REAL-TIME MONITORING ON VIBRATION- BASED DIAGNOSTICS OF RECIPROCATING COMPRESSORS

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Abstract. The article considers the issues of using different physical processes parameters in systems for real-time condition monitoring of reciprocating compressors.
The locations for sensors of absolute and relative vibration are defined.
Trends of parameters of absolute and relative vibration at emergence of malfunctions and defects are given.
Examples of diagnosing of reciprocating compressors in parameters of relative and absolute vibration are reviewed.
It is shown that real-time monitoring of the absolute vibration parameters and the relative position of rod provides observability of the piston compressors' condition and, consequently, their safe operation.

Keywords: reciprocating compressors, vibration, monitoring, diagnostics, condition

1 Introduction

The fundamental principle of safe resource-saving operation of potentially hazardous industries is a real-time condition monitoring of facilities. This is proved by many years of using condition monitoring systems at refineries of Russia, Bulgaria and other countries. Condition of reciprocating compressors can be evaluated by the parameters of absolute and relative vibration of assemblies and details of reciprocating compressors temperature of assemblies, details, lubrication and compressed gas, gas pressure in decreasing space, in inlet and discharge manifolds [1, 5, 6, 7, 8, 9, 10].
The criteria of any monitoring system's effectiveness is, on one hand, providing safety of operation piston compressors and timely reaction of the monitoring system to emergence of fast-developing and potentially dangerous (considering the consequences) defects, and on the other hand – minimal cost of the system, which is determined by the system's architecture and number of measuring channels [1, 6, 8, 9, 14, 15].

2 The choice of primary transducers

The results of many years of researches [1, 2, 3, 7, 10, 11] show that values of machinery absolute vibration parameters change are caused by the change of structural parameters of details and assemblies, i.e., as a rule, increased clearance between interconnected and communicated details which determine the machinery condition. That's why, the control of the absolute vibration is a very common way to provide crash protection and diagnosis of piston compressors.
Installation of absolute vibration sensors in most cases does not require interference with the machinery structure, which is determinant for hazardous production facilities [1, 4, 8].
Measurement and analysis of thermodynamic parameters of reciprocating compressors is one of the most effective methods of checking the compressing regime compliance to reciprocating compressors operational conditions [8, 9]. However, they should be provided by the production process conditions, which are controlled and supported by the automatic control systems. Along with that, the additional means of gas temperature and pressure measurement require special primary transducer installation activities, which usually lead to alteration of reciprocating compressors assemblies' construction and its interconnecting piping.
The most vulnerable parts of the piston compressor, subjected to the influence of many factors of wear are the piston rings. It works in dry friction mode and is subjected to mechanical wear. Its intensity can grow substantially in case of compressed gas technical parameters or composition changes. Especially strong impact on wear process developing has mechanical impurity and dripping liquid. Such changes of gas composition often are impossible to detect by means of the process parameters control. The vibration parameter measurement in that case will not be effective enough.

As a matter of fact, such processes can appear during start-up operations on technological units. When the operating practice is correct they can be determined by the changes in composition of raw materials, reagents, changes of units' performance.
For a reciprocating machine operating in normal condition the wear speed does not exceed up 100 to 150 μm per 3600 hours, the acceptable wear speed is considered to be up 100 to 150 μm per 1000 hours of operation, when the wear limit is 800 μm it determines measurements of a carrier ring wear size each 2000-3000 hours of continuous operation of reciprocating compressors and periodical alignment of a rod.
Wear of the compression rings leads to performance losses of the compressor. Wear rider ring leads to sagging of the rod, the occurrence of bending stresses and their concentrations in the attachment area of the rod to the crosshead or in the attachment area of the rod to the piston. The increased stresses while having normal steady load are causing decrease of fatigue limit, accumulation of fatigue damages and micro-cracks, and, eventually, to destruction of a rod in the place of stresses concentration. Guide rings wear and rod metal structure degradation can develop really quickly – from a few hours (non-steady load) to a few days (steady loads), which is determined by the quality of compressed gas, amount of condensate and impurities in it. That is why to ensure safe operation of compressor, it is an urgent task – to control the carrier piston rings wear in real time.
To solve this task – it makes sense to place vortex-current rod position sensors in vertical, or, sometimes, radial directions. In some systems this method of measurements and rod position control on an operating machine is called "rod drop" [1, 8, 9].

3 The choice of the sensors installation point

In the last two or three years in the operation of reciprocating compressors 4GM10-28/43-56 has been a sharp increase in the wear rate of the rider rings.
Four-cylinder opposed horizontal compressors 4GM10-28/43-56 operate at a process unit GDS-850 of oil refinery.
The refinery's managers have made a decision to equip the compressors with a monitoring system, installing absolute vibration sensors at the main assemblies and rod position sensors per each cylinder.
In addition, a sensor of angular position of the shaft (keyphasor probe) is installed on each.
All in all, on each compressor installed 26 sensors. Condition monitoring and diagnosis are carried out by more than 300 parameters of vibration and the relative rod position.

4 The results of the monitoring system's operation

Since the beginning of its operation, the condition monitoring system which used vortex-current sensors parameters has repeatedly warned the personnel about the wear of guide rings, which allowed to prevent an overload and destruction of rods. Along with that, the absolute vibration parameters are used by the personnel for control of compressors' operating practices and their assemblies' condition.
Trend of relative rod position on Fig.1 shows rings wear process (sector 1), operation of the compressor with worn rings and changes in rod position towards the sensor with increased gaps between a cylinder and a piston (sector 2) and a moment of rod destruction (sector 3). The rings wear process was lasting for 22 hours. Since the wear process was complete (end of sector 1) till the moment of rod destruction due to fatigue damages (sector 3) about 23 days passed. The maintenance personnel were convinced with correctness of the system's readings, and later, prompted by the monitoring system, they repeatedly and timely shut down the compressors (fig 2), thereby, preventing accidents. The measuring of rings wear physical values with an error caused by measurement dispersion was the same as the monitoring system readings. The trend shows (fig. 2) that rings wear process was lasting for 48 hours and the system warned personnel in time that the compressor had to be stopped and the rings had to be checked-up.
An experience in reciprocating compressors operation under the monitoring system control revealed that when reciprocating compressor is operating in normal conditions with no surge of condensate, rings wear happens in a time interval which varies from several hours to several days (fig.3).
Operating personnel often underestimate the influence of a reciprocating compressor's operation conditions on its reliability and operation life. One of the main technological problems in piston compressors operation is a penetration into the decreasing space of condensate or even liquids and other impurities, which can contain an abrasive dust. The last mentioned factor is a reason of increased speed of piston rings wear. Gas vapor in decreasing space creates increased loads on assemblies and details of reciprocating compressors, which causes premature failures. Although, statistic data on failure causes in Russia and abroad shows that

reciprocating compressors overload in 28% of cases and surge of condensate or other foreign substances in 18% of cases are the reasons of forced shutdowns [1, 8, 9], these problems are not considered enough. In this regard, it can be useful to examine a case showing developing of a reciprocating compressors hydroblow.

The compressor started its operation 25/12/2012 at 2^{09} (fig. 4, sector 1). At 3^{09} a condensate surge happened (sector 2) and some of the vibration parameters of the 1st cylinder reached "Actions requires" state (ARS) and "Unacceptable" state (UAS) values [4]. Other cylinders have not shown such strong influence of condensate, but some of their parameters became closer to UAS area. At 4^{45} the condensate started to be carried away (sector 3). Absolute vibration parameter trends (fig.5) show that in the same time valves were overloaded. It should be noted, that neither during later start-ups, nor during operation of the compressor there were no condensate surge in such volume, although, small amounts of it reached the cylinder (fig.5). It seems that a little bit of condensate surged right before the compressor's shutdown (5^{00}-7^{00}pm) (fig.4, sector 4), and that caused rod destruction speed-up. From 5^{00} to 7^{00}pm 25/12/2012 there was growth of rod relative position parameter SPA (from 2100 μm to 2700 μm) and vibration amplitude of rod relative position per one revolution of shaft (from 100 μm to 700 μm), which reached a UAS state (fig.6). The system was informing the personnel about that with verbal and text messages. The personnel had about 1 hour to shutdown the compressor. The rapid increase of SPA and SPR in 2 hours along with insignificant increased of absolute vibration parameters (in vibration acceleration) shows that the rider rings are worn-out, and the additional load on the rod in the moment of the compressor start-up and before its shutdown has led to accumulation of fatigue damage, catastrophic growth of micro-cracks, and destruction of the rod, after its bending.

5 The Conclusion

The applied principles of reciprocating compressors diagnostic and monitoring technology [1, 5-15],

The applied principles of diagnosis and monitoring technology of reciprocating compressors [1, 5-15], proved by many years of experience operation of monitoring and diagnosis systems , testify, that using only 5 vibration sensors on piston compressor (on a cylinder in axial direction, inlet and outlet valves, crosshead, main bearing) and keyphasor probe we can generate at least 15 diagnostic signs of faults by the vibroacoustic parameters collected from each sensor. By means of the diagnostic signs the diagnosis and monitoring system using unconditional algorithm automatically in real time detects 36 problems causing vibration activity of reciprocating compressors.

Relative vibration analysis (static and dynamic rod position) allows to make valid control of changes in distance between the rod and sensor (i.e. rod drop), which, according to the control measurement, are correlated to size of the rider rings wear.

In the systems are using scientifically grounded period for establishing diagnosis which provides real-time condition monitoring when static and dynamic error values are less than 5% [1, 4, 12, 13, 15], which allows to use them for machinery condition monitoring, which is the first and other categories of danger, as well as the whole production facility.

The monitoring systems [5, 6, 8, 10] have serial-parallel structure, which requires much less sensors and cables, and, consequently, less mounting and maintenance expenditures, and it ensures low owning cost and high economic efficiency of implementation, and also allows to carry out condition-based operation of reciprocating compressors.

Today, real-time condition monitoring systems, such as COMPACS® carry out monitoring and diagnosis of more than 70 different types of piston compressors*:* 4GM16-22/17-37, 4HF/2 (Nuovo Pignone), 2TV2 (EUROTECNICA), SRM 1375-35 (BOGE), 4M16M-45/35-55, BDCB 30/30/20/20 (Worthington) on process installations 35/11-1000, 25-12, L-24/9, «Aromatica» of Omsk Refinery; 4M16-22,4/23-64, 2GM2,5–6,2/38–46C of Achinsk Refinery; 4M16M-45/35-55 of «LUKOIL Neftehim Burgaz» AD; 4SGV, 5G600/42-60, 305GP-20/8 of Angarsk Petrochemical company; 2 GM 16-20/42-60CM2 of Astrakhan Gas Processing Plant; 5G-600/42-60, 2 GM 16-24/40-60, 4GM16M-45/35-55 of Saratov Refinery; 4GM10-28/43-56 of «LUKOIL-Uhtaneftepererabotka»; 2M10-11/42-60 of Syzran Refinery and other enterprises. Catalytic reforming units and diesel hydrotreaters of Saratov refinery now are able to control leakage in direct way by using vortex flowmeters DY015-EBLCA4-2D (YOKOGAWA) in a drain line.

An experience in implementation and operation of real-time condition monitoring systems for compressors and other machinery [1, 4 - 15], used by many refinery and petrochemical companies has shown efficiency of such systems application. Along with that, real-time monitoring of absolute vibration parameters and relative rod position provides observability of reciprocating compressors' health and, consequently, their safe operation.

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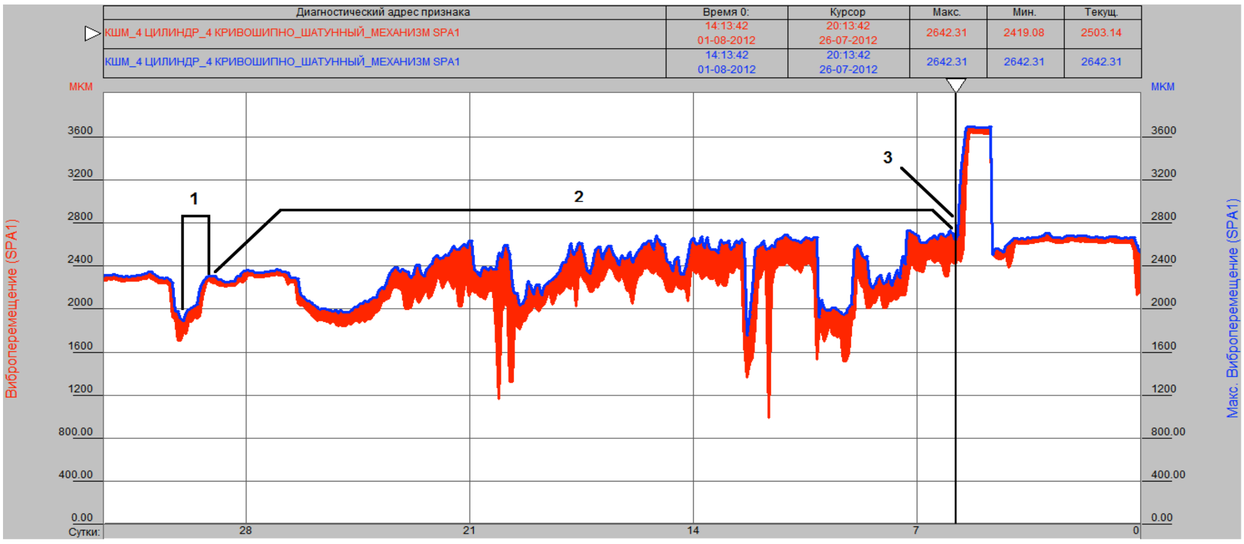
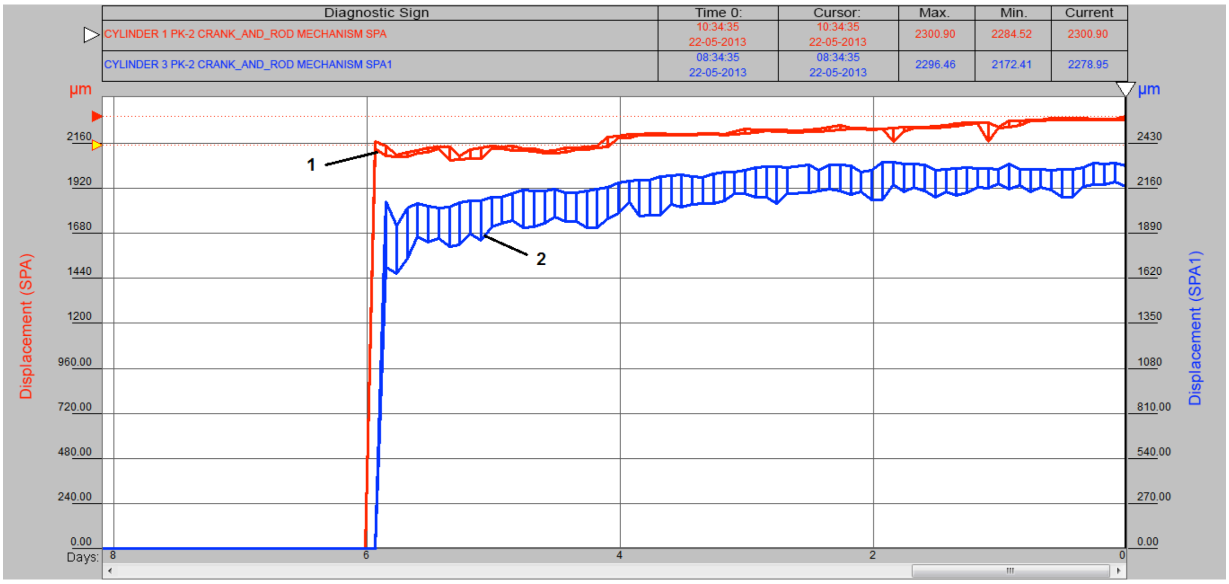


Fig.1 – Trend of relative rod position

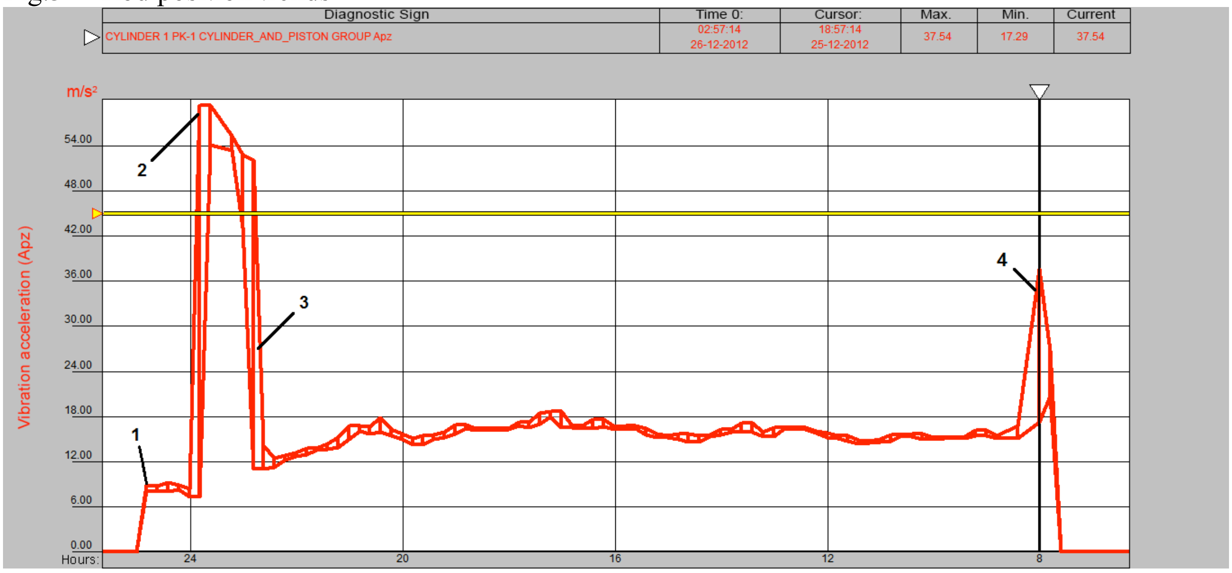
Fig.2 – Trend of relative rod position showing the guide rings wear process



1 – First cylinder piston rings wear process was lasting for about 6 days

2 – Third cylinder piston rings wear process took 3 days

Fig.3 – Rod position trends



1 – RC start-up; 2 – hydroblow during start-up; 3 – condensate is carried away; 4 – hydroblow during RC shutdown

Fig.4 – Absolute cylinder vibration trend

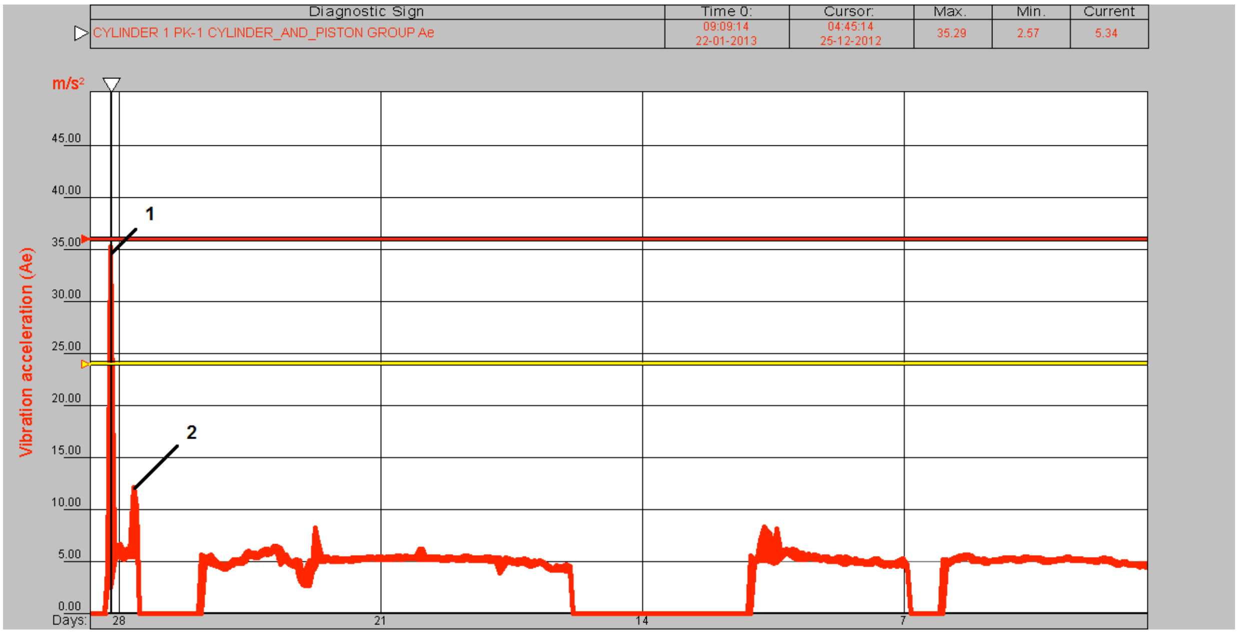


Fig.5 – Surge and hydoblow during start-up (1) and shutdown (2) of RC is diagnosed using absolute vibration parameters

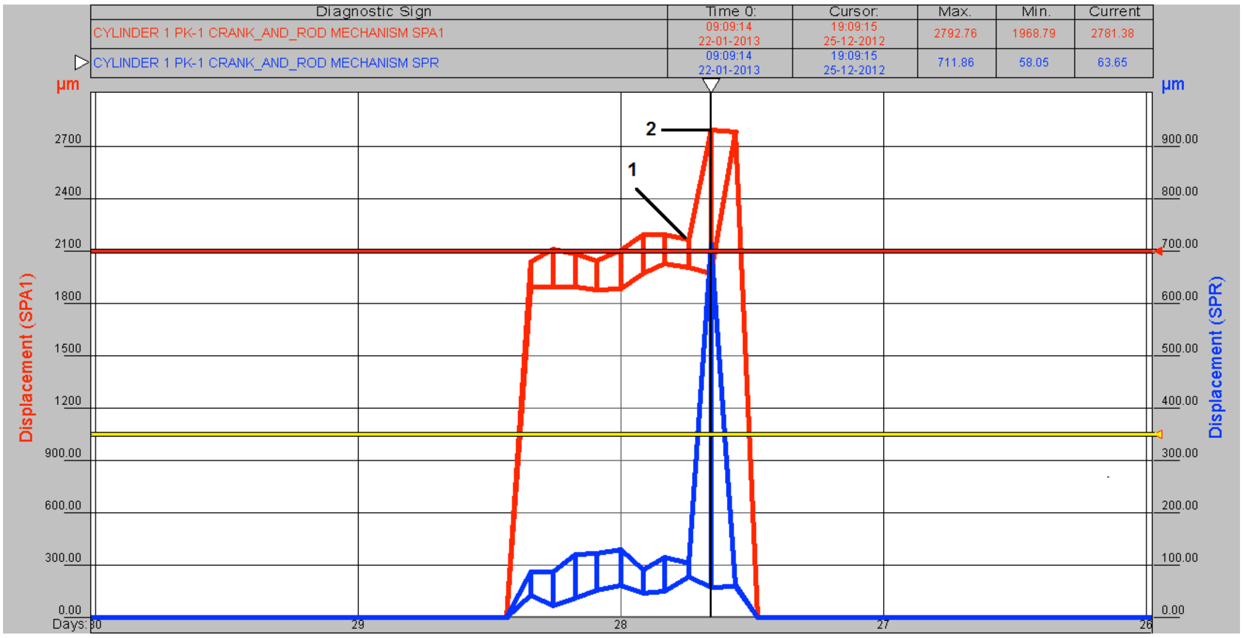


Fig.6 – Relative rod position trends: SPA growth from 2100 µm (1) to 2700 µm (2) and SPR (from 100 µm to 700 µm)