Reducing Technical Risk Associated with Large Machinery Replacement or Retrofit Projects

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The United States electrical power generation market is quite complex, and currently in a significant state of change. Baseload coal plants are closing, and natural gas, with a highly variable fuel cost, is the prescribed replacement. New nuclear construction is currently plagued by the familiar bugbears of schedule and cost overruns, making investment in additional plants uncertain.

Enter license renewals for nuclear reactors. The US Nuclear Regulatory Commission (NRC) original license for nuclear power plants is 40 years. 10 CFR 54 was issued to provide for a 20-year extension to the original license, and 42 sites (74 reactors) have since received a license extension, with several more applications under review[1]. Given the success of the program, and the plants under extension, Second License Renewals (SLRs) are currently under consideration, which would extend the total life of the plant to 80 years.

In order to safely and effectively extend the life of the plant, major equipment must be refurbished or replaced. An example of a major component being actively replaced in the nuclear industry is the main feedwater pump. In the past few years, several plants have replaced or refurbished their main feedwater pumps, including: Point Beach (2011), Monticello (2013), Fermi (2013), Duane Arnold (2014), and Peach Bottom (2015). Occasionally with these installations, all does not go as planned and the installed system exhibits unanticipated behaviors.

Nuclear is indeed “special and unique”, and one of the unique attributes of a strong nuclear safety culture is that “employees understand that complex technologies can fail in unpredicted ways. They are aware that latent problems can exist, and they make conservative decisions considering this potential.”[2]

In one such example of an unpredicted challenge, a plant replaced their main feedwater pumps and experienced abnormally high vibrations after installation. The authors’ company, which specializes in resolving situations like this, was brought in to diagnose the problem. Extensive

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[1] http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 8/25/15.

[2] Institute of Nuclear Power Operations (INPO), “Principles for a Strong Nuclear Safety Culture”, 2004.

testing was performed, including: Experimental Modal Analysis (EMA) testing offline and online to identify any natural frequencies in the system that may be excited during operation; and Operating Deflection Shape (ODS) testing, by gathering vibration data at over 700 locations/ directions in order to identify the specific characteristics of movement during operation (see Figure 1).

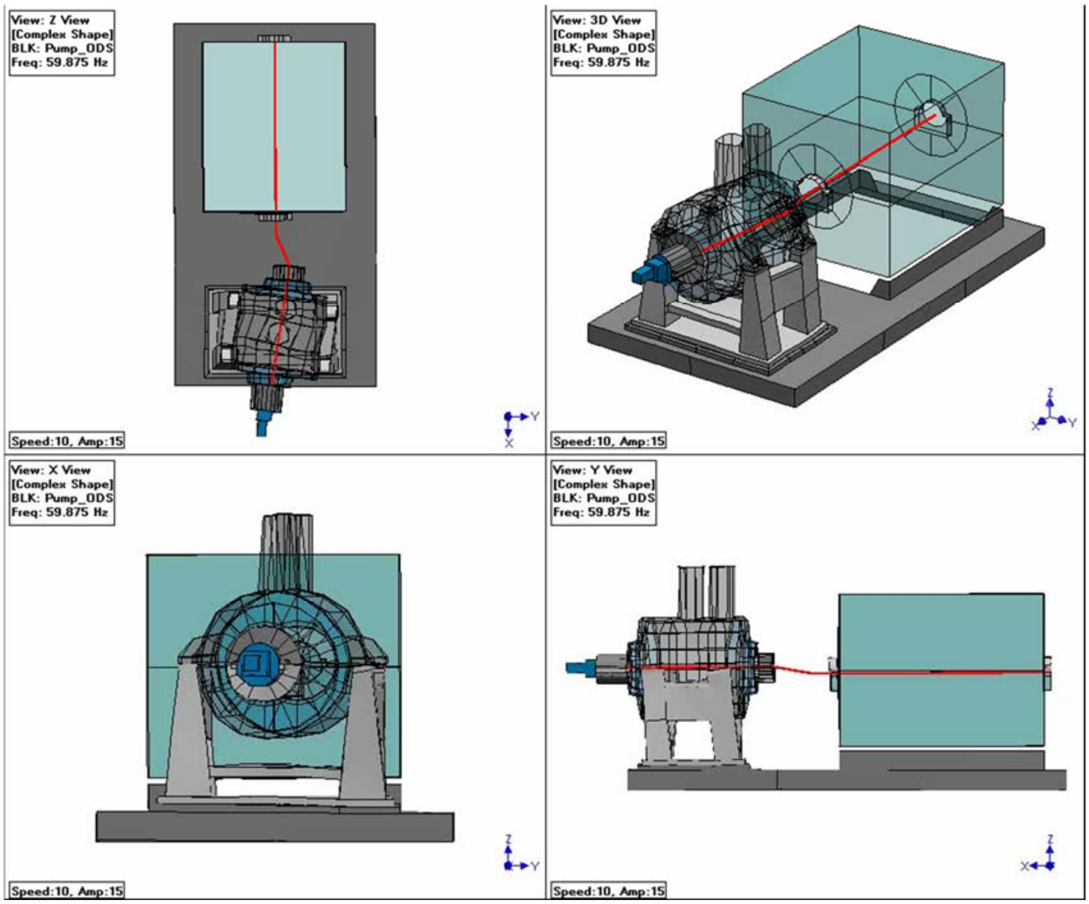

Figure 1. Still frame image of a typical feedwater pump Operating Deflection Shape (ODS) video using real world vibration data overlaid and animated on a solid model. This analysis indicates a twist mode of the pump structure.

The test results clearly indicated that a structural natural frequency (twist mode) was close to the running speed of the pump. In addition, it was determined that a potential foreign material could have been the cause of the high vibration issue (high imbalance load). Upon internal inspection, it was discovered that a suction straightening vane had broken loose and lodged within the pump, and the center bushing had worn to over twice its original clearance due to the resultant imbalance. The vane design was inadequate for the application, and was not discovered until a failure during plant operations. Such a system influenced component issue could have been resolved during the design process with appropriate system and component level analyses. A new design was successfully implemented, with no further issues. Analysis of the pump alone without consideration of system effects would not have been sufficient.

It is imperative to realize that when major components are replaced, they are part of an electro-mechanical system and the pre-installation analysis should reflect that. This “system perspective” is complicated not only by the assortment of components involved (e.g., pump, motor, piping, and fluid flow), but also the cast of characters responsible for each component. These vendors are often very qualified to analyze their piece of the whole, but seldom account for interactions with other components, making responsibility for real world problems difficult to determine, and not likely to be identified by component vendors during analysis.

Additionally, the real world nuclear plant is not a static environment, so dynamic analysis is required, looking at both the rotating and structural systems together. Furthermore, interactions between the mover and the moved, or Fluid Structural Interaction (FSI), may need to be evaluated to check for potential problems in a simulated environment, such as the example above.

How should one determine what is an appropriate level of analysis prior to equipment installation? Surely not every piece of equipment warrants the plethora of analysis options available. Although not specifically focused on the nuclear industry, an example of how to scale the level of analysis based on equipment and customer factors is provided in Hydraulic Institute’s “Rotodynamic Pumps - Guideline for Dynamics of Pumping Machinery,” Standard 9.6.8.[3]

ANSI/HI 9.6.8 describes and recommends various levels of detailed evaluation and validation that are commensurate with the degree of equipment uncertainty and application risk. Equipment uncertainty (U), is based on the specific pump type, with weighted criteria for drive, coupling, power, etc. Application risk (R) quantifies the degree to which the design has been proven in the field. When these two aspects of the project are combined, they yield a risk uncertainty number (RUN).

Various levels of analysis are then recommended based on the calculated RUN and described, with specific recommendations based on the industry (including “power generation”). These analyses will then appropriately and practically evaluate pumping machinery design attributes and relevant site characteristics in order to determine the effects of dynamic performance on equipment life and reliability. For example, dynamic perturbations may result in the excitation of structural resonance. With increasing use of variable speed drives (a factor in determining “U”), avoiding these “excitation frequencies” has become increasingly more difficult, and identifying these frequencies is more important than ever to ensure that resultant problems caused by high vibration are properly addressed and mitigated during the design phase.

Further development of the analytical tools and techniques used to identify these issues has also dramatically increased. However, it is not always clear which tools are available and how to use them in various applications across various markets and diverse products. Equally, the range of preventive measures remains quite diverse, ranging from simple to complex. The associated expense can be small to relatively large when compared to the cost of the equipment. In all cases

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[3] Refer to Hydraulic Institutes website at www.pumps.org for more information.

it is better to avoid a problem than to fix it after the fact.

This methodology was applied to a significant pump project, the replacement New Orleans Flood Control pump stations, designed to transfer floodwaters from within the city to Lake Pontchartrain. The "system" consists of motors, gear boxes, pumps, foundation and support system, including the soil itself, related piping and its supports. The goal of the dynamics analysis was to reduce risk by identifying potential vibration and fluid dynamics problems and correct them during the design phase. Focus was given not only to immediate issues during start-up, but also to potential problems over the long term, upwards of 30 years.

The authors' company was contracted to evaluate these permanent systems, based on previous work performed to validate the temporary flood control facilities. The dynamics analysis included an evaluation of structural vibration and stress using Finite Element Analysis (FEA) and torsional rotordynamics analysis of the motor, gear box, and pump rotating components. Originally, the pump was to be fixed both at the base plate and the motor. As shown in Figure 2, FEA data revealed that the stress associated with thermal contraction would stress the upper structure, which was addressed with a guided constraint. Additionally, an expansion joint was optimized to help with thermal issues, as well as reaction loads, deflection, and bolting stresses.

Additional FSI analysis included Computational Fluid Dynamics (CFD) analysis coupled with FEA of the rotating impeller and the stationary diffuser vanes, in order to optimize the fluid dynamic performance and the fatigue life of the diffuser vanes. Based on this analysis, the inlet guide vanes were headed for fatigue failure (Figure 3), and a design modification was added to address the situation (Figure 4).

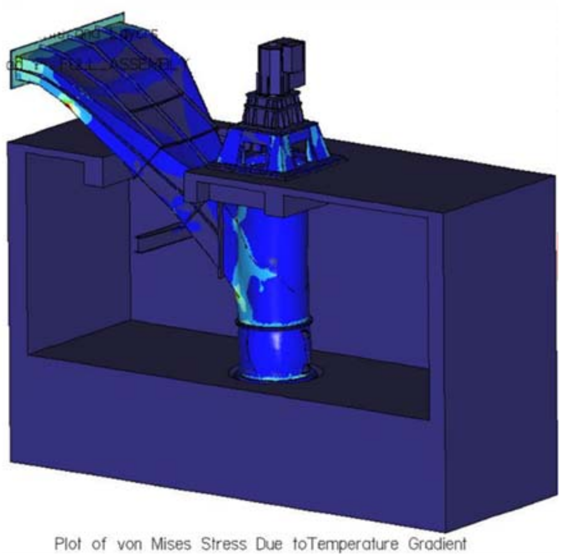

Figure 2. Stress analysis from thermal shrinkage demonstrated the need for an optimized expansion joint and guided constraints for the upper mounts.

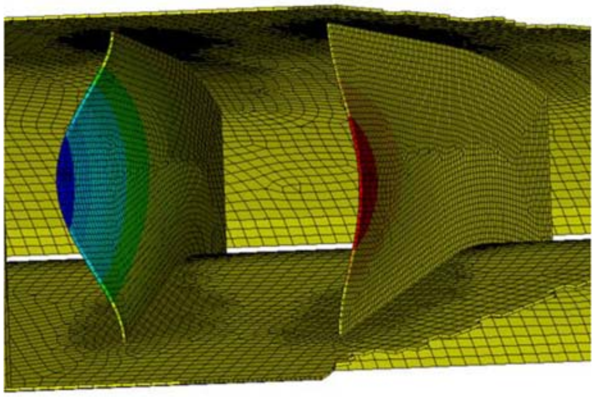

Figure 3. Original inlet vane design analysis showed likely fatigue failure.

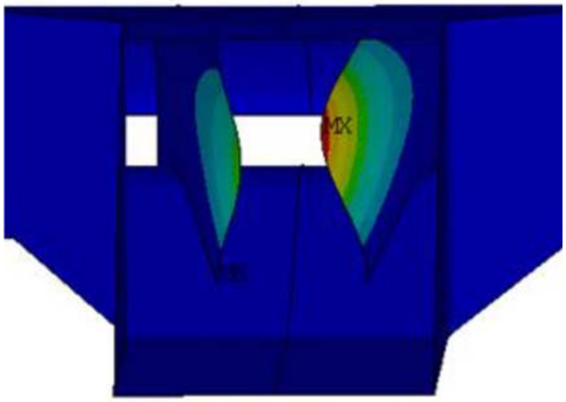

Figure 4. Modified inlet vane design significantly reduced the likelihood of fatigue failure.

Each of these modifications would have been costly to troubleshoot and remedy after installation, with downtime impacting public safety, not revenues. Furthermore, these critical findings were based on a dynamic analysis, including how the structural and static components would react during operation with fluid in the system.

As nuclear power plants continue to age, major equipment replacement will be the order of the day. In order to stay in "prevention mode" and not be stuck making reactive decisions in "correction mode", a dynamics analysis of the entire system associated with new equipment can help reveal problems before they happen. Developing a guideline to select the necessary level and type of analysis for your plant will ensure decision makers understand the value of reduced risk, as the industry continues its drive for excellence.

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