Rod Load Monitoring for Reciprocating Compressors

We were talking to engineers supporting maintenance and operations around a fleet of reciprocating HC gas compressors. This particular company had experienced major compressor wrecks involving broken rods, crossheads, pin bushings, and frame cracks which they said were caused more often by exceeding maximum piston rod load than by any other event.

Before the introduction of technology that made direct measurement of piston rod loading practicable[1], best-in-class reliability strategies for reciprocating compressors involved calculating rod loads in order to operate below Original Equipment Manufacturers' (OEM) load limits. Many modern operations with only fundamental monitoring capabilities still consider this practice both reliable and effective to this day. We recommended therefore, basic rod load monitoring because our client was in a similar technology category.

Rod failure potential is at the thread root, which is the weakest location on a piston rod. The rod load at the thread root is calculated with the following formula:

$$\mathbf{RL = (P_d D_b^2 - P_s(D_b^2 - D_r^2)) / D_{tr}^2}$$

Where:

$\mathbf{RL}$ is the rod load at the thread root, psi (Mpa)
$\mathbf{P_d}$ is the cylinder discharge pressure, psig (Mpa)
$\mathbf{P_s}$ is the cylinder suction pressure, psig (Mpa)
$\mathbf{D_b}$ is the cylinder bore diameter, inches (m)
$\mathbf{D_r}$ is the rod diameter, inches (m)
$\mathbf{D_{tr}}$ is the rod diameter at the thread root, inches (m)

Initially, the company's intent was to collect data that was to expose shifts in equipment operational risks to be discussed with reliability and production stakeholders. We then recommended from practical experience that the rod load at the thread root should not exceed 8,000 psi (55 Mpa). Further we recommended that after rod load monitoring points populated their monitoring database for reciprocating compressors (through DCS), they should compare their operation with the recommended limit.

Enters Rod Life Tracking. Traditionally, rod load limits are being observed by appropriate pressure controls and differential pressure relief valves across compressor stages. This is what we suggested to our client: If they felt that they had an operating environment where rod loading could not always be controlled they should explore the application of a concept of rod life tracking.

[1] What is meant here are diagnostic asset management programs for cylinder performance which usually require pressure taps etc.

This concept is based on the assumption that computerized monitoring of transient rod load excursions could yield a record of calculated rod load and duration of overload episodes or cycles in order to compute remaining rod life based on *Palmgren-Miner's Linear Damage Rule*[2]. For this they would need fatigue failure information such as, for example, is shown on the hypothetical S-N chart, Figure 1. More exact information could be obtained from the OEM or steel atlases based on compressor rod material analysis and hardness.

In order to determine how much of fatigue life is left on a compressor piston rods after recorded episodes of overload one could use the following *Palmgren-Miner* formula:

$$\sum \frac{n_i}{N_i} = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \cdots = 1$$

N_1, N_2 equal the life at a particular stress level and are taken from the fatigue line shown in Figure 1, whereas n_1, n_2 are actual cycles at their respective stress levels.

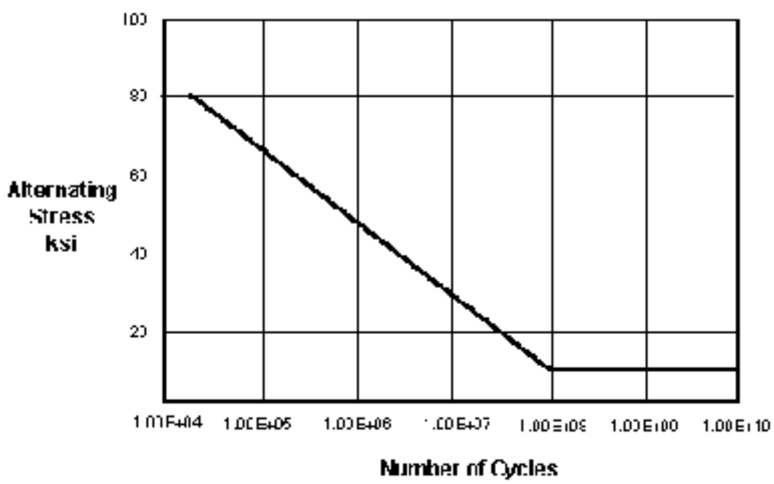

Figure1. S-N Diagram.

Say, on a 300 rpm reciprocating compressor we experienced a number of overload episodes with accumulated times as shown in Table 1:

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[2] ASM Handbook, Fatigue and Fracture, V-19, ASM, 1996, or the Internet.

Table 1.

No.	Overload ksi	Accumulated Operating Hrs.	*n* Actual Cycles	*N* Life Cycles From Fig.1
1	10	250	$4.5X0^6$	$8.3X10^7$
2	15	200	$3.6X0^6$	$5.4X10^7$
3	20	100	$1.8X10^6$	$3.1X10^7$

Sample calculation using the hypothetical data in Figure 1 and Table 1:

$$4.5 X 10^6 / 8.3X10^7 + 3.6 X10^6 / 5.4X10^7 + 1.8 X 10^6 / 3.1X10^7 + n_4 / 10^8 = 1$$

$$0.05 + 0.07 + 0.06 + n_4 / 10^8 = 0.18 + n_4 / 10^8 = 1$$

$$n_4 = (1 - 0.18) X 10^8$$

$n_4 = 0.82 X 10^8$ cycles.

By conversion, $8.2 X 10^7$ cycles represent 4,555 hours - or ½ year of continuous operation - minimum expected total operating time provided no further rod load excursions occurred. Also, earlier, there might have been already operating hours at normal rod load accumulated.

The foregoing shows that stress is accumulative suggesting process machinery having memory and keeping track of punishment it receives during its lifetime.

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