Analyzing and Solving Stability Problems during the Commissioning of the Steam Turbine

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***Abstract:** The commissioning of the steam turbine in the CCPP of Vlore (Albania) was carried out after a shutdown of about one year. During previous operation of the unit, in particular in a couple of shutdowns, were observed high vibration at bearing MAD 21. Before the restart, the oil deflector of the MAD21 bearing (the bearing located in the front standard, on the inlet side of the steam turbine and adjacent to the clutch) was modified increasing the radial clearance on the part of the oil deflector acting as a thermal shield with the aim of eliminating / preventing the risk of rubbings. Rubs at the location of the above mention oil deflector were considered as the very likely cause of high vibration at bearing MAD 21. A lot of tests were carried out during the recommissioning phase and the data received were analyzed. This paper details the discovery of the problems, initial attempts to address them and the use of the rotor dynamics tools to find a solution of the problem by the optimization of the bearings.*

The bearings were not optimized as per rotordynamics analysis (RDA) findings, because it was a too expensive solution. The solution was found making some modification on control system of the ST, without affecting the mechanical integrity of the machine.

***Keywords:** bearing vibration, critical speed, shut down and start up trends, trip limit.*

I. INTRODUCTION

A review study was carried out based on previous experience and the international literature which treat the vibration behavior of ST during the start – ups [1]. The steam turbine (ST) is of a mixed pressure design, it consist of three sections, low pressure section (LP), intermediate pressure (IP) and high pressure (HP). The ST is connected through a self synchronized clutch with the generator and it is synchronized with the generator once the ST reach 3000 rpm. The subject steam turbine has been restarted, after a shutdown of about one year. During the commissioning, before the shutdown of the plant, were verified high vibration in the MAD 21 and MAD 23 bearings of the steam turbine. This behavior was mainly verified during the cold start up, near the critical speeds [2], as well as during the shutdown of the steam turbine Before the restart, the oil deflector of the MAD21 bearing (the bearing located in the front standard, on the inlet side of the steam turbine and adjacent to the clutch) was modified increasing the radial clearance on the part of the oil deflector acting as a thermal shield with the aim of eliminating / preventing the risk of rubbings [3].

Rubs at the location of the above said oil deflector were considered as the very likely cause of high vibration at bearing MAD21 observed in few occasions during operation of the unit, in particular in a couple of shutdowns.

II. DATA COLLECTION AND ANALYSIS

The vibration behavior of the steam turbine has been monitored after the above said modification, i.e after the restart. During the commissioning the vibration of the steam turbine were measured for all the conditions that steam turbine operate and data regarding the following events are available.

1. Cold restart - Figure 1
2. Shut down (trip from base load) – Figure 2
3. Hot restart – Figure 3
4. Operation at base load – Figure 4

Analysis of the above data indicates:

a) acceptable vibration behaviour during startups: the maximum vibration is recorded at bearing MAD21 at the 1st critical speed of the steam turbine and it is about 80-85 µm, 0-p (relative vibration of rotating parts: alarm set at 75 µm 0-p). Significantly lower vibration levels at bearing MAD 23.

b) no differences during the cold or hot startup [4].

c) good vibration behaviour during shut down, with a max vibration level of about 45 µm 0-p at bearing MAD 21.

d) good vibration behaviour at load: about 31 µm 0-p at brg. MAD21, about 20 µm 0-p at brg. MAD23. Both values refer to rotating parts.

e) low vibration levels, both during speed transients and at load, for both bearings on stationary parts.

Some comments are due regarding the above points:

Usually the vibration behaviour is rougher during runs down than runs up, because speed gradients through critical speeds cannot be controlled during shutdown and therefore the speed gradient is lower, allowing vibrations to develop at crtical speeds. A bearing reaching and passing alarm level during speed transient can be accepted if vibration levels at load are good. No accepted common vibration standard requires vibration below alarm level during speed transients.

As a matter of fact the vibration behaviour of the steam turbine after the correction activity was reasonably good. In particolar during the rundowns, no vibration increase was observed at all or related to rubs as previously occurred.

At load the vibration behaviour of the steam turbine can be classified as just within class A of ISO 7919-2 (A/B boundary 80 µm pp per ISO 7919-2) [5].

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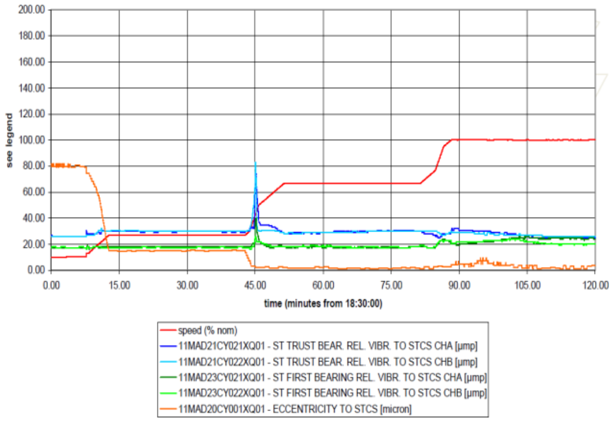

Figure. 1. Cold start trends

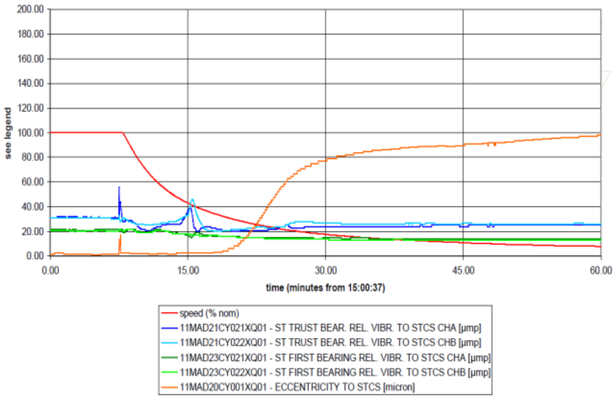

Figure. 2. Shut down from base load

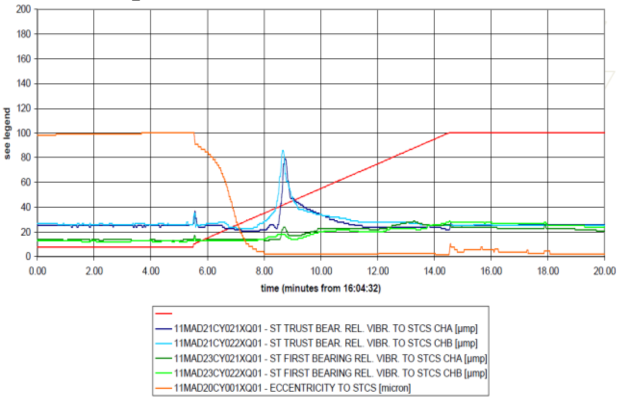

Figure. 3. Hot start

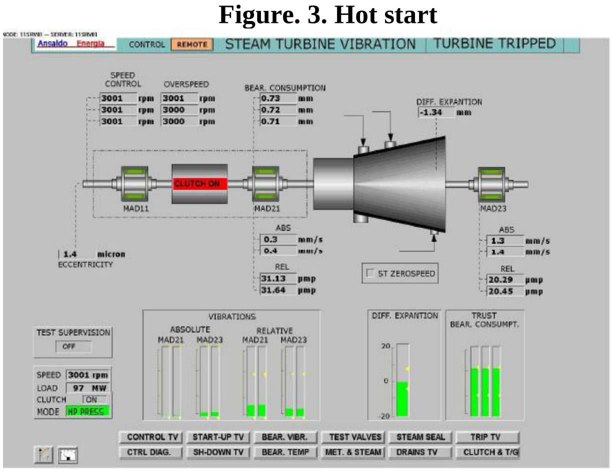

Figure. 4. Print screen of operation at load (clutch engaged)

Some trips of steam turbine due to high vibration occurred during the commissioning and the behavior of ST during this trips was analyzed.

Data available:

- Trip and first restart – figure 5
- 3rd restart after two trips – figure 6

A steam turbine trip occurred due to high vibration of brg. MAD21 (MAD21CY22 sensor).

It was quite immediately clear that the high vibration was due to a spike occurred at sensor MAD21CY11 (relative vibration, rotating part) of brg MAD21. Analyses carried out on the data provided by site confirmed the initial findings:

- No vibration occurred at sensor A of brg. MAD21, neither to brg MAD23
- No vibration increases occurred on stationary parts

Other spikes were recorded before and after the trip at the same sensor. Checks carried out later on the signals and sensors indicated a probe converter faulty for the relative vibration measurement of brg. MAD21 sensor A.

A restart of the steam turbine, after about 1 ½ hour from the trip, was carried out but a trip occurred at about 1100 rpm, for high vibration at brg. MAD21.

A second restart after further 50 minutes failed again due to trip for high vibration at brg. MAD21 (data non available).

Finally the unit was restarted about eight hours after the trip and full speed was reached, in spite of quite high vibration at brg. MAD21 (above 140 μm 0-p with a readjusted trip limit of 125 μm 0-p plus a delay of the trip of 1,5 seconds) [6].

Analysis of the data provided shows a quite uncommon behavior of bearing MAD21 vibration (at both sensors A and B) during run down, i.e a significant vibration level increase during run down with a maximum of 75 μm about one hour after the trip with the steam turbine at about 300 rpm. This is a very high and uncommon vibration level for such a low rotating speed [7]. Later the vibration behaviour trends tend to decrease, but at the moment of the 1st (aborted) restart still higher than the value that (looking at the data of other run down and start up) can be considered typical for the unit [3].

Also the eccentricity reading, compared with readings of other run downs and run ups, indicates an uncommon behaviour (increase up to 155 μm about one hour after the trip, against usual values of 80-100 μm) [4].

It is quite clear that the high vibration levels at the restarts are related to a temporary bowed rotor.

The causes of the bowing and of the resulting “high eccentricity” were not known.

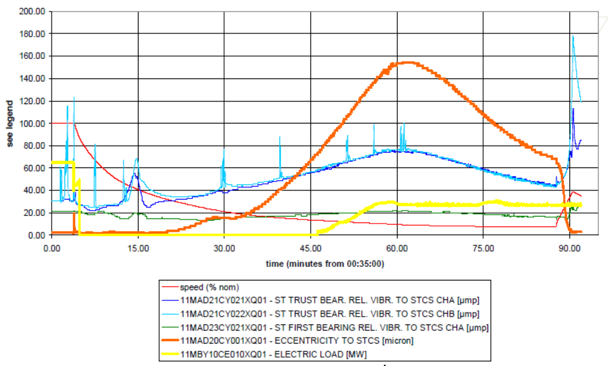

Figure. 5. Trip and 1st restart

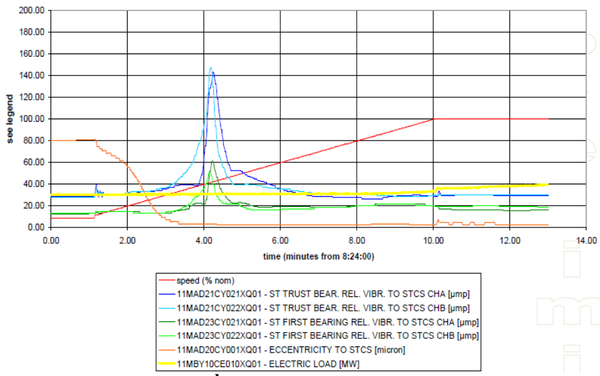

Figure. 6. 3rd (hot) restart after two trips

In order to understand the cause of the bowing and the "high eccentricity" values, further test were carried out in site.

Data available

- Trip of ST during shut down – figure 7
- Startup of ST after trip, hot condition – figure 8
- Shutdown of ST due to a trip – figures 9
- Startup of ST, cold condition – figures 10
- Emergency shutdown – figures 11
- Trip of ST, high relative vibration – figure 12

A further trip due to brg. MAD21 relative vibration (probe CY22) spikes occurred during run down of the ST. Vibrations during run down were quite low, some increase of vibration level at brg. MAD21 as well as of the eccentricity occurred again but with levels significantly lower than the previous observed.

The steam turbine was restarted about 3 ½ hours after the trip and full speed was reached with relatively high vibrations at brg. MAD21 at the critical speed (about 135 µm 0-p)

Then a further trip occurred on the power Station (not related to steam turbine). Vibration behaviour was good during run down, 65 µm 0-p at brg. MAD21 passing through critical speed. No increase of vibration at low speed were observed and the eccentricity was "normal".

The data of this trip, provide also a better understanding of the eccentricity reading, with the unit on turning gear. The p-p eccentricity (i.e. the so called TIR) is slightly less than 30 µm.

Operation of the steam turbine during a few events was monitored too. In particolar a startup, a shutdown and a trip were analyzed.

During the startup (a cold one), vibrations level were relatively low also at critical speed (< of 80 µm 0-p). Vibration levels at load were to acceptable values and the operation of the ST was stable.

It is also worth of note that the eccentricity before startup (with the stam turbine on turning gear) was about 30 µm pp and reached a reading of 80 – 90 µm with the steam turbine revolving at a couple of hundreds of rpm.

During the shutdown, vibrations at critical speed were quite similar to them on start up. No significant increase of vibration at low speed, eccentricity behaviour "regular" with usual 30 µm on turning gear.

A steam turbine trip occurred due to spikes of the MAD21 sensor CY22 (relative vibration). Vibration at MAD21 brg at critical speed were normal as well as at low speed. Eccentricity at low speed (no turning gear data available) still "normal".

The steam turbine was restarted one hour later and clutched (synchronized). There are not data available, but no any problem was reported from site.

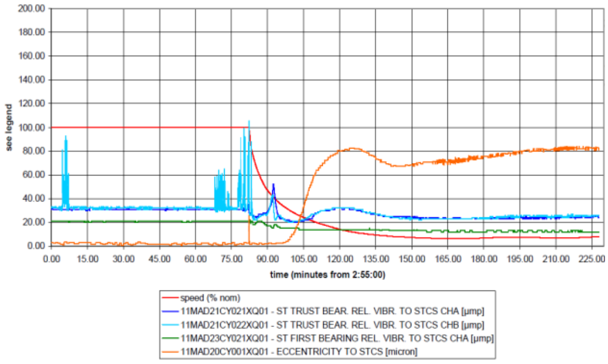

Figure. 7. Trip of ST during shut down

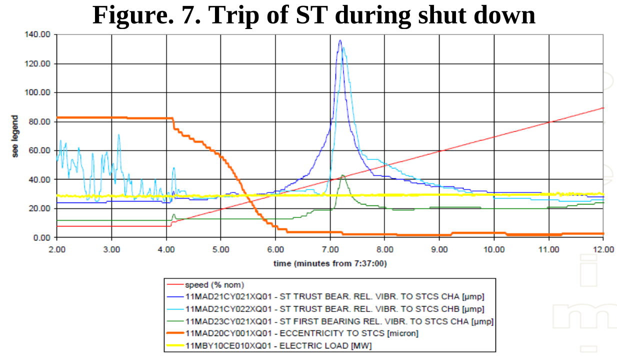

Figure. 8. Hot restart of ST

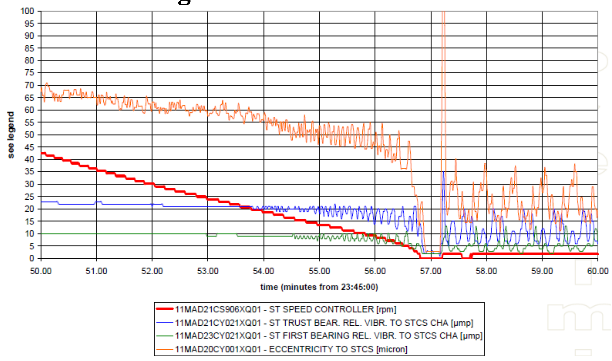

Figure. 9. Trip of ST (eccentricity on turning gear)

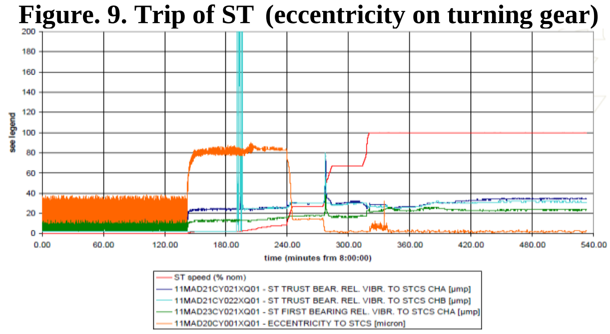

Figure. 10. Startup of ST, cold condition

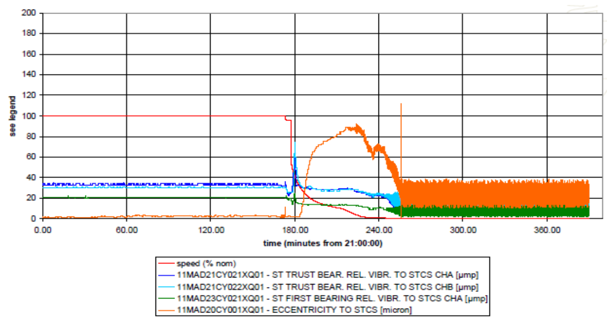

Figure. 11. Emergency shutdown

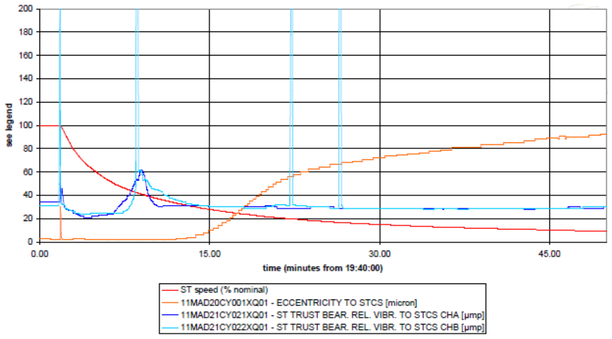

Figure. 12. Trip of ST, high relative vibration

From above data analyzing it was note the presence of high amplitude vibration at bearing MAD21 either during run up and run down and it was thought that possibly the static loading on that bearing was low. This could introduce substantial cross-coupling, resulting in oil whip. An alignment change was made, in order to increase the unit load on this bearing. The MAD21 bearing elevation was raised and as effect this bearing could accept more static journal load. It was expected that the increase in the bearing loading would reduce the cross-coupling enough to avoid the instability. However, this action did not have the expected effect and there was no change in vibration behavior.

A computer model of the steam turbine train (as shown in Fig 4) was built up. The rotor of the ST was supported by springs that represent the stiffness and damping of the fluid film bearings. In the middle of each spring was put the mass of the support structure and the spring below the mass models the stiffness and damping of the support to ground [8]. For this analysis specific bearing pedestal information was taken from the manufacturer AEN (Ansaldo Energia). Eight percent of critical damping was assigned to each support based on experience with similar machines. The AEN provide sufficient drawings of the turbine rotor and bearings.

All the above information was used in modelling the turbines for the rotordynamics analysis (RDA). The model results analyzing show clear that the bearing MAD21 should be optimized for solving the problem. The contractor didn't accept to change the bearing and proposed to make further tests in site and in the end after an accurate assessment to provide an acceptable solution.

The behavior of the ST was observed further as per below events:

Data available (partially)

- Startup of ST, cold condition – figure 13
- Shutdown of ST – figure 14
- Failed startup, warm condition – figure 15

Vibration up to 140 µm 0-p at MAD21 brg. were observed during the startup in cold condition. This vibration level is about twice the vibration observed during the previous cold startup, but at the same level of other hot starts.

At load, the vibrations are at the usual levels (30 µm 0-p for brg.MAD21, 20 µm 0-p for brg. MAD23)

The shutdown of ST was with low vibrations at brg. MAD21 (just above 50 µm 0-p), there were no significant vibration at low speed, eccentricity initially regular with some increase after turning gear engagement at low speed (max value from the data available 100 µm).

At the restart of ST in warm condition, 15 hours after the trip, the vibration increased soon to high levels causing the trip of the unit. The vibration levels just before the trip were within normal values as well as the eccentricity.

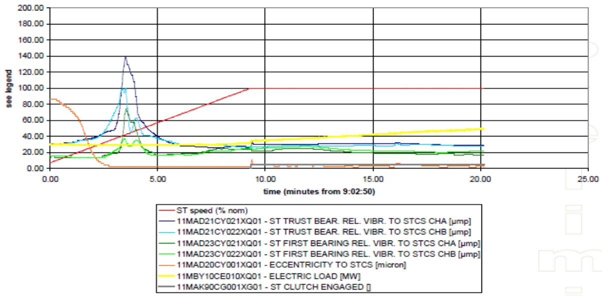

Figure. 13. Startup of ST, cold condition

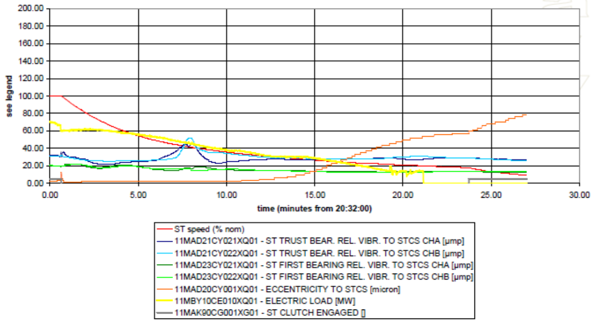

Figure. 14. Shutdown of ST

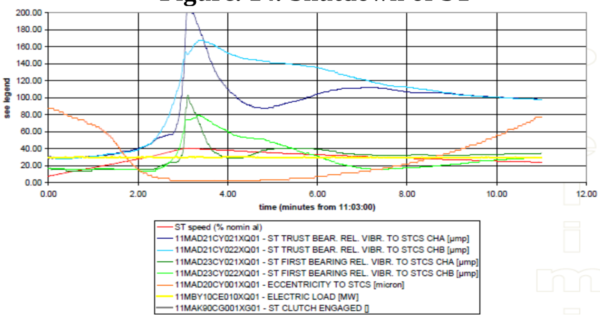

Figure. 15. Failed startup, warm condition

III. RESULT AND DISCUSSION

The rotordynamics analysis (RDA) make with computer model show clear that in order to avoid the high vibration, the bearing MAD21 should be modified. The proposed optimization was considered a radical change in bearing design and an optimization study for the bearing upgrade was necessary to be performed. This solution wasn't accepted from the manufacturer of the machine.

After all the tests carried out and data collection analyzing, the results are listed here below.

1) The behavior of the steam turbine is quite repetitive.
2) The vibration behavior of the ST during all the shutdowns (both planned or due trips, for example for spikes of one of the relative vibration sensor) is good and also better of the vibration behavior during startups.
3) Vibration levels during cold startups seem to be quite good for both ST bearings.
4) High vibration are developed only during hot startups, at brg. MAD21, reaching values close or above the trip limit.
5) In at least one case, a very high eccentricity was developed at low speed after a trip.

6) Eccentricity at low speed and on turning gear is relatively high, in all cases. This relatively high eccentricity does not have effect on vibration behavior for the cold startups.
7) The vibration levels reached during the failed startup, were unusually high. The causes cannot be defined from the data collected.
8) Deepest analysis of vibration behavior (including vibration phases, etc) were necessary and should be carried out to find out the root causes of the high vibration levels occurring during the hot startups. This should be done using data collected with TVA system (both recorded or of new startups and shutdowns) or with other advanced methods directly on site
9) Some other operating data (steam and metal temperatures) will be collected with the same aim.
10) The vibration behavior of the ST at full speed and at load is good (within class A of international standard ISO 7919-2).
11) In order to avoid the ST trip during the hot starts, due to high vibration three corrective actions were recommended. To increase the threshold and time

delay of trip for relative vibrations and to increase the gradient of the speed near the critical velocity.

IV. CONCLUSION

The best and definitive solution was to optimize the design of the bearing and to produce a new one. As alternative the solution to intervent in the ST control system was addopted. After the aplication of the corrective actions in the ST control system the vibration behavior of the machine during the operation was reasonable good. No more trips due to high vibration were verified and the mechanical integrity of the machine was not affected.

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