INFLUENCE OF THERMAL EXPANSION ON STEAM TURBINE SHAFT ALIGNMENT

PENGARUH PEMUAIAN PANAS TERHADAP KELURUSAN POROS TURBIN UAP

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Abstract

Most of failures occurred in rotating machines, including steam turbines, are caused by shaft misalignment. In the steam turbine, heat that propagates to the casing can change steam turbine dimension due to thermal expansion which affects the shaft alignment. Thermal expansion values need to be known as one of the specifications in shaft alignment setup. In this study, thermal expansion on 3 MW steam turbine was investigated by measuring the shaft alignment in hot after shut down and cold condition using laser alignment method. Results show that thermal expansion has an influence on shaft alignment due to difference of alignment values when hot and cold conditions, namely 0.025 mm (gap) and 0.071 mm (offset.) in vertical plane then -0.025 mm (gap) and -0.069 mm (offset.) in horizontal plane.

Keywords: Steam Turbine; Thermal expansion; Shaft alignment

Abstrak

Sebagian besar kegagalan yang terjadi pada mesin-mesin rotasi, termasuk turbin uap, disebabkan oleh poros yang berputar dalam kondisi tidak lurus dengan poros lain yang tersambung. Pada turbin uap, panas yang merambat pada rumah turbin dapat merubah dimensi turbin uap karena adanya pemuaian (ekspansi termal) sehingga mempengaruhi kelurusan poros saat berputar. Nilai ekspansi termal ini perlu diketahui sebagai salah satu spesifikasi dalam penyetelan poros sebelum turbin beroperasi. Dalam studi ini, ekspansi termal pada turbin uap 3 MW diinvestigasi dengan mengukur kelurusan poros dalam kondisi panas setelah berhenti berputar dan dingin menggunakan metode laser. Hasil pengukuran menunjukkan bahwa ekspansi termal memberikan pengaruh terhadap kelurusan poros karena ada selisih nilai kelurusan poros saat kondisi panas dan dingin yaitu 0,025 mm (gap) dan 0,071 mm (offset.) pada bidang vertikal kemudian -0,025 mm (gap) dan -0,069 mm (offset.) pada bidang horizontal.

Kata kunci: Turbin uap; Ekspansi termal; Kelurusan poros

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INTRODUCTION

Steam turbines are type of rotating machines widely used for boat propellers, plant equipment and electric generators[1–3]. The turbines often experience misalignment condition that is responsible to abnormalities in shaft running and failures. In fact, 60% of the failures occur in steam turbine are due to that reason[4].

Steam turbines have a shaft connected with other rotating machines using coupling into machine train. When the machine train rotates, each of the shaft tends to rotate on axis lines. To achieved normal rotation, the shaft axis should be adjusted to appropriate position before the engine starts. This procedure is a part of preventive maintenance to ensure the lifespan of the machine[5].

Numerous studies about misalignment on rotating machines have examined how to reduce risk of damage and to improve maintenance efficiency. Mankowski et al., conducted real time monitoring of shaft alignment between generator and wind turbine blade using laser measurement[6,7]. Khan et al., diagnosed airplane gearbox misalignment statistically by vibration and sound spectrums[8]. Qu et al., identified shaft misalignment through dynamic rotor response characteristic changes diagnostic[9]. Darmawan et al.,[10] and Raharjo et al.,[11] detected misalignment using vibration signal analysis in steady-state conditions. Tonks et al., detected wind turbine shaft misalignment using temperature monitoring[12].

Steam turbines are rotating machines used heat energy to produce mechanical energy. The heat propagated in turbine casing will result heat expansion so that casing dimension will increase. Casing dimension changes due to thermal expansion will affect machines shaft alignment when rotating.

In the process of a shaft adjusting during maintenance, additional casing dimension need to be added to shaft alignment specifications. Manufactures usually provide thermal expansion value for the shaft adjusting process but for new turbine prototype it is necessary to determine of values both theoretically and experimentally.

Theoretically, expansion of casing material dimension, ΔL in mm unit is calculated using the following equation:

$$\Delta L = T \, x \, L \, x \, C \qquad (1)$$

Where T is casing temperature difference during and before operation (°C), L is distance from casing bottom to shaft axis (mm) and C is casing material thermal coefficients (°C^{-1})[13]. But this is one direction value and real measurements are needed to obtain the thermal expansion values in accordance with operational conditions and others misalignment direction can be known.

However, a review of the literature found no study that explains influence of material dimension increase in rotating machines due to thermal expansion through direct measurement in the field. This study will investigate dimension increase occurred due to thermal expansion on steam turbine casing using misalignment measurement in hot and cold conditions.

The objectives of this research are to find the increasing rate in dimension of turbine casing due to high temperature and to determine thermal expansion specification of turbine shaft as required for the need of operation and maintenance.

METHODOLOGY

In this research, measurements were conducted on 3 MW steam turbine prototype. This turbine shaft connected with gearbox shaft using spacer coupling as shown in Figure 1.

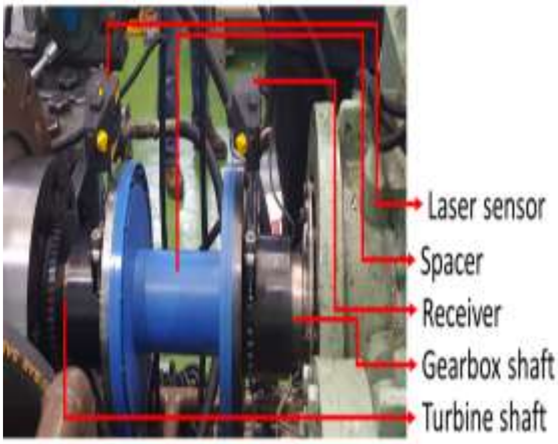

Figure 1.
Measurement set up

Misalignment measurement conducted using laser based measurement method where the laser sensor installed on turbine shaft determined as stationery and receiver or laser position reader installed on gearbox shaft as shown in Figure 1.

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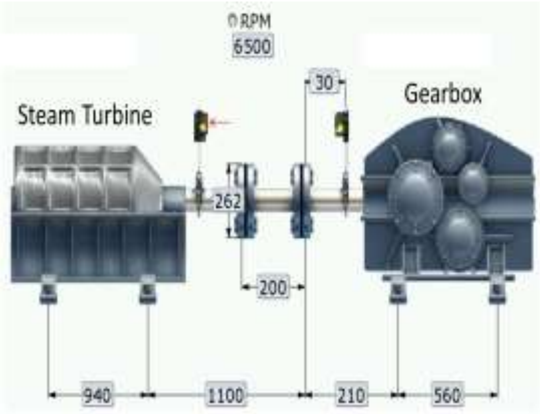

Figure 2.
Machine train dimensions

Overall, configuration and dimensions in this steam turbine shaft misalignment measurement depicted in Figure 2. Units that used in configuration are mm for machine dimensions and misalignment values.

In laser alignment method, shaft slowly rotated manually using crane support minimum 60°. At every rotation stop point, receiver will record laser position changes then calculated automatically into the gap and offset misalignment values as shown in Figure 3. This method refers to ANSI/ASA S2.75-2017/Part 1 Shaft Alignment Methodology.

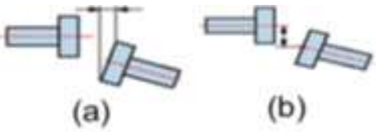

Figure 3.
(a) Gap misalignment
(b) Offset misalignment

Misalignment position as depicted in Figure 3 are positive misalignment. If misalignment measurement resulting negative values the right shaft will be otherwise.

Misalignment data are average result on every measurement. In this research, measurement conducted 4 times in accordance with the turbine testing in the field.

From performance test that have been carried out, the misalignment measurement is done four times only as not every test should be done in hot temperature. The measurement using hot alignment is costly and requires an excellent coordination between personnel.

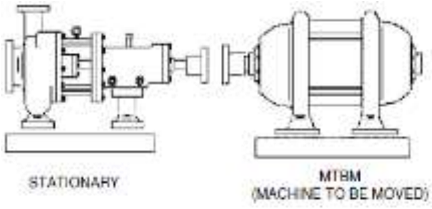

Figure 4.
Machine vertical plane[5)]

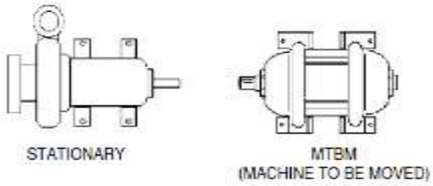

Figure 5.
Machine horizontal plane[5)]

Misalignment values obtained is divided into two according machine plane, namely vertical and horizontal planes. Figure 4 shows machine vertical plane or side view where in this study the turbine as stasionery and gearbox as machine to be moved or will adjusted the position when needed correction in shaft alignment process.

Figure 5 shows machine horizontal plane or top view with a turbine and gearbox same position as shown in Figure 4. In This study, every measurement will obtain misalignment values for gap and offset on vertical and horizontal plane.

Turbine shaft misalignment measured when the machine train stop and hot condition (±80°C) after testing (hot alignment). After turbine temperature decreases with ambient temperature (±22°C), misalignment measurement is conducted again in cold condition (cold alignment). The hot measurement results compared with cold measurement results to find out the magnitude of influence of thermal expansion on shaft alignment between the turbine and gearbox.

RESULTS AND DISCUSSIONS

Results

Theoretically, increase of turbine casing dimension, ΔL due to thermal expansion according to Eq. (1) is:

$$\Delta L = 58 \, x \, 690 \, x \, 0.000012 = 0.480 \, mm$$

Where casing temperature difference during and before operation, T = 58 °C, distance from casing bottom to shaft axis, L = 690 mm and casing material (cast iron) thermal coefficients, C = 0.000012 °C^{-1}.

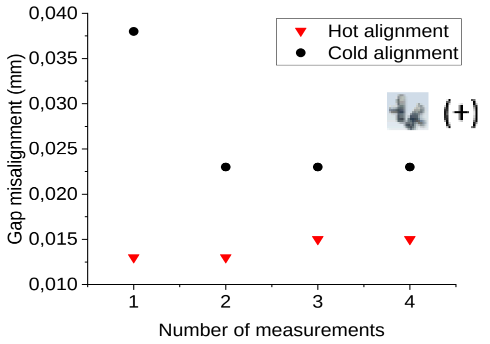

Figure 6.
Gap misalignment in the vertical plane

The results of measurements in the field give different results from the result of calculations in theory. After 4 times measurements on turbine shaft then it is obtained steam turbine shaft misalignment values in hot and cold conditions.

Figure 6 illustrates gap shaft misalignment data in the vertical plane. Regarding measurement carried out, there are difference of gap misalignment values. The difference is 0.025 mm in measurement 1, 0.010 mm in measurement 2, 0.008 mm in measurements 3 and 4.

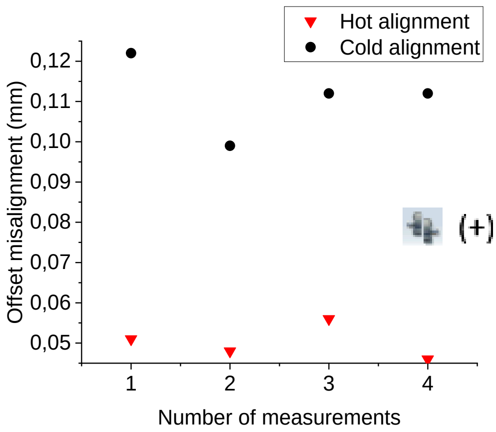

Figure 7.
Offset misalignment in the vertical plane

Measurement result of offset misalignment in the vertical plane shown in Figure 7. The difference of offset misalignment in hot and cold conditions are 0.071 mm in measurement 1, 0.051 mm in measurement 2, 0.056 mm in measurement 3 and 0.066 mm in measurement 4.

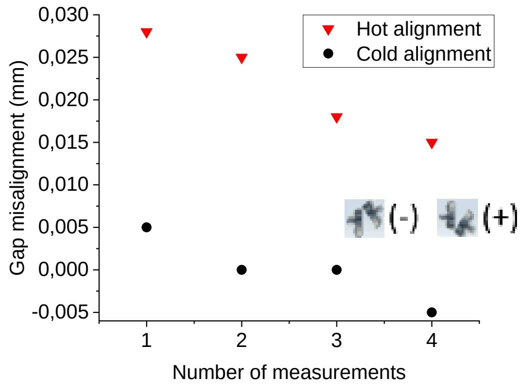

Figure 8.
Gap misalignment in the horizontal plane

In the horizontal plane, misalignment values in hot and cold conditions shown in Figure 8 and 9. The difference of gap misalignment in the horizontal plane as depicted in Figure 8 are -0.023 mm in measurement 1, -0.025 mm in measurement 2, -0.018 mm in measurement 3 and -0.020 mm in measurement 4.

Figure 9 shows difference of offset misalignment values in hot and cold conditions. There are -0.064 mm in measurement 1, 2, 3 and -0.069 mm in measurement 4.

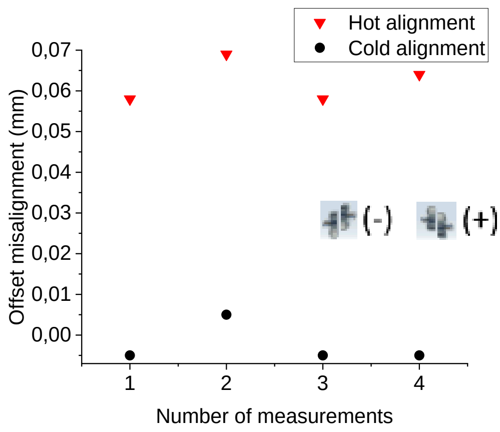

Figure 9.
Offset misalignment in the horizontal plane

Discussions

Misalignment measurement using laser method on a steam turbine and gearbox shaft train is measurement carried out in line with performance testing of 3 MW steam turbine. Number of measurements made is very limited because to conducting steam

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turbine performance testing requires expensive costs and field personnel assistance.

Regarding the result of misalignment measurement, there are difference of values in hot and cold measurement conditions. The difference of misalignment values shows in steam turbine casing occurs material expansion that cause dimension addition so that changes the steam turbine shaft alignment position.

Difference of misalignment values that resulted at each measurement illustrates differences because of ambient factors where steam turbine existed. Ambient temperature changes during the day and night. The changes affect the temperature of turbine casing, both in operation and idle.

Besides, the quickness of data retrieval when hot condition also affects the hot misalignment measurement values (hot alignment data). Extreme ambient temperature will speed up the cooling process of casing after turbine shut down.

There are differences in results between the carried-out measurement and theoretical calculation. The differences are due to the complexity of steam turbine geometry. Theoretical calculation is accurate for simpler geometry. Moreover, the measurement of the steam turbine was carried out in the field thus the results is greatly affected by operational condition.

In Figure 6, it can be identified that there is a value gap between the first measurement and the later measurements. This difference is due to the prohibition during the first measurement to open the lower cover of the coupling. This limits the data acquisition only to reach 180°. This situation is different for the next measurements where data points are obtained until 360°.

The difference in the offset value in the vertical plane as shown in Figure 7 is the biggest difference in the value of misalignment compared to other gap or offset values. The geometry of the steam turbine which tends to be symmetrical and only supported on it foots at the baseplate indicates the majority of the material expansion in vertical direction. Therefore, the most significant misalignment value is offset in the vertical plane.

This research show that the theoretical calculation may not be enough to determine thermal expansion occurred in steam turbines. The theoretical approach only considers the material expansion of alignment offset aspect which only cover vertical-wise direction. In contrary, the thermal expansion that occurs in casing also influence the gap and offset values in both horizontal and vertical plane.

Table 1.
Thermal expansion recommendation

Thermal expansion	Gap (mm)	Offset (mm)
Vertical	0.025	0.071
Horizontal	-0.025	-0.069

From this research, it is recommended to use thermal expansion values to aid the adjustment of the misalignment of 3 MW steam turbine during maintenance activity. In summary, the values of thermal expansion that can be added to the shaft alignment specification are shown in Table 1.

CONCLUSION

Misalignment of shaft train is very influential on rotating machines failure. In a 3 MW steam turbine, thermal expansion in casing influences the alignment of shafts between a turbine and gearbox. The highest thermal expansion values obtained were 0.025 mm (gap) and 0.071 mm (offset) in vertical plane then -0.025 mm (gap) and -0.069 mm (offset) in horizontal plane. Even though the value of thermal expansion is very small but it shows the influence of heat expansion in turbine casing on steam turbine shaft alignment.

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REFERENCES

1. Mrzljak, V., Poljak, I. & Medica-Viola, V. Dual fuel consumption and efficiency of marine steam generators for the propulsion of LNG carrier. *Appl. Therm. Eng.* **119**, 331–346 (2017).

2. Stifanese, R., Belsanti, L., Toselli, M., Letardi, P. & Traverso, P. Corrosion investigation of a steam turbine after power generator failure onboard a vessel: A case study. *Eng. Fail. Anal.* **64**, 58–66 (2016).
3. Xu, B., Chen, D., Zhang, H., Li, C. & Zhou, J. Shaft mis-alignment induced vibration of a hydraulic turbine generating system considering parametric uncertainties. *J. Sound Vib.* **435**, 74–90 (2018).
4. Bahadori, A. & Vuthaluru, H. B. Estimation of performance of steam turbines using a simple predictive tool. *Appl. Therm. Eng.* **30**, 1832–1838 (2010).
5. Mobley, R. K. *Maintenance fundamentals*. (Elsevier, 2011).
6. Mankowski, O. & Wang, Q. Real-time monitoring of wind turbine generator shaft alignment using laser measurement. *Procedia CIRP* **11**, 291–295 (2013).
7. Mankowski, O. & Wang, Q. Real-time Monitoring of Wind Turbine Blade Alignment Using Laser Measurement. *Procedia CIRP* **56**, 128–132 (2016).
8. Khan, M. A. *et al.* Gear misalignment diagnosis using statistical features of vibration and airborne sound spectrums. *Meas. J. Int. Meas. Confed.* **145**, 419–435 (2019).
9. Qu, L., Lin, J., Liao, Y. & Zhao, M. Changes in rotor response characteristics based diagnostic method and its application to identification of misalignment. *Meas. J. Int. Meas. Confed.* **138**, 91–105 (2019).
10. Darmawan, D. D., Widodo, A. & Haryanto, I. Misalignment Kopling Dengan Analisis Sinyal Getaran Kondisi Steady State Menggunakan Metode Reverse. *J. Tek. Mesin S-1* **4**, 197–206 (2016).
11. Raharjo, I. A., Widodo, A. & Haryanto, I. Analisis Misalignment Kopling Pada Mesin Rotary Menggunakan SINYAL GETARAN STEADY STATE DENGAN METODE RIM AND FACE. *J. Tek. Mesin S-1* **4**, 214–223 (2016).
12. Tonks, O. & Wang, Q. The detection of wind turbine shaft misalignment using temperature monitoring. *CIRP J. Manuf. Sci. Technol.* **17**, 71–79 (2017).
13. Prizevaitis, A., Litvinov, D. & Gerins, E. Thermal Growth Influence on The Shaft Alignment and Vibration of Centrifugal Pump. in *16th International Research/Expert Conference : 'Trends in the Development of Machinery and Associated Technology'* 319–322 (2012).