# EVN AG
# Vibration Problem
# TG2 2014

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Заглавие/Überschrift:
Visit Report – Balancing LP Rotor

| | |
|---|---|
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# GENERAL

In TEZ Plovdiv Server the steam turbine of Power Unit TG2 was taken out of operation due to vibration Problems in December 2014.

The turbine is built 1972 in Bryn. It is a 30 MW turbine with 2 casings, the HP and the LP casing. Between the HP and LP Casing is a controlled extraction. (Att1. *ST-cross-section*)
There are 3 bearings on the turbine rotor, bearing 1 is at the rotor end of the HP turbine, bearing 2 between HP and LP Rotor has the axial bearing and bearing 3 is on the generator side.
During one overhaul in the past, the last 2 stages of the turbine where taken away.
The last main overhaul was done by Bright Engineering and General Turbo in 2013.

The last trial to operate the turbine took place on 13th December 2014
The HD Part of the turbine was opened on 5th January 2015.
The rotor was taken out on 16th Januay 2015.

The following investigation report is aimed to find the reasons of the turbine problems and to consult on following measures to bring the turbine back to operation.

The report is based on

1. Visual inspection of the opened HD turbine on 7th Jan. 2015
2. Visual inspection of the opened HD turbine on 19th Jan. 2015
3. Discussion of behavior of the steam turbine during start up with operators
4. Trends from startup trials provided by EVN
5. Documents like clearance protocols from last overhaul
6. Clearance protocols and measurements taken after opening the steam turbine

**Main Events in the last months**

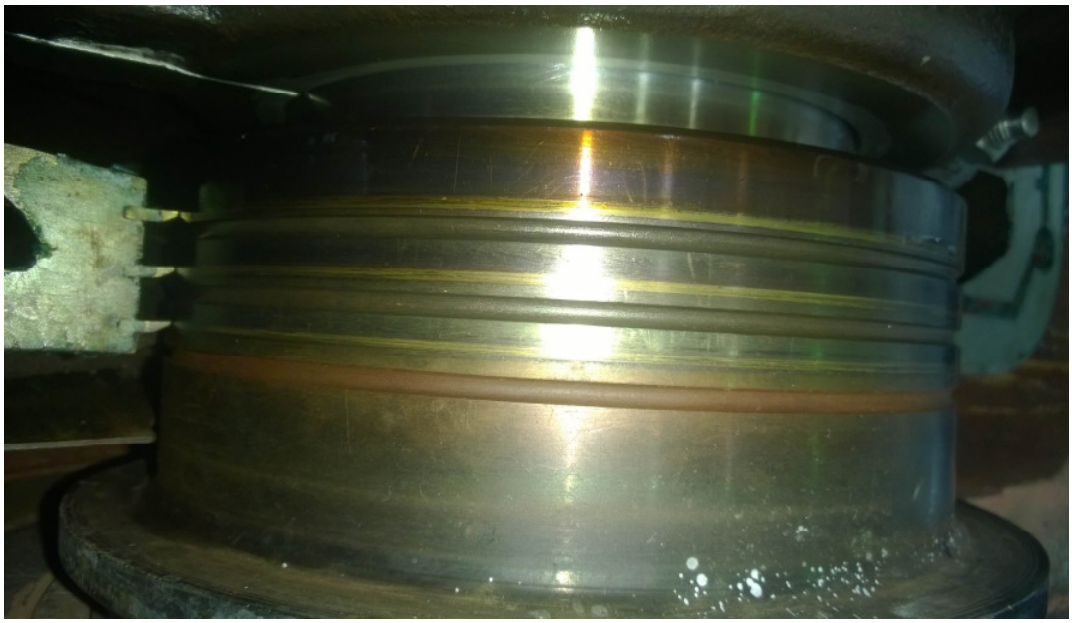
| | |
|---|---|
| Commissioning end and first successful startup after overhaul in 2013 | 28.12.2013 |
| Last successful operation winter season 2013/14 | 23.04.2014 |
| First startup winter season 2014/15 (successful??) | 03.11.2014 |
| Testing over speed protection after Bentley problems | 02.11.2014 |
| Several startup trails with vibration problems in bearing 3, then synchronization and trip due to vacuum – not vibration! | 03.11.2014 |
| Several startups with vibration problems in bearing 3 and first time in bearing 1 – but finally successful synchronization and 4 days operation | 15.11.2014 |
| Several startup trails with vibration problems in bearing 3, then synchronization and trip due **to vibration in Bearing 1** | 25.11.2014 |
| Several trials to synchronize, but always after some minutes trip due to vibration bearing 1 | 26-27.11.2014 |
| Inspection of bearings 1 and 2:<br>Run out of HP rotor at bearing 1 were found to be at 0,28 (should be 0,02). Correction of coupling between HP an LP rotor to get required values. | 30.11.2014 to 12.12.2014 |
| Several startup trails with vibration problems in bearing 3, then synchronization and vibration trip in bearing 1 (2 times) | 13.12.2014 |

# Findings based on Visual Inspection

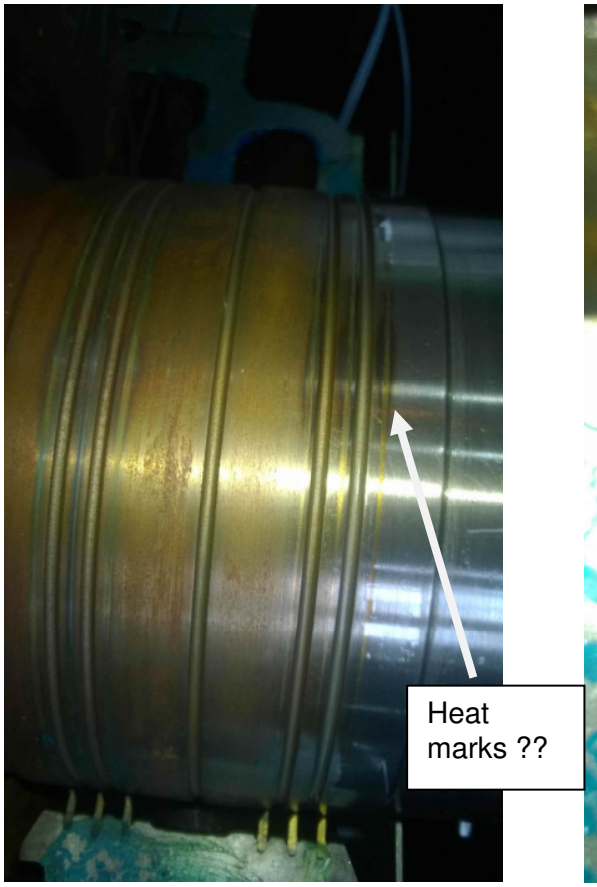
## General

Two visual inspections took place, one on 7th January after opening the HP casing and the bearings 1 and 2 and another on 19th January after removing the HP rotor.

## Oil Labyrinth Seals

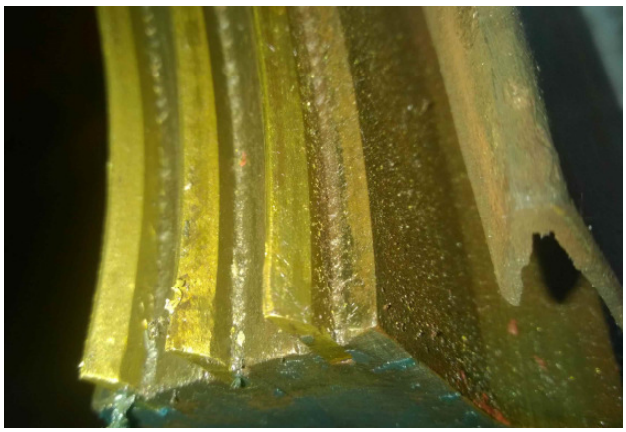


*Oil labyrinth seals*

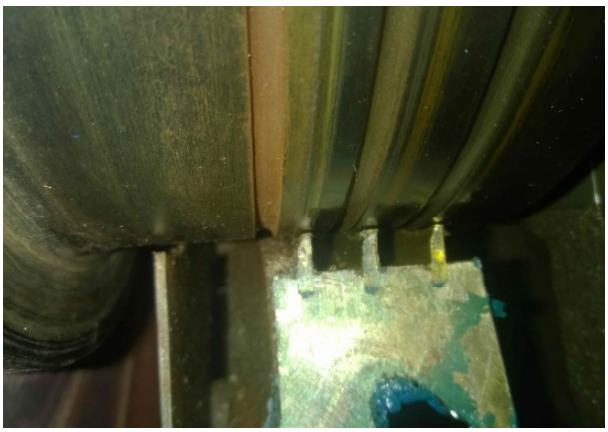



*Oil labyrinth seals*

*Oil labyrinth seals*



*Oil labyrinth seals*



*Oil labyrinth seals*

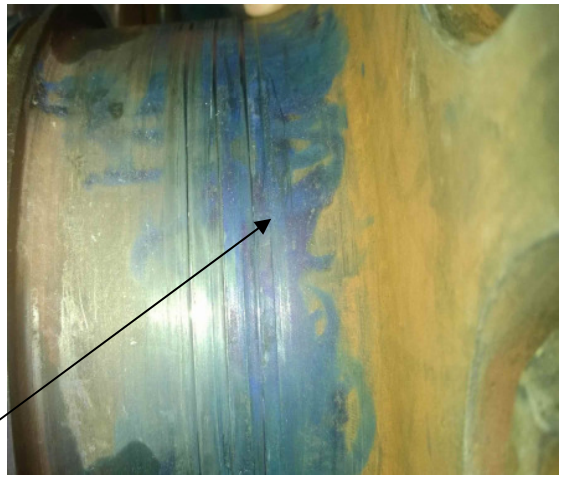
The oil labyrinth seals at bearing 1, left and right from coupling HP/LP rotor and left and right from bearing 2 have the same picture:
Strong wear on the sealing ring tips, strong rubbing marks on the rotor.

The rubbing marks are not constant around the circumference at coupling and at bearing 2. At bearing 1 the rubbing marks are nearly even on 360° of the rotor.

In some areas it seems that local heating left colored marks (may be misleading, as there are many effects, coloring the rotor).
See photos above!

At the HP/LP coupling on the HP side even grooves on the rotor are visible. See photos below

*Oil labyrinth marks at coupling*



*Oil labyrinth marks at coupling*

Deep grooves, inside not shiny
=> older, but after overhaul 2013!!

**Steam Labyrinth Seals**

All labyrinth seals have rubbing marks. In some areas they are strongly bended and deformed. In general close to the bearings, the labyrinths are in better condition, the severest damages are at the balance piston
See photos below!

*Steam labyrinth sealing - bearing*

*Steam labyrinth sealing - bearing*

*Labyrinth sealing – balance piston*

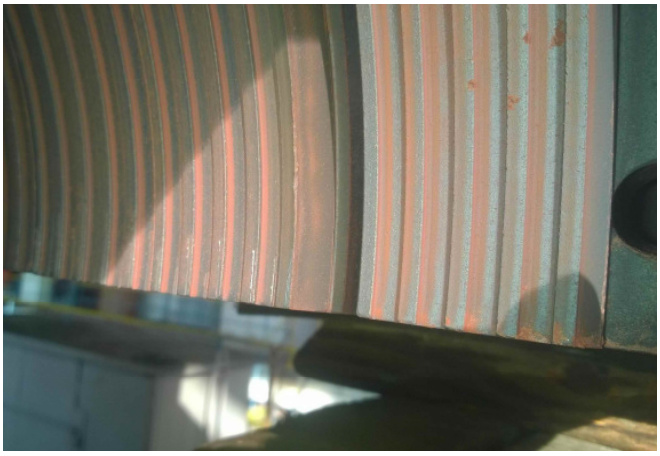
*Labyrinth sealing – balance piston*

*Labyrinth sealing – balance piston*

*Labyrinth sealing – balance piston*

Turning the rotor the severest damages correspond with the strongest rubbing marks of the oil labyrinths.
This is a hint, that the rotor bends before rubbing – not the casing.

On the photo right, there are new rubbing marks of the labyrinth seals close to the horizontal joint.
In the top of the stator no such rubbing marks could be seen.
This rubbing marks are not considered as dramatic, this means they could appear in any turbine running without problems.



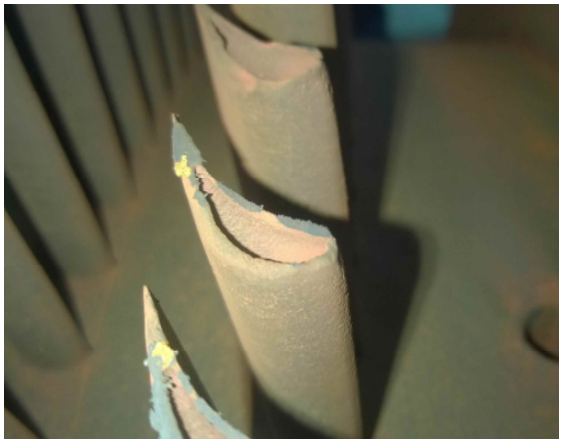
*Labyrinth sealing - stator*

**Blades at stages 1 to 30.**

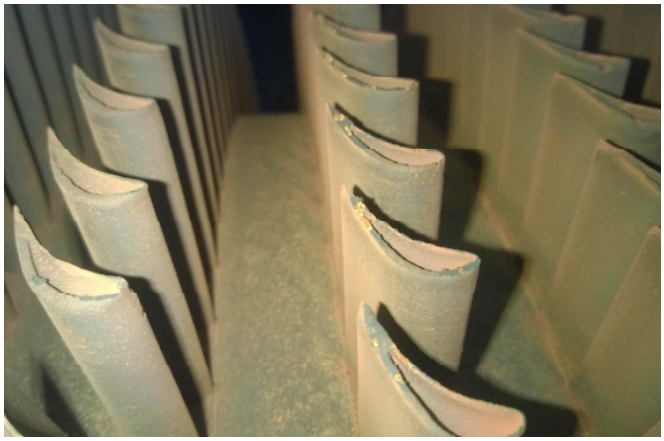
The HP stages 1 to 30 were not exchanged during the overhaul 2013. The blades were cleaned and tips rectified manually or even whole position was rectified, as some blades where bended before overhaul 2013.
The opposite side of the rotor blade tips is just the plane casing – no labyrinth. The clearance is generally more than 1 mm.
Even though in the middle part of the hp rotor (from stage 1 to 25) had clear rubbing marks of the blade tips. In the center of the rotor the marks were strongest and on circumference the biggest number of blades were affected.
This means as well the blades give the clear picture of a bended rotor in the moment rubbing happens – not a buckling casing.

*Rotor Blades 1-30*

*Rotor Blades 1-30*



*Rotor Blades 1-30*



*Rotor Blades 1-30*

On the upper left photo the stages 29 und 30 can be seen. They have no rubbing marks, as they are very close to bearing 1.

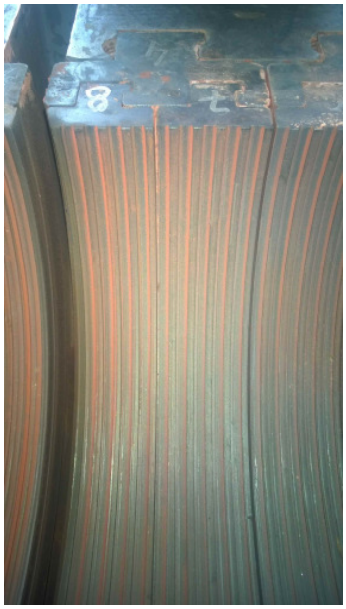
On the blade tips the shiny marks show rubbing during the last operation. Other not shine rubbing marks may have happened weeks or as well years ago. This cannot be identified at the moment. These not shiny marks could be fined on any blade, there is no structure for distribution on the HP rotor.

As well on the upper left photo white marks (like salt) at the blade foot are visible. This means there is an issue with steam quality. Such marks in the HP part of a steam turbine are not common.

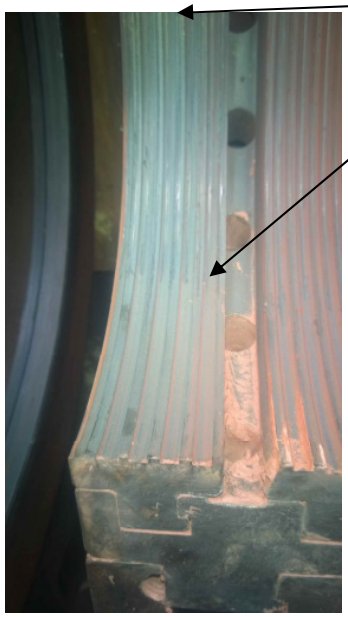
Some blades (2 or 3) were found bended as a whole. The position of these blades where not corresponding with the rubbing marks.

**Stator - lower half**

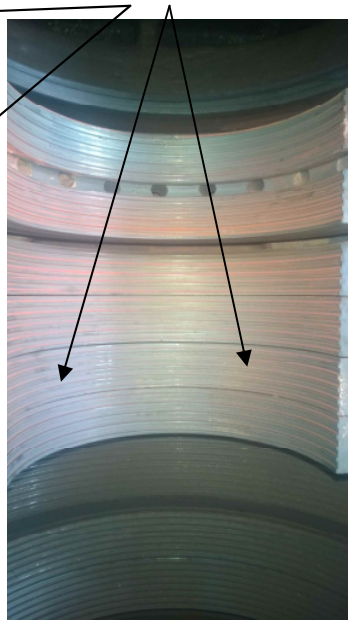
The stator of the labyrinth seals at bearing 1 shows slight rubbing marks in 180° position.



*Stator – lower half*



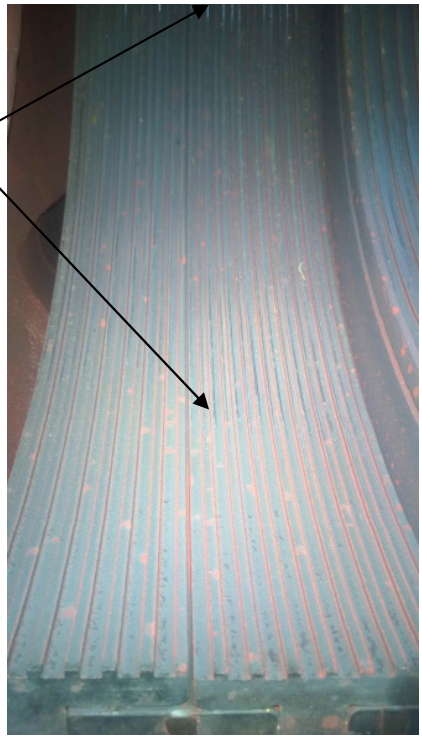
*Stator – lower half*



*Stator – lower half*

The stator of the labyrinth seals at the balance piston has as well fresh rubbing marks only at a segment center down.

The marks are very thin. They are not considered as dramatic.



*Stator – lower half*

A different picture show the rubbing marks from the rotor blades in the lower half of the HP casing. Marks at the left side (looking direction LP steam flow / generator) are dominating, see following photos.

*Lower HP casing - Left side*

*Lower HP casing – center down*

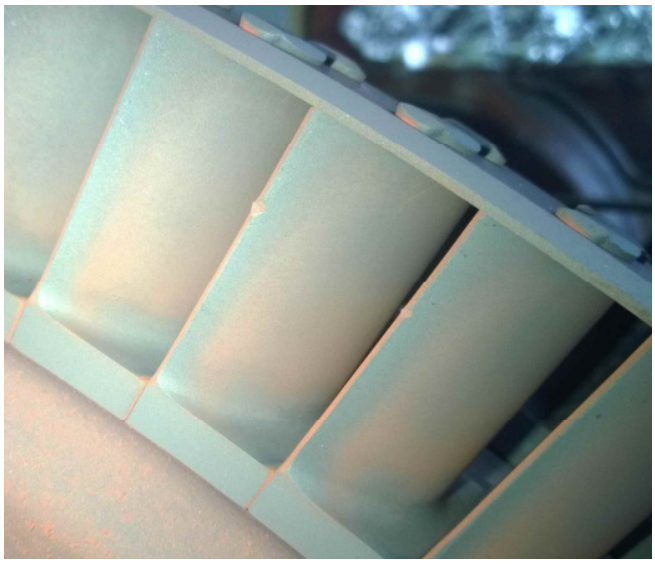
The rubbing marks do not show the typical picture of a casing, which is buckling due to uneven top / down heating during start up, because they do not appear at the bottom center but on one side.

*Lower HP casing - Left side*

## Control stages

The control stages were exchanged during overhaul 2013.
On the top there are no rubbing marks.

Some defects from not clean steam were found, photos below.

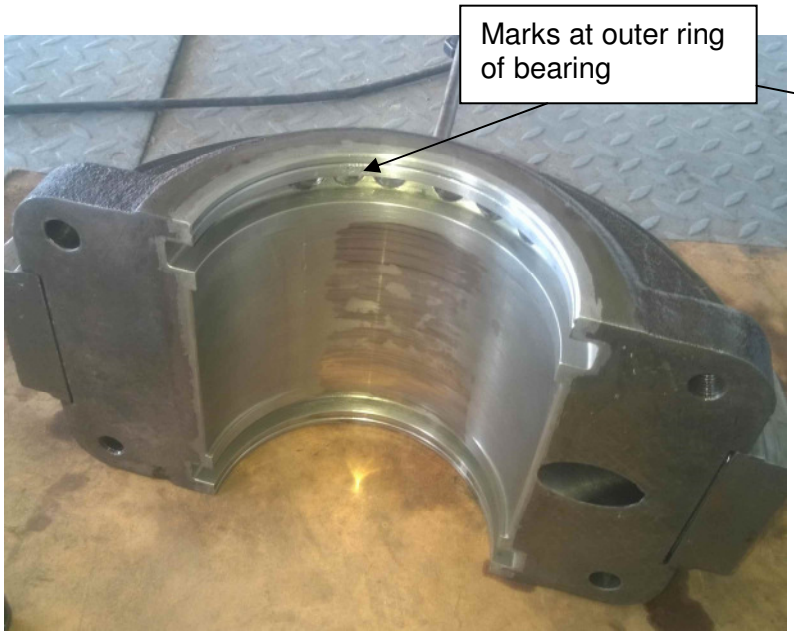


*Control stage HP rotor*

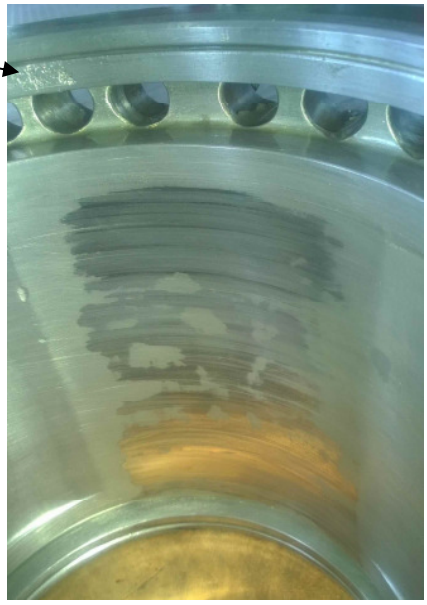
*Control stage HP rotor*

## Bearing 1

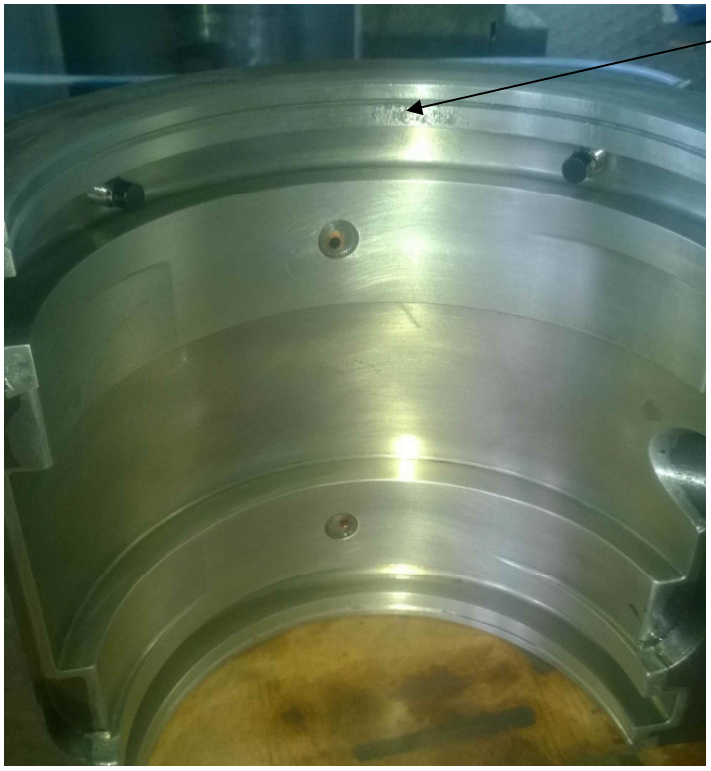
The bearing looked in general not like new, but ok. The rubbing marks at the lower half could be the result of many start stop operations and operation in turning gear with not sufficient oil supply, which is normal for such systems without jacking oil.




*Bearing 1 – lower half*



*Bearing 1 – lower half*




*Bearing 1 – upper half*

There are many fine grooves, which will have not a notable impact on operation at the moment, but is a hint for not sufficient cleanliness of the lubrication oil.

There are some marks at the outer ring of the bearing, but not considered as relevant impact to vibration.

# Findings based on Vibration Trends

## General

For analyzing the vibration behavior, data starting from 2.11.2014 are available.
The following trends have the same time window and sampling rate 20 s.

The trends show the vibration of bearing 1 and 3, bearing 2 is not shown for having an easier overview. In general the vibrations at bearing 2 are at the same range.

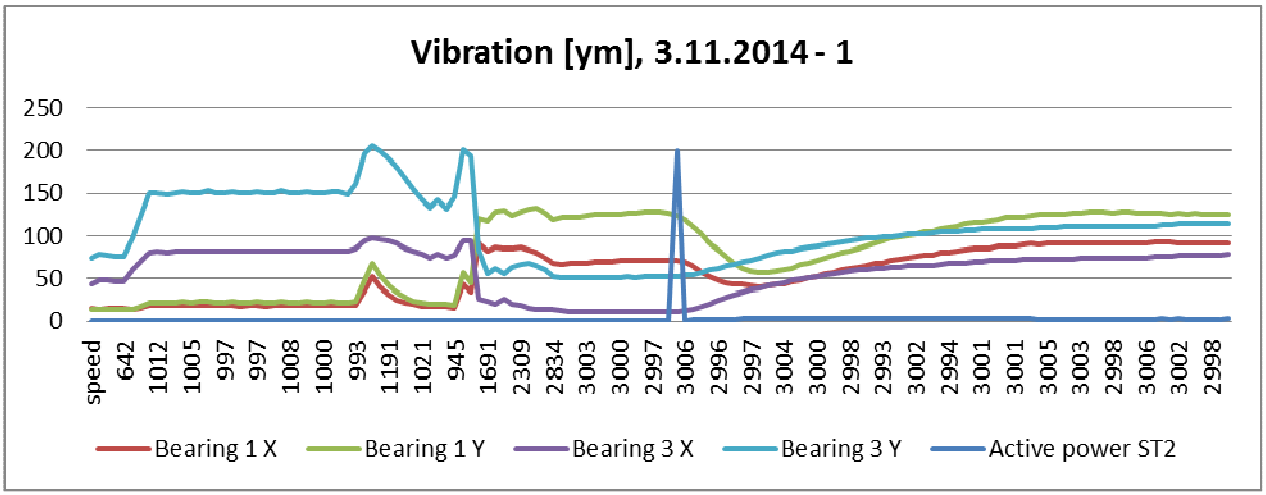
According the event list (see above) in this report the trends on 3.11. , 26/27.11 and 13.12 are presented, because:

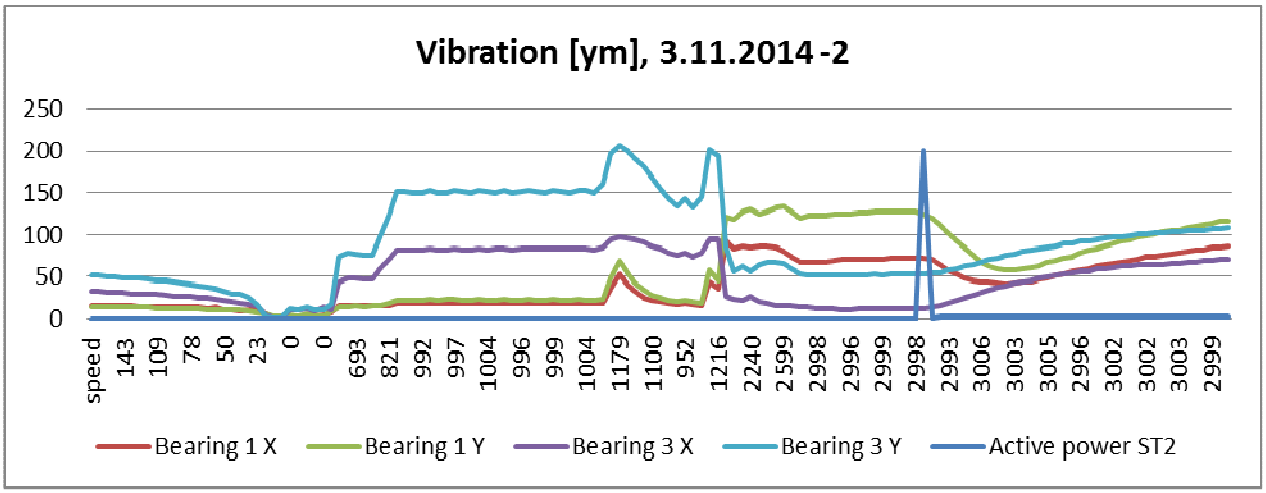
| | |
|---|---|
| 3.11. | date, at which actual problem did not exist (vibration trip bearing 1 after synchronization) |
| 26/27.11. | date, at which actual problem happened |
| 13.12. | date after bearing check and realigning HP Rotor |

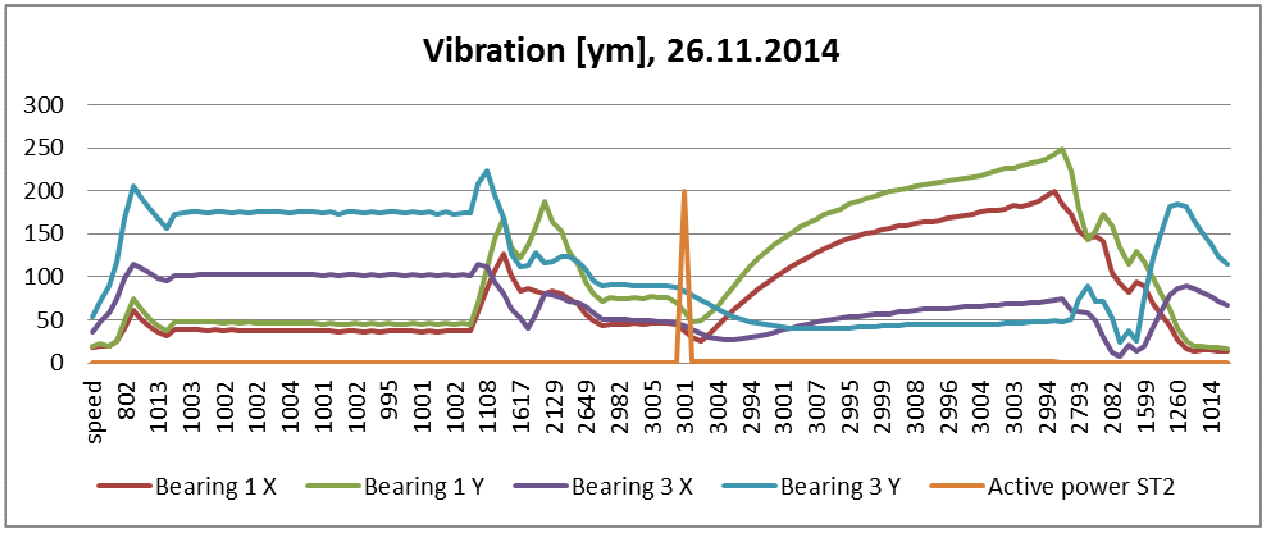
The active power has a peak to 200 in the moment of synchronization – just for better visibility.

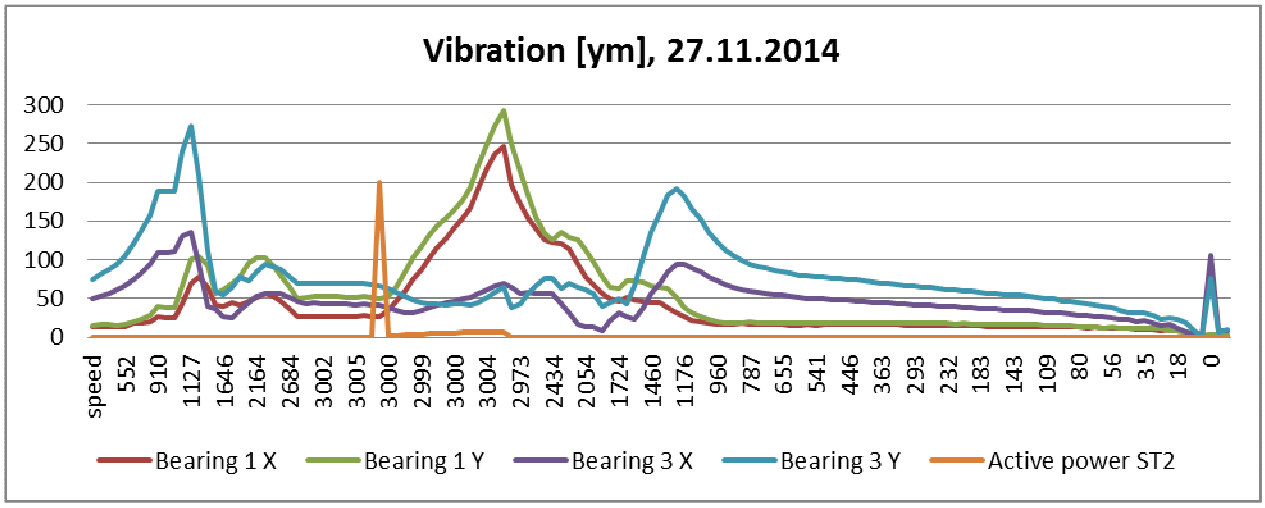
## Findings

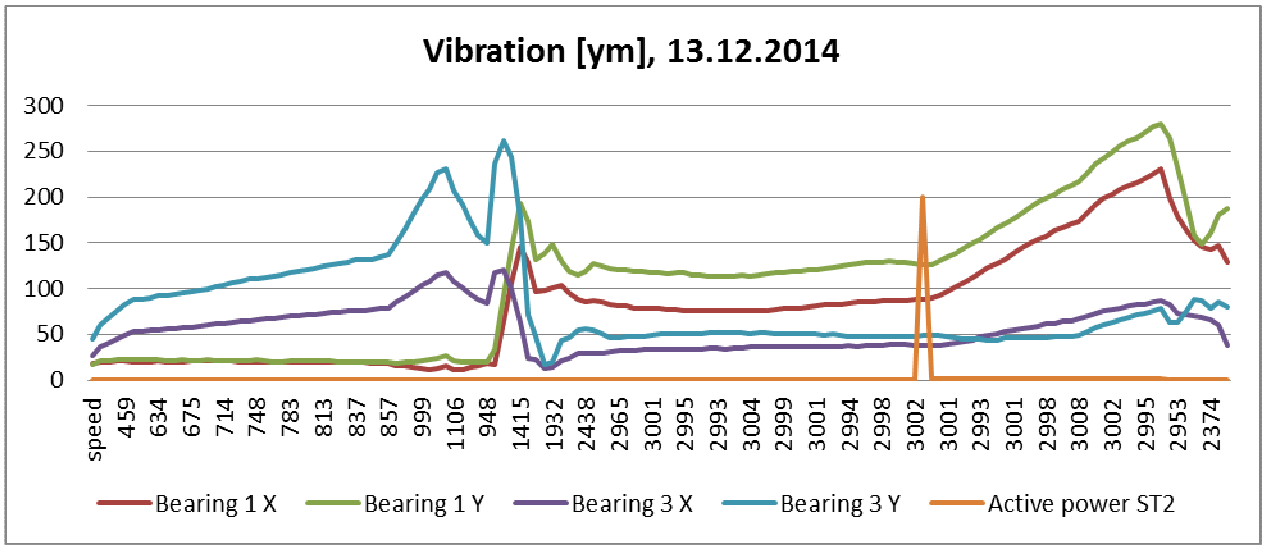
Before synchronization (peak of active Power) on each trend there is a time period with synchron speed for several minutes.






Comparing the values at the different dates show on 3.11. and 13.12. nearly the same picture, bearing 1 between 70 µm and 130 µm, bearing 3 close or below 50 µm. On 26/27 the values for bearing 1 are even lower, for bearing 3 a little higher.
The run out correction before the 13th at bearing 1 seems to have very small effect.

**In the phase of passing the critical speed**,
a worsening of the situation may be observed. On 3rd bearing 3 reaching around 200 µm, on 26th 220 µm up to 270 and 260 µm on 27th and 13th.
But an unclear picture is given by bearing one, on 26th and 13th relatively high, but on 27th and 3rd very small!

**The mayor difference is the phase after synchronization:**
On 3rd the vibration in bearing 1 going first down and then slightly increasing up to a value of 120 µm
On 26th in general the same behavior can be observed, but the increasing after going down is not so smooth any more, seems to stabilize, but then finally just not manages to stabilize.
On 27th the picture looks much more drastic, but on this trial the load after synchronizing were increased faster – as a consequence the vibration went up faster - no chance!!
On 13th as well directly up after synchronization, no hint for stabilization but quite slower increase compared with 27th as well load were not increased so fast.

To sum up all observations from vibration trends, including as well all trends not shown in this report:

- It cannot be observed, that a **severe** event has had **one big impact** to the vibration behavior of the turbine.
- In all trends since 2.11. there are high vibration situation during startup which cannot be considered as normal – especially for bearing 3 – very often trip during passing critical speed
- The actual problem is not something tremendously new in the overall vibration picture, but an additional change in a bad direction, may be “the last drop” … or let it be some more drops!

## Findings from alignment check and clearance measurement

**Alignment check of HP Rotor**

On 30th Nov. 2014 the alignment of the HP Rotor where checked, It was found that the radial run-out at bearing 1 was up to 0,28 mm. By shaping the coupling at bearing 2 the run-out was corrected to a range of 0 to 0,01 mm. (Att2. *Coupling-check-prot*) See corrected area at the coupling in photo right!

*Title*

The checking of the alignment after opening the HP casing now:
Run out at bearing 1: As adjusted on 30th Nov 2014 – small increase by 0,04
(Att5. *Protocols_runout-EN)*
Run out at coupling to LP rotor: As adjusted on 30th Nov 2014
Run out at coupling to the generator: max 0,1 – not very good (Att3. *gen coupling-check )*

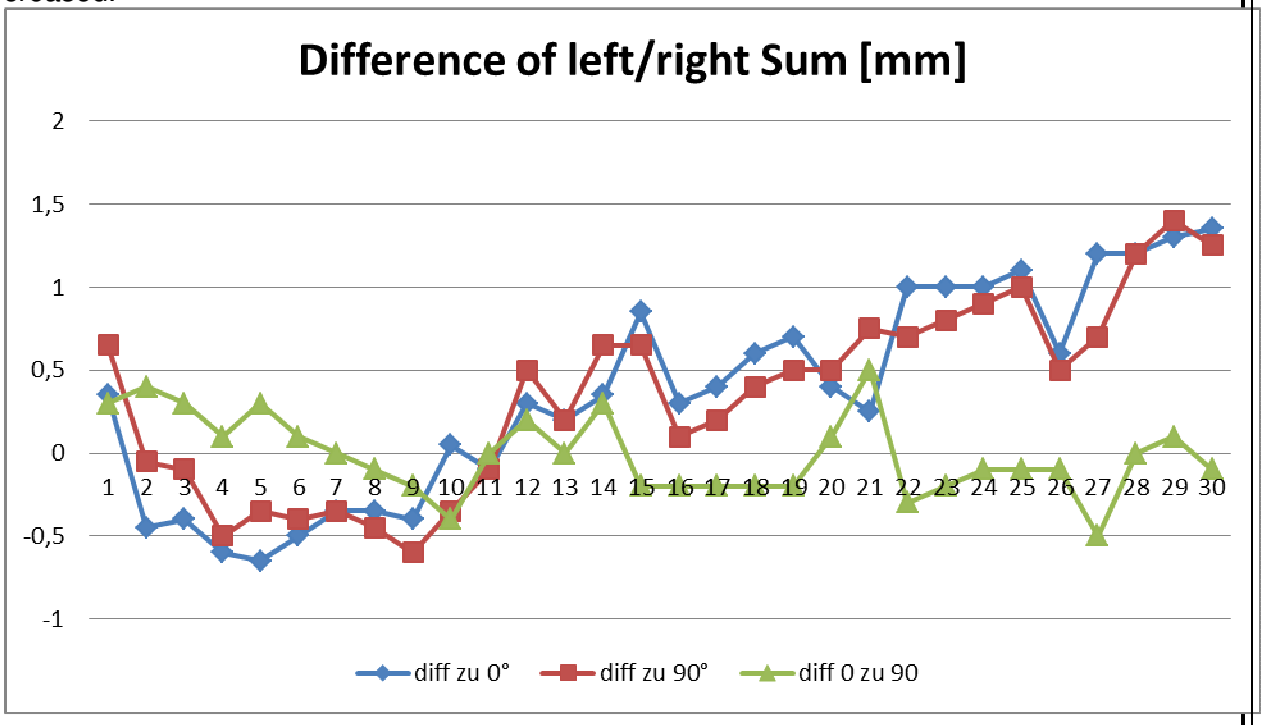
The run out at various points of the HP rotor was measured on 06.12.2014 (Att5 *Protocols_runout-EN*). There are max values of 0,04mm as an exception, mainly the values are between 0 and 0,02 which shows a good condition.

**Clearance measurement**

The clearance measurement was carried out in 2 rotor positions - one with main rubbing marks at the rotor blade tips in up position (12 o'clock) and one position turned by 90°.

The clearance measurement and comparison of the clearances after overhaul in 2013 shows (Att4 *Clearance-prot*)

1. **Front HP Labyrinth Seals (at B1)**
   After overhaul 0,35 to 0,4 now increased to 0,6 to 1,4.
   The turning by 90° shows left and right smaller values, which means the strips have oval shaped wear or just because damages are uneven distributed over the circumference.
2. **Back HP Labyrinth Seals (at B2)**
   After overhaul 0,35 to 0,4 now increased to 0,3 to 1,0.
   The turning by 90° shows left and right smaller values, which means the strips have oval shaped wear or just because damages are uneven distributed over the circumference.
3. **Balance piston Labyrinth Seals (at B2)**
   After overhaul 0,8 to 0,9 now increased to 0,7 to 1,7.
   The turning by 90° shows left nearly same values, but right by 0,3 to 0,6 mm reduced values.
   Damages are quite uneven distributed over the circumference.
4. **Blades stages 1…30**
   The blades of stages 1…30 were not exchanged during the overhaul in 2013. There are no labyrinth seals on the opposite sides of the blade tips. Therefore the clearance of the blade tips was quite big, mainly between 1,2 and 1,7 mm.
   The measurements now seem to be very unregularly, see graphic below:
   On x Axis there are the stage number. For each stage the sum of the right and left measurement was calculated, to make the clearance independent from rotor position. Then from the sum after overhaul, the sum of the measurement left right in position 0° is subtracted - blue. (other graph 90° - red)
   The Result should be 0 or slightly negative – which would mean total clearance slightly increased.




Obviously the effect of uneven blade length and error from measurement is bigger than any

real effect of increase of clearance. So result is “No Result!!
The green line shows the difference between the sums of left/right clearance at 0° and the sum of 90°. Ideally it should be a line at zero, but alternations are significant.
The variation on clearance from blade to blade is probably the reason.

5. **Clearance of oil labyrinth seals and bearings:**
These measurements were not repeated now, but from visual inspection it can be derived, that the bearings are unchanged left/right. Maybe a very small increased vertically could be expected, but should not be significant
The oil labyrinth seals are definitely with increased clearance now, maybe not much, because the thickness of this seals are much bigger than steam labyrinth strips and the material has a good sliding property, this means wear takes time and a lot of effort!

**But remarkable from the protocol after the overhaul in 2013 (Att6 *bearing-oil-sealing-clearance* – see red clouds in the protocol) is the following:**
During overhaul 2013 the lateral clearance at Bearing 1 has increased to 0,45 mm(0,25 before overhaul). But at the same time, the clearance of the oil seals was reduced to 0,1 mm (from 0,3 before overhaul).

Similar Situation, less drastic, applies for bearing 2.

**Normally the oil seals close to the bearing have to have minimum same, or even a little more clearance than the bearing.**

## Other Findings

**Operation on start up:**
With the operators and on the base of trends was checked, if special steam or warm up conditions could be a reason for the problem.
Without documenting details in this report it seems very unlikely, that this is the case.

It seems to be the other way round: The high sensitivity for vibration of the system made it necessary, to warm up before passing critical speed without trip due to high vibration.

## Summarization and Conclusion

The fact finding give a picture, which does **not** describe a direct and clear cause of the actual problem – raising vibration direct after synchronization
and of the general vibration problem – often vibration trip during speed ramp at critical speed.

Destroyed sealing strips, and rub marks at casing and blade tips are more likely to be a consequence of operation with high vibration, but not the reason!

Quite sure is:

1. The vibration is **not caused** by buckling of the casing due to uneven preheating, the rubbing marks and the vibration trends do not give any hint in this direction.
2. The vibration is **not caused** by unbalanced rotor due to broken blades, lost balance weights or other mass losses,
   the visual inspection do not give any indication in this direction.
3. The vibration is **not caused** by bearing problems due to shortage of oil or not sliding bearing housing etc.
4. The rubbing marks at blades, with more than 1mm clearance, are result of high vibrations and **not root** cause for the vibration problems.
5. Deviation from original alignment is **alone** not an explanation for the vibration problem. The correction before 13$^{th}$ of December had a quite small impact.

The only finding, which normally is not presented in operated steam turbines, is the rubbing of the oil seals on the rotor. The rubbing is considered as significant – the marks cannot be seen as slight or not relevant!
The oil seals rings from brass have much smaller clearance than the bearings, which led to rubbing at the rotor – proven by the severe rubbing marks on the rotor and on the brass rings.

The question is**: Does such rubbing off oil seals brass rings could cause high vibration?**
The answer is **YES**! There are such examples in industrial steam turbine experience.

The brass rings are relatively strong, compared to sealing rings of steam labyrinths.
The rubbing of the brass rings at the rotor induces heat at the rotor.
If the heat induction is not 100% symmetric – which is normally the case- it will cause rotor bending, which will increase the same rubbing effect.

Depending on the level of friction, rubbing force, and reaction forces to rotor deformation, this process may get instable, or not. This means it could lead to increase of vibration but only to a certain limit, but as well it could lead to a not ending increase of vibration over some time – as observed after synchronization.

**Directly appearing two questions:**

**Why exactly the instable behavior after synchronization and not before?**
The generator and its magnetic field give a more restrained position for the rotor, which could increase the rubbing force at brass sealing strips.

**Why this did not happen before, directly after overhaul?**
Always the turbine suffered high vibration levels after the overhaul. The effect could have been less intensive as long as alignment still was perfect. Slight changes with the time could have intensified this effect and turned from stable and limited increase of vibration to unstable, unlimited increase of vibration. Any defect – maybe something not seen yet – could have intensified this effect

Both answers are not sure, but possible.

And the findings do not give another more likely theory up to now.

The behavior of increasing vibrations over some minutes without any indication of stopping (instability) is significant **AND** known to be possibly caused by rubbing oil seals of a bearing housing at a steam turbine rotor.

**Resulting Measures:**

1. All damages of the rotor should be repaired, clearances on steam labyrinths should be rechecked for improvement (0,35 is as well less than bearing clearance!!??)
2. Bearings clearance und oil seals clearance should be rechecked. Probably oils seals should have same or 0.05 bigger clearance than bearings. At the coupling even more!
3. Assembly with alignment together with LP rotor and generator rotor
4. During start up after assembly additional vibration measurement

Optional:

5. The lower stator parts may be lowered by 0,05 to 0,1 mm, because steam labyrinth seals had rubbing marks at the bottom, but no marks on the top.
6. Because the given explanation is not 100% sure, the rotor could be checked for balancing and cracks.

Anyway the measures 1. to 4. will show, if the presented theory is correct, or fact finding and analyzing need to be continued.

Ramon Harps
RAP systems

## Attachments

*Att1 ST-cross-section*
*Att2 Coupling-check-prot*
*Att3 gen coupling-check*
*Att3 Clearance-prot-20150107*
*Att5 Protocols_runout-EN*
*Att6 bearing-oil-sealing-clearance*