Developing a Complex Approach to the Definition of a Technical Condition of Pump-and-Compressor Equipment

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Abstract. There is much concern about early breakdowns of pump-and-compressor equipment being of long-term usage. The conditions of increased wear and high dynamic loads of this type of equipment necessitate the improvement of the maintenance and diagnostics concerns of fault detection of pump-and-compressor equipment as soon as possible. The article discusses a complex approach to the definition of a technical condition of pump-and-compressor equipment, based on vibrodiagnostics, parametric inspection and tensometry in real-time mode.

1. Introduction

Increasing volumes of hydrocarbon supply, building new facilities and increasing useful capacities of old ones can be recognized as contemporary tendencies in transporting sector of Russian fuel and energy complex. Thus, the requirement for reliability and energy efficiency of both new and old pump-and-compressor equipment (PCE) is increasing.

A significant part of gas-pumping and oil-pumping units being operated in the oil and gas trunk pipeline system presently has exhausted its performance potential or is short of remaining life supplied by manufacturer. The age of more than 60% of oil and gas pumping units is 20-30 years or more [1, 2]. So, we can’t take into account the moral and physical wear and tear of this equipment, which is being operated in excess of standard operation time. It seems clear that the operation of the being overage PCE carries high risks of sudden failures, unit destruction, and as a consequence, early repair works.

It should be noted that the actual problems of oil and gas transportation enterprises of Russian fuel and energy complex are as follows:
- problem of accelerated wear of components and parts of on-site equipment at oil fields stations and compressor stations;
- increase of a number of sudden failures, early removals and unplanned expenses for emergency and recovery repair;
- decrease of failure intervals, especially in mechanical components;
- increase of operational costs;
- general decrease in reliability indicators of on-site equipment at oil fields stations and compressor stations.
Long years of experience have shown that minor components wear is almost always accompanied by high vibration that often leads to emergency shut-ups. There is no doubt that the housing vibration is an indicator of actual technical condition of the rotor equipment [2].

Any mechanism has useful lifetime and because of its exhaustion the operation is becoming either dangerous or economically unviable.

Figure 1 shows the range of failure causes of oil transfer facilities of NM type in last 15 years [1].

![Figure 1. Statistics of failure causes in NM-type trunk rotary pumps.](image1)

A similar situation is observed for oil transfer facilities with shipboard-type drive unit which is being operated in compressor stations. Figure 2 shows the range of failure causes in shipboard-type drive engine of «DR59L» type, being a part of gas processing plant - 10 in operation for about last 15 years in one of subsidiaries of PJSC Gazprom.

The diagram shows that the failures in the mechanical part and the minor components destruction make up a total of 47% of all failures. It’s here that we have the greatest material and technical expenditures, loss of units’ working capacities and equipment downtime.

As for this type of drive units, in recent years there has been noticed a tendency to reduce failure intervals (from 12,000 to 8,000 motor-hours), as well as the growth of failures in mechanical parts [3]. This fact is explained not only by excess operating time, but also by an increase of loads on this type of gas pumping unit due to an increase of in the volume of transported gas in Unified gas supply system of Russia.

2. Existing technical monitoring of pump-and-compressor equipment

The basic concept of maintaining conditions of the existing pump-and-compressor equipment is based on planned preventive maintenance, i.e. according to the regulations [3, 4].

The intervals between maintenance, diagnostics and repairs, their volume and content are determined on the basis of manufacturer recommendations as well as statistical data collected from all units owned by the enterprise for a long period of operation. Herein, the specifics of a particular unit, actual operating conditions, stochastic changes in loads, pumping modes and quality of service are neglected.

Being based on such an approach, the concept of maintenance and repair of pump-and-compressor equipment has a number of significant weak points [4]:

- the equipment in its optimal technical stage which doesn’t need any repairing is being subjected to such repair and adjustment works being carried out according to the plan and as a consequence the technical conditions of this equipment are being deteriorated;
- practically, minor deficiencies have not been eliminated, and being subjected to repairs during scheduled maintenance these hidden failures have matured and often failure happens before these planned operations;
- complete information about actual technical condition and damage degree of pump-and-compressor equipment is analyzed during periodic vibration diagnostics. In inter-control period the technical condition is being monitored recording only failure and emergency shutdowns; it is not possible to eliminate completely sudden failures as their number and deterioration grade are determined not only by operation conditions, but the quality of corrective maintenance.

Together with all the undeniable advantages of predictive and preventive maintenance, the statistics shows that the level of accidents and the number of sudden failures remains at a sufficiently high level [2, 5]. Moreover, the analysis of failure causes showed that maturing defects, leading to an emergency shutdowns and efficiency losses, has a significant dynamics. At the same time, the vibration level measured before the emergency shutdowns could meet the standards. This fact is confirmed by statistical observations that more than 70% of emergency failures occur at the level of vibration corresponding to the accepted «PERMISSIBLE» level [2,4].

Traditional pattern of technical state diagnostics and monitoring based on periodic examining doesn’t provide by full and sufficient information on actual technical condition of the PCE.

3. Developing of complex approach to the definition of a technical condition of pump-and-compressor equipment

Thus to increase the accuracy and efficiency of fault detection of PCE at early stage, the authors have been working on the developing the complex approach to determine the actual technical condition. This complex approach consists of interconnected assessment of actual technical condition and determining the general diagnostic attributes by the following methods and techniques:

- real-time mode vibrodiagnostics (spectral analysis of narrow frequency intervals);
- real-time mode parametric investigation based on threshold, trend and statistical analysis;
- tensometry (the tensospectrum analysis, obtained from bearings of diagnosed component with a view of identifying defects locally by fixing general diagnostic attributes by vibro and tensospectrum, obtained from the same component)[5]

This being developed complex approach unifying some types of diagnostics in real-time mode, will help to determine the actual technical state of the facility in complex, will show the defects in early stage of their development by vibrodiagnostic, parametric and tensometric attributes and to forecast the critical state development of the discovered defect.

The first stage of complex approach is implemented at this point, namely the vibrodiagnostics in real-time mode.

For example, a system of remote vibratory monitoring of engines DR59L with the possibility of conducting narrow-band vibrodiagnostics in real-time mode on the basis of the existing automatic control system of gas processing unit is being developed as part of the implementation of concept “digital gas processing unit”.

Basic procedure of developing is the standard of the manufacturer М029.002-99 on vibration survey of units of GPU-10. This standard for each survey station of vibration level consists of 8 (eight) narrow-band frequency ranges with individual units for each band [6].

Table 1 shows a part of the low frequency spectral component thresholds for the front flange of the low pressure compressor (LPC) (ТН - blower turbine (power turbine); КВД – a high-pressure compressor; КНД – a low-pressure compressor; RMS – root mean square value of the vibration signal; Amp – amplitude value.)

The analysis of historical data of 21 (twenty one) prescheduled removed engines DR59L of one of the subsidiaries of PJSC Gazprom was carried out to confirm the standard correctness and has identified certain defective attributes, adapted for the standard requirements. It was discovered that in all cases the vibration velocity amplitude of developed defect has exceeded threshold values concerned to the presence of the defect. In addition to this an interconnection of spectral analysis accumulated database of pre-emergency engines and factory standard allows talking about the primary database establishment of this engine defect, or in simple words vibrodiagnostic engine passports. Furthermore all necessary conditions are created in establishing similar vibrodiagnostic passports for
Automation of diagnostic process and creation of more exact stationary system of diagnostics adapted for concrete type machines.

Table 1. Spectral components of the front flange of the housing LPC.

| Control band, Hz | Discrete spectra components | RMS and amplitude level of components V, mm/sec | Normal RMS | Accepted RMS | Unacceptable RMS (matured defect) RMS |
|------------------|------------------------------|-----------------------------------------------|------------|-------------|-------------------------------------|
|                  |                              |                                               | 2.2        | 2.9         | 2.8                                 |
|                  |                              |                                               | 10-65 0.5xКВД; |            |            | 3.7                                 |
|                  |                              |                                               |            | 5.0         | 6.5                                 |
|                  |                              |                                               | 65-80 1xТН | 4.6         | 6.0                                 |
|                  |                              |                                               | 8.0        | 7.8         | 10.0                                |
|                  |                              |                                               |            | 11.0        | 14.3                                |
|                  |                              |                                               | 10-400 General level | 13       | 16.9                                |

Figure 3. Primary database of engine DR59L defects.

Along with that the capability assessment of implementation narrow-band vibrodiagnostics on the operating system of an automatic control and regulation was carried out, the adoption conception was developed, primary frequency model of engine DR59L was compiled. The software and auxiliary equipment were developed for signal decomposition of vibration velocity RMS in narrowband spectrum in real-time mode – a block of spectrum analysis, based on Fast Fourier Transform (Figure 4).

The block of spectrum analysis prototype was implemented on the basis of modern high-performance microcontroller STM32F4 and it is performing the following functions:

1) measuring the input signal and noise removal by algorithms of digital filtration;
2) evaluation the spectrum of filtered signal with the use of high-speed methods of Fourier transformation;
3) decomposition of spectrum estimation results on controlled frequency range with evaluation of root mean square signal in each band;
4) transfer of data processing results to automatic control system of high level on the basis of industrial protocol Modbus RTU.

Figure 4. Block of spectrum analysis prototype.

Figure 5. Structural pattern implementation of the first stage of complex approach to the assessment of technical condition of gas turbine engine.

Figure 5 shows structural pattern system of removed vibration monitoring engine DR59L.

Structural pattern presented on figure 3 allows creating additional spectral vibration monitoring of engine technical condition on the basis of operational controlling systems, nevertheless, cheap and simple way of implementation is being proposed.

To confirm the postulates about complex diagnostics of rotor equipment as real-time mode vibration and tensometry there has been carried out a laboratory testing of diagnostic system prototype at vibration table TIK-VV (NPP "TIK", Perm) (Figure 6). On the Figure 6 1 – vibration plate TIK-VV; 2 – vibration detectors BK 310; 3 – tension detectors (strain – compression detectors); 4 – signal conditioning block; 5 – Personal computer (PC) (software on spectra signal decomposition).

The sensor of instantaneous amplitude of vibration speed BK-310 produced by LLC ViKont (Moscow) is located on a vibrating chute of the stand oscillating with 50 Hz (2) frequency. Tensor detectors H4 produced by "Tenzo-M" (Moscow) are located under the supports of the stand (3). The signal conditioning block (4) is designed to convert an analog signal into a digital signal for further decomposition into Fourier series to obtain a spectrum.

As a result of the system testing on a vibration stand with the use of Delphi software, the combined frequency spectrum of vibration and noise signals in real time mode were obtained (Figure 7).

Figure 6. Laboratory setup of complex diagnostics system being developed.

Figure 7. Working window of the program on decomposing unified spectra of tenso- and vibrosignals.

Spectra marked in blue correspond to vibro-spectrum, and in red to tenso-spectrum.
Merging and aliasing of vibration and tenso-signals were conducted to identify the linkages and common diagnostic characteristics; it allows identifying the hardware faults locally.

Figure 7 shows that in the center of a band pass frequency of the revolving frequency of the stand being 50 Hz, there are observed total frequency peaks and great intensity bursts. This fact can confirm earlier assumptions about the presence of some relationship in the defect influence on the vibro- and tensor spectrum.

4. Developing of complex approach to the definition of a technical condition of pump-and-compressor equipment

Summing up, it can be noted that the introduction of automated systems of complex diagnostics, based on creating individual vibrodiagnostic and parametric passports with the possibility of local confirmed presence of the defect, using the tensometry spectrum analysis will provide the following effects:
- improve the quality of assessing the current technical condition of individual units and the unit as a whole;
- continuously provided wide range of operational and retrospective information about the technical condition of the unit;
- maintenance of the equipment is carried out according to the actual technical condition, which, in turn, allows more efficient planning of repair works;
- opportunity to calculate and plan the optimum term of maintenance shutdowns for decreasing its cost.

All these factors together will contribute to the sustainable and trouble-free operation of PCEs, as well as to the reduction of significant financial exploitation resources.

5. References

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