

A RATIONAL APPROACH TO EVALUATE A STEAM TURBINE ROTOR GRABBING AND LOCKING EVENT

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ABSTRACT

In the paper, an unique event of a steam turbine rotor grabbing and locking will be described and evaluated. The turbine power is 21,740 kW and it is used in a pulp and paper production plant. The turbine is a high speed machine, 8,300 rpm, reaction multi-stage type, coupled by a reduction gear to a 4-pole electric generator, with 1,800 rpm.

The steam turbine rotor grabbing and locking event evaluation is based on a proposed rational approach, i. e., based on the connection of the failure mechanisms observed and the identification of possible causes of these mechanisms.

It is important to notice that the failure mechanisms and their causes are not the same. The failure mechanisms are the damages observed such as wear, fracture, severe deformation, etc. that impair or limit the safe and economical operation of a mechanical component. The causes, on the other hand, are the operational characteristics, the aging factors, the loads, etc. that introduce conditions to the failure mechanisms development.

Using the proposed rational approach, the failure mechanisms causes that induce this unique event of steam turbine grabbing and locking are identified. Also, corrective and improvement actions based on the proposed rational approach are addressed to evaluate similar events and to avoid such a type of event in similar components.

INTRODUCTION

This paper presents and discusses an unique event of the rotor grabbing and locking of a steam turbine whose maximum power is 21,740 kW, used in a paper and pulp production plant. The turbine is a machine of high rotation, 8.300 rpm, reaction

multi-stage type, coupled by a reduction gear to a 4-pole electric generator, with 1,800 rpm.

The steam turbine main characteristics are:

Superheated steam pressure	82 kgf/cm ² (g)
Superheated steam temperature	475°C
Extraction pressure	13 kgf/cm ² (g)
Exit pressure	4 kgf/cm ² (g)
Max. inlet steam flow	140 t/h
Max. extraction steam flow	47 t/h
Max. exit steam flow	140 t/h

To assess the steam turbine rotor grabbing and locking the proposed approach follows the main recommendations from [01]. It is called a rational approach because it is based on the connection of the failure mechanisms observed and the identification of possible causes of these mechanisms.

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STEAM TURBINE OPERATION DESCRIPTION

To convert the live steam thermal potential energy in mechanical work, the steam turbine receives 140,0 t/h (maximum) of superheated steam (at 82 kgf/cm²(g) e 475°C) from a chemical recovery boiler and expand it to the process consuming pressures (medium and low pressures). The live steam flows through a quick close valve and three control valves (depending on the load). On their side, the control valves drive the partial flow through three chambers in the turbine casing inlet to the injection nozzles that are located prior to the control stage. The steam enthalpic drop, through the 13 reaction stages and the 2 action stages, is transformed in the mechanical energy in a continuous process.

The turbine has an extraction after the 10th reaction stage. The extracted steam is sent to the process and the remaining steam to the extraction control valves. Two extraction control valves drive the flow to the extraction control wheel while two other valves inject steam directly in the 11th reaction stage, mixing it to the steam from the other two.

The quick close valves (inlet/extraction) are designed to avoid external power to actuate them and are actuated by the turbine steam. The opening and closing controls are performed by a governor device that is a connection between the hydraulic and turbine steam systems.

There are three steam inlet valves to control the steam supply to the turbine and, consequently, to control the process variables (pressure and speed). These valves are actuated by servo hydraulic motors.

Sealing strips and labyrinths are fixed to the rotor, between the stages and in the stator (stationary blades) to avoid the steam flow through the stationary parts and the rotating parts (rotor with the blades).

The extraction control valves controls the steam extraction (after the tenth reaction stage) and are actuated by servo hydraulic motors. They also control the turbine extraction pressure and, with the inlet control valve, are responsible for controlling the other variables of the turbine.

The turbine casing supports are located in the frontal region (steam inlet side) as in the end region (steam exit side) over case bearings. The frontal case bearing has freedom to move in the turbine axial direction keeping the whole assembly alignment with the turbine thermal expansion.

The turbine has two journal bearings and one thrust bearing with forced lubrication. The thrust bearing, located in the frontal case bearing, absorb the axial thrusts from the assembly in both directions.

THE TURBINE ROTOR LOCKING

The turbine rotor locking occurred approximately 36 months after the ending of the turbo-generator commissioning. In this period the turbo-generator was submitted to non programmed

outages and to tests (the tests outages had, many times, the purpose to test the turbo-generator after correction of design errors, installation errors, etc.)

The rotor locking was observed after a programmed outage. In this case, the turbo-generator had his load progressively reduced to the complete shutdown, in the way the plant areas are removed from operation.

According to the operational history, this last outage was the 108th steam turbine shutdown. It is also estimated that the steam turbine has been submitted to 150 shutdowns before the rotor locking, including non recorded commissioning and tests outages. As each turbine startup/shutdown corresponds to 30 hours of operation, the 150 events resulted in ~4,500 hours of equivalent operation to the steam turbine.

After the shutdown, the turbine operated in low speed rotation. Few minutes later (~40 minutes), it occurred the low speed rotation system electric motor thermal trip. The turbine was kept in stationary condition with the oil system operating according to turbine manufacturer recommendations.

In the day after, it was noticed, from rotor displacement measurements, that the thrust bearing gaps were greater than the allowable tolerances. It was decided to open the turbine,

Two days after, the turbine was open and the rotor was removed. With the turbine opened and the rotor out the casing, a visual inspection was performed to evaluate the internals condition. It was observed the following problems (see Figures 1 to 4):

- [i] Damages in the sealing strips and labyrinths in the sealing regions.
- [ii] Scratches and rubs in the cover of some rotor blade stages.
- [iii] Damages in the end covers (small diameter) do stationary blades (axial rubs).
- [iv] Rubs in the journal bearings pads and in the back stop flange.



Figure 1: Damage in stationary parts

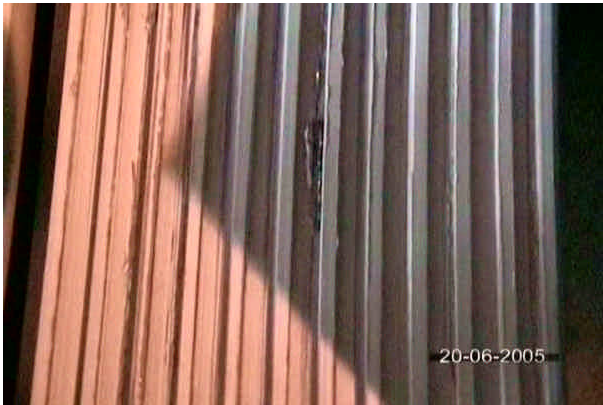


Figure 2: Damage in stationary parts



Figure 3: Damages in rotating parts



Figure 4: Damage in sealing parts

From the damaged condition of the rotor and the turbine casing, the evaluation of the visual inspections records revealed that the rotor grabbing in the turbine casing occurred in speeds greater than the low speed rotation. Further, from the rotor sealing strips conditions e from the damage in the labyrinth it was evident that the grabbing occurred at relatively high speeds. The rotor sealing strips and labyrinths were, in some positions, and almost completely destroyed. In other places, the sealing strips were crushed and broken.

CAUSES ASSESSMENT OF THE LOCKING AND OF THE TURBINE DETECTED DAMAGES

It is extremely difficult that an isolated cause results in an accident or failure of a flow rotating machine as a steam turbine. Commonly, accidents or failures in rotating machines are induced by a combination of two or more causes, occurring simultaneously or not, and repetitively.

The causes of accidents, failures or forced outages can be classified in:

[i] Determining causes: design errors and fabrication/installation errors that appears under abnormal operational situations (due to design, fabrication or installation, or due to atypical operational conditions), and operational conditions not adequate to the equipment sizing/materials/fabrication.

[ii] Precipitating causes: one or more cumulative atypical operational situations (outages, startups, shutdowns, load rejection, motorization, etc.).

Many times the precipitating causes are identified as determining causes because the later ones are not easily noticed and can be related to equipment hidden vices and defects.

The hidden vices and defects may be generated in the design, in the fabrication, in the installation, and, also, in the commissioning. In a general way, they do not appear during the normal operation of the equipment.

Some machines are more exposed to hidden vices and defects than others (they can have more unidentified defects during normal operation).

Unfortunately, the turbo-generator under evaluation may be considered a machine with high risk, not due to the technological aspects of the machine, but due to the plant equipment integration design, the delivery of the Balance of the Plant (BOP) and the inadequate commissioning. In the first years of operation, the turbo-generator was submitted to a lot of trips due the delivery problems and abnormal operational conditions that revealed its hidden vices and defects.

The event under evaluation, the rotor locking, had the rotor grabbing to the turbine casing as its start point. The rotor-to-stator rubbing in steam turbines is a secondary operational problem resulting from one or more primary causes.

One of the more common ways that are used to increase the efficiency of these rotating machines is the reduction of the

tolerances and the dimensional gaps. Consequently, if the machine is not operating under normal conditions the risk of the contact between the stationary and rotating parts (grabbing) increases. As primary causes for the grabbing, it can be mentioned:

- [i] Rotor unbalancing.
- [ii] Thermal transients in the machine.
- [iii] Misalignment in the installation or in the operation.
- [iv] Steam flow induced vibrations.
- [v] Debris from internals.
- [vi] Loose parts impacts.
- [vii] Excessive deformation in the stationary parts caused by external loads (as the nozzle loads from the piping).
- [viii] Thermal fatigue from the cyclic thermal stresses due to the temperature changes during startup and shutdown, and during load conditions changes.

The assessment of the potential causes for the case under evaluation was performed using the rational approach and following the main recommendations given in [01].

Also, a relation between the observed damages from the grabbing between stationary and rotating parts and the potential causes were assessed.

It was collected information from all phases of the equipment life from its design, to fabrication, installation, commissioning, operations and maintenances. A special consideration was given to the records from the visual inspections of the turbine parts after its opening after the rotor locking.

From the assessment done, it is showed below the causes that were considered as contributing to the turbine rotor locking:

Operational Thermal Transients

Flow thermal machines are, generally, designed to operate in permanent regimes. They must follow load ramps specified by the manufacturers as pressure and temperature ramps indicated in codes (e. g., IEC 45 [02]) when submitted to changes in load as in pressure and temperature (mainly, the last one)

Depending on their location and amplitudes, the thermal transients may: cause accidents due to sudden changes in temperature; or cause fatigue in some of the turbine components that may result in a failure.

In a paper and pulp production plant where the turbine has only a chemical recovery boiler as its energy source (there is not a high pressure balance boiler), the machine is submitted to some limitations from black liquor burn process and from the boiler failures.

This turbine under evaluation is a machine that controls the load and pressures (through vapor mass flow changes) using

only valves. From the first startup to the rotor locking (~36 months) it operated with partial load (average generation from 8,000 to 12,000 kW), i.e., with partial steam inlet because it was sized for a pulp production greater than the plant produced usually. So, the turbine during the load changes from 8,000 to 12,000 kW was more stressed due to thermal distortions because the temperatures were higher in the extraction and in the exit than the temperatures, in the same positions, under full load.

In the beginning of its operation, during almost 15 months, several emergency trips occurred due to the inlet steam high and low temperatures. Also, many trips resulting from the chemical recovery boiler trips occurred.

From the first startup to the rotor locking, based on the operational data logs, it was noticed that the turbine operated under a lot of severe live steam temperature changes (~500 to 1,000 times in ~36 months of operation) and under low loads, resulting in lots of severe thermal transients. Some of them, possibly, caused steam leakages in live steam flanges also reported in operational and maintenance records.

Thus, from the operational history, the live steam temperature changes in the turbine inlet, and the turbine operation at low loads possibly contributed to cause the observed damages before the rotor locking.

Misalignment in Installation and in Operation

The misalignment is known as the cause of contacts and grabbings and, in several rotor lockings, as the cause of catastrophic damages.

The misalignment may be generated during the machine installation due to design or workmen errors. It also may grow during the operation due to internal and external loads. In this case, the growing of the misalignment may be slow depending on the values of the internal and external loads.

The turbine operated at partial load during ~36 months under piping nozzle loads greater than those recommended in the code NEMA SM 24 [03] (see 5.3 below). Several tests were performed and the machine was submitted to several trips to correct some defects.

Those several heatup/cooldown transients added to the piping external loads in the machine (at low loads) greater than the recommended values in NEMA SM-24 [03] certainly affected the turbine alignment.

Two year after the first startup, in a programmed outage, a misalignment between the turbine and the reduction gear was evaluated. The measured values at that time were 0,53 mm in the vertical direction and 0,54 mm in horizontal direction. These values were above the maximum values allowed by the manufacturer, i. e., vertical $0,35 \pm 0,03$ mm and horizontal $0,24 \pm 0,03$ mm. For reasons not well completely explained and recorded, the manufacturer did not correct the misalignment and allowed the machine operation.

From the above explained, it is possible to state that the turbine misalignment was a direct cause for the blades rubbing in the casing and for the rotor locking.

Excessive Deformation in Stationary Parts Caused by External Loads (such as piping nozzle loads)

The steam turbine casings are submitted to external loads almost exclusively from the steam piping nozzles.

A fracture in the turbo-generator foundations with some differential settlement may cause some impact in the machine operation. Also, the use of an inadequate grout may lead to undesirable problems. But, these situations are not easy to find.

As the steam piping loads the steam turbine casing, the piping must be designed in a way that the nozzle piping loads do not exceed the allowable value recommended by codes or by the manufacturer in any operational condition.

Some situations often appear where the piping loads the machine beyond the allowable values. The more common are: errors in the design criteria; design errors; field modifications in the design to adequate the building and structures erection and machine installation. These excessive loads can deform the casing in hot condition and cause the progressive turbine misalignment.

In the case under evaluation, in the "as built" steam piping arrangement, the calculated resultant nozzle piping loads were 20 to 30% greater than the allowable values in the moments in global combination check (component superposition in the three directions) as in the moment in the vertical direction check, according to NEMA SM-24 [03], for the low load and no load conditions of the turbine. It is important to notice that the no load condition is the most unfavorable condition to the turbine because in it the large temperature differences and the large nozzle piping loads occur. The turbo-generator was operating always much close to low load and no load conditions far away from the full load condition where the temperature differences and nozzle piping loads are small.

It is not possible to characterize that the nozzle piping loads are the unique cause to the turbine rotor locking. But, it can be stated that certainly the loads greater than the allowable values contribute to the observed failure.

So, the turbine could be progressively misaligned by the nozzle piping loads at low power during the many heatup/cool-down events (test and trips).

CONCLUSIONS AND RECOMMENDATIONS

It is proposed a rational approach to assess the unique event of a steam turbine grabbing and locking. The proposed approach is based on the main recommendations from [01] and connects the observed failure mechanisms with the identification of possible causes of these mechanisms.

From the collected information and the visual inspection of the internals and parts of the steam turbine it was possible to perform a wide assessment of its rotor locking. The main

causes of the failure were identified and based on the evaluation of the identified causes some recommendations can be stated to evaluate similar events and to avoid such type of events in similar components.

In this unique case under study, the turbine had a rotor locking with damage to the internal parts. These damages were crush, fractures, and failure of the sealing strips and the labyrinths, and scratches and rubs in several points such as rotating and stationary blades.

The evaluation of the operational history of the machine before the failure, of the buildings, structures and systems that surround the machine, of the design documents, of the installation, commissioning and maintenance records implies that the locking was caused by the following combination of unfavorable situations to the machine operation:

[i] Many heatup/cool-down transients under low load conditions (~500 to 1,000 times in ~36 months of operation).

[ii] Nozzle piping loads impairing the turbine casing in low power condition greater than the allowable values specified by the code NEMA SM-24 [03].

[iii] Extended turbine operation (more than 15 minutes) practically without load, under exit steam temperatures greater than 320 °C and machine shutdown with exit steam at this temperature.

[iv] Internal and external turbine misalignment progressively built in ~150 trips in transient conditions described in [i] to [iii] above.

Under these operational conditions, the rotor temperature after the programmed outage was above 300°C in the coldest part. The previous progressive misalignment plus this temperature equilibrium conditions (without steam expansion) probably caused a high sagging in the rotor and grabbing and locking with the stationary parts.

Steam turbines are not fabricated to operate continuously at loads below 15-20% of the nominal load. In the case under evaluation case, it must be forbidden to operate continuously below 5,000 kW.

The turbine must not and can not operate at low loads. The operation at low loads causes the excessive heating of the machine and of the extraction and exit steam piping that may damage the turbine in such way described here.

For the plant configuration under evaluation, it is recommended to remove the inlet steam high temperature trip signal and to install a system for alarm and trip with 2 sensors inserted in the quick close valve body to capture the metal temperature gradients that can trip the turbine to avoid casing distortions.

Finally, it is recommended that the commissioning must be done using a systemic approach, testing and operating exhaustively the systems separated before the operation of the complete set avoiding unnecessary emergency trips of the turbo-generator.

REFERENCES

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