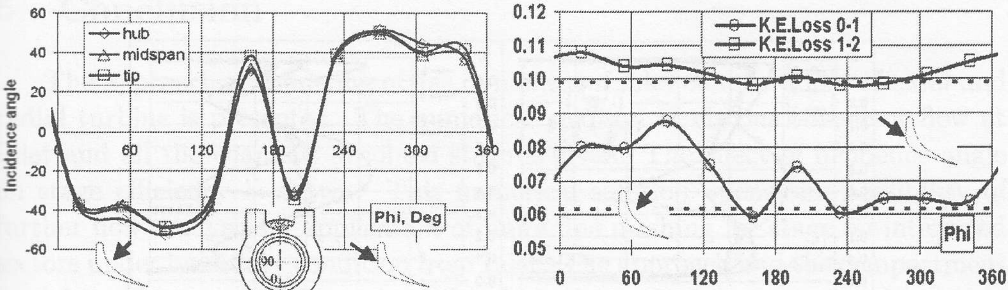

Figure 6. The circular distribution of vane incidence angle and stator, rotor K.E. loss.

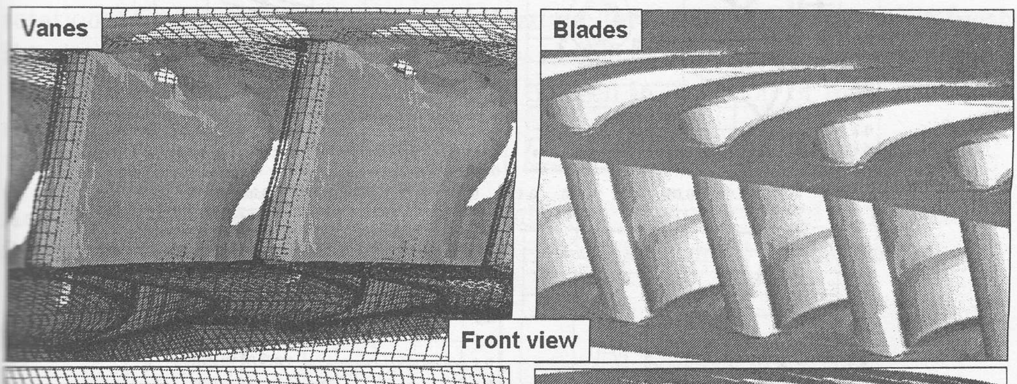

Figure 7. The isosurfaces of T.P. loss in nozzles and blade passages; sector $\varphi = 90°$.

The distinctions in orientation of vanes relatively to incidence flow along the circumference of supply cause the different level of kinetic energy (K.E.) loss in vanes and blades of stage (Fig. 6). The K.E. loss in stage nozzles and row channels under radial incidence on stage in section A-A (see Fig. 1) is shown for comparison in Fig. 6 by dotted lines. So, the K.E. loss in stage is essentially determined by incidence flow conditions. Fig. 7 shows the propagation through the blade row of passage vortices, arising in channels of stator. In figure the surfaces of constant values of total pressure (T.P.) loss are shown for sector near $\varphi = 90^{\circ}$ when the incidence into pressure side of vane profile occurs.

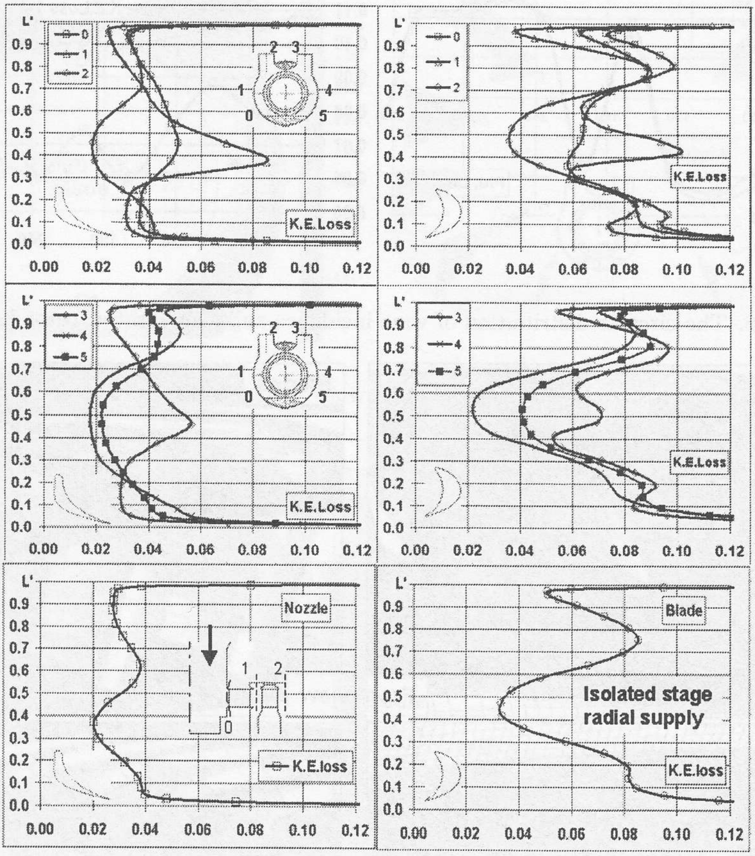

Figure 8. K.E. loss on vanes and blades for different sectors, also for isolated stage under radial supply.

The pitch averaged radial distributions of K.E. loss in channel of stator and rotor are presented in Fig. 8. For comparison the similar radial distributions of K.E. loss in channels of isolated stage under radial flow incidence in section A-A are given. The incidence into pressure side of profile corresponds to sectors Nos. 0, 1, the incidence into suction side is realized for sectors Nos. 4, 5; for sectors Nos. 2, 3 the character of incidence is changed inversely. Boundary layer swelling and separation in stage inlet section 0-0 because of sharp flow turn stimulate the development of horse shoe vortices which are transformed in nozzles into channel vortices, propagate into blade passages and interact with secondary flows in blade row. The flow pattern and the behavior of vortex filaments mainly correspond to standard conception [13].

5 Conclusion

The approach to modeling of gas dynamics of inlet compartment of axial and radial turbine is presented. The numerical solution of viscous turbulent flow at Inlet and all the channels of joined stage is given. The effect of incidence angle on stage efficiency is shown. This numerical solution opens the possibility of further flow analysis by application of more fine meshing for stage on interested sectors under boundary condition from Inlet. The approach and the compartment model could be applied for variety of turbine theory and design tasks: for supply optimal design in order to minimize K.E. stage loss; for solution of partial supply problem; for analysis of flow pattern in near extraction stages; for estimation of rotational frequency variable forces on blading; for sector vane adjustment (with thin leading edges mainly), for direct flow modeling of one stage turbine etc.

The development of this work could be seen in direction of unsteady stage model application.

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