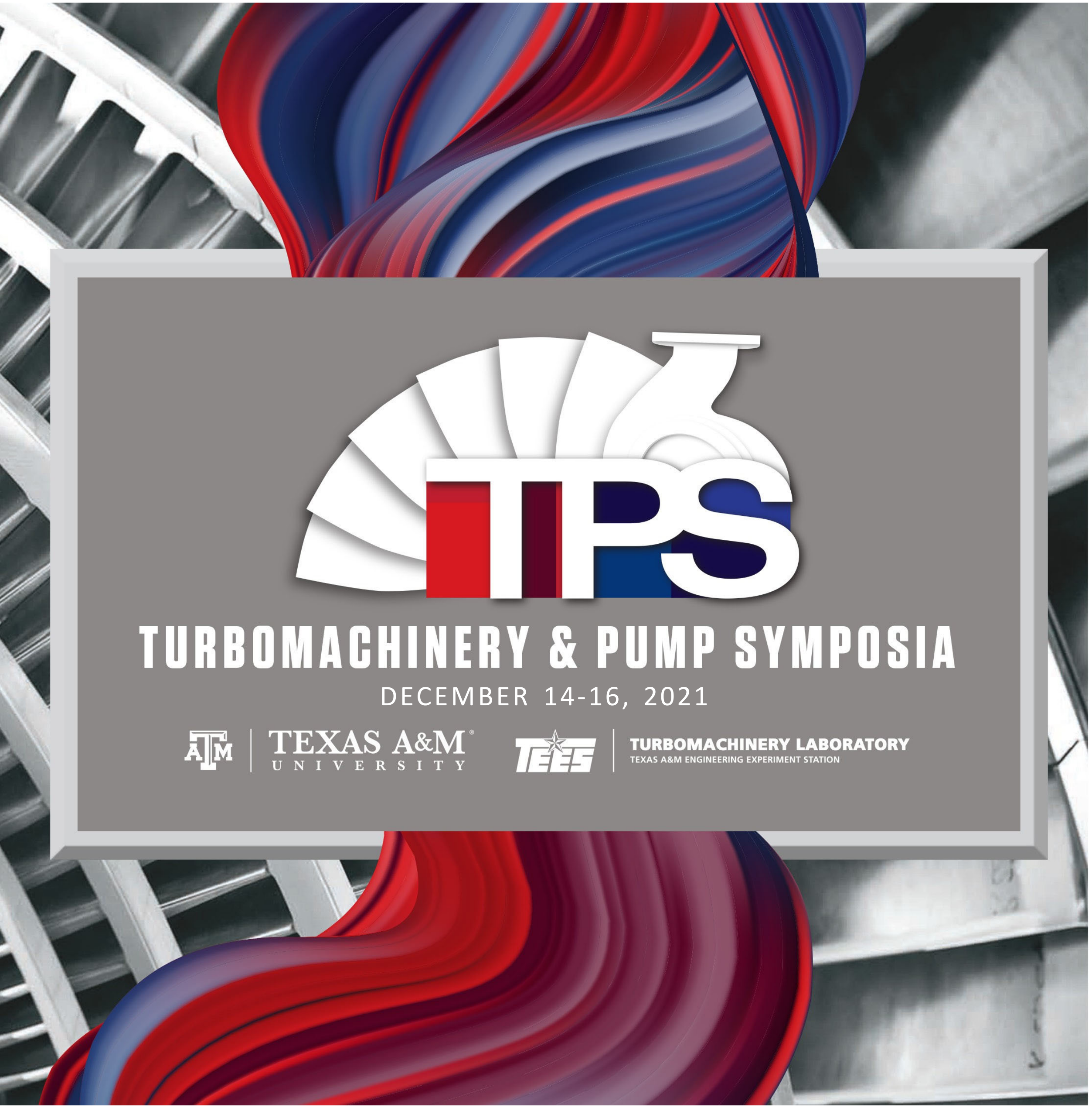

Troubleshooting of Start-up for Rerated & Old Steam Turbine

MITSUBISHI HEAVY INDUSTRIES COMPRESSOR

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Problem Statement

During the start-up of an old steam turbine (about 30 years old), that was internally revamped, it was tripped due to high rotor vibrations.

Site investigation was done to find out the root cause. Abnormal casing deformation and rubbing between labyrinth and rotor was found during the investigation.

In this study we would like to introduce the detail phenomenon, the root cause analysis, what we learned and what we should have done. We hope this would be beneficial for EPC and the end user to know the impact in case the old steam turbine was partially revamped.

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1. Background
2. Site Observations
3. Root Cause Analysis (RCA)
4. RCA Summary
5. Site Countermeasure
6. Lessons Learned

TURBOMACHINERY & PUMP SYMPOSIA

1. Background

During start-up of old turbines, approximately 30 years old,

- Steam turbine was tripped due to high vibrations.
- Multiple start-up trials were unsuccessful due to high rotor vibrations.
- Due to this reason, the turbine start-up was problematic.

The turbine spec for this case study is given in Table-1.

Table-1 : Turbine Spec	
Service	Synthesis Gas
Model	Extraction Condensing Turbine
Max. Output	Approx. 28,000 kW
Max. Speed	Approx. 12,000 rpm
Inlet Steam	106 ata x 505 deg-C

TURBOMACHINERY & PUMP SYMPOSIA

1. Background

- Operation history for the turbine is described in Table-2

Table-2 : Operation History

Year	1986/3	~	2020/9	2020/9,10
Action	Shipment of original turbine	Continuous Operation	Internal revamp (To decrease the steam consumption and increase the performance)	Site operation after internal revamp
New Parts	Steam turbine assembly	-	Rotor, blade, nozzle, diaphragm, labyrinth seal	-
Design Philosophy	Old	→	Latest	→
Note	More than 30 years of operation. Sometimes during the past solo run tests abnormal speed increase around 2nd warming up speed was observed. But no signification issues like high vibrations were observed.		[Reused parts] Casing, governing valve (GV), extraction control valve (ECV), trip & throttle valve (TTV) etc. Combination of old design style (reused casing without casing drain line) and new design philosophy (internal parts)	High vibrations were observed during start-up in multiple trials.

TURBOMACHINERY & PUMP SYMPOSIA

1. Background

- In Fig-1, the highlighted parts (yellow) are revamped, and the remaining parts are reused.

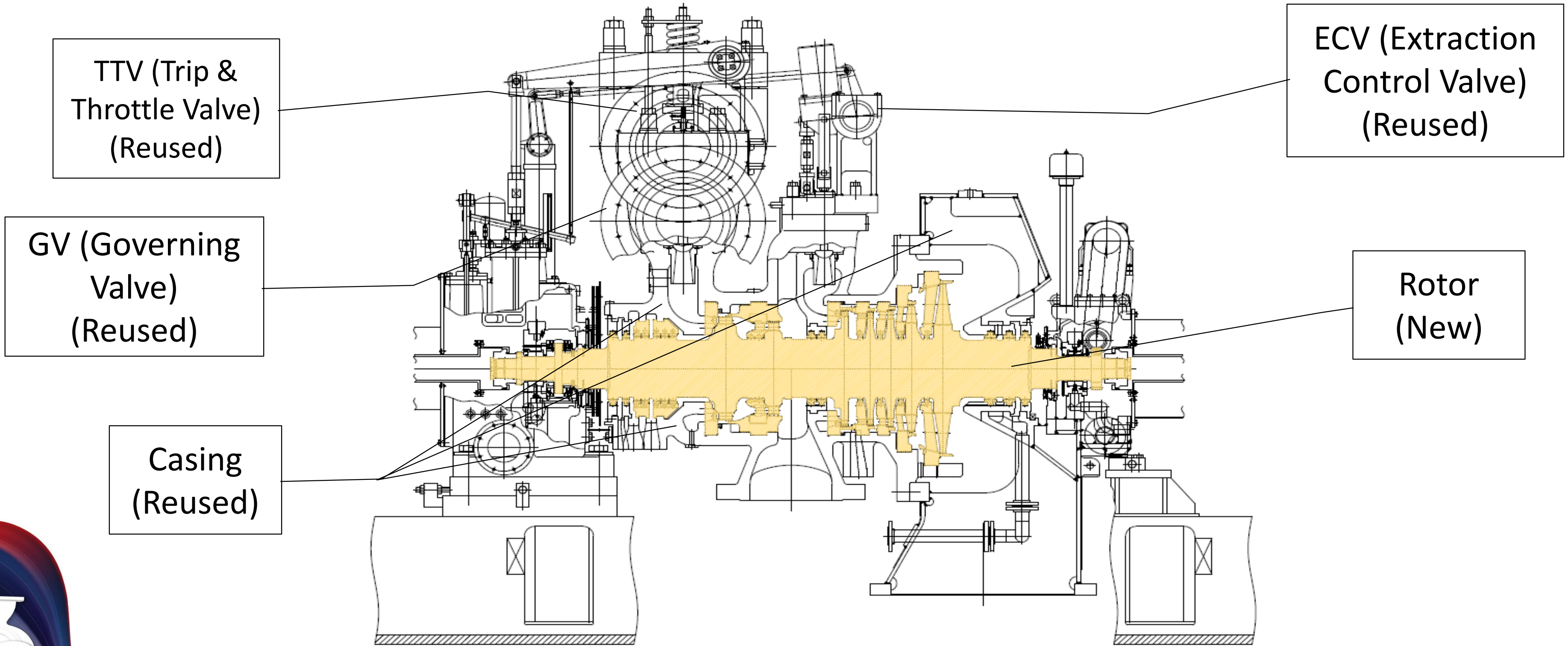


Figure-1 : Internal Revamp Modifications

1. Background

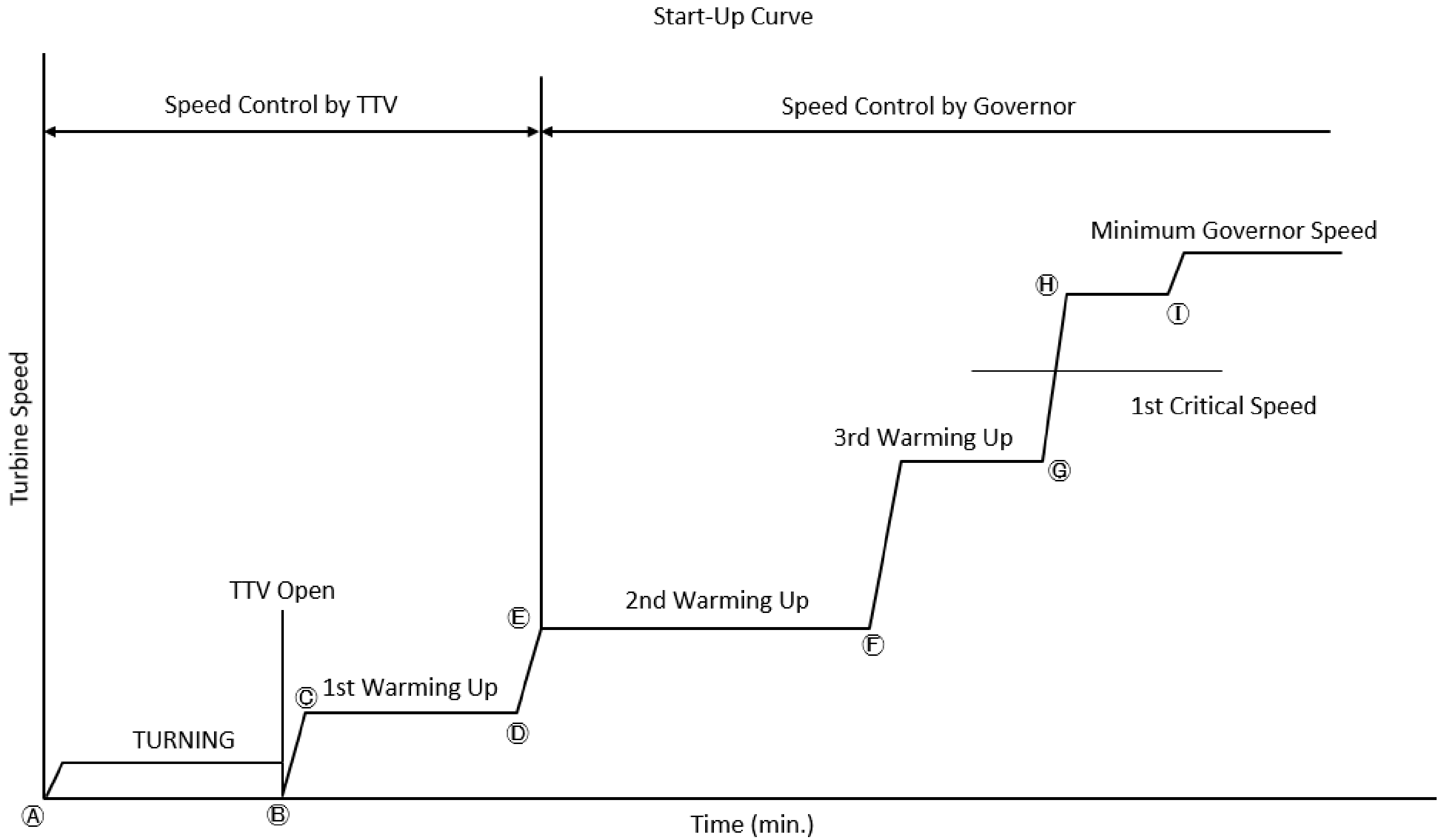


Figure-2 : Start-Up Diagram

Remarks :
Upto the 1st warming-up speed, TTV speed control is applied, so that better uniform heating of turbine casing can be achieved.

2. Site Observations

Trials 1-4: During Commissioning Solo Run with Working Rotor

- Multiple trials were conducted by TTV start-up (speed increase by manual operation).
- In the 1st trial (Fig-3) there was a sudden increase in speed and vibration (Speed increase upto 4 times the target speed).
- After every trial, residual unbalance record showed varying rotor deformation.

From the 5th trial spare rotor was used instead of the working rotor (used for 1st – 4th trial).

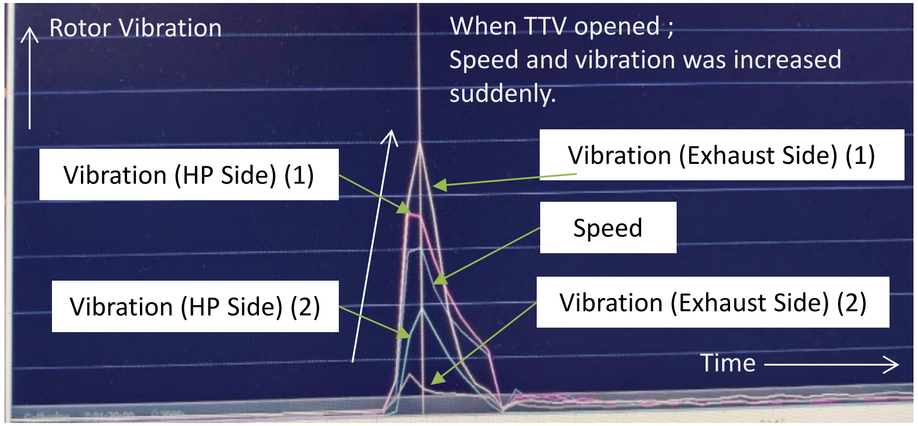


Figure-3 : Speed & Vibration Trend for 1st Trial

Remarks : Similar trend was observed for next 3 trials

Quality of manual start-ups depends on the operator skill. Therefore, this phenomenon (rubbing due to the sudden speed ramp up) may be occurred in the past operation. It is required to turn (open direction) the TTV handle slowly to prevent the sudden speed ramp up. Operator has to turn (close direction) the handle of TTV immediately when the rotor start the rotation to prevent the sudden speed ramp up. The sudden speed ramp up is occurred due to the friction of bearing is reduced from the large static friction to the small dynamic friction. The great skill is required for these operator activities (slowly open and quick close).

2. Site Observations

Trial 5th: Solo Run with Spare Rotor

- Due to abnormal increase in rotating speed, there is a possibility of rotor rubbing with stationary parts.
- Labyrinth clearance was increased to prevent any potential rubbing of rotor.
- Similar to previous starts, speed control was difficult & turbine was tripped again due to high vibration (Fig-4).
- Due to the difficulty faced by operator in TTV start-up, GV start-up was applied from the next trial (6th trial) and the result was a successful (This could prevent the sudden speed ramp up.).

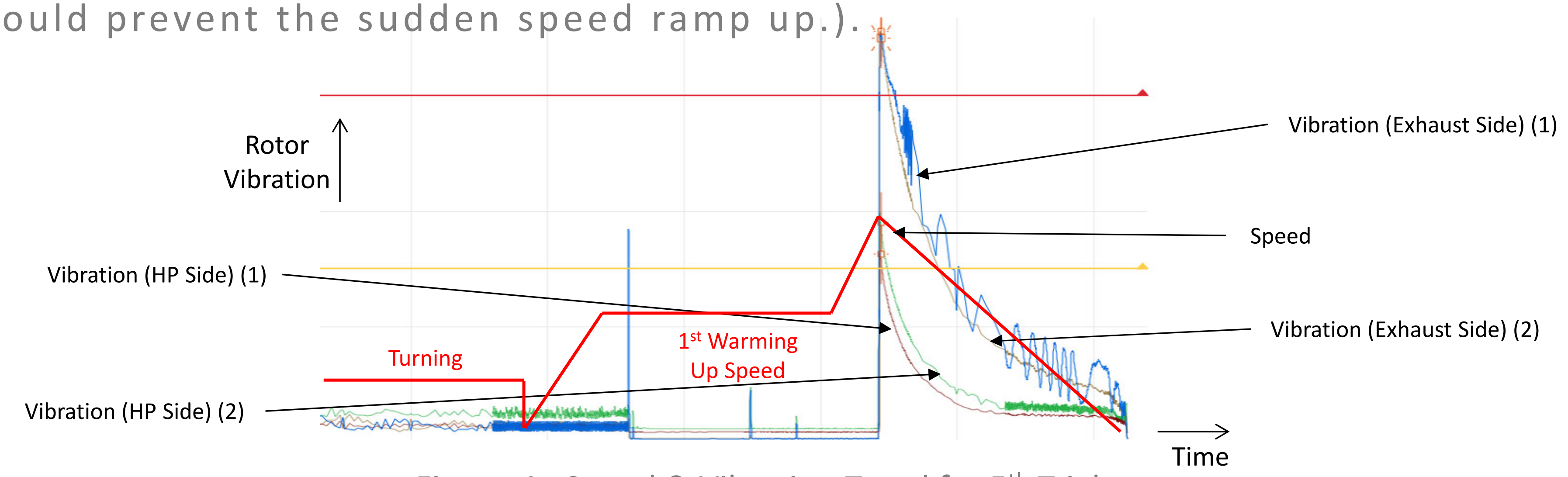


Figure-4 : Speed & Vibration Trend for 5th Trial

2. Site Observations

9th Trial: String Condition with Spare Rotor

- Speed control was a success & Speed was gradually increased (GV Start) to 2nd warming up speed without any issues (Fig-5).
- At 3rd warming up speed high vibrations occurred, so the speed was decreased.
- Vibration fluctuations were observed at different speeds.
- So, the turbine speed was increased and decreased based on the fluctuations and finally the operator was able to achieve Minimum Governor Speed (MGS).

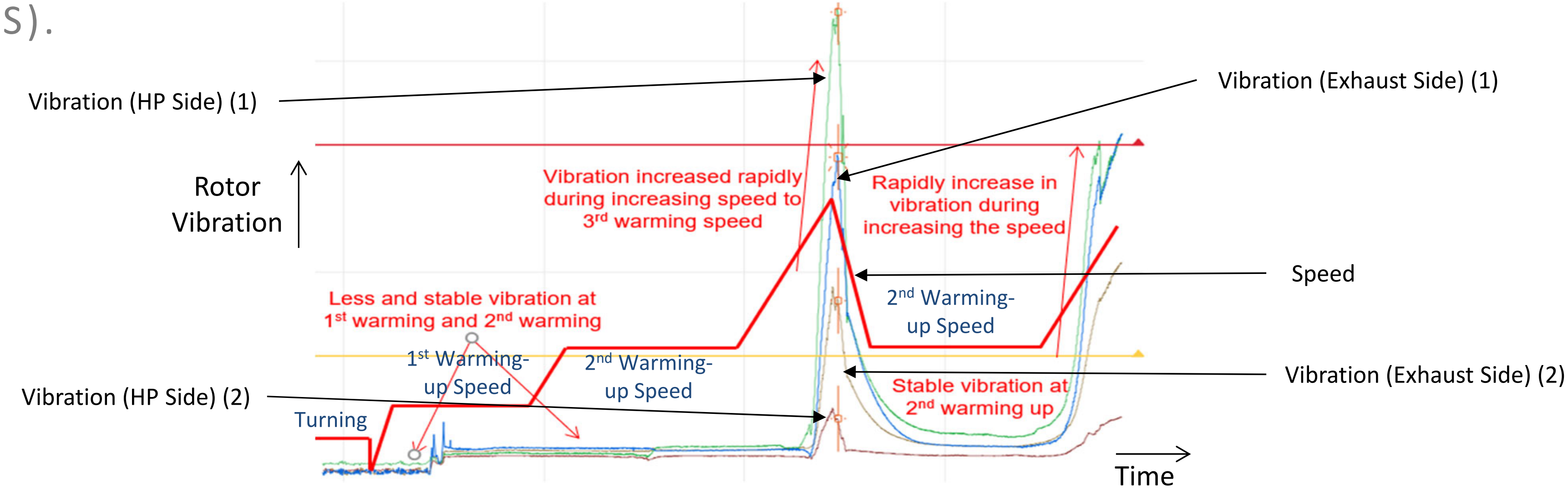
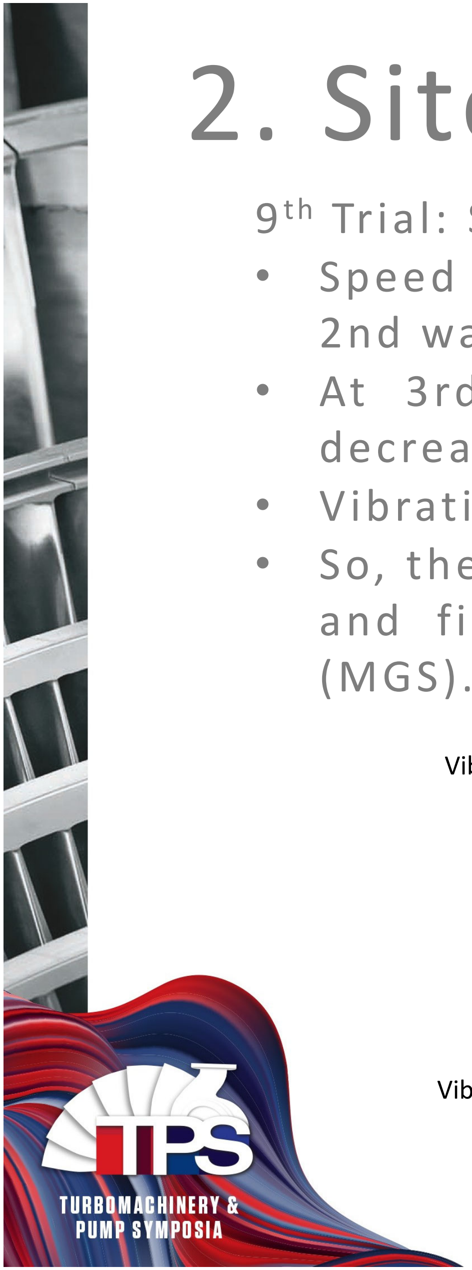
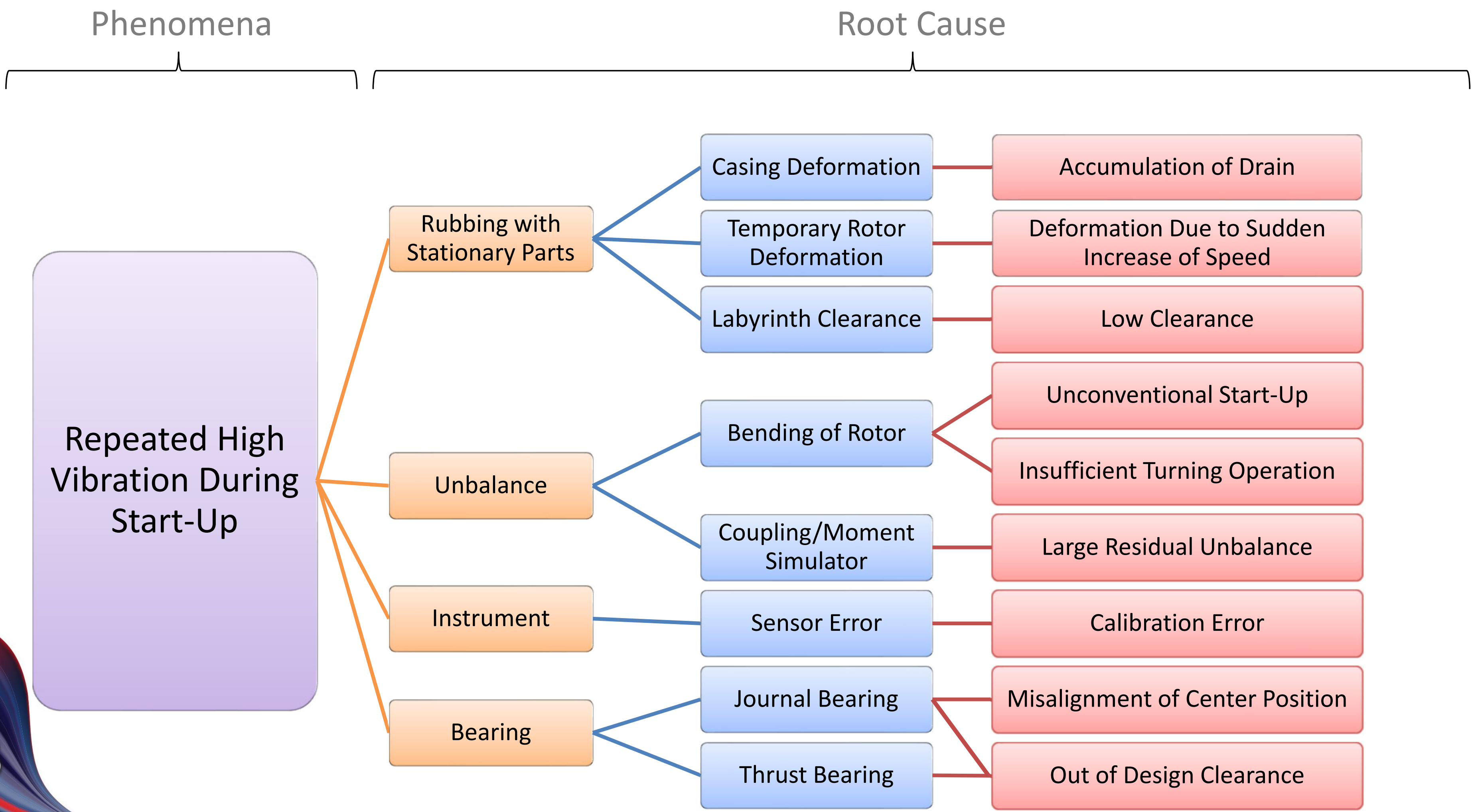


Figure-5 : Speed & Vibration Trend for 9th Trial



3. Root Cause Analysis (RCA)



TURBOMACHINERY & PUMP SYMPOSIA

3. Root Cause Analysis (RCA)

Possible Causes

Root Cause	How to Verify	Verification Result	Judgement
Accumulation of Drain	Check for drain accumulation	Due to no drain line, accumulated drain was observed.	High Possibility
Deformation Due to Sudden Increase of Speed	Operation Record Check	Sudden increase in speed just after opening TTV. This might have caused high vibrations and rubbing with stationary parts.	High Possibility
Low Clearance	Clearance Check	Operating clearance is lower than the current standard design. i.e. The operating clearance depends on the clearance at cold condition and the casing deformation. The cold clearance of this revamp project is the small clearance based on the current standard design which consider the small casing deformation due to the casing drain removing. Casing deformation of this reused turbine is lager than the casing based on the current design which consider the casing drain removing. Therefore, operating clearance is lower than the current standard design.	High Possibility

3. Root Cause Analysis (RCA)

Possible Causes

Root Cause	How to Verify	Verification Result	Judgement
Unconventional Start-up	Operation Record Check	Large increment in speed, which is not suitable for start-up.	Moderate Possibility
Stopping Turning Operation before Start-up	Operation Record Check	Turning operation stopped in about 15 minutes. Due to this the lower half of shaft may be heated up by sealing steam.	Moderate Possibility
Large Residual Unbalance	Residual Unbalance Record Check	Residual unbalance was within the criteria.	Not Possible
Sensor Calibration Error	Calibration Record Check	Calibration record showed no problem.	Not Possible
Misalignment of Center Position	Operating Data Check	Shaft center position deviation was within criteria from our experience of similar turbine.	Not Possible
Out Design Clearance	Clearance Check	Bearing clearance was within the acceptance criteria at assembly stage.	Not Possible

3. Root Cause Analysis (RCA)

Root Cause | Research / Evaluation | Judgement

Possible Causes

- **Accumulation of Casing Drain**: Long Term Operation (30 Years) + No Casing Drain Line (Old Design Philosophy) = Unexpected Temporary Casing Deformation → High Possibility
- **Rotor Temporary Deformation Due to Sudden Increase of Speed**: Insufficient Warming-Up of Rotor & Casing + Sudden Increase in Speed Near 1st Critical Speed (High Possibility of Rubbing) + Repeated Rubbing with Increasing Intensity = Unexpected Temporary Rotor Deformation → High Possibility
- **Less Labyrinth Clearance**: Sudden Increase in Turbine Speed + Combination of old-style casing & labyrinth clearance as per latest DP = Vibration Amplitude higher than Clearance Limit → High Possibility

4. RCA Summary

After 1st Revamp → **Drain Accumulation** → **Sudden Increase in Operating Speed** → **High Vibrations**

After 1st Revamp

- Internal parts were revamped
- Existing Casing was reused
- Less clearance compared to original case (Latest Design Philosophy) with no drain line

Drain Accumulation

- Gradual accumulation of condensate due to lack of casing drain resulted in thermal bending of casing

Sudden Increase in Operating Speed

- Speed control by manual TTV start-up was difficult due to deformed casing of old design style & insufficient operator skills
- Sudden increase in speed and repeatedly increasing rubbing resulted in temporary rotor deformation

High Vibrations

- Rubbing of rotor with stationary parts

5. Site Countermeasures

Following countermeasures were taken for a robust start-up:

- TTV manual start-up was difficult due to deformed casing of old design style and insufficient operator skills.
- GV automatic start-up was applied instead of TTV manual operation. This allowed better control of the steam admission & therefore a slower speed ramp-up.
- If vibration is increased during transition, operating speed should be decreased to previous operating speed.
- Sudden change in operating conditions should be avoided except the critical speed band to perform the gradual warming-up.

6. Lessons Learned

Problem

Phenomena	Root Cause	Solution	
High Vibrations during Start-up	Temporary Casing Deformation due to drain accumulation	Installation of Casing Drain Line	Permanent Solution
Sudden increase in Rotation Speed without warming up	TTV Manual Start-Up is hard to control.	GV Automatic Start-Up to be applied	Permanent Solution
Rotor Rubbing with Stationary Parts	Combination of old-style casing & less labyrinth clearance (Latest DP)	Suitable Labyrinth Clearance should be applied considering the casing and internal parts	Permanent Solution

Added casing drain line is nearly low point.
Casing drain line is usually installed in the lowest point and this casing drain line is used the line for casing internal pressure measurement (PG, PT) as common.
In this project, the existing casing internal pressure measurement (PT) line was used as the added casing drain line.

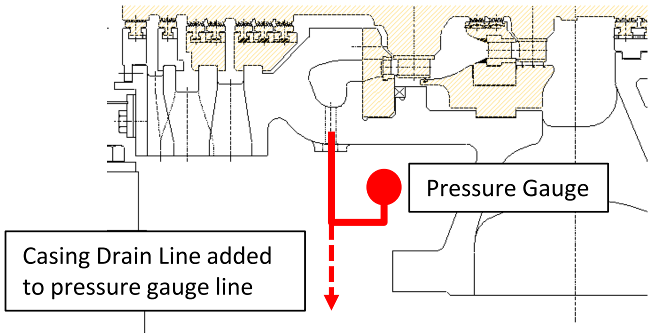


Figure-6 : Casing Drain

6. Lessons Learned

Final conclusions from the case study:

- Casing drain line installation should be considered for the revamp of old steam turbines (Turbine age indicate if the casing drain line was installed or not).
- For turbines which are currently in operation and don’t need revamp should also consider addition of casing drain line as a countermeasure for any future issues.
- Sudden change in operating conditions should be avoided to prevent any abnormal change in rotating speed.
- For deformed casing of old design style turbine start-up should be robust to prevent rotor deformation due to rubbing with stationary parts.
- If GV start-up is applied, large labyrinth clearance should be considered & customer’s approval is required for performance deterioration.
- In case of internal revamp of old steam turbine, suitable labyrinth clearance should be applied.