Journal of Machine
Construction
and Maintenance
PROBLEMY EKSPLOATACJI
QUARTERLY
ISSN 1232-9312 3/2017 (106)
p. 83–89

Paweł BIAŁEK
Grupa LOTOS S.A.
Elbląska 135 Street, Gdańsk, Poland
pawel.bialek@grupalotos.pl

REDUCED FAILURE RATE OF HYDROGEN COMPRESSOR VALVES THROUGH OPTIMIZED CYLINDER LUBRICATING OIL SUPPLY

Key words: failure analysis, hydrogen reciprocating compressors, reciprocating compressor valves, lubrication of reciprocating compressor cylinders.

Abstract: Hydrogen reciprocating compressors are essential elements of technological systems in refineries. The methodology of failure analysis and basic methods of hazard analysis are described. The biggest percentage share of reciprocating compressor component failures falls on valves. Images of typical working valve failures in reciprocating compressors are described. Failure mechanisms taking place in valves are characterized, resulting from excessive doses of oil lubricating compressor cylinders. Causes of the compressor functional unit failures are systematically listed. The problem under consideration is the methodology of research aimed at the identification of causes, solutions to the problem and the effects of introduced changes.

Obniżenie częstości uszkodzeń zaworów sprężarek wodoru poprzez optymalny dobór dawki oleju smarującego cylindry

Słowa kluczowe: analiza uszkodzeń, sprężarki tłokowe wodoru, zawory sprężarek tłokowych, smarowanie cylindrów sprężarek tłokowych.

Streszczenie: Wskazano na sprężarki tłokowe wodoru jako bardzo istotne elementy systemów technologicznych rafinerii. Opisano metodykę analizy uszkodzeń oraz scharakteryzowano podstawowe metody analizy zagrożeń. Wskazano iż największy udział procentowy uszkodzeń elementów sprężarek tłokowych przypisuje się zaworom roboczym. Wskazano i opisano typowe obrazy uszkodzeń zaworów roboczych sprężarek tłokowych. Scharakteryzowano mechanizmy uszkodzeń zaworów roboczych powstałych w wyniku dozowania zbyt dużych ilości oleju smarującego cylindry. Usystematyzowano przyczyny uszkodzeń zespołów funkcjonalnych sprężarek tłokowych. Przedstawiono rzeczywisty problem, metodykę badań mających na celu określenie przyczyn problemu, oraz jego rozwiązanie i efekty wprowadzonych zmian.

Introduction

A high frequency of machine failures in the production system results in losses in production and failure repair costs. An unacceptably large portion of failures forces the users to take actions that start with ‘failure analysis’. Such an analysis may lead to the identification of the failure cause. The causes of failures include errors in design, manufacture, or errors made during the operation of a machine and the production system. The most important aspects for the production system user are causes of failures arising from operating errors. Knowing the cause, the user can attempt to remove or reduce its occurrence. Valves of hydrogen reciprocating compressors in oil refinery installations are the leading elements with an unacceptably high frequency of failures.

1. Failure analysis methodology

There are two basic technical states of an item (object) (Fig. 1): up state and down state. In the latter, an item is incapable of performing specific functions in a specified time. In terms of a dual state of an item, a *diagnosis* means an indication of one of the two states. *Prediction* is a term referring to a change of the state, and *origin* means the indication of elements that, when damaged, caused a change of the state of an item.

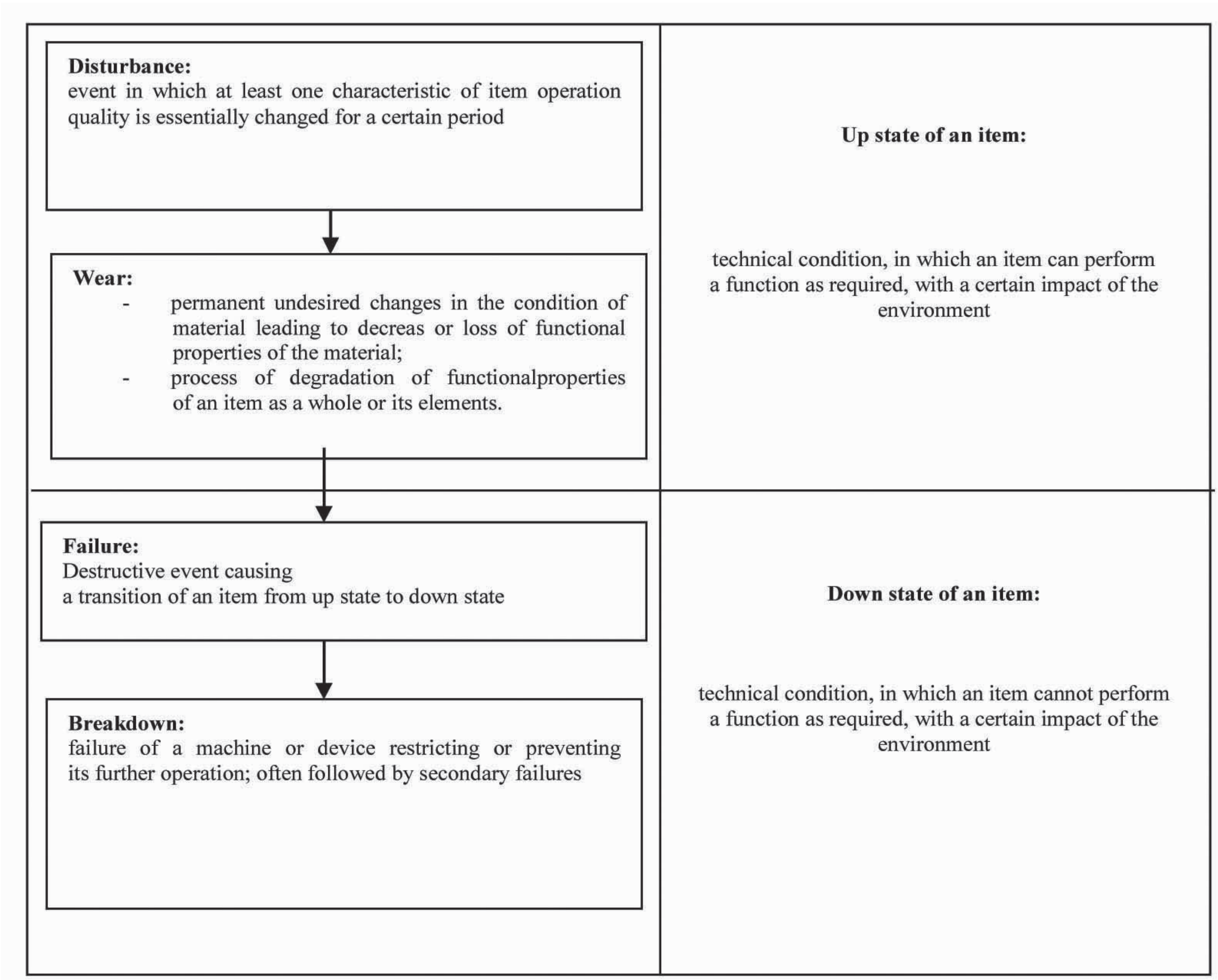

Fig. 1. Defining concepts associated with the degradation of items

Source: Bielawski P., Identyfikacja obiektów technicznych systemów produkcyjnych, Wydawnictwo Naukowe Akademii Morskiej w Szczecinie, Szczecin 2014.

A *failure* is an undesired, often unpredictable event. This event is of destructive character and, depending on the characteristics and functions of a defective component, carries a large risk [1]. In order to avoid further identical failures, their causes should be identified through a failure analysis, then, if possible, the cause should be eliminated. In the process of failure analysis, we can infer the cause inductively or deductively. The inductive method comes down to an image comparison of the failure image to an image of a failure whose cause has been already established. This is done using "failure catalogues," "post-failure reports" or experience. It should be borne in mind, however, that two identical images of failure may have two different causes. The deductive reasoning requires more time and more knowledge of the person concerned. Based on a failure image, the failure mechanism should be established by specifying the conditions affecting the damaged element and its physicochemical properties. The identified mechanism of a failure leads directly to the identification of a cause or a few equally possible causes. Listed below are tools, i.e. methods of hazard analysis, which enable the systematic approach to linking causes and effects of a failure and thus identifying system-item elements that are critical for dependability [6]:

– Failure Mode and Effects Analysis (FMEA)
  A method in which various potential failures of individual elements of the system are examined and their impact on other elements and the whole system are determined.
– Fault Tree Analysis (FTA)
  The fault tree is a logical display of interrelations between a peak event (breakdown) and a failure of a system element (basic event).
– Event Tree Analysis (ETA)
  This method consists in identifying all possible developments of basic events (element failure) until the peak event is identified (breakdown), and analysis is based on the yes/no logical pattern.
– Cause-Consequence Analysis (CCA)
  It is a combination of FTA and ETA methods.

2. Failure analysis item

A hydrogen reciprocating compressor is an item in the production system of a refinery. It performs important tasks in the technological process of crude oil treatment. It is believed that breakdowns of these machines are very expensive in terms of losses incurred as a result of wear margin loss by production installations and costs resulting from the applied repair technology. This research focuses on three two-stage hydrogen compressors of the 2HG/2 type made by Nuovo Pignone (now GE Oil & Gas), equipped with two double-acting cylinders. The main technical parameters characterizing these machines are the discharge pressure of 18.211 MPa, a power efficiency of 51829 Nm^3/h, and a shaft power output 3.332 MW.

The machines are fitted with cylinder lubrication systems and a main packing of the box lubricator [4] with sight well pumps (Fig. 2).

The timing function in the machine is executed by six pairs of ring valves; in addition, the suction valves are fitted with pneumatically controlled finger unloaders (Fig. 3).

According to the research carried out at LOTOS S.A. Group refinery [1], timing as a functional unit of a hydrogen reciprocating compressor has the highest percentage of failures − 50.7% (Fig. 4). These authors, using post-repair documentation of 21 machines, determined the percentage of failures of hydrogen reciprocating compressors operated in compliance with service life and use diagnostics.

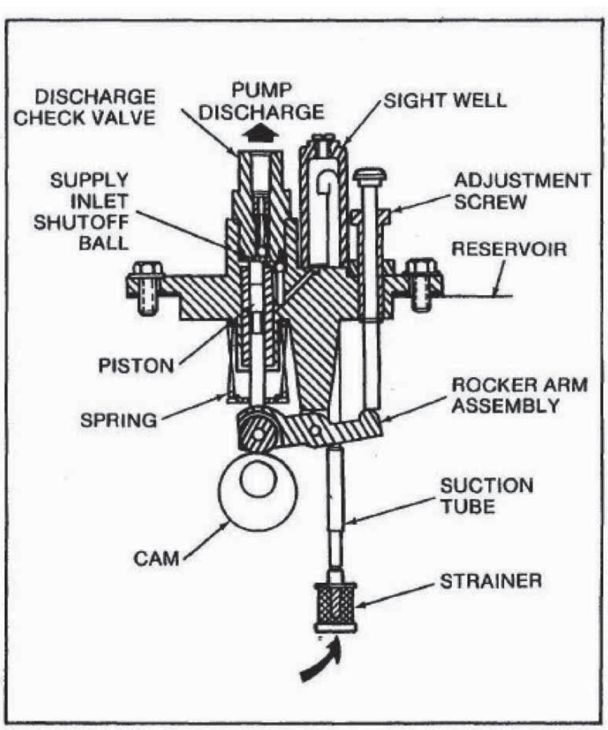

Fig. 2. A sight well pump of a box lubricator

Source: Bloch H., Hoefner J., Reciprocating compressors: operation & maintenance, Gulf Publishing Company, Houston, TX 1996.

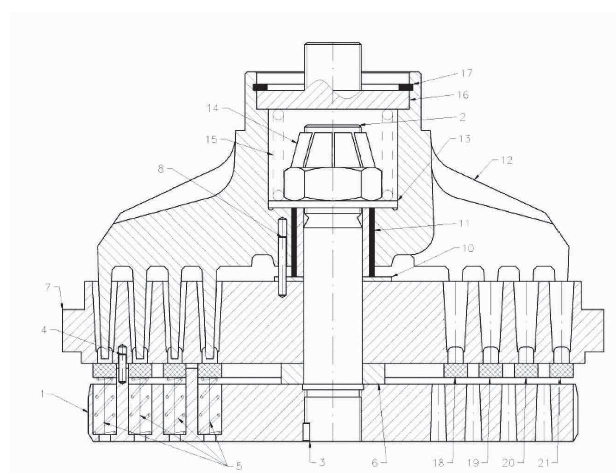

Fig. 3. A suction valve with a finger unloader

Source: Technical documentation of the 2HG/2 compressors, General Electric Oil & Gas, 2008.

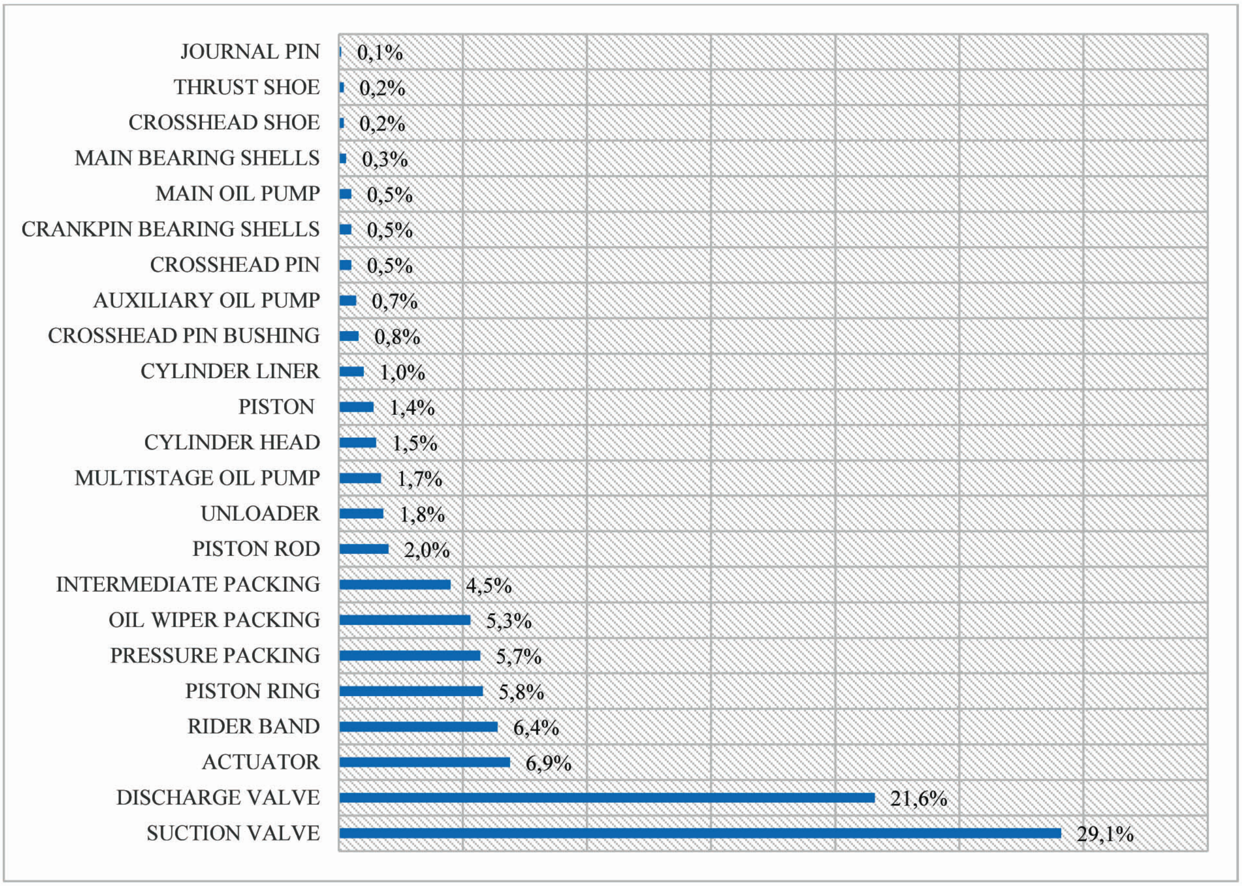

Fig. 4. Failure percentage share relating to hydrogen reciprocating compressor elements at LOTOS S.A. Group refinery

Source: Bialek P., Bielawski P., Failure analysis of Hydrogen piston compressors, ICTD-CMMNO Congress, Gliwice 2016.

3. An analysis of the valve failures in reciprocating compressors

Suction and discharge valves are the most loaded elements of reciprocating compressors, and they are affected by combined heavy duty mechanical loads and thermal loads. The moment referring to the crankshaft rotation angle and the valve opening time depend on the difference in the pressures before and after the valve, which directly translates into the technical condition of the valve as an executive element. These valves are expected to feature the following [2]:

– Possibly a long service life,
– Operating repeatability and dependability,
– Small opening and closing lags,
– Tightness when closed,
– Small pressure losses when open (low flow resistance),
– Diagnosability, and
– Quick replaceability.

There are four phases of valve operation; they are successively as follows [2]:

– Opening,
– Open,
– Closing, and
– Closed.

The most common failures of valves are seal ring cracks (Fig. 5). These failures are dangerous because of the high likelihood of secondary damage to other valves, or even the sliding surface of the cylinder liner, fatigue cracking of springs, erosive, and abrasive and friction wear of valve seat faces.

Contamination of the compressed gas is a factor that significantly accelerates piston compressor valve wear, so that the valve may get completely stick (Fig. 6).

Valve failures are caused by errors that can be divided depending on the stage of their life cycle:

– Design (wrong materials, improper flow capacity, etc.);
– Manufacture (material defects, geometric inaccuracy), etc.; and,
– Operation.

Operating errors can, in turn, be divided into those made during maintenance, including repairs (improper

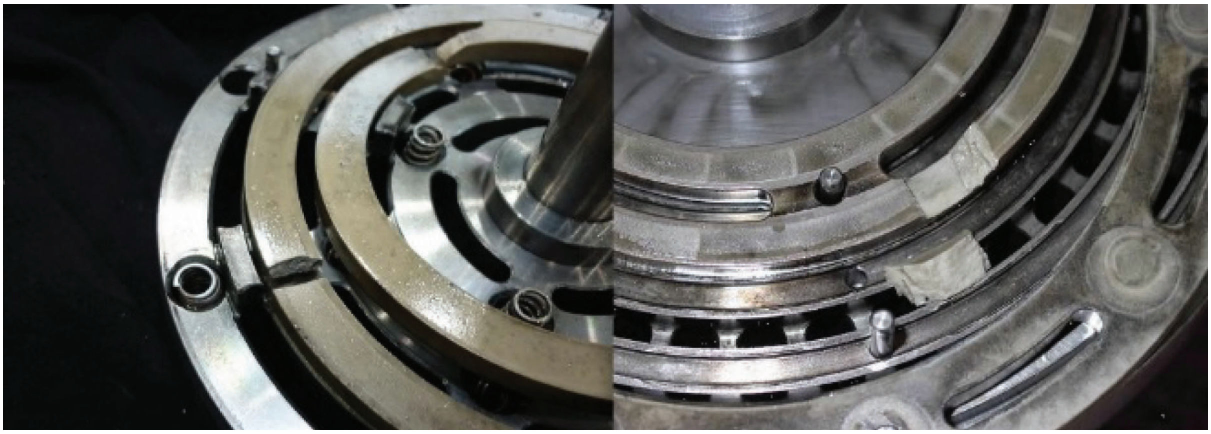

Fig. 5. Example seal ring cracks in hydrogen piston compressor valves

Source: Bialek P., Bielawski P., Failure analysis of hydrogen piston compressors, ICTD-CMMNO Congress, Gliwice 2016.

Fig. 6. A heavily contaminated discharge valve seat

Source: Author.

repair technology), and errors made during use. Errors made during machine use can be divided into external (disturbance in the technological process – sudden changes in density and composition of gas, liquid and solid contaminants in gas), and internal errors, related to compressor work organization (control of compressor functional units, or failing to assure proper pressure and temperature parameters on the suction and discharges sides of the compressor). The parameters given in the documentation may not be tailored to the working conditions of a given machine in the production system. Experience shows that one of the valve failure causes is overdosing of the oil lubricating the cylinder. Excessive lube oil in the cylinders results in failures of the operating valves of the piston compressor. These failures can be grouped by the type of wear mechanism as follows [4]:

– Sticking effect:
  As a result of adhesive forces acting between the lube oil film and the ring seat and stopper, there will be a valve ring sticking effect. The value of the force resulting from the pressure difference needed to open and close the valve will be increasing, resulting in larger impact energy of the rings on the valve seat and the stopper. Valve rings will then be subjected to higher mechanical loads.
– The hydraulic impact effect:
  Excessive quantities of lube oil in the valve of a reciprocating compressor will act like a gas reflux. Lubricating oil, like any liquid, can be considered as incompressible; therefore, if the accumulated quantities of liquid exceed maximum valve flow capacity, “hydraulic impact” will take place,

leading to valve damage. This phenomenon usually occurs during machine start-up. Because when it is stopped, lube oil gathered on the cylinder liner flows down to the lowest, closed discharge valves.

– Coking effect and thermal degradation:
Both the "coking process" and "thermal degradation" of lube oil, due to the temperature conditions, will be mostly related to discharge valves. At high temperatures and in the presence of oxygen, coking and thermal oil degradation may develop, resulting in hydrocarbon deposits deteriorating the adhesion of packing rings to the valve seat and thereby reducing its tightness. These hard contaminants may also contribute to the cracking of seal rings.

It seems that the correct operation of functional units of reciprocating compressors has a vital influence on their reliability. The proper maintenance and use of functional units of cylinder lubrication may substantially extend the periods between compressor repairs by keeping valves undamaged, and consequently increase the dependability of the whole production system and reduce company financial losses.

4. Actions eliminating the causes

In order to optimise the costs of eliminating consequences of failures of three 2HG/2 compressors operated at LOTOS Group refinery, actions were taken to identify those elements whose failures were responsible for highest percentage of consequential costs. The pie charts below illustrate the percentage of working valve failures (Fig. 7) and the costs of failure elimination (Fig. 8) compared to all failures over four years of operation.

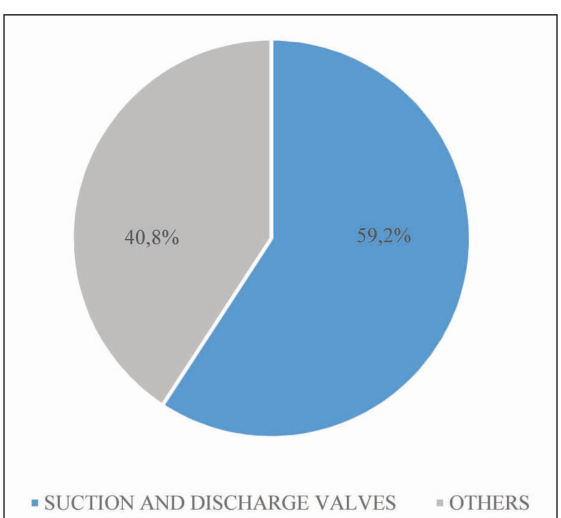

Fig. 7. Percentage share of valve failures in three 2HG/2 compressors versus all failures over four years of operation at LOTOS Group S.A refinery

Source: Author.

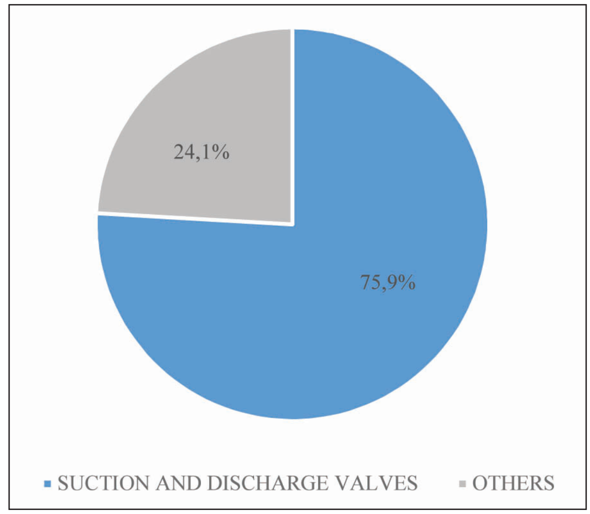

Fig. 8. Percentage share of the costs of valve failure elimination relating to three 2HG/2 compressors versus all failures over four years at LOTOS Group S.A refinery

Source: Author.

During the investigation upon the dismantling of the damaged valves, their elements were found to be excessively oiled. Based on operational practice, we should expect the dismantled valves of reciprocating compressors with lubricated cylinders to be coated with a thin layer of lubricant, and look greasy. Any excess of lubricating oil in piston compressor valves should be considered undesirable and harmful. Since the dominant damages to the valves were fatigue cracks of seal rings, it was concluded that the most likely cause was overload from excessive lubrication (sticking effect). As a result of the analysis, a decision was taken to reduce the amount of cylinder lubricating oil, because its excess accumulated in the valve seats. Valve tests were performed in which the oil doses were reduced in two steps, and the results were observed. The reduction of oil amount did not result in immediate damage, and valve elements were sufficiently lubricated. On this basis, the decision was taken to adjust the lubricating oil pump delivery rate. The final outcome of the introduced changes was a decrease in the amount of lube oil supplied to the compressor cylinders by 13.6% for the first stage and by 14.3% for the second stage.

The implemented settings of lube oil pump delivery resulted in a significant increase in the dependability of functional units of the timing and a consequent extension of periods between repairs for all of the three compressors. The average number of failures in the examined compressors due to the wear margin of the working valves decreased by 91% for the next two years of operation.

Conclusions

1. In order to optimise the costs associated with the removal of failure consequences, we should always establish the cause of damage, and then implement measures aimed at reducing the likelihood of such failures in the future.
2. The best tool for determining the cause of a failure is deductive failure analysis.
3. Suction and discharge valves are the major cause of failures in reciprocating compressors.
4. Failures of working valves in reciprocating compressors are likely to be followed by secondary failures.
5. In compressors equipped with lubricated cylinder liners, the quantity of oil in the cylinder has a very big impact on the reliability of working valves.
6. Minor changes of lube oil quantities delivered to the cylinder liner may substantially contribute to increased dependability of the timing gear of a reciprocating compressor.

References

1. Białek P., Bielawski P., Failure analysis of Hydrogen piston compressors, ICTD-CMMNO congress, Gliwice 2016.
2. Bielawski P., Problemy diagnozowania zaworów maszyn tłokowych, Pomiary Automatyka Robotyka 12/2013.
3. Bielawski P., Identyfikacja obiektów technicznych systemów produkcyjnych, Wydawnictwo Naukowe Akademii Morskiej w Szczecinie, Szczecin 2014.
4. Bloch H., Hoefner J., Reciprocating compressors: operation & maintenance, Gulf Publishing Company, Houston, TX 1996.
5. Dokumentacja techniczna sprężarki 2HG/2, General Electric Oil & Gas, 2008.
6. Praca zbiorowa pod redakcją A. Markowskiego, Zapobieganie stratom w przemyśle, część III – Zarządzanie bezpieczeństwem procesowym, Wydawnictwo Politechniki Łódzkiej, Łódź 2000.