Open Access Journal

Journal of Power Technologies 92 (4) (2012) 241–248

journal homepage:papers.itc.pw.edu.pl

Performance analysis of a new LP stage located upstream of the extraction point in a 225 MW turbine☆

Andrzej Gardzilewicz*, Mariusz Szymaniak, Jerzy Głuch

Institute of Fluid-Flow Machinery of PASc.
Gdansk, Poland

Abstract

A new design of steam turbine stages upstream of an extraction point is presented. In this solution a special ring guides the steam leakage flow directly to the heat exchanger. The experiments and calculations have confirmed the advantages of the new design as manifested by turbine operating features and efficiency. The design has been applied in 30 old turbines with Baumann stages. Recently, the patent was used in the LP exit ND-41A of upgraded 225 MW turbines in the Polaniec and Kozienice power plants.

Keywords: Steam turbine, Steam turbine stage, Performance analysis, Extraction point

1. Introduction

In the steam turbine design it is necessary, for operating reasons, to keep clearances over the blades. The steam flow through the clearances is characterized by higher specific energy as compared to the main stream of the flow direction. These circumstances are responsible for losses in this part of the turbine duct resulting from the generation of swirl zones, intensive mixing processes and the choking of flow to heat exchangers. The intensity of the dissipative processes is at its highest in the peripheral area of the unshrouded rotor blades in the last stages of the LP section, where the steam flowing out of the clearances displays transonic velocity. These anomalies have been confirmed by experimental investigations carried out on 200 MW turbines [2]. The thermal measurement instrumentation is presented in Figure 1.

Using the plate probes inserted into the flow space, the pressure, temperature, and velocity distributions were evaluated with large accuracy, as described in detail in [1]. Based on detailed analyses, a new, very efficient solution has been proposed, patented and practically applied [4]. The idea of the new solution of the steam turbine stage before regenerative extraction is shown in Figure 2. A similar solution was patented in Russia by Zaryankin [5] in 2002. The majority of world-known manufacturers eliminate leakages at this site by introducing shrouds of different types. For long rotor blading of the LP section these solutions are expensive and pose technical problems for the manufacturer. The resulting clearances get often damaged or even destroyed during operation.

A properly shaped ring installed in the area of tip clearance of an unshrouded rotor blade guides the

---

☆Paper presented at the 10th International Conference on Research & Development in Power Engineering 2011, Warsaw, Poland

*Corresponding author

Email addresses: `gar@imp.gda.pl` (Andrzej Gardzilewicz*), `mariusz.szymaniak@imp.gda.pl` (Mariusz Szymaniak), `jgluch@pg.gda.pl` (Jerzy Głuch)

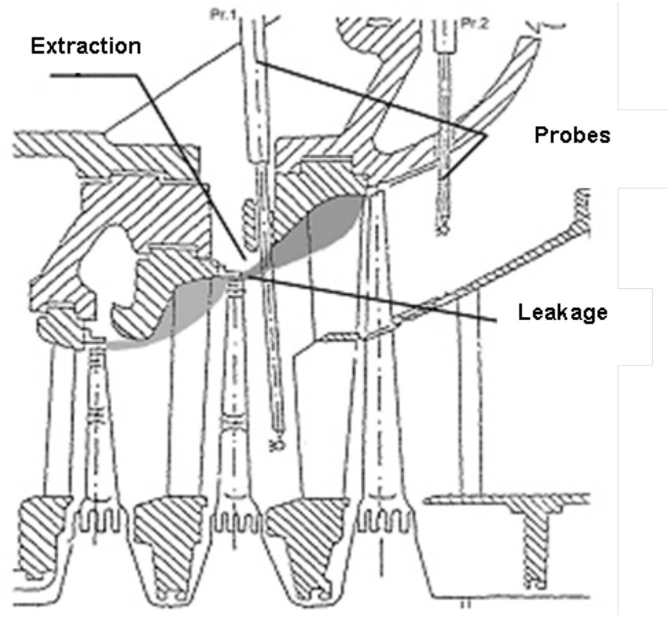

Figure 1: Thermal measurement equipment in the LP section of 200 MW turbine with Baumann stage; zones of the tip leakage flow influence are shadowed in grey [1]

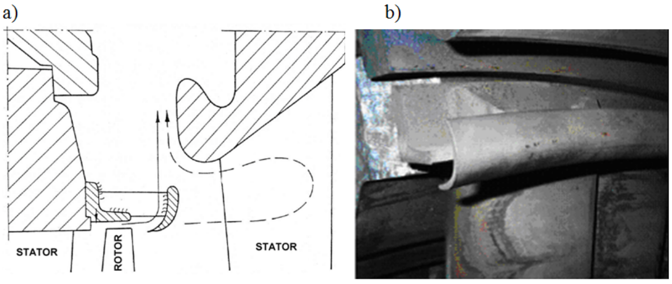

Figure 2: New design of the stage upstream of an extraction point (a). Ring inside the turbine flow path (b) [3]

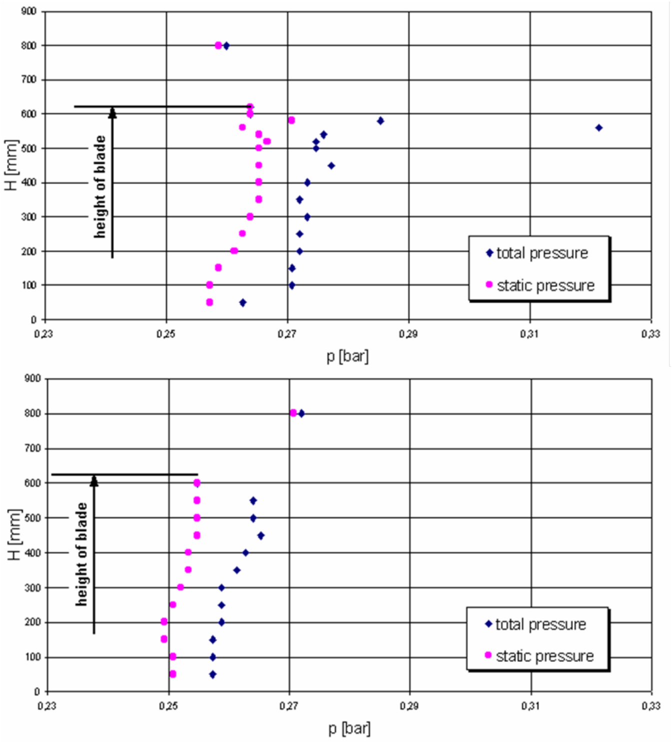

Figure 3: Distribution of total and static pressure along the probing traverse before (upper diagram) and after the upgrade (lower diagram) behind the height of the blade [3]

leakage flow to the extraction chamber. The flow direction of the steam upstream and downstream of the ring is shown schematically in Fig. 2a by arrows. Without entering into the details of the patent, the advantage of such a solution can be seen in eliminating the swirl zone in the flow field due to the removal of the aerodynamic curtain resulting from transonic steam flow in the tip clearance area.

At the same time, the steam flow capacity of the stage downstream of the extraction point is increased significantly by:

- eliminating the mixing between the tip leakage stream and the main stream, by directing the leakage stream directly to the extraction chamber;
- thermal reloading of the first regenerative exchanger resulting from utilizing the high-energy leakage stream in the extraction chamber. It is noted that the mass flow rate of the leakage 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 present in this part of the steam turbine.

Pressure measurement results behind the penultimate rotor blade taken before and after the upgrade are shown in Figure 3 [3]. These measurements and calculations of velocity (see Fig. 4) confirm the advantages of the new solution.

The benefits from use of the patent for the older turbine design have been evaluated for 400–800 kW, depending on operating conditions. Over the period 1991–2002 the new solution was applied in thirty 200 MW turbines. No operational troubles were observed [3]. A photo of the ring inside the older type turbine is presented in Fig. 2b.

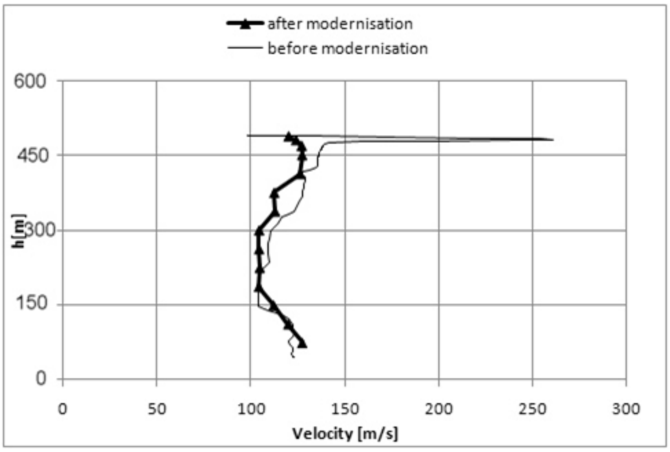

Figure 4: Distribution of velocity along the probing traverse before and after the upgrade behind the height of the blade [3]

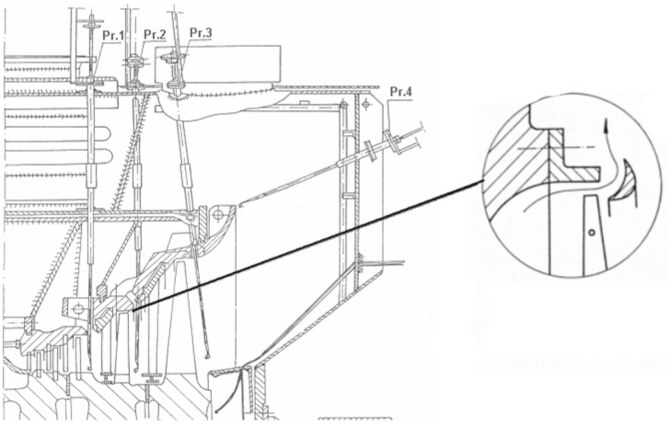

Figure 5: The concept of the solution in the new LP part of 225 MW turbine (ND-37 exhaust) [6]

2. Proposal of stage modernisation in a 225 MW turbine LP part

Possible applications of the patent in the low-pressure parts of 225 MW turbines, which were upgraded in Poland, were presented in 2002 [6]. The applications mentioned are the fruit of close collaboration with the company ABB. The concept of the solution (Fig. 4) was developed further to experimental investigations performed in a full-scale steam turbine with an ND-37 exit. A schematic diagram of the measurement system is shown in Fig. 5. The performed measurements revealed the presence of a jet downstream of the tips of unshrouded rotor blades in the penultimate stage. As in older constructions, this jet disturbed the flow structure by blocking the steam admission to the regenerative extraction system.

These measurement results have been confirmed by complementary computer simulations. Calculated and measured pressure distributions along a chosen traversing line of the measurement probe before the upgrade are shown in Fig. 6, while the total pressures in the stage before and after application of the mentioned ring are compared in Fig. 7. The pressure in the extraction chamber is raised as a result of leakage flow stagnation at the ring and it being directed to the extraction chamber. For the wet steam area this means that the saturation temperature of steam condensation in the regenerative heat exchanger is also raised. Thus the regenerative heat exchangers of the higher numbers need less steam for the regenerative heating, which is advantageous for the efficiency of the power cycle. Elimination of the leakages also leads to a small rise in stage efficiency.

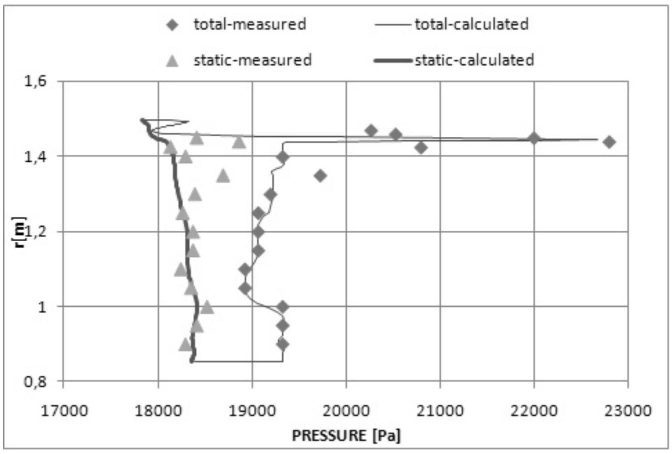

Figure 6: Comparing total and static pressure distribution along the radius of the blade as calculated and measured on a full-scale object [6]

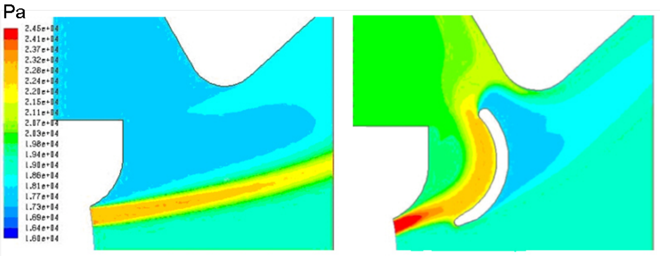

Figure 7: Graphic representations of total pressures in the gap between 225 MW turbine stages 3 and 4 [6]

The application by Alstom of shrouded clearances above the penultimate rotor blades of the ND-37 exit put the implementation of the proposed solution on hold in this particular case.

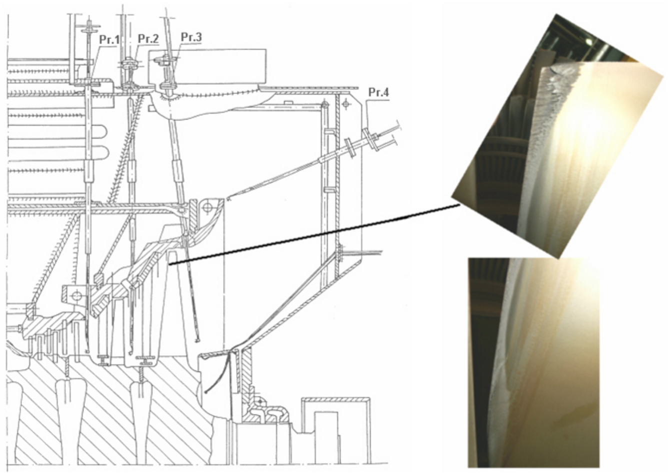

Figure 8: Leading edge damage patterns observed in the last stage stator blade of a 225 MW turbine with an ND-41A exhaust [7]

Further measurements conducted at Kozienice Power Station in an upgraded 225 MW turbine have shown that such intensive jet also existed in the ND-41 exhaust. The presence of the jet flow and blockage was confirmed by salt deposits observed on the surfaces of the last stage stator blades in a full-scale turbine [7, 8]. In fact, this jet was not only the source of energy losses, but also resulted in untypical erosion damage of the last stage Fig. 7.

Intensified damage of the leading edges in their tip sections were mainly caused by large water droplets, observed in the steam flow, which were not disintegrated in the blockage area. Minor damage observed in the remaining part of the leading edge was generated by small droplets splashed by the leakage flow. The highest threat for turbine operation was created by the erosion defects situated in the blade area beyond the hardened zone, marked with arrows in Fig. 8. The water droplets reaching this area were acidic in nature (pH<6), which could be the source of dangerous cracks in the erosion zone [8–10].

To eliminate those unfavorable phenomena, a decision was made to install a ring in the blade system in the upgraded 225 MW turbine with an ND-41A exit. The design of the new solution is shown in Fig. 9 [11, 12].

To assess the benefits and check the new solution, the experimental investigation and CFD technique was employed [11–13]. Due to the fact that the flow in the blade system was better organized and the installed ring removed the effect of mixing, actual benefits were acquired. Hence the layout of the ring in the flow path was also optimized.

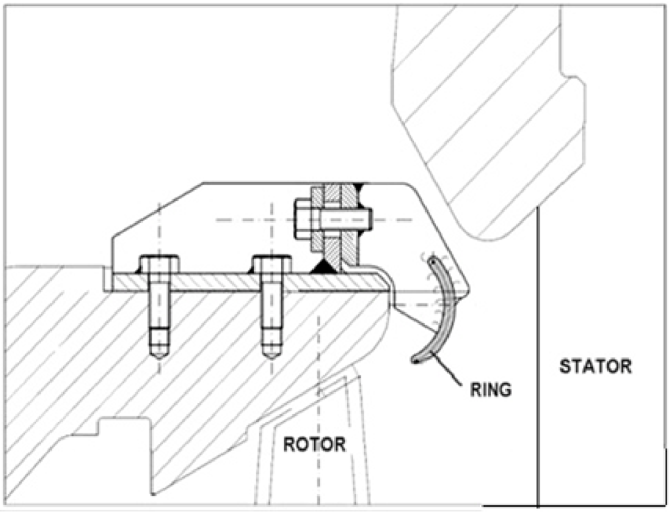

Figure 9: Design of ring assembly, using the patent, in the upgraded exhaust ND-41A [11]

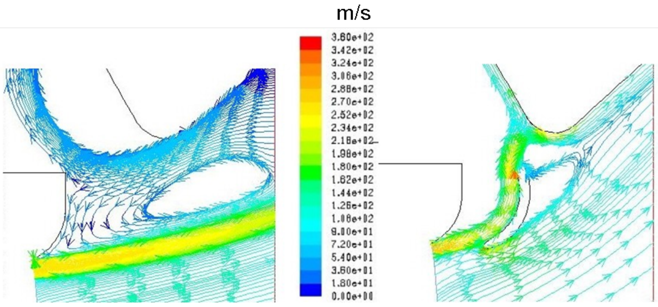

Figure 11: Comparing streamline patterns behind stage 3 before and after the upgrade [11]

When the ring is installed too high it divides the flow into two parts without eliminating the choking effect. It does not separate the water droplets collecting behind the penultimate stage either (see Fig. 10a). On the other hand, when the ring is placed too low, it increases the swirl zone in the aerodynamic wake in the flow and unfavorably reduces the pressure in the extraction chamber.

When the ring was too short, it rapidly stopped the leakage flow on the flow confining wall, which was the source of energy losses and possible erosion of the stator grip (Fig. 10b). When it was too long, it undesirably intensified swirls in the extraction chamber (Fig. 10c).

Streamline patterns in the meridional section for

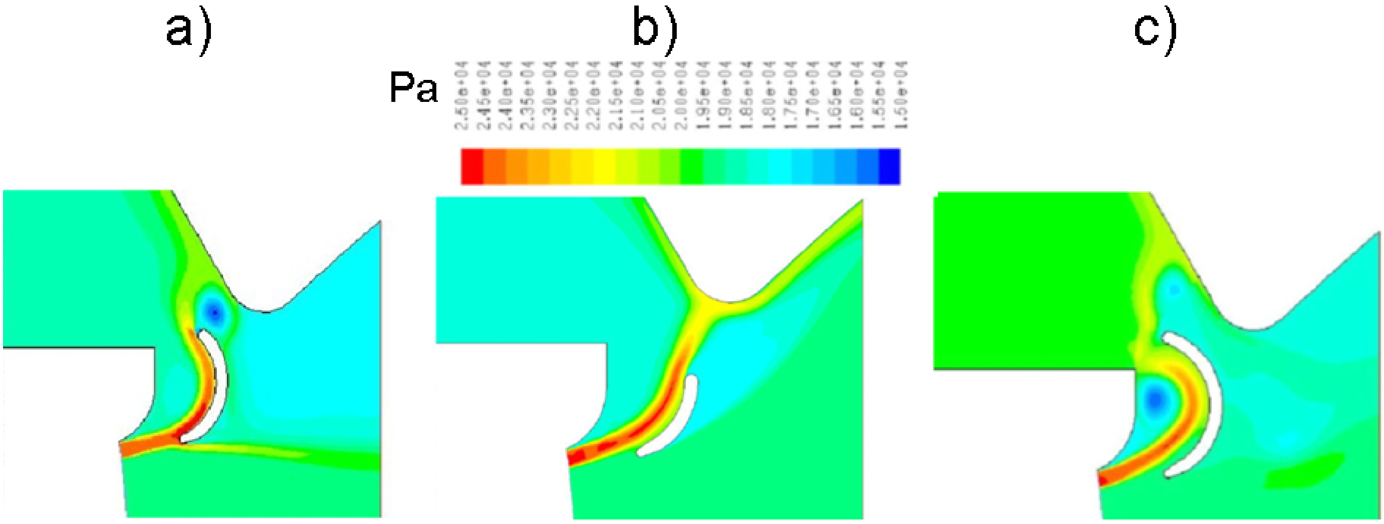

Figure 10: Total pressure distribution downstream the second-to-last stage for different ring installations in the turbine flow (a) ring too high, (b) ring too short, (c) ring too long [11]

optimum ring position and size are shown and compared with the flow pattern before the upgrade in Fig. 11.

The CFD calculations have shown that swirls still present in the expanding flow downstream the ring are stable in nature. The numerical calculations revealed that after the upgrade the efficiency of the last stage increases by about 1%, assuming unchanged efficiency levels in the other stages. This efficiency increase results mainly from more uniform velocity distribution at the inlet to the last stage stator blade system in the blade tip region, after the upgrade. The gains are not impressive but worthy of notice if we take into account that the rated power of the last stages in two LP parts exceeds 20 MW.

The whole cycle of the power unit must be calculated for the purposes of evaluating the efficiency gains. Its thermal scheme is presented in Fig. 12 [15]. To aid numerical calculations, it is transformed into numerical graph form.

It is important to notice that with the new ring position, the pressure in the extraction chamber increased by 2–3 kPa, which is equivalent to a 3–4 deg C rise of feed water temperature downstream of the first exchanger. This result has been confirmed by performance tests conducted on a full-scale unit.

The present data, referring both to the stage efficiency changes and pressure changes in the extraction chamber, were used for calculating the gains resulting from use of the patent, based on the thermal cycle balance of the entire turbine. The calculations were performed using the in-house DIAGAR code, tuned to the turbine operation parameters as measured in the upgraded power plant [13, 14]. The accuracy of this code is approximately ±20 kW, which has been confirmed by diagnostic measurements [14].

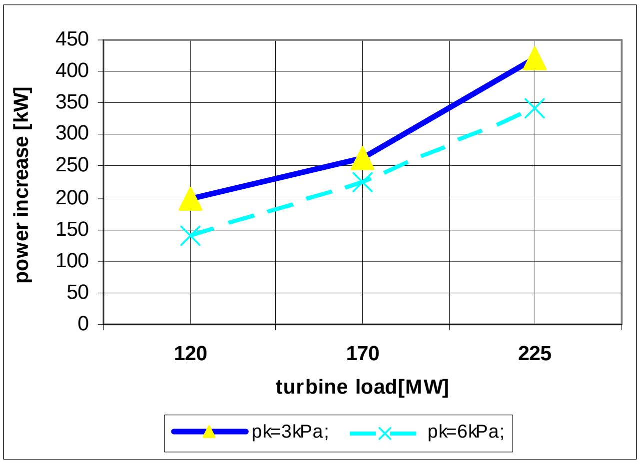

Figure 13: Power increase after applying the patent in the 225 MW turbine [11]

Fig. 13 shows power increase as a function of load and condenser pressure for the same thermal parameters at turbine inlet and exit before and after the upgrade.

For turbine load ranging between 120 and

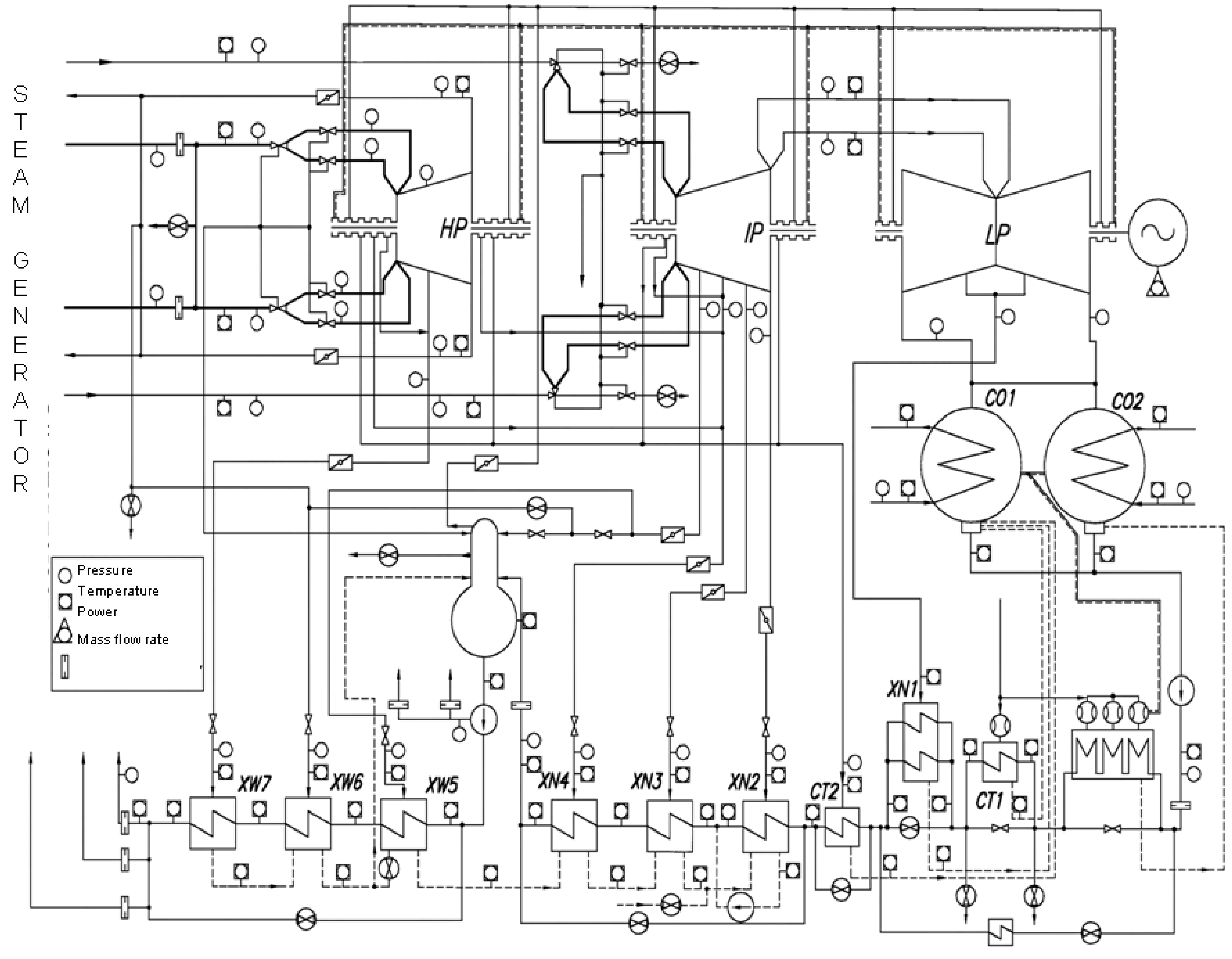

Figure 12: Schematic diagram of the power cycle assumed for numerical modeling [14]

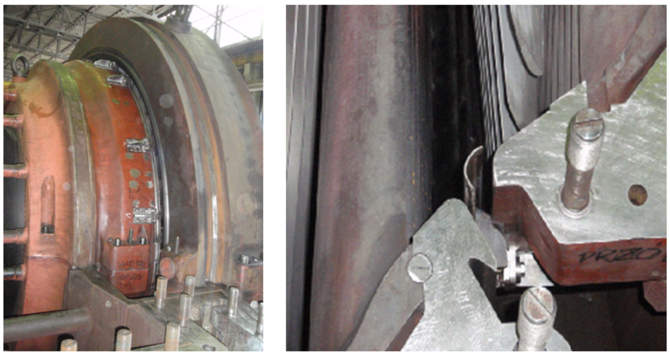

Figure 14: Photos of ring installed on stator grips in a 225 MW turbine [11]

225 MW and condenser pressure of 3 kPa we can expect the maximum turbine power to increase by 420 kW; for the same loads and condenser pressure of 6 kPa we can expect the maximum turbine power to increase by 300 kW. Those changes correspond to a reduction of specific heat consumption by 10–15 kJ/kWh.

The adopted design solution was carefully analyzed in terms of strength and dynamic aspects. The structure of the ring was shown to be safe and reliable. The performed calculations took into account different operating conditions, including start-ups and shut-downs [16].

The manufacturing and assembly technology was developed through careful procedure [17], taking into account specific steam turbine operational conditions. The ring installed in the turbine is shown in Fig. 14. The work on the application was conducted under the supervision of Alstom.

The visual inspections, conducted after 2 years of turbine operation with installed rings, did not reveal any increase in erosion.

3. Conclusions

1. The application of a new stage construction upstream of the extraction point in the low pressure part of a 225 MW turbine with an ND41 exit can generate power gains exceeding 400 kW, which is equivalent to a 15 kJ/kWh reduction in specific heat consumption. These gains result from the higher load of the first exchanger and improved flow efficiency in the last stage.
2. Introducing the ring in the diffuser downstream of stage 3 not only removes the steam leakage, but also eliminates water droplets separated in this turbine part. This should reduce damage to the last-stage stator blade leading edges, especially their unhardened sections.
3. The newly designed component turned out to be relatively easy as regards assembly and was 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 rotating and stationary turbine parts during turbine start-ups and shut-downs.
4. The planned future final verification of the obtained gains will be based on more precise thermodynamic measurements, and a detailed inspection of the blade surfaces will be made to assess erosion.

References

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

[2] A. Gardzilewicz, Analysis of regenerative extractions of turbine based on thermal measurements in power plants, in: VDI Berichte 1186, Erlangen, 1995, pp. 427–443.

[3] A. Gardzilewicz, S. Marcinkowski, H. Sobera, Z. Józefowicz, Experimental experience of patent no. 160-805 application in 200 mw turbines, Energetyka (3) (1994) 73–78, in Polish.

[4] A. Gardzilewicz, S. Marcinkowski, Stage of steam turbine (1997).

[5] A. Zaryankin, B. Simonov, Exhaust hoods of steam and gas turbines, MEI, Moscow, 2002, p. 273, in Russian.

[6] A. Gardzilewicz, S. Marcinkowski, M. Karcz, M. Bielecki, J. Badur, M. Banaszkiewicz, A. Malec, Proposal of modernisation of system turbine stage, Task Quarterly 6 (4) (2002) 577–581.

[7] A. Gardzilewicz, S. Marcinkowski, M. Szymaniak, Surveys and erosion threat analysis of lasts stages of 225 mw turbine (power unit 3) in kozienice power station, Tech. Rep. 6/09, Diagnostyka Maszyn Ltd., in Polish (2009).

[8] A. Gardzilewicz, S. Marcinkowski, Corrosive-erosive threat to the lp stages of steam turbines, in: Proc. XVIII Workshop on Turbomachinery, Plzen, 2004.

[9] A. Gardzilewicz, S. Marcinkowski, Some problems of flow in real steam turbine stages, in: Proc. of IX Conf. Steam Turbines of Large Output, Karlovy Vary, 1989, pp. 78–83.

[10] R. Svoboda, H. Pflig, T. Warzecha, Investigation into the composition of the early condensate in steam turbine power plant, Chemistry (5).

[11] A. Gardzilewicz, M. Szymaniak, A. Palzewicz, J. Gluch, Concept of application of the new stage before extraction (patent p-160805) on turboset no. 5 in kozienice power station, Tech. Rep. 04/08, Diagnostyka Maszyn Ltd., in Polish (2008).

[12] A. Gardzilewicz, A. Palzewicz, M. Szymaniak, J. Gluch, J. Gronert, P. Graczyk, Application of new solution for lp stages in the power unit no. 3 in polaniec power station, Tech. Rep. 26/10, Diagnostyka Maszyn Ltd., in Polish (2009).

[13] A. Gardzilewicz, S. Marcinkowski, Investigations of steam flow in the lp part of 225 mw modernised turbine (power unit 4) in polaniec power station, Tech. Rep. 6/93, Diagnostyka Maszyn Ltd., in Polish (1993).

[14] A. Gardzilewicz, J. Gluch, M. Bogulicz, W. Uzieblo, Diagar program version 2002, Tech. Rep. 28/02, Diagnostyka Maszyn Ltd., in Polish (2002).

[15] A. Gardzilewicz, J. Gluch, M. Bogulicz, R. Walkowiak, M. Najwer, J. Kiebdoj, Experience in application of thermal diagnostics in the turow power station, in: ASME International Joint Power Conference'2003, no. IJPGC2003-40017, Atlanta, 2003.

[16] J. Badur, D. Slawinski, Strength and dynamic calculation for the patent no. p160805, Tech. Rep. 05/08, Diagnostyka Maszyn Ltd. (2008).

[17] T. Graczyk, P. Graczyk, J. Gronert, Technology of manufacturing and assembly of ring in the steam turbine, Tech. Rep. 07/08, Posteor Ltd., in Polish (2008).