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Adaptation of Steam Turbine to Operation with Biomass Fired Boiler

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This paper presents experience connected with steam turbine retrofits and particularly specific issues related to retrofit combined with adaptation of existing steam turbine to operation with biomass–fired boiler. A new biomass–fired boiler which is dimensioned to suit the footprint of a hard coal–fired boiler has usually lower capacity comparing to the existing solution. The retrofit shall take into consideration an appropriate decrease of HP turbine swallowing capacity. At the same time Purchaser expects a solution which would allow in future to increase live steam flow into the turbine, should it be necessary to switch back to firing hard coal. Using a throttle–bypass control with live steam constant pressure is the essence of 13K215 turbine retrofit, Unit 8 in Polaniec Power Plant.

Keywords: Steam turbine, biomass fired boiler, adoptations, rettrofit

1. General

ALSTOM Power is one of the largest suppliers of equipment and services for power generation. Besides turn–key deliveries of complete power plants and district heating plants, ALSTOM Power offers also boilers, steam and gas turbines, generators, hydro and wind turbines and environment protection installations. The company has extensive know–how and experience in engineering, manufacturing, service and modernization of boilers, steam turbines, generators and auxiliaries.

Thanks to changes in power engineering and energy market in recent years, supply of components, systems and equipment as well as services necessary for steam turbine and generator retrofits and modernizations became an important business for ALSTOM Power. Alstom is the world's leading supplier of steam turbine retrofits not only delivered originally by Alstom, but also by other turbine suppliers. As a consequence of continuing ageing of fleet installed between 1960 and 1990 and significant acceleration of turbine technology development observed in the last 25 years, modernization projects have become one of the most economically viable concepts for restoration and development of power generation capacity. By using state–of–the–art technology, the replacement of worn elements not only restores lifetime and increases availability, but also enhances the efficiency of turbines.

Advantages of steam turbines modernizations involving application of state–of–the–art blading as well as diverse optimisation activities, thus significantly increasing efficiency, include increase of electricity production and decrease of specific fuel consumption. When assessing potential benefits of a retrofit it shall be remembered that possible gains depend not only on the technology level difference: today's vs. that of forty or fifty years ago, but additionally also on improvement of technical parameters related to removal of permanent effects of ageing accrued during the course of operation.

Anticipating the requirements and expectations of the energy market in Poland, ALSTOM Power has developed and offers a wide range of modernization and service packages basing on ALSTOM's own technology. It involves among others 200/215 MW and 500 MW turbines of LMZ design, 120 MW turbines of Metopolitan Vickers design and 360 MW turbines of BBC design – see [1], [2], [3], [4]. A module structure of the modernization packages facilitates implementation of more or less comprehensive modernization programs to suit the requirements, possibilities and priorities of each power station.

Usually preparation of final technical solution is preceded by preliminary analyses and detailed investigation of local conditions and needs, so it is possible to plan the modernization scope with relatively short payback period as well as to implement the modernization during a major overhaul. When proposing a new solution to a specific power plant, we strive to make the best possible use of the existing equipment, as long as their condition permits compliance with requirements.

ALSTOM Power continues to develop its products. Experience in the recent years indicates that modernization programs which were offered and implemented introducing most recent developments in turbine technology, meet Customers' expectations.

2. ALSTOM experience in boiler adaptation to biomass firing

ALSTOM's business activity involving products related to biomass firing in dust boilers deals with high capacity installations for utility boilers. Examples of such solutions are projects implemented in Fiddlers–Ferry P.P. and in Drax P.P, both in United Kingdom.

The Fiddlers–Ferry project consisted of adaptation of two 500 MWel boilers to biomass co-firing. Calorific portion of biomass was determined in the range app. 20 % of rated chemical energy demand in fuel. The project was implemented in 2004 and was the first installation of dedicated biomass co–firing in United Kingdom.

The installation was designed for a wide range of fuels such as: wood pellets, palm seeds, olive stones, olive pomace. The only restriction was moisture content in fuel up to 15 %.

The Drax project consisted of construction of biomass firing installation for 6 boilers 660 MWel each. The total power output of the biomass installation is 400 MWel, which allows to decrease CO_2 emission by app. 2 million tons per year.

The installation is adapted to fire a wide range of fuels, which decreases risk connected with delivery of biomass fuel. Acceptable fuels include wood pellets, palm seeds, olive stones, olive pomace. Similarly to the previous project, moisture content in fuel was limited to 15 %.

Both project were implemented in two stages.

In the first stage restrictions for firing biomass in boiler were determined. During that time engineering and tests of existing auxiliaries were performed. Basing on boiler CFD model an analysis of boiler behaviour was performed as well. The model, programmed basing on the boiler actual operating data, was used to analyse boiler behaviour for each biomass fuel analysed during that stage. As a result of the first stage of the project, a feasibility study was prepared, defining the scope of technical changes necessary to obtain effects anticipated for the project.

The second stage was an implementation of the biomass installation basing on data obtained during the first stage of the project.

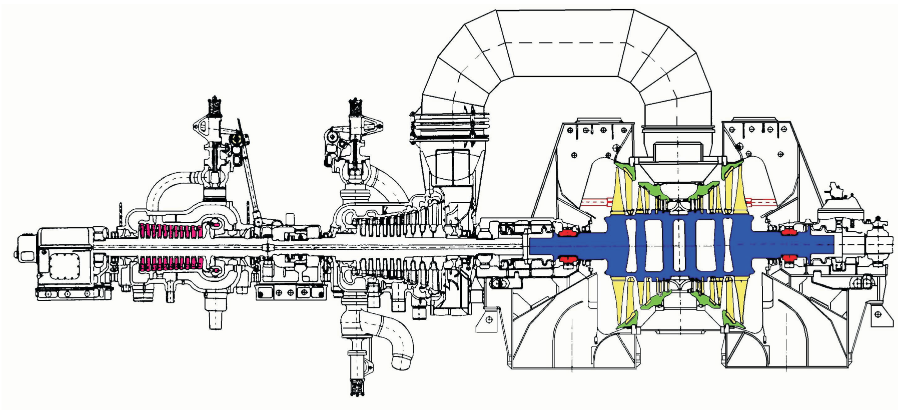

Figure 1 Longitudinal section of 13K215 turbine after modernisation in 1995

3. Modernization of turbine hall equipment, unit 8 in Połaniec P.P.

Elektrownia Połaniec Spółka Akcyjna – Grupa GDF Suez Energia Polska (Połaniec Power Plant), with registered office in Zawada 26, is located in the south–east part of Świętokrzyskie voivodship. There are eight 215 MW units in the Power Plant, commissioned between 1979 and 1983. The major equipment in the Power Plant are 13K215 turbines made by Mechanical Works ZAMECH (currently ALSTOM Power Sp. z o. o.) as well as steam boilers EP 650–137 made by Boiler Factory "Krasnyi kotel'shchik" in Taganrog.

Between 1992 and 1995 company ABB Zamech Ltd (currently ALSTOM Power Sp. z o. o.) modernised turbines in Połaniec Power Plant. The modernisation included: LP turbine retrofit using RS41A type blades, with an annular surface area 8.9 m^2, as well as modernisation of HP turbine, by replacing the rotor blading and diaphragms into new ones of higher swallowing capacity (see Fig. 1). Turbine modernization significantly increased the internal efficiency of LP turbine, decreased turbine heat rate by app. 5 % and increased power output at generator terminals to 235 MW. Also the turbine swallowing capacity was adjusted to the actual boiler capacity in the range of 720 t/h. The original rated swallowing capacity of 13K215 turbine was 656 t/h. At the same time company ABB Dolmel Ltd (currently ALSTOM Power Sp. z o. o.) modernised generators, thus allowing for active power increase from 215 to 235 MW.

In October 2004 a biomass dosing and preparation installation was commissioned in Polaniec Power Plant. As a result of modernisation activities carried out since 1992, Polaniec Power Plant is a typical fossil fuel power plant with open cooling cycle (water is taken from nearby Vistula river), hard–coal–fired with co–firing of biomass. With obtainable power output 1800 MWe (eight units 225 MWe each), it is one of the biggest utilities in Poland.

The next stage of power plant development was commenced in July 2010, by placing a cornerstone for construction of the biggest biomass–fired power generation unit in the world. The boiler for the new unit is to be supplied by company Foster Wheeler. The biomass fired in the boiler will be consisting of trees and boughs from thinning and trimming of forests, boughs from wood production, waste from wood industry as well as agricultural biomass, mostly straw pellets.

4. 13K215–ND41–M1 turbine retrofit

In March 2011 Elektrownia Połaniec Spółka Akcyjna - Grupa GDF Suez Energia Polska and ALSTOM Power Sp. z o.o. in Warsaw Branch in Elblg concluded an agreement for modernisation and adaptation to operate with a new, fluidized bed biomass–fired boiler of 13K215–ND41–M1 turbine, in existing unit 8.

According to the contract, the swallowing capacity of the modernised turbine shall be such, so as to obtain live steam flow 570 t/h with live steam parameters 127.5 bar / 535 ^{o}C and reheat steam parameters 19.5 bar / 535 ^{o}C. Turbine shall be controlled with constant live steam pressure upstream the HP turbine stop valves. It was assumed that the unit with biomass–fired boiler will be operated in base load mode. At the same time it shall be possible to operate the turbine with live steam flow increased to 650 t/h, maintaining rated live steam parameters, when switching back to coal–fired operation. The implemented solution shall moreover take into consideration re–use of existing systems and turbine hall equipment such as: generator, HP and LP regeneration lines including deaerator, vacuum system and IP/LP bypass system. The modernised turbine will be mounted on existing foundation without intervention in the foundation structure. The anticipated turbine lifetime after current modernisation is 20 years.

The implementation of turbine retrofit will result in thermal cycle efficiency increase (decrease of heat rate), increase of power output at generator terminals, CO_2, SO_X and NO_X emission reduction, increase of reliability and availability and increase of period between major overhauls.

First of all, adaptation of the steam turbine for operation with a biomass–fired boiler in Polaniec P.P. required the analysis of both live steam and reheat steam parameters as well as feed water temperature assumed for boiler design. When selecting the swallowing capacity of each group of stages of modernised HP and IP turbine it was necessary to consider the restrictions, on one hand resulting from the assumption that the existing HP and LP regeneration lines will be re–used, and on the other hand stemming from Purchaser's expectations, that it should be possible to operate the turbine with increased live steam flow by 14 % (up to 650 t/h), when switching back to hard coal operation. It shall be noted that boiler with reheat system, steam turbine and regeneration preheating systems are very closely interconnected in the thermal cycle. Their proper matching has essential influence on both power output and the unit specific fuel consumption. For the project in question, an integrated approach to modernization of the unit main components has made it possible to optimize their solutions in such manner, so as to maximize economic effect (NPV, IRR) for the entire project.

In order to develop the best possible solution, various possibilities of modernisation of both HP and IP turbine have been analysed. For HP turbine the following variants of modules have been considered:

- Turbine with control stage (nozzle control) with maximum swallowing capacity 650 t/h
- Turbine with control stage (nozzle control) with swallowing capacity app. 600 t/h. To obtain capacity in the range of 650 t/h it would be necessary to replace a part of blading.
- Turbine without control stage (throttle control) designed for swallowing capacity in the range of 600 t/h. To obtain capacity in the range of 650 t/h it would be necessary to replace a part or entire HP blading
- Turbine with control stage and with nozzle–bypass control
- Turbine without control stage and with throttle–bypass control

Considering the preconditions defined by Polaniec Power Plant as the best possible solution the last option from those listed above have been selected. Such a solution ensures the maximum power generation efficiency around rated parameters and with biomass–fired boiler.

Isentropic efficiency difference between HP turbine for the chosen variant and HP turbine with nozzle control variant vs. live steam mass flow is shown in Fig. 2.

A comparative analysis of possible variants of the turbine control was carried out, among others to investigate impact on heat rate. Heat rate difference between the variant with throttle–bypass control and nozzle control variant vs. live steam mass flow is shown in Fig. 3.

Considering the course of the curve from Fig. 3 it is obvious that the solution of HP turbine with throttle–bypass control is better and results in lower heat rate in the range of live steam mass flow from 480 t/h up to 616 t/h (i.e. from 84 % up to 108 % of the rated load).

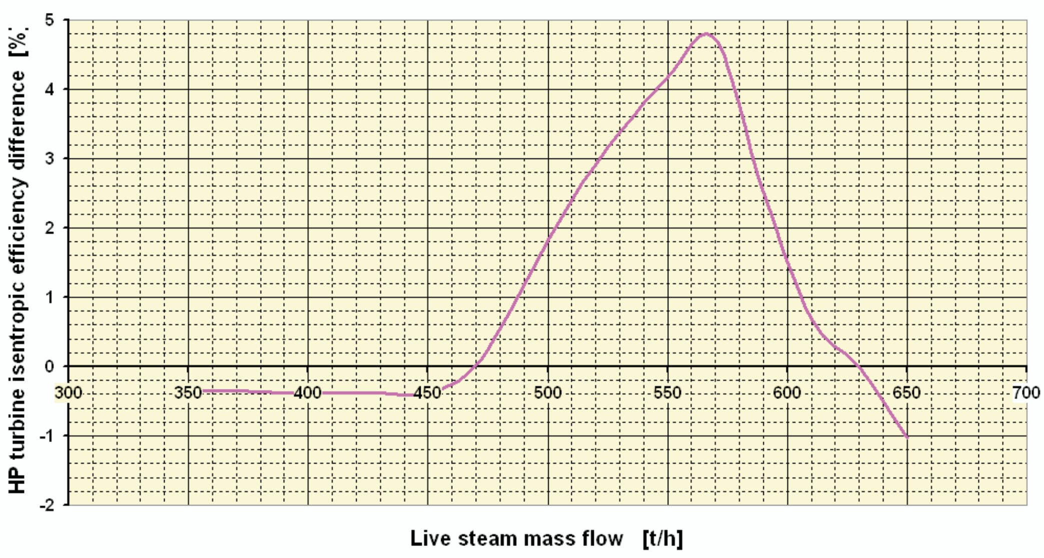

Figure 2 Difference between HP turbine isentropic efficiency for throttle–bypass control variant and nozzle control variant

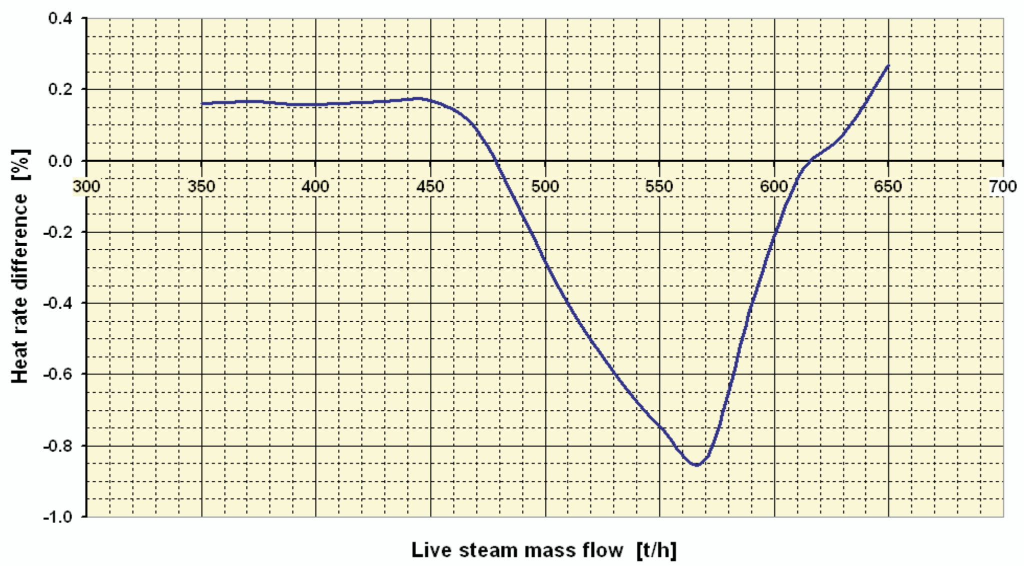

Figure 3 Relative difference of turbine heat rate between throttle–bypass control variant and nozzle control variant

The main components of 13K215–ND41–M1 turbine retrofit carried out by ALSTOM Power are as follows:

- HP turbine retrofit – new HP turbine including HP steam admission system
- IP turbine retrofit – new IP turbine including IP steam admission system (however excluding IP stop valves and IP stop valve chests)
- front bearing pedestal modernization – new journal bearing No. 1
- HP/IP bearing pedestal modernization – new journal-thrust bearing
- IP/LP bearing pedestal modernization – new journal bearing No. 3
- modernization of LP/GEN coupling – new fastening bolts for coupling sleeves
- I&C modernization – new instrumentation and wiring for newly delivered turbine components
- lube oil system modernization
- turbine gland steam system modernization
- turbine drain system modernization.

4.1. *HP turbine retrofit*

The new HP turbine module is similarly as the existing one designed as a double shell solution (with inner and outer casing). To maximise it's efficiency the latest generation of Alstom reaction blading was selected. Additionally thanks to the outer shaft glands solution optimisation it was possible to maximise the number of HP turbine stages.

In the scope of HP turbine retrofit all components will be replaced by new – see [5]. Steam from stop valves is admitted to control valves through interconnecting piping. Three control valves control live steam admission within the range of 570 t/h and direct it into the reaction HP steam path. The fourth valve is used for control of live steam flow above nominal value within the range 570 – 650 t/h and it directs steam flow to interstage steam chamber. New HP module (Fig. 4.) is manufactured in accordance with state–of–the–art technology. It will be adapted to reused bearing pedestals, existing foundation, as well as to reused main steam and extraction piping.

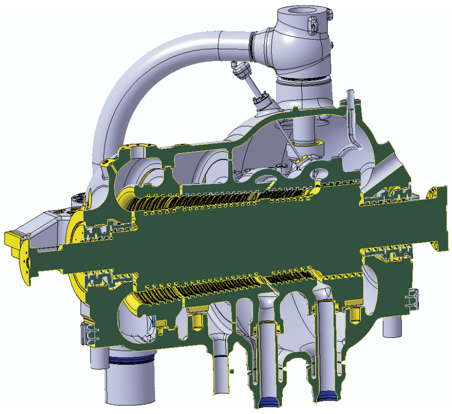

Figure 4 HP turbine module after retrofit

The HP turbine module will be shipped to the site as completely assembled.

4.1.1. *HP turbine cesings and blade carrier*

In general the shape of HP outer casing (Fig. 5) is similar to the existing one. However the concept is adapted for application of new technology and new conditions in the following areas:

– end glands areas are modified for application of modern end glands and in order to eliminate disadvantages of the original solution

– joint plane flange will be designed in accordance with the new design rules (narrow flange). It will be equipped with stud bolts for hydraulic tightening.

– connection of the pipe loop from the fourth control valve to the HP casing was shifted to the rear side to allow to direct the steam between proper stages of the blading

– system of internal guiding and fixing keys was adapted to new requirements

– casing is equipped with openings for endoscopy and balancing of HP rotor

– new type of material was used for castings

New inner casing (Fig. 6) is made of two alloy steel castings. It is split horizontally for upper and lower parts that are joined together by flanges and stud bolts (hydraulically tightened). The rows of stationary reaction blading and strips of interstage sealing are fixed directly in circumferential grooves of inner casing.

New blade carrier will be provided for HP turbine retrofit. It will be made of alloy steel castings. It will be split in horizontal joint and held together by stud bolts with cup nuts maintained on flanges. Axially it will be fitted in circumferential groove of the outer casing. It will be hanged on blocks in horizontal joint and centred in axis by central key maintained at the bottom. Such solution of fixing will enable free radial and axial expansion of blade carrier thus keeping it in central position to turbine axis independently of thermal conditions of outer casing. The rows of stationary reaction blading and strips of interstage sealing are fixed directly in circumferential grooves of blade carrier.

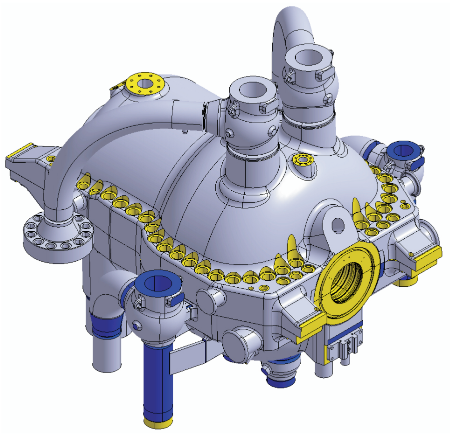

Figure 5 HP outer casing

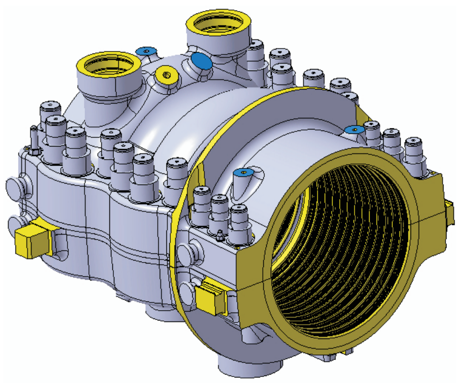

Figure 6 HP inner casing

4.1.2. *HP turbine rotor*

The rotor is made of solid forging made of steel with high chromium contents. The rotating blading is assembled on it and blading shrouds are finally machined. At the area of end glands and balance piston gland the sealing strips are tapped in the rotor grooves. Ready assembled rotor is high speed balanced and tested for overspeed. Standard overspeed test is performed at 3600 rpm with duration of 3 min.

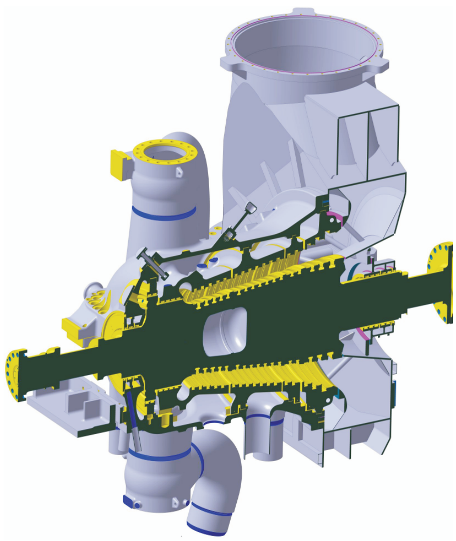

Figure 7 IP turbine module after retrofit

4.2. *IP turbine retrofit*

To optimise the utilisation of existing interfaces the new IP turbine module is similarly as the existing one designed with the casted front and fabricated rear part of the outer casing (see Fig. 7.). Thanks to such a solution the loading of foundation is nearly the same as before modernisation. To maximise it's efficiency the latest generation of Alstom reaction blading was selected.

In the scope of IP turbine retrofit all components will be replaced by new – see [5]. It includes the following items:

– outer casing with joint plane bolts, as well as with internal and external guiding and fixing keys

– inner casing with joint plane bolts and part of stationary blading and sealing rings of balance piston (for balancing of thrust force generated by the blading incorporated within inner casing)

– blade carriers (3 sets) with joint plane bolts and part of stationary blading

– rotor with set of rotating blading and coupling bolts on LP side
– balance piston gland casing (higher step) with joint plane bolts
– front and rear gland casing with sets of sealing rings and joint plane bolts.

The module will be factory assembled as complete module. However, to avoid limitation during transport of module (large dimensions and weights) it will be delivered to site with major components dismantled. Reassembly on site require only repetition of shop assembly.

4.2.1. *IP turbine casings and blade carriers*

New outer casing (Fig. 8) of IP turbine consists of two parts – the part made of cast steel and the welded part – both joined on vertical plane by bolts. Casing as whole is split in horizontal plane and joined by hydraulically tightened bolts. It was designed with application of state-of-the-art technology and modern material. The following areas of casing are different in comparison to existing ones:

– end glands areas are modified for application of modern end glands
– joint plane flange will be designed in accordance with the new design rules (narrow flange). It will be equipped with joint plane bolts for hydraulic tightening.
– system of internal guiding and fixing keys is adapted to new requirements
– casing is equipped with openings for endoscopy and balancing of IP rotor
– new type of material for castings was used
– adaptation to shorter installation time.

Nozzles of critical piping (extraction line and steam exhaust) will remain without changes of dimensions. They will be adapted (in scope of dimension and material) for connection to existing pipelines.

New inner casing (Fig. 9) is made of two alloy steel castings. It is split horizontally into upper and lower parts that are joint together by flanges and stud bolts (hydraulically tightened). Inner casing is charged through 4 ducts (two in upper and 2 in bottom parts) thermo–elastically connected with diffusers of control valves installed in outer casing. The rows of stationary reaction blading and strips of interstage sealing are fixed directly in circumferential grooves of inner casing.

Each of new blade carriers is made of two alloy steel castings. They are split in horizontal joint and held together by stud bolts with cup nuts maintained on flange. Axially they are fitted in circumferential groove of the outer casing. They are hanged on blocks in horizontal joint and centred in axis by central key maintained at the bottom. Such solution of fixing will enable free radial and axial expansion of blade carrier thus keeping it in central position to turbine axis independently of thermal conditions of outer casing. The rows of stationary reaction blading and strips of interstage sealing are fixed directly in circumferential grooves of blade carrier.

4.2.2. *IP turbine rotor*

The IP rotor is welded of two forgings made of steel with high chromium contents. The rotating blading is assembled on it and blading shrouds are finally machined. At the area of end glands and balance piston gland the sealing strips are tapped in the rotor grooves. Ready assembled rotor is high speed balanced and tested for overspeed.

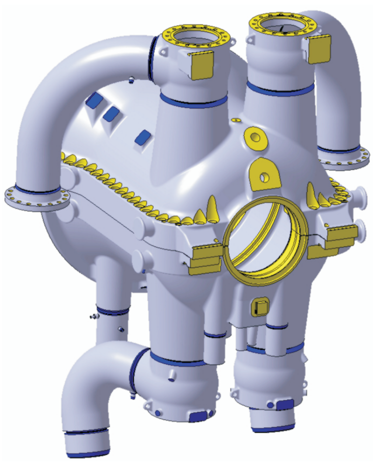

Figure 8 IP outer casing (cast part)

Figure 9 IP inner casing

On control side the rotor has the coupling disc that meet the dimensions of HP coupling disc for connection on expansion sleeve coupling. On generator side the rotor will have coupling disc for connection with reused IP coupling sleeve of IP/LP coupling.

4.2.3. *HP and IP turbine blading*

Proposed blading of HP and IP turbines consists of:

– project tailor made groups of reaction fixed and moving blades

– fixed and moving interstage sealing maintained at each stage.

The blading consist of high performance reaction blades of ALSTOM newest generation. They are characterized by:

– optimised filet radius at the shroud and root,

– thin exhaust edge

– high performance profile.

The blades are milled as solid pieces with integral blade root and shroud. In general the advanced blading utilizes the flexibility of 3D blade-foil shapes to reduce the losses in a turbine stage. Fixed and moving blades are milled of high chromium rolled steel bars. Moving blades are inserted into rotor circumferential grooves of T shape. During assembly the blades are preliminary tensioned by twisting of shroud in relation to root. Such solution ensures circumferential integrity of row in every operation conditions thus eliminating vibration resonance of rotating blades out of operation speed range.

Interstage sealing is a kind of labyrinth formed by recesses on blade shrouds and sealing strips tapped in rotor and inner casing by means of caulking wire. Radial and axial clearances between stationary and rotating parts are optimised considering real relative elongation of rotor, its maximum vibration amplitude and clearances in bearings.

Proposed type of blading was verified in various operation conditions thus presenting exceptionally high efficiency and operational reliability. The blading proposed by ALSTOM is characterised by the following advantages:

– minimum losses ensuring high performance

– no vibration from single independent blades

– no blade batches

– gap and clearance–free shroud band of high rigidity

– excellent damping due to pre–twisting technique enabling wide range of operational speed deviation

– easy maintenance of the individual blades during overhaul in the unlikely event that this is needed.

Properties and functions of IP blading are similar to HP blading and geometry difference results mainly from the higher steam volumetric flow that occurs in the IP turbine steam path. IP blading was tailor designed to keep the steam parameters in extractions as close as possible to the original.

On the following pictures (Fig. 10, 11, and 12) example blading is presented.

Figure 10 3D reaction type fixed and moving blade

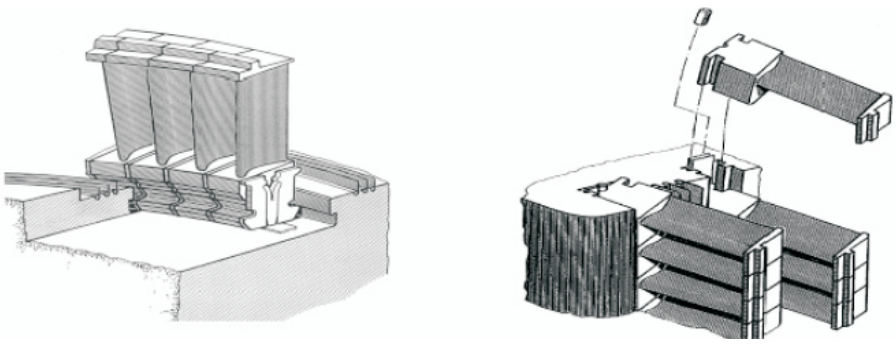

Figure 11 Assembly of moving and fixed blades

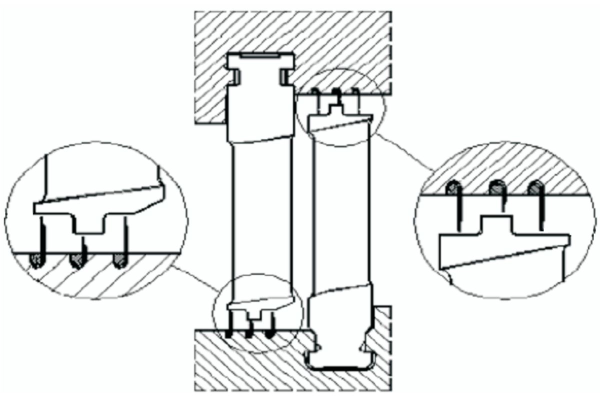

Figure 12 Interstage sealing in blading path

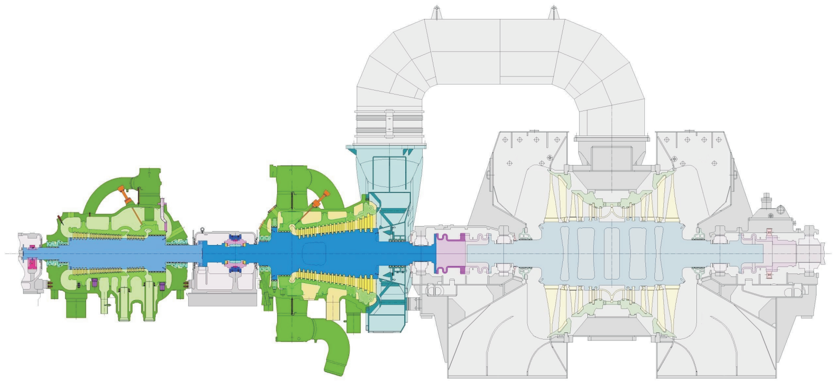

Figure 13 Longitudinal section of turbine after modernisation

5. Summary

The first modernization of 13K215 turbine of the Unit No. 8 in Polaniec P.P. was carried out in 1995 after 12 years of operation. Prior to that modernisation, the turbine had operated for 68 382 hours. Now, after the next 16 years (and more than 80 000 hours) the next modernization is implemented. This time the turbine modernization is first of all aimed at adaptation of the Unit 8 process equipment to changing requirements of the Polish energy market. Increasingly, the marked is influenced by factors resulting from the national environment policy concerning among others limits of SO_X, NO_X, CO_2 and dust emissions into atmosphere. According to EC guidelines, in 2020 app. 15 % of electricity produced in Poland should originate from renewable sources. At the same time CO_2 emission shall be limited by 20 %. Analyses performed by Polaniec P.P. show that firing biomass instead of hard coal in modernized Unit 8 will make it possible to decrease CO_2 emission by more than 1.2 million tons annually.

Retrofit of HP and IP turbines of 13K215–ND41–M1 turbine in Polaniec P.P. (see Fig. 13) will allow to obtain the following in new operating conditions i.e. live steam supply from biomass–fired boiler (compared to the status before the retrofit):

– efficiency increase of HP turbine at full load by 12.6 %, and

– efficiency increase of IP turbine at full load by 3.0 %.

As a result, power output of the turbogenerator at full load operation (live steam mass flow 570 t/h) shall increase by 6.5 % and heat rate shall decrease by 3.4 %.

Obviously, in appropriate relation specific emissions to atmosphere shall decrease as well.

Adaptation of steam turbine to operation with biomass–fired boiler, selected as the subject of this paper, is on one hand a new development in retrofit products offered by our company and on the other hand a notable example of influence of gradually more stringent regulations concerning emission restrictions on trends and methods of modernization of existing facilities.

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