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Transient loadings — Are they the peak loadings?

Many times when we are designing static and rotating equipment it starts with a specifications sheet that lists the performance expectations and requirements. Most often any startup or shutdown requirements are not listed. For static equipment this could be heat up rates or sequencing of process feeds to the equipment. For rotating equipment it could be ramping conditions through critical speeds. Many times during a startup of a plant, opportunities for relatively high transient loadings are present. Let's discuss a few examples to "home in" on some design considerations.

The first example is the heat up rate of thick walled reactors and heat exchangers. When these components heat up, localized thermal gradients produce stresses. If the firing rate of the equipment is too quick, the thermal gradient induced can cause detrimental stress to the vessel. You might wonder how this can happen if the peak temperature is not reached. The key is to look at the transient heat transfer. The firing rate will be dependent on the process fluid conditions, geometry and materials. Many times the surface on the "hot side" will heat up fast and the outer surfaces will remain colder due to thermal lag. Because of this, the transient thermal gradient can be higher than steady state. In some cases for static equipment the local thermal gradient is high, even though the ASME code is satisfied. However, during these peak transients the code is not satisfied.

Another situation involves the startup of rotating equipment. Many times a compressor or turbine is "false loaded" to bring the system on line. During these periods there can be performance issues that can effect the equipment. Dynamic stresses during startup can be higher than normal. Also, for compressors there can be transient loads involving the loss of cooling on intercoolers. Sometimes the process fluid changes during startup due to yield achieved. This can also lead to response changes in the equipment. Some polymer equipment has polymer-lubricated bearings whose performance is affected by interactions of heat, speed and differential pressure. For compressors sometimes transients exist that simply involve a molecular weight change. Because of the process change experienced, the acoustics in the system will change. That can lead to failures. In the system, the acoustic natural frequencies will shift that can couple with the existing driving forces in the system. A resonant vibration can occur, leading to a quick failure.

Most of the startup issues discussed are not analyzed during process and detailed design phase of the plant. Many of these situations were too difficult to analyze, and trial and error and experience were used to determine startup procedures. This is no longer the case for many applications. Where in the past transient process and mechanical analysis was very rare, it is now conducted on a regular basis. This is due to faster computers, better numerical methods and economical solution methodologies.

The solution methodology for startup analysis of static equipment might be as follows:

1. Develop a finite element (FE) model of the equipment.
2. Calculate the transient heat transfer film coefficients — that is film coefficient versus time.
3. Perform a transient heat transfer FE analysis.
4. Perform a transient stress FE analysis.

The solution methodology for simulation of intercooler failure for a compressor might be as follows:

1. Set up parameters of compressor performance model.
2. Evaluate the transient heat transfer in the intercooler.
3. Forward step the compressor performance model in time, simulating the loss of cooling.

It is often helpful to perform parametric studies to determine the sensitivity of the design to transient conditions.

Remember, the peak stresses are not always the steady state stresses. New methodologies and tools can tell you what you need to know to operate your equipment safely and reliably. In all cases, a professional engineer competent with the equipment should review and approve the design as fit for service for the transient and steady state conditions.

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