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STEAM TURBINE STAGE MODERNISATION IN FRONT OF THE EXTRACTION POINT

Mariusz Szymaniak
Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Poland

ABSTRACT

The paper presents modernisation of the steam turbine stage situated in front of the turbine extraction point, based on a 225 MW turbine LP stage as an example. The modernised design is intended to better control the steam flow in this area. In the presented design a special ring is used to drive the steam leakage flow directly to the heat exchanger. The performed experiments and numerical analyses confirmed measurable exploitation and efficiency advantages of the introduced modernisation. So far, it has been successfully applied in a number of turbines working in inland power plants, but its use can be easily extended, without need for further modification and without advantage loss, to marine turbines, especially those used as main propulsion in sea-going vessels.

Keywords: turbine stages,leakages,extraction point,axial flow turbines

NOMENCLATURE

N	[MW-]	power
C_m	[m/s]	axial velocity
p_t	[bar]	total pressure
p	[kPa]	static pressure
H	[mm]	height of blade
t	[degC]	temperature
q_k	[kJ/kWh]	specific heat consumption

INTRODUCTION

For operating reasons, some clearances are to be preserved over the rotor blades in the steam turbine design. The tip leakage flow of steam through the clearances has higher energy and different direction, as compared to the main flow, which is the source of losses in this part of the turbine duct, due to the generation of swirl zones, intensive mixing processes, and blockage of the flow to regenerative heat exchangers. These dissipative processes are particularly intensive in the last stages of LP turbines, where the velocity of the steam flow leaving the clearances over the unshrouded rotor blades is transonic. This effect has firstly been observed in experimental investigations carried out on 200 MW turbines with Bauman stage [1,2]. The thermal measurement instrumentation used for this purpose is shown in Fig. 1.

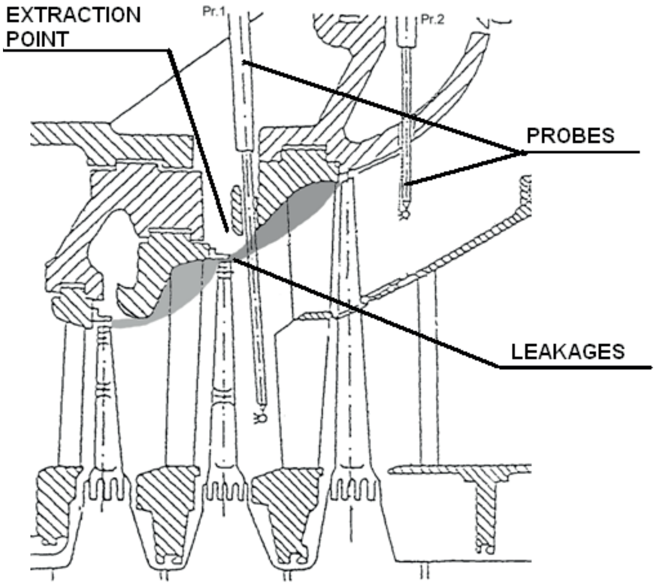

Fig. 1. Thermal measurement equipment in the LP section of 200 MW turbine with Bauman stage; zones of influence of the tip leakage flow are shadowed in grey

Plate probes inserted into the flow duct have made it possible to record pressure, temperature, and velocity distributions with high accuracy. Based on the results recorded in the turbine stages before modernisation, a new, more efficient design of steam turbine stage in front of the regenerative extraction point has been proposed, patented and practically applied [3], [4].

The idea of the new design is shown in Fig. 2. It mainly consists in installing a properly shaped ring in the tip clearance area of the unshrouded rotor blades to direct the leakage flow to the extraction chamber. Generally, the advantage of the presence of the ring results from eliminating the swirl zone in the flow, as the ring removes the so-called aerodynamic curtain generated by the transonic steam flow within the tip clearance area, see Fig. 2.

a)

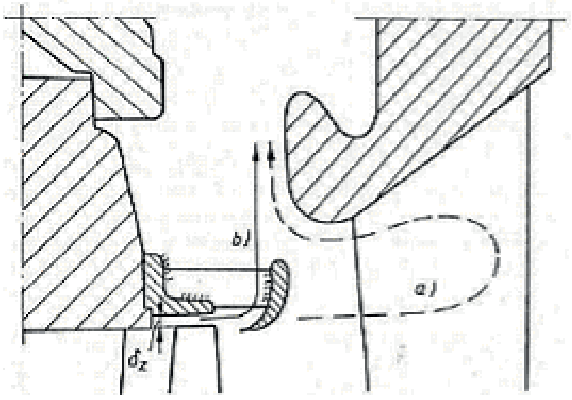

Fig. 2. New design of the stage in front of the extraction point

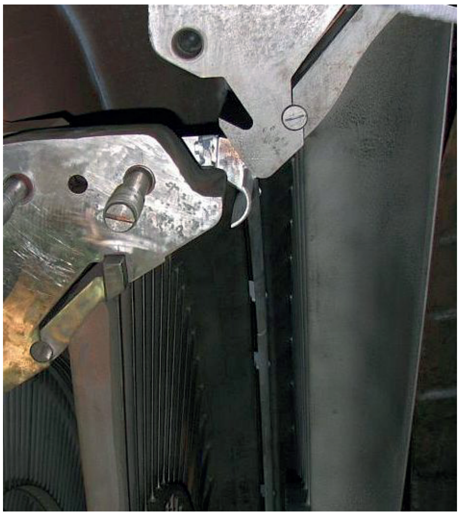

Fig.3. View of the ring inside the turbine flow path [3]

The steam flow capacity of the stage situated behind the extraction point is significantly increased by:

- eliminating the mixing of the tip leakage steam with the main stream, and directing the leakage steam directly to the extraction chamber;
- higher thermal loading of the first (usually underheated) regenerative exchanger, which results from utilizing the high-energy leakage stream in the extraction chamber. It is noteworthy that the mass flow rate of the leakage flow is equivalent to that of the extraction steam;
- eliminating the liquid phase from the flow, since the ring operates as a separator of secondary water droplets existing in the steam flow through that turbine part.

In the turbines where this solution was applied, the resultant benefits were evaluated as equal to 400 - 800 kW, depending on operating conditions. Over the years 2008–2015, the new solution was applied in seventeen 200 MW turbines. No operational problems were observed, see Fig.3.

STAGE MODERNISATION IN 225 MW TURBINE LP PART.

Based on the results of examination of the ring operation in a number of old 200 MW turbines, a decision was made to install those rings also in LP sections of new 225 MW turbines which were modernised in Poland in 2008, in the diffuser area between the two last stages [5], [6]. One of basic motivations for this decision was intensive damages of rotor blade leading edge tip sections in the stages situated directly behind the diffuser, which were observed when inspecting this turbine part, see Fig. 4. These damages were believed to be mainly caused by large water droplets, transported with the steam flow, which were not disintegrated in the blockage area. Additional minor damages observed in the remaining part of the leading edges were most likely generated by smaller droplets splashed by the leakage flow. Of highest threat for turbine operation were the erosion defects situated in the blade area beyond the hardened zone. Water droplets which reached this area had highly acidic nature (pH<5) and were a possible source of dangerous cracks in the erosion zone [7].

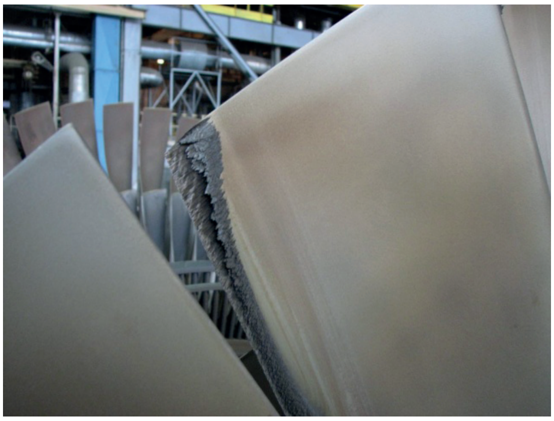

Fig. 4. Leading edge damage patterns observed in the 225 MW turbine last stage rotor blade system

The ring design applied to remove these highly unfavourable effects. It was developed as a result of analyses of experimental data recorded in a real steam turbine with Alstom exit. A schematic diagram of the placement of measuring probes installed in this turbine is shown in Fig. 5. Like in older constructions, the performed measurements have revealed the presence of a jet flow leaving the tips of unshrouded rotor blades in the last-but-one stage. This jet interfered then into the flow structure by blocking the steam admission to the regenerative extraction system.

The presence and action of this jet flow and blockage before ring installation were also confirmed by salt deposits observed on the surfaces of the last stage stator blades in the inspected real turbines [8,9,10].

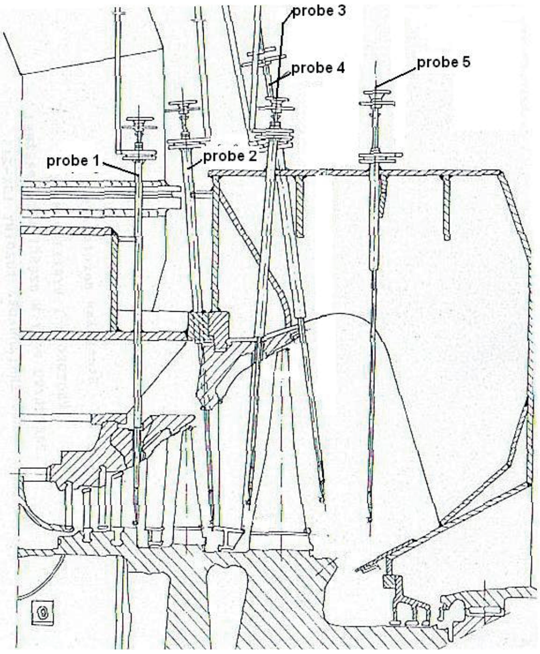

Fig. 5. Placement of measuring probes in the LP part of 225 MW turbine with Alstom exit

The results of experimental measurements of the flow through this turbine part were confronted with those obtained in numerical CFD calculations. The calculation domain included two last LP turbine stages and the interstage diffuser with extraction point situated between them. Two variants of turbine geometry were prepared, which differed by the presence or absence of the ring.

The calculations were performed using the model of compressible and viscous fluid flow, complemented by the two-equation k-ω turbulence model. The thermodynamic state of the steam was modelled by the equations valid for perfect gas. The thermodynamic constants, determined for conditions corresponding to the wet steam flow, were equal to: $R = 437.5$ J/kg k and $k = 1.13$.

The calculations of the flow through the interstage diffuser allowed to determine the pressure change in the extraction chamber, which was caused by directing the high-energy rotor tip leakage flow from the extraction point into it. This leakage flow energy can be utilised in the regenerative heat exchanger.

In preliminary tests, comparing the calculated radial distributions of pressure, velocity and temperature with those measured along the traversing line of the measuring probe confirmed the correctness and physical reliability of the boundary conditions assumed at the diffuser inlet in the calculations, see Figs. 6, 8.

The presented diagrams reveal remarkable effect of the stage 3 rotor tip leakage flow on the distributions of thermodynamic parameters in the diffuser. This effect manifests itself, among others, in incorrect flow inlet angles when the flow approaches stage 4 stator blades.

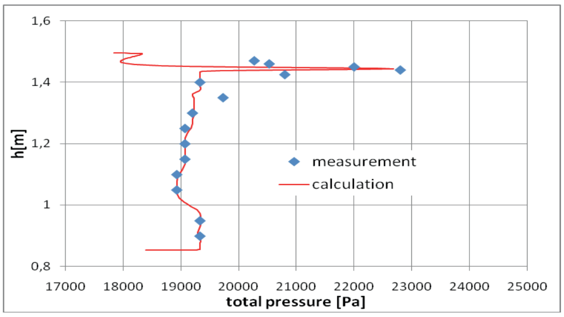

Fig. 6. Comparing the calculated radial distributions of total pressure with those measured in the real turbine

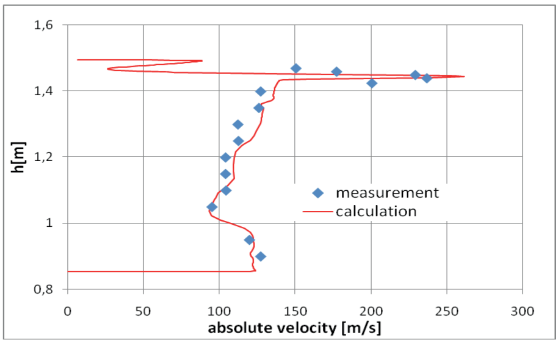

Fig. 7. Comparing the calculated radial distributions of absolute velocity with those measured in the real turbine

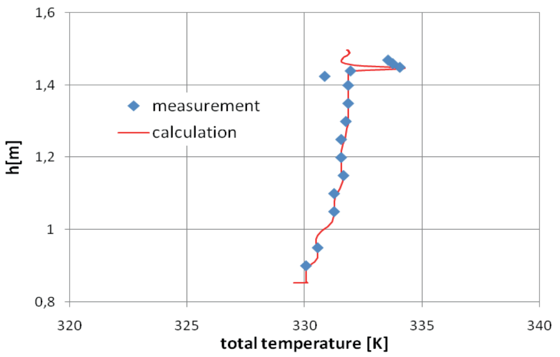

Fig. 8 Comparing the calculated radial distributions of total temperature with those measured in the real turbine

The effect of the presence of the ring in the turbine is demonstrated in Fig. 9, which compares total pressure distributions before and after ring installation. In particular, driving the leakage flow towards the extraction chamber, with the resultant more uniform distribution of main flow parameters in the downstream area, are clearly recognisable.

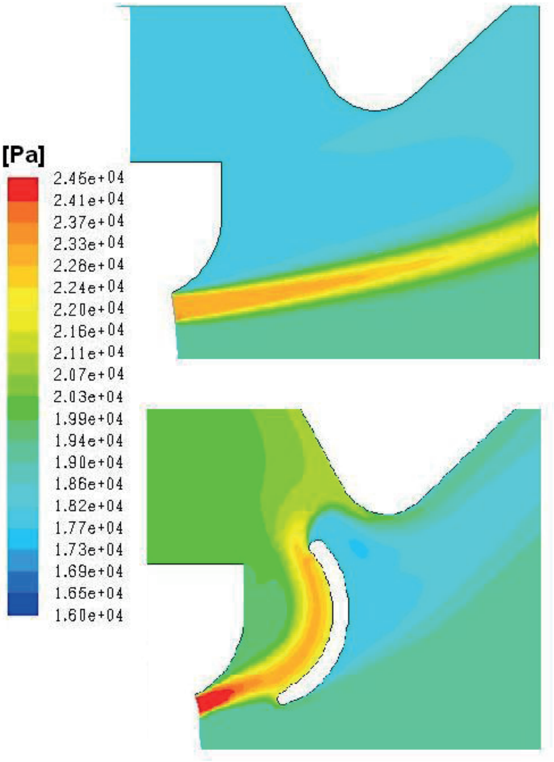

Fig. 9 Graphic presentations of pressure patterns in the gap between stage 3 and 4 [5]

The shape and position of the ring in the flow duct were subject to optimisation. Checking the intermediate and final ring/blade system configurations, and estimating the resultant benefits, based on experimental investigations [11] and CFD analyses [12].

In general, better flow organisation and removal of swirl, mixing and blockage effects in the blade system leads to recordable efficiency benefits. And for particular individual ring/blade system arrangements, some important and interesting tendencies have been observed, see Fig. 10. For instance, when the ring was positioned too high it did not eliminate the blockage, but divided the flow into two parts. It did not separate the water droplets collecting behind the last-but-one stage either (see Fig. 10a). On the other hand, when the ring was too low, it increased the swirl zone in the aerodynamic wake in the flow and unfavourably decreased the pressure in the extraction chamber. When the ring was too short, it rapidly stopped the leakage flow on the limiting wall, which was a source of energy losses and possible erosion of the stator grip (Fig. 10b). And when it was too long, it undesirably intensified swirls in the extraction chamber (Fig. 10c).

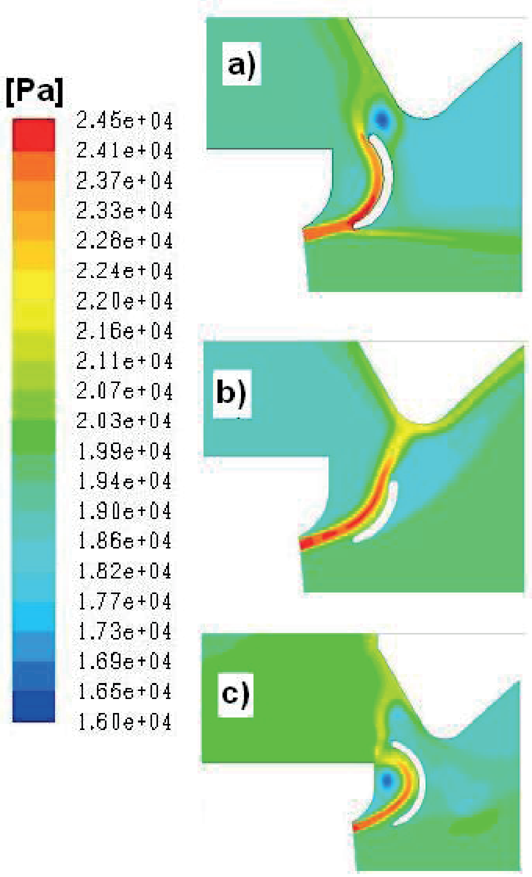

Fig. 10 Total pressure distribution behind the last-but-one stage for different ring positions in the turbine flow (a) ring too high, (b) ring too short, (c) ring too long

Streamline patterns for the final, efficiently optimal ring position and dimension are shown in Fig.11 and compared with the pattern before modernisation.

For this ring position, and for the thermodynamic data corresponding to conditions of real turbine operation, the pressure increase calculated in the extraction chamber was equal to 2-3 kPa, which is equivalent to 3-4 deg C of the feed water temperature rise behind the first exchanger.

The numerical analyses have also confirmed the efficiency increase after modernisation. In this case the efficiency of the last stage increased by about 1%, assuming that the efficiency levels in the remaining stages did not change. This efficiency increase resulted mainly from more uniform velocity distribution at inlet to the last stage stator blade system after modernisation. These gains may seem unimpressive, but are well worth noticing when we take into account that the nominal power of the last stages in two turbine LP parts exceeds 20 MW.

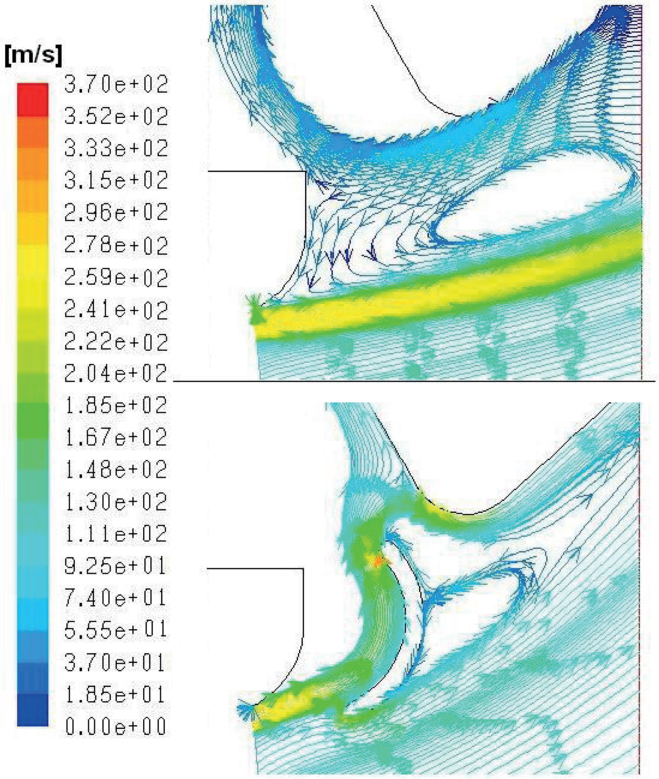

Fig. 11. Comparing streamline patterns behind stage 3 before and after modernisation

The obtained results, referring both to efficiency changes and pressure changes in the extraction chamber, were used for calculating the gains resulting from the applied modernisation, based on the thermal cycle balance of the entire turbine. The calculations were performed using the in-home code DIAGAR, tuned to the turbine operation parameters measured in the power plant [13].

Figure 12 shows power increase as a function of load and condenser pressure for the same thermal parameters at turbine inlet and exit before and after modernisation. For turbine load ranging within 120-225 MW and condenser pressure equal to 3-6 kPa we can expect the turbine power increase by 150-420 kW, which corresponds to the reduction of the specific heat consumption by 10-15kJ/kWh.

The adopted modernisation was carefully analysed in strength and dynamic aspects. The structure of the ring turned out safe and reliable. The performed calculations took into account different operating conditions, including start-ups and shut-downs [14].

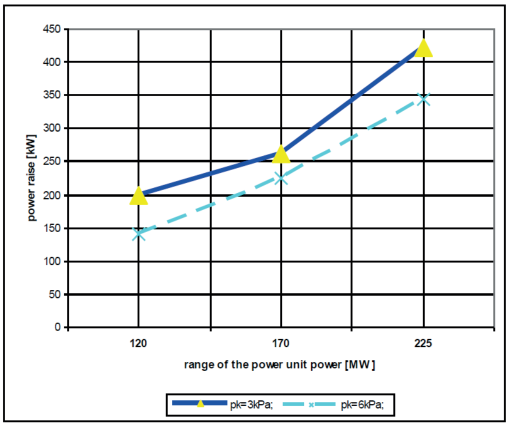

Fig. 12. 225 MW turbine power raise after modernisation [16].

Fig. 13. Photos of the ring installed on stator grips in 225 MW turbine

The technology of manufacturing and assembly was carefully elaborated [15], taking into account specific conditions of steam turbine operation. The ring installed in the turbine is shown in Fig.13 [16].

Visual inspections, done after 2 years of turbine operation with the installed ring, did not reveal any increase of erosion threat.

CONCLUSIONS

1. The design modernisation of the stage situated in front of the extraction point in the 225MW turbine LP part allows to obtain power gains exceeding 400 kW, which is equivalent to the reduction of the specific heat consumption by 10-15 kJ/kWh. These gains result from higher load of the exchanger and improved flow efficiency in the last stage.
2. Introducing the ring in the diffuser between the two last stages not only removes the steam leakage, but also eliminates water droplets separated in this turbine part, because the installed ring operates as an ejector. This should reduce damages of the last-stage stator blade leading edges, especially in their unhardened sections.
3. The new construction is estimated as relatively easy to assembly in both inland and marine applications, and safe in operation. The rings are to be precisely fixed in the turbine with respect to the stator grips, taking into account not only machining tolerances but also relative movements of the moving and stationary turbine parts during turbine start-ups and shut-downs.
4. The planned further verification of the obtained gains will base on more precise thermodynamic measurements, and detailed inspection of blade surfaces to assess erosion progress.

REFERENCES

1. Gardzilewicz A, Marcinkowski S, 1995 *Diagnosis of LP Steam Turbine prospects of Measuring Technique,* PWR Vol. 28 1995, Joint Power Generation Vol. 3 ASME 1995, pp. 349-358,

2. Gardzilewicz A, 1995 *Analysis of Regenerative Extractions of Turbine Based on Thermal Measurements in Power Plants,* VDI Berichte 1186, 1995 Erlangen, pp. 427-443, 8

3. Gardzilewicz A and Marcinkowski S, 1997 *Stage of Steam Turbine,* Patent No 160-805, Warsaw, Poland (in Polish),

4. Gardzilewicz A, Marcinkowski S, Sobera H. and Józefowicz Z 1994 *Experimental Experience of Patent No. 160-805 Application in 200 MW Turbines*, Energetyka *(No. 3), pp. 73-78,* (in Polish),

5. Szymaniak M., Gardzilewicz A, 2009, *CFD Technique Applied for the Modernisation of a Steam Turbine Construction in the Regenerative Extraction Area*, Proc. IX ISAIF, Gyeongju (Korea) 2009,

6. Szymaniak M., Świrydczuk J., Gardzilewicz A., Karcz M., 2011, Circumferential flow asymmetry in steam turbines, 9th European Conference on Turbomachinery - Fluid Dynamics and Thermodynamics, vols I and II, pp. 1435-1444, Istanbul Tech Univ, Istanbul, TURKEY, MAR 21-25, 2011

7. Gardzilewicz A, Marcinkowski S., 2004, *Corrosive-Erosive Threat to the LP Stages of Steam Turbines*, Proc. XVIII Workshop on Turbomachinery, Plzen 2004,

8. Gardzilewicz A, Marcinkowski S, Szymaniak M., 2009, *Surveys and Erosion Threat Analysis of Lasts Stages of 225 MW Turbine (Power Unit 3) in Kozienice Power Station*, Diagnostyka Maszyn Ltd. Report No. 6/09, (in Polish),

9. Szymaniak M., 2012, Report on monitoring the implementation and installation of a new stage in the turbine 13K-225 unit 11 in Łaziska Power Station, IMP PAN, Report No. 913/12(in Polish)

10. Szymaniak M., Gardzilewicz A, Gluch J., 2014, *Application of new Solution for LP Stages in the Power Unit No. 7 in Kozienice Power Station*, IMP PAN, Report No. 892/14, (in Polish),

11. Gardzilewicz A, Marcinkowski S, 1993, *Investigations of steam flow in the LP part of 225 MW Modernised Turbine (Power Unit 4) in Polaniec Power Station*, Diagnostyka Maszyn Ltd. Report No. 6/93, (in Polish),

12. Szymaniak M., Gardzilewicz A, 2015, *CFD Calculation of New LP Stage Before the Extraction Point in a 225 MW Turbine*, Conference on Modelling Fluid Flow (CMFF'15), The 16th International Conference on Fluid Flow Technologies, Budapest, Hungary, September 1-4, 2015,

13. 13 Gardzilewicz A., Gluch J., Bogulicz M., Uzieblo W., 2002, *DIAGAR Program Version 2002*, Diagnostyka Maszyn Ltd. Report No. 28/02, (in Polish),

14. Badur J., Slawinski D., 2008, *Strength and Dynamic Calculation for the Patent No. P160-805*, Diagnostyka Maszyn Ltd. Report No. 05/08.

15. Graczyk P., Graczyk T., Gronert J., 2014, *Technology of manufacturing and assembly of ring in the steam turbine*, Posteor Ltd. Report No. 07/15, (in Polish).

16. Gardzilewicz A, Palzewicz A., Szymaniak M., Gluch J., Gronert J., Graczyk P., 2009, *Application of new Solution for LP Stages in the Power Unit No. 3 in Polaniec Power Station*, Diagnostyka Maszyn Ltd. Report No. 26/10, (in Polish).

CONTACT WITH THE AUTHOR

Mariusz Szymaniak
e-mail: masz@imp.gda.pl

Institute of Fluid-Flow Machinery
Polish Academy of Sciences
Fiszera 14
Gdańsk 80-231
Poland