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Advanced Troubleshooting Techniques for Emergency Testing of a Nuclear Power Plant Rod Control Cooling Fan

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Mr. Lebo is an Engineer and Business Development Manager for Mechanical Solutions. He received his BS in Chemical Engineering from Rutgers University and has worked in a number of different roles in the Oil & Gas, Refinery, Chemical, Power, Marine, and Water and Wastewater industries including Operations, Design, Logistics, Applications Engineering, and Sales over the past 15 years. At MSI, his focus is on working with industry partners to eliminate vibration problems in rotating equipment preferably before they even happen.

ABSTRACT

When vibration issues arise and machinery becomes damaged or unusable, costly down periods are sure to ensue. Motion-Magnified Videos (MMV) can aid in troubleshooting efforts and need only a fraction of the setup and post processing time typically required by traditional testing methods. However, one of these traditional methods, such as an Operating Deflection Shape (ODS) test, can directly support the results from Motion-Magnified Videos. Having testing methods that can validate one another is imperative when troubleshooting sensitive equipment, as a solution needs to be sufficient and target the source of vibration on the first implementation. Nuclear power plants for example, do not have the benefit of fine-tuning modifications in the field. Using both methods can allow personnel to capture Motion-Magnified Videos that reveal the vibration issue and allow immediate preparation of a solution. During solution planning, an Operating Deflection Shape test can be accomplished to verify the Motion-Magnified Video results, creating a seamless transition of verifying the issue into applying a solution. Using this process can save hours or even days of suspended operation. Going a step further, the proposed solution could even be verified with Finite Element Analysis (FEA) to ensure its success. This paper will cover a case of troubleshooting and resolving vibration on a nuclear power plant rod control cooling fan with the methods described.

Keywords: Finite Element Analysis, imbalance, machinery diagnostics, measurement accuracy, Motion Magnification, nuclear power, Operating Deflection Shape, rotating machinery

INTRODUCTION

Nuclear plants generate power through nuclear fission, a sensitive process that requires constant supervision and depends heavily on successful operation of associated systems. Nuclear power plants maintain the highest standards for safety and will not function unless all systems are operational. Every component has an important role, so when specific equipment either fails or shows signs of failure, immediate action needs to be taken to provide corrective measures and ensure healthy plant operation.

Elevated vibration is one of the first signs that certain factors have been introduced which negatively influence machinery and can potentially lead to failure, which turns into costly downtime. Factors that cause heightened vibration include, but are not limited to: rotor imbalance, misalignment, fluid dynamic forces, piping or ducting vibration, installation issues such as soft foot, or structural and lateral resonances issues. Without knowing the direct cause for vibration, developing an adequate solution would be extremely difficult, if not impossible.

Field testing is the first step in troubleshooting the issue. Traditional tools used to diagnose vibration range from accelerometers, proximity probes, laser alignment tools, operating deflection shape (ODS) testing, finite element analysis (FEA), and much more. These traditional methods, while they surely provide accurate results, can take time to post-process and evaluate. Newer video-based methods (such as motion magnified video testing) have been developed that give real-time results to quickly pinpoint the issues at hand, allowing a “head-start” to solving the problem. These methods can be used in tandem to fully understand the system and ensure an adequate solution can be reached.

BACKGROUND

A rod control cooling fan (used to cool the control rod drive mechanism) was experiencing elevated vibration and it was suspected by the plant that some structural looseness existed at its pedestal and/or at the anchor bolts which the pedestal mounts to. This unit had not experienced heightened vibration in the past, so something within the system had changed since its original installation. Major components of this fan include: the pedestal, volute, pillow blocks, motor, and shaft with fan impeller, represented within the model shown in Figure 1.

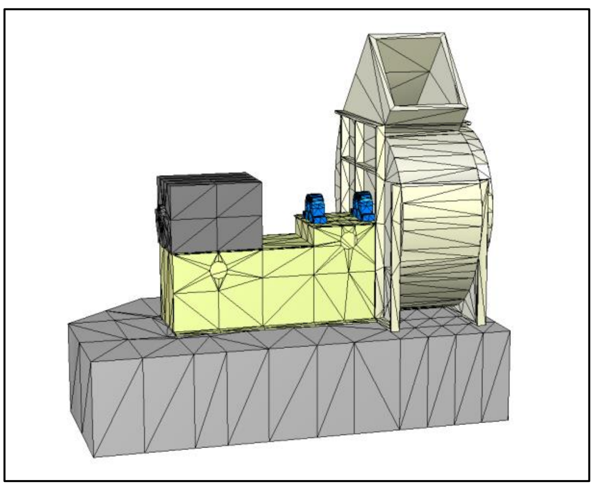

Figure 1: Rod Control Cooling Fan Model.

VIBRATION TROUBLESHOOTING

Given that the rod control cooling fan could not be shut down, field testing methods were limited to motion magnified video testing (MMV) and operating deflection shape testing (ODS) as these are accomplished when the equipment is running. The main objectives of these tests were to either confirm or deny the existence of structural looseness at the pedestal, or locate the true source of vibration if that was not it. Regions of particular interest included the perimeter base of the pedestal and the pillow blocks.

Motion Magnified Video Testing

Motion magnified video displays 2-scale but greatly exaggerated, slowed-down motion of the captured area at various frequencies of interest. This method utilizes a high-speed camera to record a few seconds of the equipment during operation, which is then processed immediately to result in an animated vibration mode shape. More on this method has also been covered in recent literature by various authors [2-9].

In regards to the rod control cooling fan, video was recorded at multiple views around the pedestal, as well as a close-up of the pillow blocks. Initial inspection of MMV capture from the pedestal suggested the pedestal was rigidly attached to the surrounding concrete and no looseness at the base was present. However, when MMV was taken of the pillow blocks, it was noticed that the inboard pillow block had significant rocking and bouncing at running speed. The rocking would deform the plate it rested upon. A sample still image of this modeshape is shown in Figure 2, with arrows to call out the vibration direction of each respective component. This pillow block contained the fixed bearing which provides stiffness against both radial and axial motion of the shaft. Potential imbalance of the fan impeller could lead to this motion exhibited at the inboard pillow block, as this imbalance would create forces too large for the pedestal plate to keep the pillow block stationary. Immediately upon this discovery, the information was shared with plant personnel to determine the best corrective measure.

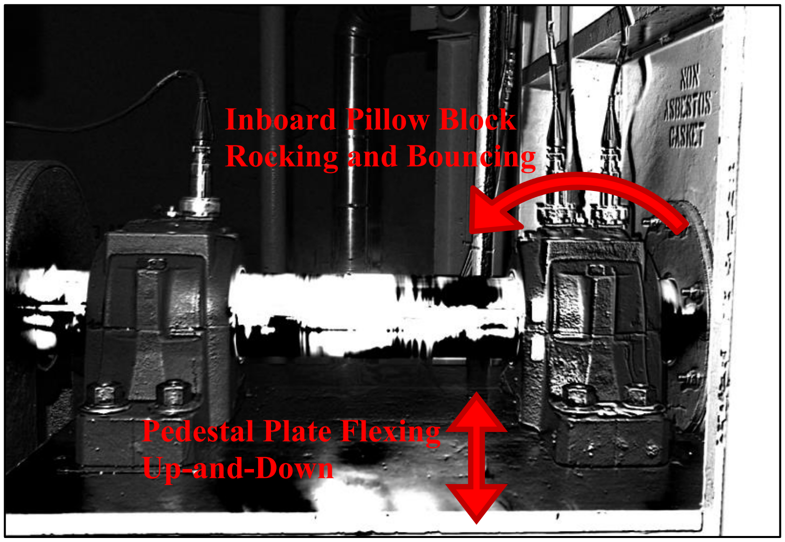

Figure 2: Still Image From MMV Capture at Running Speed.

Operating Deflection Shape Testing

Operating Deflection Shape testing involves gathering extensive vibration data (amplitude and phase) over the entire system, and then visualizing the data in a computer animated 3D model. Vibration at individual frequencies can be animated, with its motion amplified to better understand how the system is moving. Onari and Boyadjis discuss using ODS, along with other methods such as finite element analysis (FEA) to resolve vibration issues [1]. The visualization from ODS can confirm results from other testing methods, as well as uncover root causes that were previously hidden. With the MMV results, extensive focus was placed on the pillow blocks, but the entire fan still had data collected across it. This was to completely rule-out structural looseness at the base of the pedestal, and to ensure no vibration issues were present other than the pillow block rocking. The ODS model confirmed the rocking inboard pillow block and deformation of the plate it rests upon. Figure 3 shows a still image of an ODS animation, magnifying the vibration motion of the system at running speed. Note that a competing method using cell phone video had been tried by the plant. However, the pixel depth was not sufficient to display the vibration accurately, and the video indicated large motion in components that were found by accelerometers to be stiff and experience low vibration. This is how the plant originally believed that elevated vibration was sourced from structural looseness at the base of the pedestal.

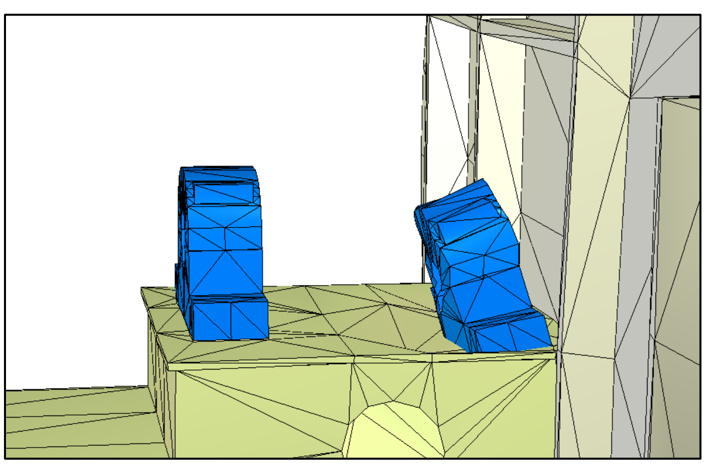

Figure 3: Still Image From ODS Animation at Running Speed.

FIELD TESTING RESULTS

Major findings from field testing were distinguishing the motion of the inboard pillow block, and the absence of structural looseness at the pedestal base. Vibration measurements (extracted from the ODS data) taken from the top of the inboard pillow block were read to be 0.55 in/s 0-pk in axial and vertical directions, which was in line with the plants' vibration monitoring system. Vibration levels at other locations of the fan system were reasonable and did not draw concern. Since the fan impeller had not been given maintenance for a long time, it was likely residue had built up on it and caused an imbalance. The imbalance forces were strong enough to cause the inboard pillow block to push into and deform its supporting plate.

Typically, if an imbalance due to residue was recognized, the respective equipment would be shut down and respective maintenance would be performed. However, constant operation of this fan was necessary, so a solution that avoided shutdown was required. Since the plant was made aware of the imbalance immediately upon its discovery from MMV testing, an adequate solution was already being developed, ahead of a typical schedule where post processing where traditional methods would have been performed.

SOLUTION

To prevent deformation of the pillow block supporting plate, it needed to be stiffened in a non-invasive manner, as welding and drilling could not be accomplished next to a rotating shaft. Also, since the rod control cooling fan is inside reactor containment, heavy limitations were placed on the material selection. After some deliberation, a solution was reached that met all the requirements. It involved a clamp, that would go through the access holes in the pedestal and push against robust pieces of metal to prevent deformation of the plate. The pieces used were left over from another project at the plant and were suitable to go inside containment. The design is shown below in Figure 4.

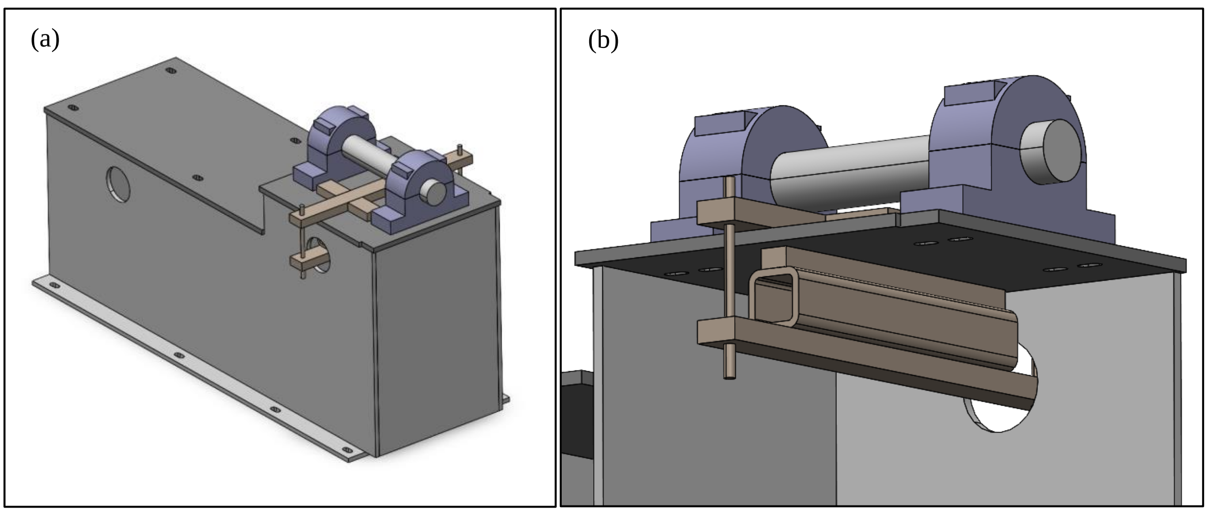

Figure 4: (a) ISO View of Clamp Design. (b) Enhanced View of Clamp Design.

FINITE ELEMENT ANALYSIS VERIFICATION

To ensure the design would be sufficient on the first implementation, a finite element analysis (FEA) was accomplished (Figure 5). As the deformation was localized to a few components, the FEA model consisted of only the pedestal, pillow blocks, and clamp. To properly sync the baseline model, the deflection of the inboard pillow block was extracted from the field-testing data (4.8 mils axial deflection). This data point was taken from the top of the inboard pillow block, on the side that faces the outboard pillow block. An axial force was applied to the inboard pillow block and scaled accordingly to produce the same deflection. Then, a subsequent run was accomplished with the clamp in place to predict the reduction in deflection (Figure 6).

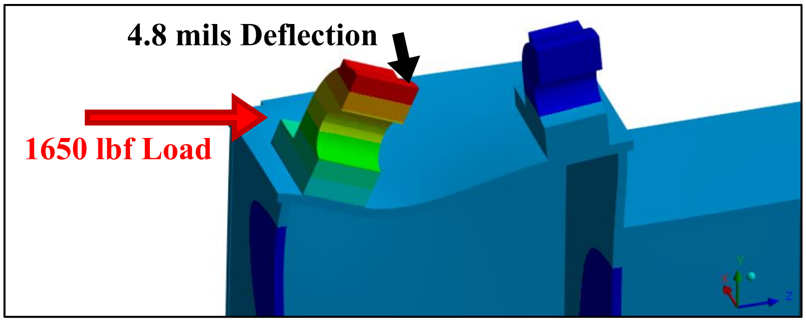

Figure 5: Baseline FEA Model.

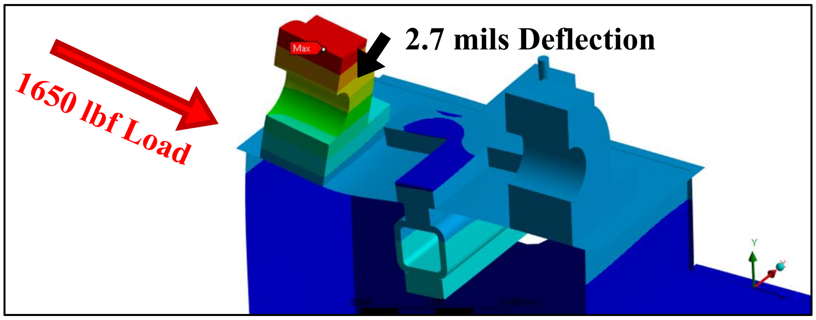

Figure 6: FEA Model with Clamp.

This model gives a general understanding of the behavior of the supporting plate when the pedestal is attached. Deflection was reduced by 44% and the clamp was predicted to be successful.

CONCLUSIONS

After the design was validated through FEA, it was implemented in the field. When the clamp was attached, vibration reduced from 0.55 in/s 0-pk down to 0.28 in/s 0-pk, in both axial and vertical directions. The clamp proved successful and would act as a "band aid" until the next outage when the fan could be shut down and appropriately balanced to eliminate the excessive forces acting on the inboard pillow block and supporting plate.

The diagnostic process was done ahead of typical schedules because of MMV testing. Having captured the inboard pillow block motion, the source of vibration became clear. Solutions could be produced before post-processing of traditional methods had even finished, which is what happened in this case. Plant personnel were immediately informed of the plate deformation discovery and provided the video to fully inspect the issue at hand. The clamp solution had started to be designed before the ODS was even finished. Upon its completion, the ODS model had further validated MMV results. When done correctly, both MMV and ODS testing methods can accurately distinguish vibration sources. However, MMV is processed immediately after its capture and does not require the same lengthy post-processing time as an ODS. MMV facilitates a "shortcut" to valuable information of the respective system. An ODS is still extremely useful to the full diagnostic procedure though, as it may uncover something hidden to MMV capture.

Furthermore, in this case FEA was used to support the solution. Given the fast development of the clamp design, time could be dedicated to ensure its effectiveness. Had only traditional methods been used, the vibration source would have been diagnosed after a much longer duration of time, at which point the plant could have been desperate to implement a solution without fully understanding the response it would create. Combining testing and analysis methods is the best approach to correcting a system.

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