Open Access Journal

Journal of Power Technologies 96 (4) (2016) 285–294

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

Thermal stress limiter for 13K215 steam turbine retrofit in Połaniec Power Plant, Poland

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Abstract

This paper studies the functioning of a thermal stress limiter for a 13K215 steam turbine in Połaniec Power Plant, which is a typical example of a 200 MW steam turbine retrofit. The share of renewable energy sources in the energy market is growing, leading to an increased demand for flexibility in conventional units, i.e., fast loading, fast unloading and fast start up etc. Thermal stress in steam turbine thick-walled elements, the steam turbine rotor in particular, is a major limit on the flexible operation of steam turbines. Therefore, steam turbine are usually controlled and protected by on-line stress control, i.e., a thermal stress limiter. In steam turbine retrofits in Połaniec Power Plant, each steam turbine was delivered by Alstom together with a thermal stress limiter implemented on a stand-alone PLC (Programmable Logic Controller). The thermal stress limiter for 13K215 steam turbine retrofits protects HP and IP rotors as well as HP and IP valve chests. The thermal stress limiter ensures safe operation of the steam turbine for the operating period required by the steam turbine owner. The thermal stress limiter also ensures the shortest possible steam turbine start up time for a guaranteed number of startups.

Keywords: thermal stress limiter, turbomax, steam turbine, stress control, lifetime

1. Introduction

The on-line thermal stress limiter is vital for flexible operation of the steam turbine and increases the chance of the steam turbine achieving its design life. Flexibility here means reduced steam turbine startup time, fast loading and unloading. The purpose of the on-line thermal stress limiter is to assess the actual stress level in the steam turbine and protect it from high thermal stress by controlling steam temperature and flow through the turbine. Stress-controlled steam turbine startup is not only faster, it also extends turbine life.

This paper considers the thermal stress limiter for a 13K215 retrofit in Polaniec Power Plant. This is a comprehensive solution for utility power plants, which protects steam turbine rotors and valve chests from high thermal stress.

2. Retrofit of 13K215 steam turbine

Połaniec Power Plant is the fifth biggest producer of electricity in Poland. It produces annually about 5 TWh of electric power. It also produces thermal energy, ash, gypsum and ash-slag for road and building construction.

Połaniec Power Plant was commissioned in 1979. The latest of eight 13K215 steam turbines designed by ZAMECH (currently Alstom Power) was launched in 1983. 13K215 was an impulse type turbine (Fig. 1), which had 3 double shell modules: single flow HP and IP and double flow LP. The live steam parameters are 535°C and 127.5 bar, whereas the reheated steam parameters are 535°C and 19.5 bar.

The first upgrades of all eight 13K215 units took place between 1992 and 1995. The upgrades included: LP turbine retrofit using RS41A type blades and replacement of HP rotor blading and diaphragms. As a result the turbine power output was increased by approximately 4.4% whereas the heat rate value of the turboset was decreased by 4.3%.

A second phase of upgrades started in 2011, courtesy of Alstom Power. The upgrades mainly included new HP and IP modules, for which the energy conversion technology was changed from impulse to reaction. The upgrades also included steam admission, but excluded IP stop valves and IP stop valves chests. HP/IP and IP/LP bearing pedestals were also improved. The pedestal upgrades included: two journal bearings and journal-thrust bearing. HP and IP modules were delivered with I&C components, which were required to upgrade the I&C system. The upgrades also included

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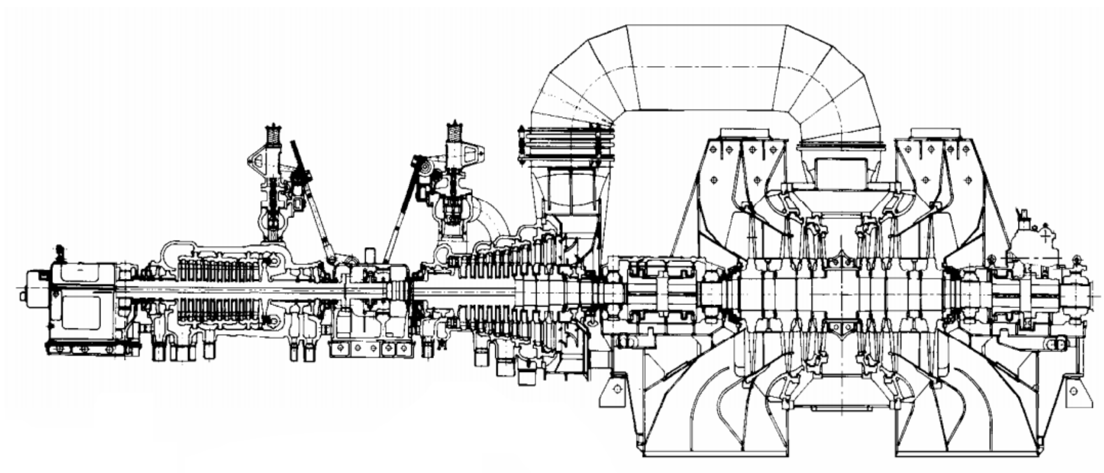


Figure 1: Longitudinal section of a 13K215 turbine

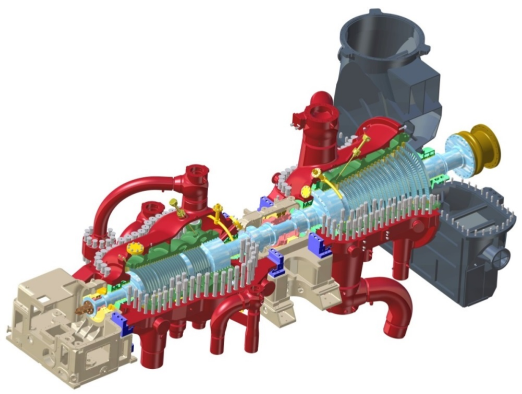


Figure 2: 13K215 steam turbine retrofit

auxiliary systems such as the lube oil system, gland steam system, drain system and erection pipes.

2.1. Design of 13K215 steam turbine retrofit

In the scope of the HP and IP turbine retrofit, all components were replaced by new ones (Fig. 2) except for the welded outlet of the IP part, which was only upgraded. Modules were adapted to reused bearing pedestals, existing foundation, and the piping of main steam and extractions.

HP and IP modules are designed as double shell, which is similar to OEM. In the case of the IP module, its design is similar for all retrofitted units. IP module main components are: rotor, inner casing, three blade carriers and outer casing. However, in the case of the HP module, there are two design variants. In both variants, rotors and outer casings are similar, but there are differences in the inner casing design. The first variant (unit 7 and unit 8, so-called Green Unit) has bolted inner casing and blade carrier, whereas the second design variant (other units) has shrink rings design inner casing.

Table 1: Startup definitions

No	Designation	Standstill time	Guarantied startup time
1	Cold start	Above 150 h	220 min
2	Cold start	Between 72 h and 150 h	200 min
3	Warm start	Between 36 h and 72 h	120 min
4	Warm start	Between 8 h and 36 h	90 min
5	Hot start	Between 2 h and 8 h	60 min
6	Restart	Up to 2 h	25 min

2.2. Requested design life of 13K215 steam turbines retrofit

The HP/ IP retrofit was designed to withstand a number of stats according to [1] i.e. 100 cold starts (CS), 700 warm starts (WS) and 3000 hot starts (HS). Moreover, Alstom guaranteed startup times for each startup category with respect to the required start up numbers. Table 1 summarizes startup definitions and guaranteed start up times. To date all commissioned units have fulfilled their startup time guarantees. Beside startup numbers and startup times, the retrofit was designed for 200,000 operating hours (OH).

During the requested design life turbine lifetime is impacted by creep and low cycle fatigue (LCF) phenomena. Consumption of steam turbine lifetime by creep is the result of the steam turbine operating at high temperature and mechanical and thermal loading of the steam turbine. In contrast steam turbine LCF lifetime consumption is the consequence of transient stresses due to transient temperature fields during steam turbine startups and shutdowns. Creep lifetime consumption (D_{creep}) can be evaluated by Robinson's time fraction rule:

$$D_{creep} = \sum \frac{t_{0i}}{t_{Ai}(\sigma_{0i}, T_{0i})} \tag{1}$$

where: t_{0i} – time of loading with σ_{i0} at T_{0i}temperature; t_{Ai}– time to crack initiation caused by σ_{i0} loading at T_{0i} temperature

LCF lifetime consumption can be assessed by the formula

$$D_{LCF} = \sum \frac{N_{Ri}}{N_{Ai}} \quad (2)$$

where: N_{Ri}– required number of specific startup – shutdown cycles; N_{Ai}– allowable number of specific startup – shutdown cycles to crack initiation

Total lifetime consumption is calculated based on Palmgren-Miner's rule. Alstom's lifetime design rule limits total lifetime consumption to 75%.

$$D_{total} = D_{creep} + D_{LCF} \leq 75\% \quad (3)$$

In order to assess turbine lifetime consumption caused by creep and LCF phenomena, finite element (FE) analyses have been performed for main steam turbine components using the Abaqus program [2].

Steam turbine creep lifetime consumption during the requested design life was evaluated for all of the vital steam turbine high-temperature components. These components were numerically retained in steady state stress conditions for a maximum continuous rate heat balance diagram, and viscous material properties were activated for these components.

Steam turbine LCF lifetime consumption for the requested number of startup – shutdown cycles was evaluated based on the required and allowable number of startup – shutdown cycles. The allowable number of cycles (N_{Ai}) for each startup – shutdown cycle type is based on the computed strain amplitude ϵ_a, at reference temperature T_{max} and LCF data with 1 hour hold time curves. The strain amplitude ϵ_a is based on elastic FE analysis with Neuber's rule or Hooke's law. The evaluation temperature T_{max} is the maximum metal temperature at the life-limiting location over the startup – shutdown cycle.

The first example of an analyzed steam turbine component is the IP rotor of unit 7 and the Green Unit. The IP rotor model is axisymmetric, designed on the nominal dimensions. The allowances for manufacturing tolerances are included in the safety factors. The second example of an analyzed steam turbine component is the HP inner casing of units 2-6. As in the case of the presented IP rotor, the casing geometry model was based on CATIAv5 CAD models. The HP inner casing model was constructed with nominal wall thickness. Allowances for manufacturing tolerances and erosion-corrosion effects are included in the safety factors. Although the HP inner casing is cyclic symmetrical, full 360° casing FE model was considered due to asymmetrical temperature distribution in the region of the casing seals (hot spot). The casing FE model also included tightening bolts and shrink rings.

Fig. 3 presents creep strain for the IP rotor of the Green Unit after steam turbine requested design life of 200'000 OH. Alstom design rules limit creep strain for the whole analyzed rotor body. In the case of the considered IP rotor, creep strain was below the allowable limit and creep strain for life limiting rotor location, i.e., the first IP rotor groove is equal to 0.63%. Based on the relaxed centrifugal and thermal stresses after the IP rotor requested design life, including a safety factor, creep lifetime consumption (equation 2.3) was assessed to be no higher than 20%.

Fig. 4 presents the Green Unit IP rotor stress analysis during a theoretical cold startup performed by means of Alstom internal software based on Abaqus [3]. The blue line stands for stress during the theoretical cold startup in an IP rotor life limiting location, i.e. first IP rotor groove. The light blue line stands for allowable stress for 911 theoretical cold startups – reference shutdown load cycles. The stress limit was reached at 100 min of the considered startup, which corresponds to about 70 MW (30% of rated power). From 100 min up to 180 min of the theoretical cold startup, the stresses were just below the stress limit, which is optimal from the rotor strength perspective.

For the considered HP inner casing of Połaniec units 2-6, the life limiting location was the transition radius between the casing spiral and the steam inlet. Figure 5a presents casing creep strain after the requested design casing life. Maximum creep strain is 0.95%. The relaxed stresses after the requested design life, including a safety factor, will cause HP inner casing creep lifetime consumption (equation 2.1) of no higher than 20%. Figure 5b shows the allowable number of representative cycles to crack initiation for the right half of the HP inner casing. For a life limiting location the allowable number of considered cycles is 334 cycles.

3. Thermal stress limiter for 13K215 steam turbines retrofit

Stress measurement for steam turbine components is extremely difficult because of high operating temperature, life limiting locations accessibility and rotational speed in the case of the steam turbine rotor. Therefore, indirect methods of stress assessment are currently used for steam turbine utility power plants. Stress in supervised steam turbine components is estimated by thermal stress limiters, monitoring systems which assess on-line current stress and allowable stress in supervised steam turbine components. However, due to limitations related to real time calculation, stresses are not assessed in the whole supervised component but only in a life limiting location, which is investigated during the life time assessment of the supervised component or experience with similar steam turbines. The main goal of the thermal stress limiter is to limit stress amplitude in the supervised steam turbine component in order to fully achieve the required number of startup – shutdown cycles. Fig. 6 shows the basic components of every thermal stress limiter, which consists of an algorithm of stress assessment, influence on steam turbine control system and instrumentation in the vicinity of the steam turbine.

The thermal stress limiter of the 13K215 steam turbine retrofit protects the HP and IP rotors and the HP and IP valve

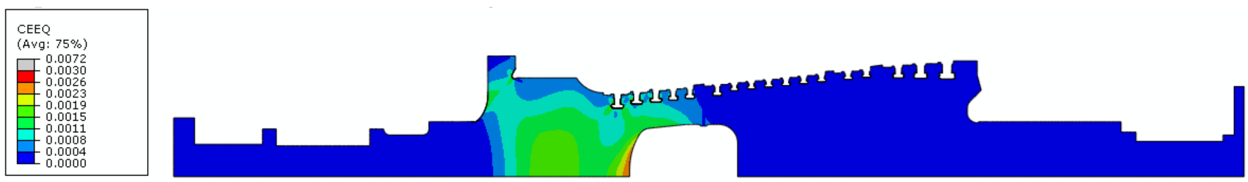


Figure 3: Figure 3. HP rotor creep strain after steam turbine requested design life

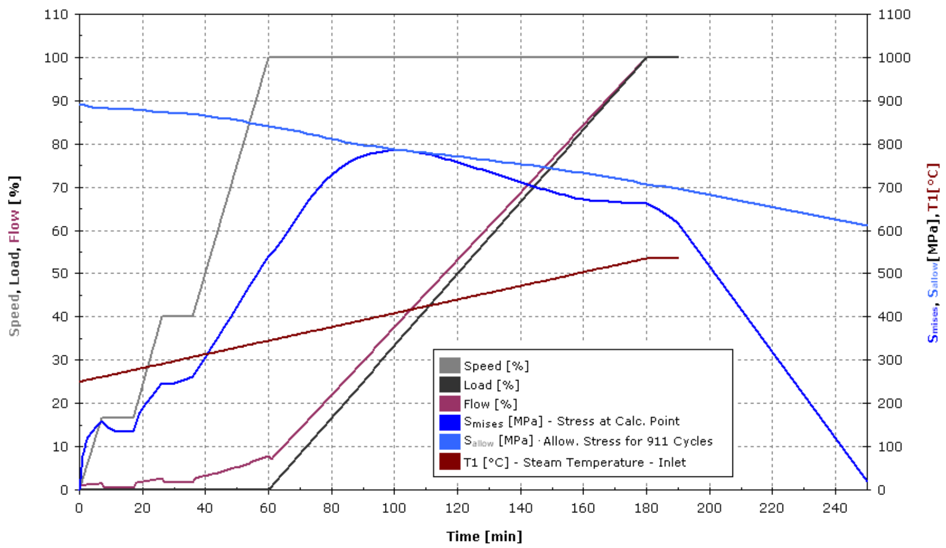


Figure 4: Stress in life limiting location of IP rotor during theoretical cold startup

chests. Calculations of current stress for these components are based on mathematical models. In the case of the HP and IP rotors, the standard Alstom TURBOMAX 7 stress limiter is used, where cylinder models are implemented in algorithm (section 3.2). Stress is calculated based on startup probe temperature measurements located in HP and IP inner casings at the steam path inlet. Stress calculations for the HP and IP valve chests are calculated using Duhamel's integral based on steam temperature measurement before the protected valve chest and metal temperature measurement of the protected chest (section 3.1). Stress limits for all supervised elements are related to the stress responsible for cumulative LCF damage in steam turbine components. Stress limits ensure that lifetime requirements (section 2.2) are fulfilled.

13K215 steam turbine retrofits in Połaniec Power Plant do not include upgrade of the turbine control system. However, standalone PLC was delivered for each upgraded turbine for the purposes of the thermal stress limiter (section 3.3). The stress limiter participates in the control and protection system of each unit through control and protective signal exchange, as described in section 4.

3.1. Supervision of HP and IP valve chests stresses

Supervision of HP and IP stop valve chests stresses is conducted based on equivalent stress, including mechanical and thermal stress components. The mechanical stresses are calculated on the basis of measured pressure of: live steam for HP valve chests and reheat steam for IP valve chests. The thermal stresses induced by an arbitrary change of steam temperature $T_P(\tau)$ are determined by Duhamel's integral [4]:

$$\sigma^T = \int_0^t \frac{dT_P(\tau)}{d\tau} f(t-\tau)\, d\tau \quad (4)$$

which employs the influence function $f(t)$ describing the evolution of stress components at the valve chest critical location induced by a unit step change of steam temperature. The unit stress response to temperature step is computed using the finite element method with exactly determined geometric and material properties of the component, and primarily the heat transfer boundary conditions [5]. A characteristic feature of the influence function is the relatively large change in stress immediately after the temperature step has occurred, and the subsequent slow decay to a steady state value [6]. Example results of temperature and stress calculations of the IP valve chest are shown in Fig. 7.

Input signals for thermal stress calculations are on-line measured temperatures:

1. for HP valve chest: live steam temperature and valve casing temperature
2. for IP valve chest: reheat steam temperature and valve casing temperature

The quantity, which is a basis for forming the limitation signals, is the component load fraction calculated as a ratio

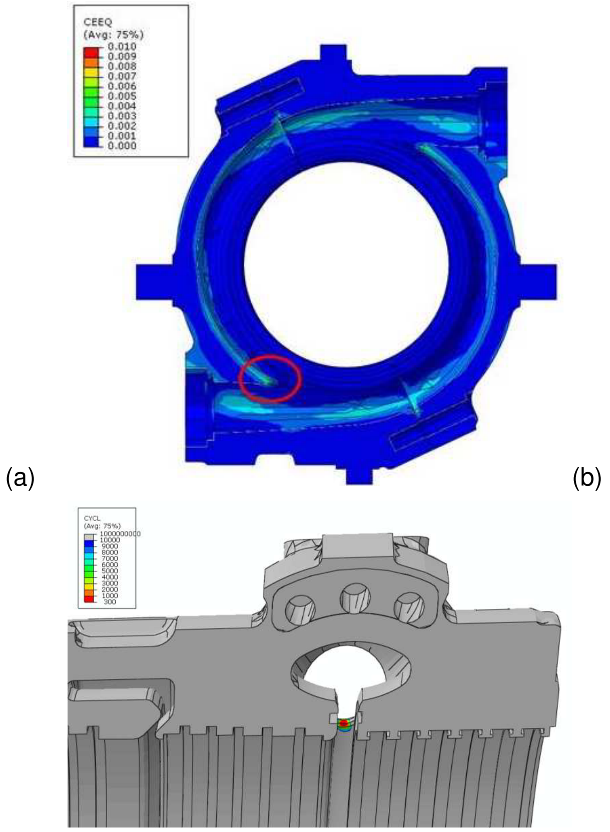


Figure 5: HP inner casing creep strain after requested design life (a) and allowable number cycles to crack initiation.

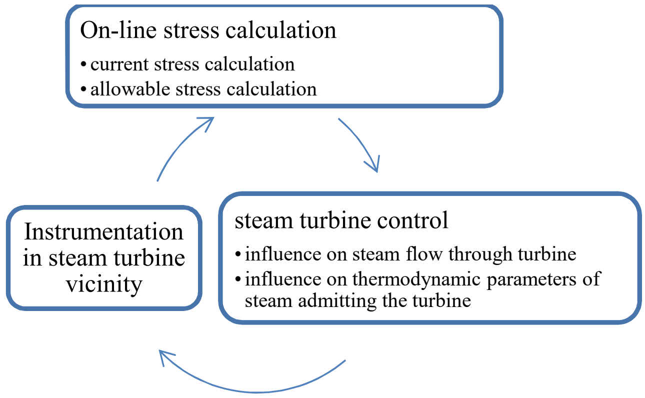


Figure 6: Idea of steam turbine thermal stress limiter

of reduced (equivalent) and control stresses. The control stresses are a function of casing metal temperature, and the function is defined separately for each typical operation mode of a turbine, such as cold, warm and hot startup, steady state and shutdown. The basic assumptions used to define these functions are: turbine design lifetime and required number and time of startups given in startup diagrams.

The limitation signal worked out by the HP chest stress supervision module is outputted to the live steam and valve chest preheating steam temperature controllers. Through these controllers it influences the steam temperature rate, reducing the set temperature rate proportionally to the load fraction of the HP valve chests.

The limitation signal worked out by the IP chest stress supervision module is outputted to the reheat steam temperature controller. Through this controller it influences the steam temperature rate, reducing the set temperature rate proportionally to the load fraction of the IP valve chests.

3.2. HP and IP rotors stress supervision

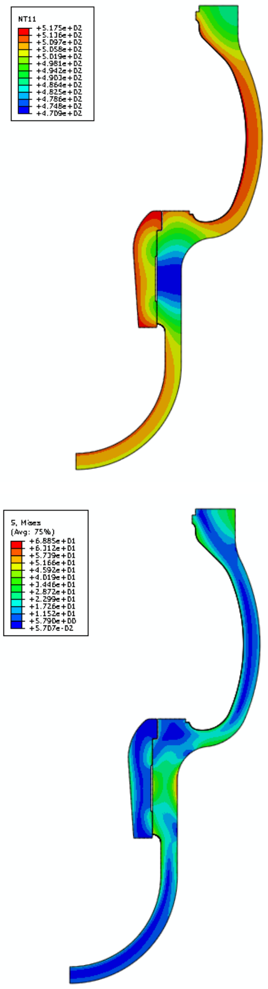
The HP and IP rotors of upgraded steam turbines in Połaniec Power Plant are protected by TURBOMAX, which is Alstom's standard thermal stress limiter. The history of TURBOMAX begins in 1957 [7]. Currently, version number seven of the system is the state of the art. Fig. 8 presents the idea of TURBOMAX 7, which consists of three pillars: instrumentation in the vicinity of the steam turbine, stress calculations in PLC and influence on the steam turbine control system.
Temperature in a critical location of the protected rotor is simulated by a startup probe, which measures temperatures in the inner casing in front of the steam path. The depth of temperature measurement by the startup probe as well as the inner casing boss in the vicinity of the startup probe provides appropriate modeling of the critical location of the protected rotor. The typical design of the startup probe is shown in Fig. 9 a). Fig. 9b) presents the HP startup probe for Połaniec units 2-6. HP startup probes for these units are located in the bottom half of the HP module. Fig. 9c) shows the IP startup probe for Połaniec units 2-7. The IP startup probe is located in the top half of the module.

TURBOMAX employs a mathematical model of a smooth cylinder in order to estimate stress in the protected rotor. The reference cylinder is selected based on individual features of the protected rotor. Fig. 10 compares the response on the predefined surface temperature of the Połaniec unit 7 HP reference cylinder against the response of the finite element model of the HP rotor. Both curves are similar for slow as well rapid changes in the surface temperature of the rotor.

In the TURBOMAX system the concept of reference stress is used. Axial stress in the rotor can be evaluated based on the following equation:

$$\sigma = K_2 \cdot E \cdot \beta \cdot \triangle T \tag{5}$$

where: K_2 – rotor dimensionless shape coefficient; E– Young modules, MPa; β – thermal expansion coefficient, 1°C; ΔT – difference between rotor average and surface temperature, °C.
Dividing equation 5 by Young modules and thermal expansion coefficient, reference stress in Celsius is derived (equation 6). Reference stress does not depend on actual rotor temperature, but depends only on the actual difference between the average and surface temperature, which is the main advantage of the reference stress concept.



(a)

(b)

Figure 7: Temperature (a) and stress (b) distribution in IP valve chest during cold startup

$$\sigma_{ref} = K_2 \cdot \triangle T \tag{6}$$

The startup probe measurement, which relates to rotor temperature in the critical location, is used as the surface temperature of the rotor model in the critical rotor radial section (Fig. 8). Average rotor temperature is calculated from the rotor mathematical model. Based on the rotor surface and average temperature, axial stress caused by this temperature difference is calculated. In TURBOMAX only thermal axial stress is taken into consideration, since this stress is mainly responsible for rotor LCF damage.

Allowable stress in TURBOMAX 7 is calculated based on the rotor material LCF characteristic. However, allowable stress is different for different rotor states (Fig. 8). During startup, when the rotor is usually heated up, allowable stress for the heated rotor is derived at the beginning of the steam turbine start up based on initial rotor temperature. Later, during the startup, the allowable stress depends on actual average rotor temperature. During steady state operation and turbine shutdowns, allowable stress for the heated rotor is constant. For all turbine states (startup, steady state, shutdown) the stress limit for the cooled rotor is constant.

3.3. Thermal stress limiter hardware

The 13K215 steam turbine retrofits were delivered with a thermal stress limiter implemented on stand-alone PLCs (Programmable Logic Controller), General Electric RX3i series (Fig. 11). PACSystems RX3i is a modular controller, offering a wide variety of CPUs equipped with powerful processors (clocked at a frequency of 300, 600, 700 or 1800 MHz), capable of industrial applications that require very fast data processing. 64 MB of memory fitted to the controller allows it to create complex control algorithms and to store other data, including files with technical documentation. The open system bus is capable of simultaneous operation of several communication modules and ensures fast data exchange with the CPU, minimizing total cycle time to a few milliseconds. Servicing the controller and modifications to the new program may be on the move during operation of the system.

In the version supplied to Połaniec, the RX3i controller is built into a DCS as an independent controller. It communicates with the master system OVATION and the DEH turbine controller via Ethernet network, using the MODBUS TCP/IP protocol. On the basis of information about the state of key parameters such as turbine speed, generator active power, steam pressures and temperatures and the current regime of operation, the following feedback signals are formed:

1. speed or load gradient limitations to the turbine controller and DCS
2. live and reheated steam temperature gradient limitations to the DCS.
3. orders to trip the turbine to the protection system if allowable stresses are exceeded.

The TSL - DCS cooperation architecture is shown in Fig. 12

4. Thermal stress limiter's influence on unit operation

Usually there are five phases of steam turbine startup in fossil fired power plants:

1. Run up to nominal rotating speed. During this the phase speed and speed gradient is controlled by the steam turbine governor.
2. Synchronization with grid and initial load in order not to allow to turbine to trip due to reverse power.
3. Load gradient control mode. During this phase steam turbine load gradient is controlled. Turbine control valves are opened to provide the required load gradient. Valves of by-pass stations are closed in order to maintain the correct pressure in live and reheated steam pipelines. The pressure controller in the turbine governor follows actual pressure before control valves.

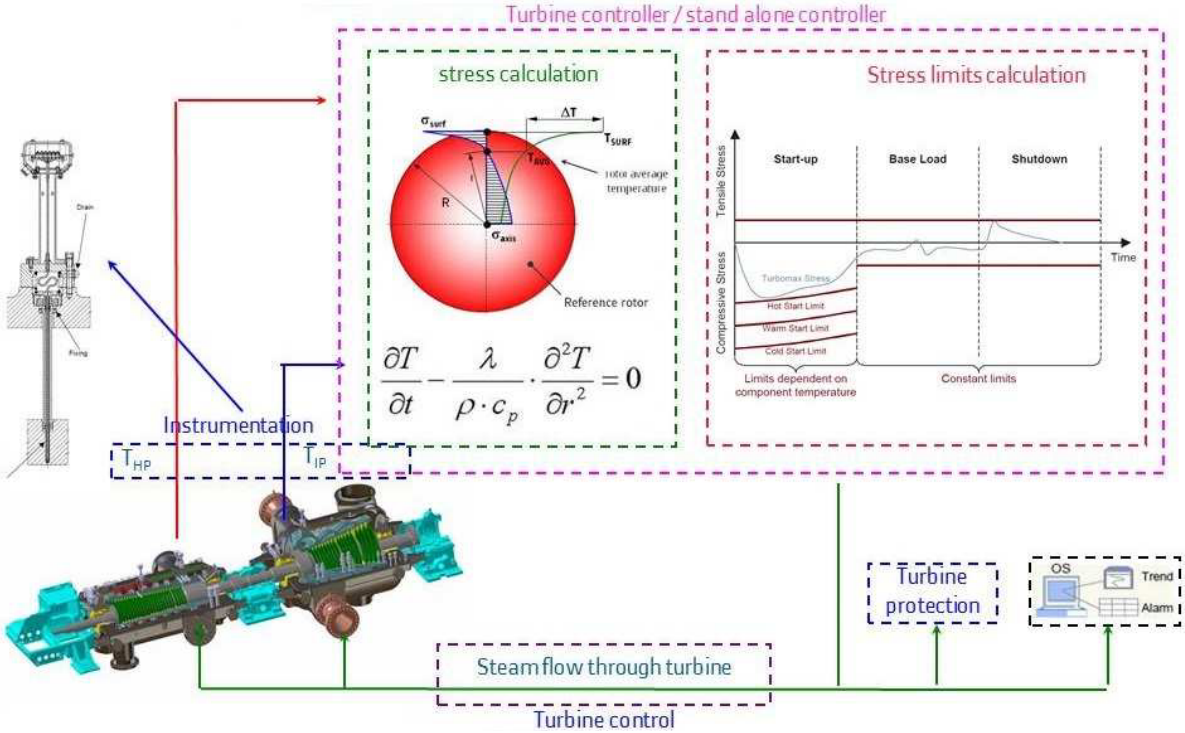


Figure 8: Idea of TURBOMAX 7

4. Pressure control mode. As soon as the by-pass stations are closed the turbine goes to pressure control mode, i.e., turbine controls pressure before the turbine but turbine load is a consequence of boiler load.
5. Coordinated mode. When boiler minimum load on primary fuel is reached, the boiler starts to control pressure and the turbine starts to control load.

As regards rotor protection, the thermal stress limiter affects the steam flow through the turbine by actual load gradient, i.e., control valve opening speed. The thermal stress limiter could also influence the boiler in order to control steam flow through the turbine. However, this would not be efficient in fossil fired boilers due to boiler inertia.

The thermal stress limiter influences turbine valves through load margin (Fig. 13). As long as stresses are below 60%, load margin is equal to 1. Above 60% stress, load margin decreases to reach value 0 at 100% stress. Actual load gradient is equal to set load gradient multiplied by load margin. However, load margin can only be used if the turbine is in load or speed control mode (startup phases: 1,3,5). When the turbine is in pressure control mode (phase 4), load margin cannot be used because the turbine valves control pressure before the turbine. When in pressure control mode the steam turbine operator is responsible for not allowing stress excursion above the allowable limit.

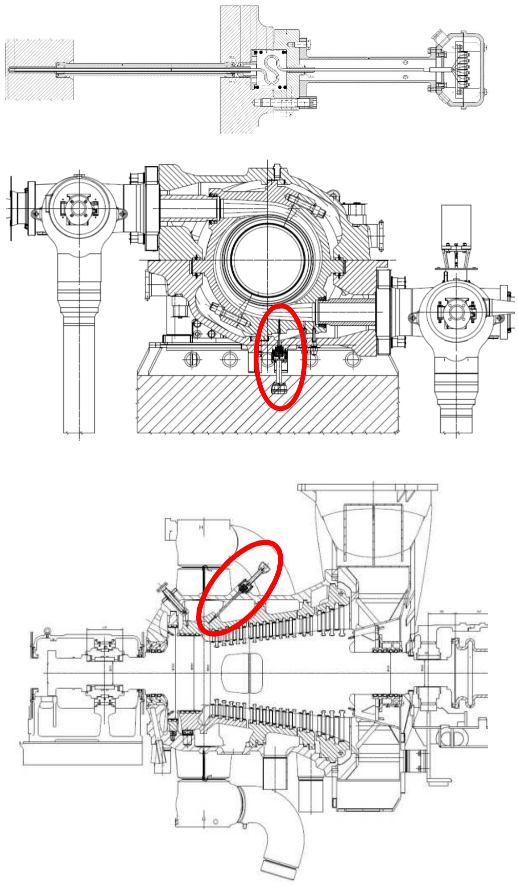
In order to stop stress exceeding the allowable limit, the thermal stress limiter can take two protective actions.

The first action takes place when the steam turbine is heated during startup. When HP or IP rotor stress reaches 95% (rotor is heated too much), the steam turbine is deloaded 10% per minute (valves are closing and rotor is no longer heated up). This protective action lasts as long as stresses are above 95%.

During turbine deloading valves are closed based on their characteristics, i.e., first the HP valves go and after them the IP valves. Sometimes it is not fast enough to protect the IP rotor from excursion over the stress limit. Therefore the second protective action is needed to protect IP rotor. When IP cooling or heating stress exceeds 98%, the thermal stress limiter deloads the IP part. At the same time valves are trimmed. Valve trimming is an algorithm of the steam turbine controller, which in this case opens HP control valves in order to maintain turbine current load. This protective action lasts as long as IP stress is above 98%.

When stresses cannot be controlled, the turbine is automatically tripped when stress exceeds 102% for over 5 minutes or stress exceeds 105% for over 1 minute when the rotor is heated. When stress exceeds 105% and the rotor is cooled, the turbine is tripped with no delay.

There is a difference between the usual startup procedure for a fossil power plant and for Połaniec Power Plant. There is no phase 3 of the usual startup procedure, i.e., the steam turbine goes directly to pressure control mode after steam turbine synchronization with the grid. The set point of the steam turbine pressure controller is a few bar lower than the by-pass station set point. This drives the opening of turbine valves and the closing of by-pass station valves. However, there was no possibility to control stress in the steam turbine after synchronization, when the highest temperature dif-



(a)

(b)

(c)

Figure 9: Typical startup probe (a), HP startup probe for units 2-6 (b), IP startup probe for units 2-7 (c)

ferences exist between turbine components and the steam flowing through the turbine. Therefore a special algorithm was prepared for the purpose of stress control in Połaniec Power Plant.

For the 13K215 retrofits in Połaniec Power Plant, stress of the HP rotor after synchronization is controlled by a thermal stress limiter, which affects the opening velocity of the HP control valves. However, the thermal stress limiter does not react in the same way to IP control valves in order to control IP rotor stress. With the IP rotor, maximum stresses are reached after the IP/LP by-pass station is fully closed. Moreover, IP rotor peak stress is below the stress limit if all requirements regarding steam conditions are fulfilled. Therefore there is no need to influence IP/LP by-pass station closing time.

HP rotor stress is controlled by impact on the difference between the pressure set point of the HP by-pass stations and the pressure set point of the turbine. This set point difference (Δ) determines control valve opening and is defined as follows:

$$\triangle = A - B \tag{7}$$

where: A– constant component; B– HP rotor stress dependent component; $B = 0$ when HP rotor stress below 70%; B_{max} when HP rotor stress equal to 90%; when HP rotor stress is above 90%, HP by-pass stations are opened.

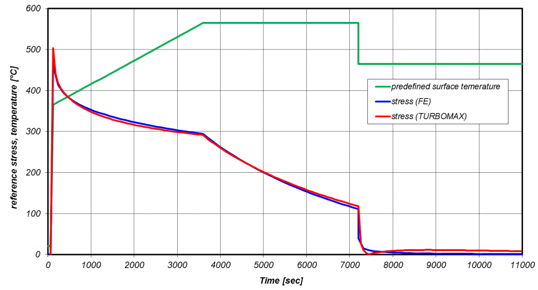


Figure 10: Comparison between Turbomax and FE rotor model

Figure 11: GE RX3i controller

Fig. 14 shows cold startup of a 13K215 retrofit. After synchronization (56 min) HP by-pass stations were closing (purple and orange lines). As soon as HP rotor stress (blue line) reached 70%, HP by-pass stations were held on. As soon as HP stress decreased below 70%, the HP by-pass stations continued to close. Warm up stop was held on 24 MW (green line) and lasted from 60 min up to 88 min. In the presented case HP stress was controlled at the level of 76%. There is some margin left to cover unpredictable boiler behavior, but there is also some margin for unit optimization.

5. Conclusions

The on-line thermal stress limiter has been presented on an example of a 13K215 steam turbine retrofit. Thermal stress supervision ensures safe and flexible turbine operation within the lifetime consumption level defined by the steam turbine owner. Moreover, a thermal stress limiter can be installed not only during steam turbine retrofit, but also in an operating unit with any control system.

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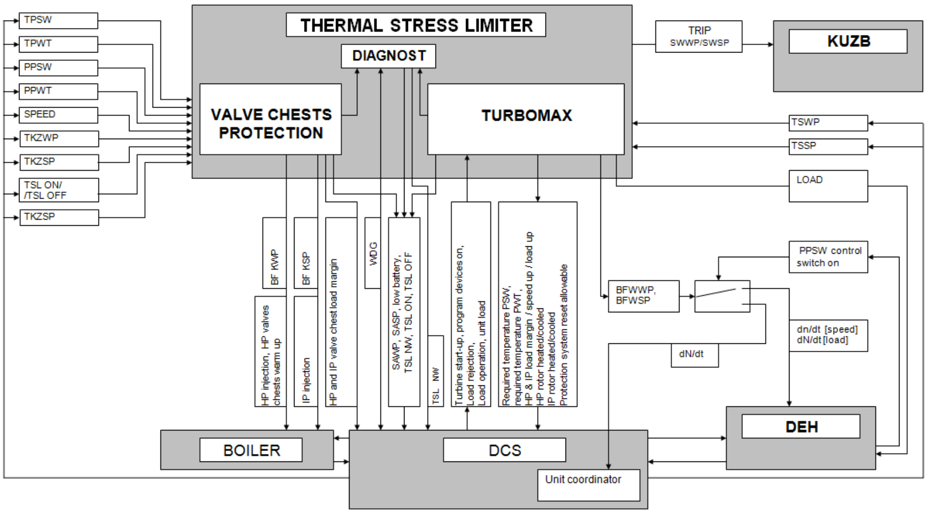

Figure 12: Unit control architecture

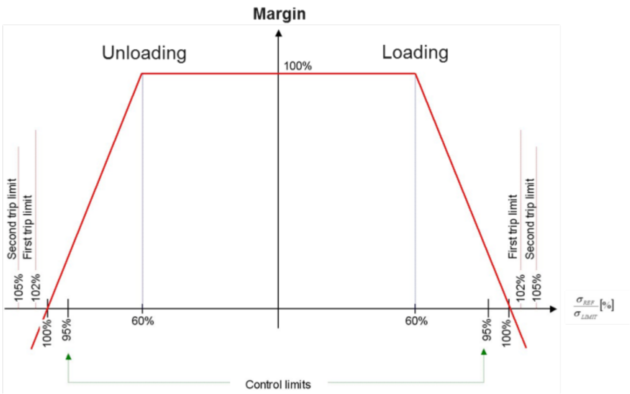

Figure 13: Load margin definition

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Nomenclature

13K215 condensing steam turbine, live steam pressure equal to 13 MPa, rated power equal to 215 MW

CAD Computer Aided Design

CPU Central Processing Unit

CS Cold Start

DCS Distributed Control System

DEH Digital Electro-Hydraulic control system

FE Finite Element

HP High Pressure

HS Hot Start

I&C Instrumentation and Control

IP Intermediate Pressure

LCF Low Cycle Fatigue

LP Low Pressure

OEM Original Equipment Manufacturer

OH Operating Hours

PLC Programmable Logic Controller

TCP/IP Transmission Control Protocol/Internet Protocol

TSL Thermal Stress Limiter

WS Warm Start

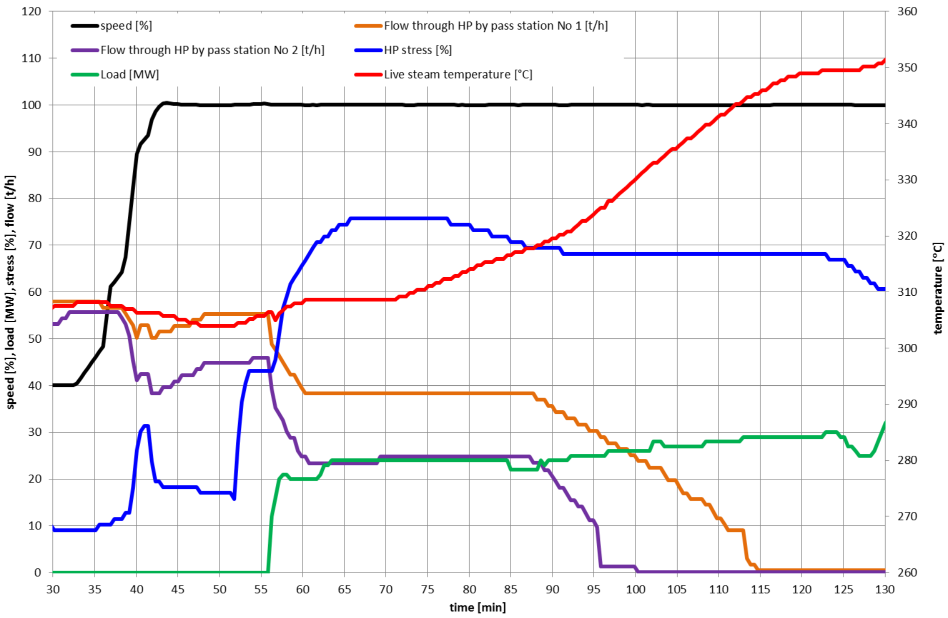

Figure 14: HP rotor stress compared with flows through HP by-pass stations during cold startup.