Abstract — Asymmetric dilatation of steam turbines is a common phenomenon that frequently occurs during warming up of steam turbines. This phenomenon can lead to misalignment and subsequently vibration problems arise. It is not evident to predict how a steam turbine will dilatate. With the traditional laser alignment system it becomes very difficult to measure complex alignment arrangements for example a flexible shaft arrangement in the gearbox. Moreover correcting misalignment usually requires disassembly of the whole turbine, which is not always economical. The present research therefore aims at presenting an alternative way for measuring asymmetric dilatation of steam turbine in a more accurate way and also performing corrective repairs without having to disassemble the entire turbine completely. In this regard, a TRITOP photogrammetry system is used for measuring the hot alignment values. This system is an optical measuring system which is used for non-contact measurement. With this system very precise measurements are performed and alignment is corrected by adjusting the generator or gearbox alignment.

Keywords — Asymmetric dilatation, thermal expansion, misalignment, turbomachinery

I. INTRODUCTION

During our work throughout Europe we have been often confronted with steam turbines and turbomachinery suffering from asymmetric dilatation (not to be confused with differential dilatation). Steam turbines have a known thermal expansion, where the rotor and stator follows a different trajectory during warming up. This behaviour is often disturbed by asymmetric steam flow, stress, or other mechanical factors. As a result, the shaft alignment is severely disturbed, leading in increased vibration. This phenomenon may lead to less power production due to the high vibrations or even lead to complete turbine shutdown to avoid the parts being severely damaged. Besides efficiency loss, there is also a lot of wear or damage due to unknown misalignment of for ex.: bearings, couplings and gears. In more severe situations the steam pad can be seriously damaged.

In practice, it is not always possible to solve the cause of asymmetric dilatation immediately. Corrective repair work sometimes requires disassembly of the entire turbine and this is preferably planned during a major maintenance downtime to limit the production loss.

The alignment is therefore often adjusted to greatly reduce the consequences of asymmetric dilatation. The existing techniques are not user-friendly and cumbersome, therefore the engineering department at Energetic has been investigating at new technologies to detect asymmetric dilatation of steam turbines and this work is presented here.

II. MATERIALS AND METHOD

Energetic uses a TRITOP photogrammetry system to measure asymmetric dilatation of steam turbines. The system is an industrial, optical measuring system which is used for non-contact and acquisition of exact 3D coordinate of points of a measuring object. The points are defined by applying reference point markers on the measuring object.

The TRITOP photogrammetry system is a stand-alone system and mainly consists of: a photogrammetry camera with Wi-Fi image transmission, scale bars, coded and uncoded reference point markers, high-performance computer or laptop and an application software.

A. Setup preparation and measuring procedure

Uncoded reference point markers are positioned on the measuring object on spots for which 3D measuring points are wanted. These reference point markers are used for determining the 3D coordinates of the measuring points. On a steam turbine, the reference points are positioned on the turbine casing, the gearbox casing and on the generator casing. Uncoded reference points also positioned on a fixed, non-movable object, for example on the floor which serves as a reference against which the displacement of the movable parts will be measured.

Two measurements are usually performed; one in hot state, when the turbine is running at working conditions and another one in cold state, when the turbine is shut down. One measurement for example the cold state is used as a reference for which the measurement in hot state is compared to.
Using the TRITOP photogrammetry camera photographs of the machine are taken from different views all around the machine. Doing so the machine together with the reference point markers is captured from different views. The images are continuously transmitted to the measuring computer via Wi-Fi. The software receives the images one by one, orients them automatically in 3D space and computes the 3D coordinates of the reference points fast and precisely. The orientation of the camera positions in 3D space is done by coded reference point markers which are also applied all around the measuring object alongside the uncoded reference points.

Additional high-precision scale bars are also placed around the measuring object which are used to determine the dimension of the measuring object. The orientation cross labeled with a green X and a blue Y is also positioned on the measuring object. This cross determines the coordinate system (XYZ) of the photogrammetry measuring project in 3D computation and helps to pre-align the resulting coordinate system.

During photogrammetry measurement it is important that the ambient temperature be stable. The machine and the scale bars should have a stable temperature, therefore all components should be together in the measuring environment for some time before the photogrammetry measuring process is started.

**B. Analysis**

The measurements in hot and cold states are imported as separate stages into a single project for analysis. The first stage, the cold state is set as nominal stage (the reference stage). Measurements performed in the hot state is set as actual data and are compared against the measurements in the cold state. Each stage is captured in its own original coordinate system. In order to analyze both stages in a useful and comparable coordinate system, they are aligned together in one common coordinate system.

The uncoded reference points which are placed on the machine parts; turbine, gearbox, generator and on the fixed reference are grouped together into separate point components. The displacement of each machine part (point component) can be analyzed in two ways:

- The absolute displacement in 3D space of each machine part can be calculated.
- The relative displacement of each part with respect to each other can be calculated. This is done with the rigid body motion compensation alignment. In this case one point component serves as reference, for example the floor. This point component is the fixed reference in 3D space. The software computes the displacement of all other point components relative to the reference point component.

The software calculates the displacement of a point component from cold to hot condition. In this way the direction of displacement as well as the value of the displacement is measured. The software displays the deviations of measuring points in a point component with a vector field. The vectors shows the direction and the extent of the deviation in hot stage compared to the cold stage (the reference stage). The software also displays the displacement for each coordinate direction (XYZ) individually, in this way all axial and radial displacements in hot stage are known. On all color deviation representations, deviation labels are created to visualize local deviations numerically.

**C. Case Study 1: Hot alignment of steam turbine MAN MARC2-B00 in paper industry**

The turbine generator (Figure 2) has too high vibrations on the turbine bearing drive-end (DE) side and there is also a lot of noise produced in the gearbox. The dial indicator values shows a misalignment on the bearing DE. Figure 3 shows the alignment of the turbine generator in cold condition.

**Figure 2: Steam turbine MAN MARC2-B00**

Photogrammetry measurements were performed on the turbine generator to determine the dilatation in hot condition. Measuring reference points were positioned on the bearing DE side, on the gearbox, on the generator and on a fix position. The photogrammetry measurements were taken in cold and hot condition.

**Figure 3: Alignment turbine generator in cold condition**
D. Case Study 2: Alstom steam turbine generator

The first bearing of the generator after the turbine coupling (bearing DE) was misaligned when the turbine warmed up, resulting in high vibrations. Previous attempts made to find a proper alignment did not work because of the complexity of the alignment and also the flexible shaft arrangement in the gearbox made the alignment by the traditional laser alignment system even more difficult. Added to this the turbine was not well designed to accommodate a proper dilatation. There were some issues with the clearance and the friction at the guides which led to asymmetric dilatation of the turbine. Due to the misalignment the turbine could work just at 20% of its maximum capacity, which led to loss of efficiency and productivity. See Figure 4 for the picture of the turbine.

![Figure 4: Alstom steam turbine generator](image)

As seen in figure 5, the turbine generator was aligned in cold condition. Taking into consideration thermal expansion and dilatation (measured from photogrammetry) it is observed that the turbine generator gets misaligned when the steam turbine gets hot (figure 6). Thanks to the TRITOP photogrammetry system, it was possible to determine the dilatation of the turbine and perform a hot alignment by adjusting the generator position.

![Figure 5: alignment in cold condition](image)

III. RESULTS AND DISCUSSION

A. Case study 1

With reference to the fixed reference, it is observed that in hot condition the turbine bearing DE moves to the left by 0.05 – 0.1mm (figure 7) and also moves upwards by 0.05 – 0.1mm (figure 8).

![Figure 7: displacement turbine bearing DE](image)
The gearbox moves right by 0.1 – 0.2mm (figure 9) and also moves downwards by 0.15 – 0.25 mm (figure 10).

Hot alignment was performed by adjusting the generator position. Shim plates were added under the generator to adjust the vertical position by 0.26mm and the generator was also shifted 0.08mm to the left. This position correspond to the position of the turbine generator in hot condition and so a hot alignment is performed. Figure 11 shows the hot alignment.

**B. Case study 2**

It is observed that w.r.t the fixed reference, the gearbox moves left by 0.1 – 0.2mm (figure 12) and moves upwards by 0.15 – 0.25mm (figure 13).
Figures 14 and 15 show the displacement of the turbine guides. One guide displaces more than the other indicating that there might have been friction issues on one guide making it to get stuck.

Bearing DE moves to the left and slightly in the vertical direction (figures 16 and 17).

Bearing NDE tends to move right with minimum displacement (figure 18) and tends to move upwards with minimum displacement as well (figure 19). Figure 20 shows the correction alignment after hot alignment is performed.
IV. CONCLUSIONS

The TRITOP photogrammetry system in combination with the Energetic Engineering experience and knowledge is a very convenient and accurate system to solve problems of asymmetric dilatation of steam turbines. Corrective action by adjusting the generator position to the rest of the steam turbine train is quite fast, reducing cost and increasing productivity. The vibration in both cases as described was considerably reduced thanks to our TRITOP photogrammetry system.

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