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Rod Load Calculations and Definitions for Reciprocating Compressor Monitoring

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Author:

Brian Howard, P.E.
Sr. Technologist
Reciprocating Compressor Condition Monitoring
GE Measurement & Control

Introduction

The term "rod load" has been used for decades to describe the maximum forces a reciprocating compressor assembly can withstand. The term has some ambiguity, but recent papers have clarified some of the key definitions and terms[1].

With the improved understanding beginning to permeate industry, customers have begun to ask questions about how GE's Bently Nevada* 3500 Series Monitoring Systems and System 1* Condition Monitoring Software (referred to as 3500/S1 hereafter) calculate these values. The purpose of this note is to answer those questions.

The terminology and context for this application note are American Petroleum Institute (API) Standard 618, 4th edition and 5th edition[2]. Previous editions of API 618 used other descriptions and definitions for rating values of reciprocating compressors. For ease of reference, the terms and definitions used herein appear at the end of this application note.

Calculation Methodology

Figure 1 shows the rod load curves and data generated by 3500/S1.

Inertial Force

The red line in *Figure 1* represents the forces due to inertia forces. The inertia mass for nearly all reciprocating compressor condition monitoring installations includes the crosshead assembly, crosshead nut, piston rod, and piston assembly. This collection of mass for inertia is consistent with the definition provided in API-618 5th Edition (Data Sheets, Page 7, line 31)[2]. 3500/S1 does allow the user to exclude the crosshead mass from the inertia force calculations (see *Figure 3*); however, the configuration is rarely encountered in the field, is not consistent with API-618 4th or 5th edition terminology, and is outside the scope of this application note.
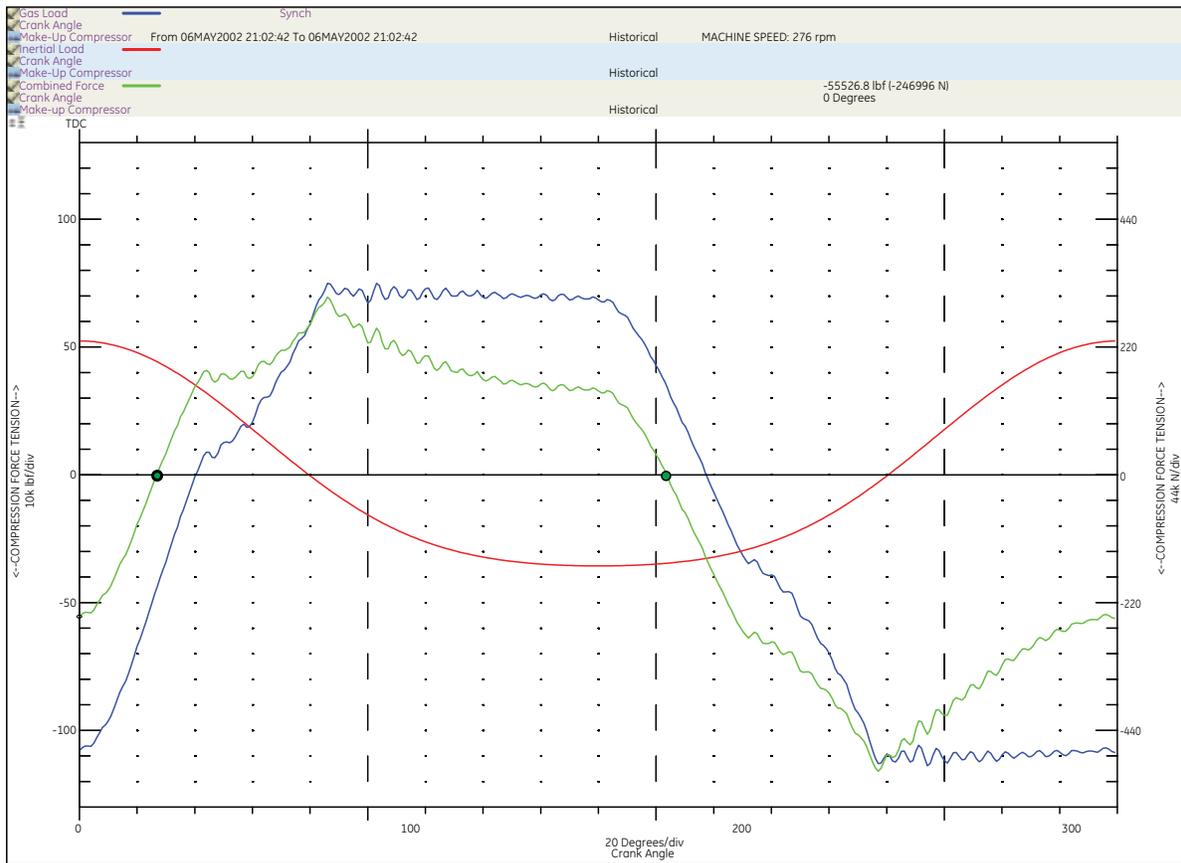

Figure 1. Rod load curves generated by 3500/S1

Gas Force

The blue line in *Figure 1* represents the gas forces acting on the compressor's static components and running gear. This force is the gas load referenced in API-618 (paragraph 6.6.2)[2]. To obtain this force, the indicated cylinder pressure on the head end is multiplied by the head end area of the piston. This is shown in green in *Figure 2* for a typical double-acting cylinder. The resultant force is then subtracted from the indicated crank end cylinder pressure times the crank end piston area (shown in brown in *Figure 2*). This summation represents the net force[1] acting on the piston rod and can be written as:

$$F_{GasLoad} = \left(A_{CrankEnd} \times P_{CrankEnd}\right) - \left(A_{HeadEnd} \times P_{HeadEnd}\right)$$

The cylinder pressure varies continuously throughout the revolution of the crankshaft so the calculations must be performed multiple times throughout the revolution to obtain a curve. For each 360 degrees of crankshaft rotation, 3500/S1 collects 720 indicated cylinder pressure data points simultaneously for both the head and crank end. The gas load calculation is thus performed 720 times for each revolution.

Figure 2. Piston areas used for gas rod load calculation

Crank End / Inner End Head
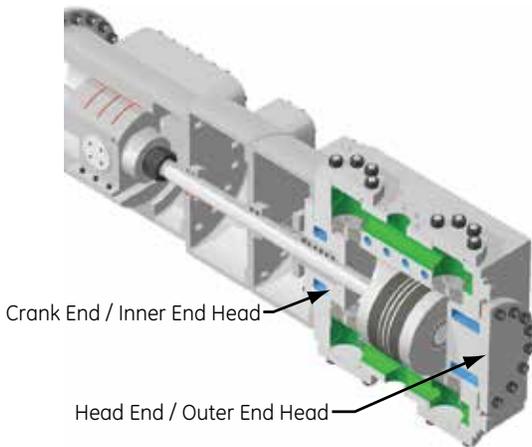
Head End / Outer End Head

Figure 3. Reciprocating compressor terminology

The gas pressures in the chamber act not only on the piston, but also on the heads of each cylinder. The combined gas force on the crank and head end heads has the same absolute value as the gas load calculated above, but acts in the opposite direction (i.e., has opposite sign).

Combined Rod Load

Finally, the green line in *Figure 1* represents the combined rod load, or crosshead pin load. This force is the combined rod load referenced in API-618 (paragraph 6.6.1)[2]. The gas load is added to the inertia force at each point of measurement to obtain this force. Since, as noted in the previous section, the gas load is computed 720 times for each crankshaft revolution, 3500/S1 also performs the combined rod load calculation 720 times for each crankshaft revolution. For each of these 720 points of measurement during the crankshaft revolution, the calculation can be written as:

$$F_{CombinedRodLoad} = F_{GasLoad} + F_{Inertia}$$

When the mass used in the inertia force calculation includes the crosshead, the smallest distance between the points of zero force (shown by black dots at approximately 35° and 200° of crank angle in *Figure 1*) represents the degrees of rod reversal referenced in API-618 (paragraph 6.6.4)[2].

Had 3500/S1 been configured to calculate rod load at the piston rod, the inertia forces would no longer include the crosshead mass. The combination of this inertia force and gas force results in the forces that act on the piston rod, next to the crosshead. Note that this force no longer reflects those acting on the crosshead pin, and therefore cannot be used to calculate rod reversal.
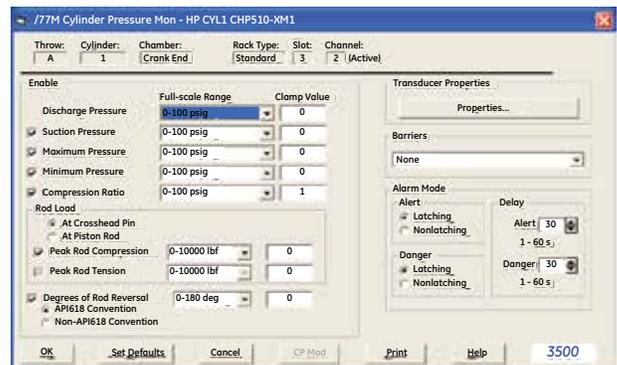

Figure 4. 3500/77M configuration screen

Conclusion

Rod load curves and peak rod load / reversal values provide important insight into the health of a reciprocating compressor. Understanding how 3500/S1 calculates these values and how they relate to OEM and API-618 definitions enables end users to better manage their reciprocating compressors.

Bibliography

1. Atkins, K.E.; Hinchliff, M.; McCain, B., "A Discussion of the Various Loads Used to Rate Reciprocating Compressors." *Proceedings of the Gas Machinery Conference*, 2005.

2. API Standard 618, Fifth Edition (2007), "Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services," American Petroleum Institute, Washington, D.C.

Terms and Definitions

The following definitions draw extensively from reference (1). The reader is encouraged to consult this reference for a complete discussion of these terms and others, as well as a valuable historical perspective.

- **Combined Rod Load:** *The sum of actual gas load (including valve and passage losses) plus inertia loads at the crosshead pin, in the direction of the piston rod.*

  This is the force curve labeled "Combined Force" in System 1 software's rod load plots when the inertia force includes the mass of the crosshead assembly. This force varies continuously throughout the revolution. The term appeared in both the 4th and 5th edition of API-618 with the same definition; however the 4th edition required that it be calculated every 10 degrees and the 5th edition required that it be calculated every 5 degrees. Reference 3.7 of API-618 5th edition for a formal definition.

- **Crosshead Pin Load:** *Same definition as "combined rod load."*

  Note this term is not defined within API-618, but is a commonly encountered industry term used to clarify the component at which the combined rod load calculations are being done.

- **Gas Load:** *The force resulting from the internal pressure in each chamber acting on the associated piston and cylinder head surfaces.*

  This is the curve labeled "Gas Force" in System 1 software plots. As it depends only on the pressure and cylinder geometry, it remains the same whether the force calculation is done at the crosshead pin or piston rod. The term appeared in both the 4th and 5th editions of API-618 with the same definition; however, 4th edition required that it be calculated every 10 degrees and the 5th edition required that it be calculated every 5 degrees.

- **Maximum Allowable Continuous Combined Rod Load (MACCRL):** *A value determined by the Original equipment Manufacturer (OEM) based on design limits of the various components in the compressor frame and the running gear (bearings, crankshaft, connecting rod, crosshead assembly, piston rod, piston assembly).*

  With minor exceptions (see 6.6.5 of API-618, 5th edition), no single value of combined rod load can exceed the manufacturer's ratings for maximum allowable continuous combined rod load (see paragraph 3.19 of API-618 5th edition for a formal definition). OEMs may have individual limits for compressive rod load, tension rod load, and compressive plus tension.

- **Maximum Allowable Continuous Gas Load (MACGL):** *A value determined by the OEM based on the design limits of the static components (frame, distance piece, cylinder and bolting).*

  With minor exceptions (see 6.6.5 of API-618, 5th edition), no single value in the gas load curve can exceed the manufacture's ratings for maximum allowable continuous gas load. Reference 3.20 of API-618 5th edition for a formal definition.

- **Rod Reversal:** *The shortest distance, measured in degrees of crank revolution, between each change in sign of force in the combined rod-loading curve.*

  Reference paragraph 3.49 of API-618 5th edition for a formal definition; however, note that the API 618 definition is not entirely accurate as it references "piston rod loading" instead of "combined rod loading."

Notes

GE Measurement & Control

1631 Bently Parkway South

Minden, NV 89423

+1 775.782.3611

www.ge-mcs.com/bently