Non-contact control of the working condition of mechanical units of the steam compressor for desalination plant

A. I. Danilin, A.Zh. Chernyavsky, S.A. Danilin, V.V. Neverov, D.A. Voroh, E.V. Blagin
Samara National Research University, Samara, Russia
Email: evgenyblagin@gmail.com

Abstract. New methods and means for monitoring working condition of the rotating elements of steam compressor unit such as blade ring of the impeller and gears of multiplier are considered. Blade control is carried out by the signalling device of pre-emergency deformation of impeller blades. Control of the gears condition is carried out by apparatus system which allows to analyse change of the signal form caused by the gears wear. Influence of the wear types on the typical information parameters of the analysed signals is described. Technical characteristics of the devices and experimental research results are presented. Described control systems allow to detect deviations equal to 1-2% from initial condition. Application of such systems gives the opportunity to improve fault diagnosis and maintenance in 2-3 times.

1. Introduction
In modern desalination plants steam compressors are often used due to their high economic efficiency [1]. Steam compressor represents difficult mechanical unit which includes rotor with blade unit (impeller) and multiplier – assembly of gear mechanisms for conversion of rotary motion parameters. Such elements of dynamic systems must meet enhanced requirements to manufacturing quality and the quality of the exploitation condition control. Today there are many publications directed at optimization of different compressors operation regimes. Some of them are researches of Samara University scientists [2,3], representing features of compressor working process optimization. Besides, suggested method of non-contact control of blades working conditions and turbomachinery elements fault diagnosis is successfully distributed on all blade elements of rotary machines – steam turbines [4], gas-turbine aircraft and ship engines [5-10] as well as different industrial fans. Active development of this research field in all industrial countries is connected with durability of most loaded units of energy plants, their lifespan and development of the criteria which determine exploitation of energy plants by their technical conditions.

2. Control of the working condition of the steam compressor impeller blade
Today, control of the working condition of the steam compressor impeller and shaft is executed by visual observation by the means of technical endoscope, vortex and magnet fault detectors. This is very hard work which requires professional skills and responsibility from technical staff. Despite the accepted actions statistics shows that there are emergency situations caused by shaft and impeller blades destruction (fig. 1).

In fact, impeller blade form deviations (gallings, blade bending) from calculated variant causes decrease of the steam compressor efficiency and, finally, causes steam compressor rotor restruction which restoration requires significant material and time costs. Thus, diagnosis of the fault condition of the steam compressor rotor is actual problem today.
As analysis of scientific literature shows that along developed methods and means of diagnosis and control of rotary units elements on exploitation steam generators most promising method is discrete-phase method (DPM), which allows to determine individual deformation condition of every impeller blade and change of the gaps between inner surface of the steam compressor shell and face part of the blade ring [11]. Acquired information is compared with geometric location of exact blade in the wheel in certain moments of time and corresponding interpretation of acquired values in the field of mechanical stresses and deformations.

Based on theoretical prerequisites of DPM, structural scheme of the signaling device for pre-emergency condition of the steam compressor impeller [12], presented on fig. 2. Structural scheme is based on principle of current time intervals (steps) measurement between faces of rotary blades, determination of the maximal and minimal values on every step and comparing this value with impeller-average step on every turn of the steam compressor rotor.

Corresponding to fig. 2., structural scheme is functioning as described below. Peripheral sensor 1, mounted in steam compressor shell above the blade face motion trajectory generates electric signal which is transformed by former 2 in rectangular impulse. Time intervals \( \tau_i \) between rectangular impulses, corresponding to circular step between blades is converted to numerical code in block 3. Maximal and minimal values for every step are also determined in this block from \( N \) current rotor turns. Acquired extreme values of every step are transferred to block 4, where averaged value of \( \tau_{si} \) is determined by expression \( \tau_{si} = (\tau_{imax} + \tau_{imin})/2 \) for every step.

Besides, rectangular impulses from former 2 are transferred to block 5 where time steps \( \tau_i \) are summarized for \( N \) rotor turns and the average one for \( N \) turns is calculated as

\[
T_s = \frac{1}{N} \sum_{j=1}^{N} \sum_{i=1}^{K} \tau_i
\]

If design realization of steam compressor allows to mount sensor 6 of the rotor turn mark, its electric signals by former 7 are converted to rectangular signals which are transferred to block 8 where average period of turning is determined as

\[
T_r = \frac{1}{N} \sum_{j=1}^{N} T_j
\]

Block of switches 9 allows to provide required operation regime of the device for both cases when turn mark is present or not. Acquired values of \( T_s \) in block 10 are divided by number of blade in the impeller, so average step along the impeller for \( N \) rotor turns is determined as \( \tau_s = T_s /K \).

Further, values of the \( \tau_{si} \) and \( \tau_s \), determined as described above, are compared between each other in comparison block 11. If \( \tau_s \) differs from \( \tau_{si} \) on certain limiting value \( p \), block 11 generates signal about fault occurrence in one or several blades.

On the basis of suggested algorithm and structural scheme signaling device of pre-emergency deformation of steam compressor blade unit (SCBU) is developed for steam compressors operating in desalination plants. External view and functional composition of SCBU is presented on figure 3. It consists of impulse sensor, mounted in steam compressor shell, measuring block with USB interface for connection to computer, patch cables with protection from noisy signal, special software.
Figure 3. The appearance and functional composition of the SCBU

Signal of fault occurrence in one or several blades in form of alarm light and sound signals is transferred to a dispatcher console. If blade fault continues to develop, SCBU forms a signal for a system of automatic unit control for normal (or emergency) stop of the steam compressor.

There is a possibility to connect SCBU with personal computer via USB interface for control of the current condition of the blades, express-analysis of their operating ability, remembering their exploitation condition, creation of the technical passport of the blades. For this purpose special software was developed which allows to maintain on-line exploitation diagnosis of the blades. Besides, SCBU provides autonomous inner memory device which turns on after pre-emergency signal occurrence and writes dynamic of the blade fault development. Inner memory storage is energy independent and writes date, time and deformation condition for every blade of the impeller. SCBU is developed and realized on modern radio-technical element base which allows to obtain compact and reliable device with double reserving and current adaptation for any type of steam compressor and impeller with different number of blades.

Technical characteristics of SCBU:
1. Range of the steam compressor rotor rotation frequencies: 100 ... 35000 r/min.
2. Range of the operation temperatures for impulse sensors:
   - option 1 -40 ... +150 °C; - option 2 -40 ... +1000 °C.
3. Range of the operation temperatures for measurement block -40 ... +50 °C.
4. Current supply for SCBU-1 is direct current with voltage +27 V.

Laboratory tests of the SCBU were carried out when fault in the form of blade face deviation was introduced in the one of the compressor blade. Fig. 4 shows SCBU operator program where deviations of every blade are shown including fault one up to 6 mm. Natural technological deviation of every other blade lies within the limits of ±0.5 mm. On the base of the carried out experimental researches, recommendations for a choice of limitation values, corresponding to pre-emergency (2 mm) and emergency (2.5 mm) deviation of the steam compressor faces were developed.

Figure 4. The screenshot of the operator’s program of the SCBU with a defective blade
3. Control of the multiplier gear mechanism wear

Working lifespan of the gear mechanism determine the coefficient of the mechanism operation failure safety which is in turn one of the critical elements of failure tree. Failure of the mechanical equipment due to wear or destruction of gears causes long fault time and requires large costs to restore its operating ability. Multipliers used in steam compressors of desalination plants, must meet high requirements for reliability, precision of the gear mechanisms manufacturing and economic efficiency during exploitation. Such multipliers provide increase of the rotation frequency up to 35000 r/min. In the same time gears, used in given mechanism suffer colossal loads which causes their accelerated wear and frequent substitution. That’s why control and diagnosis of the gears condition in multipliers during their operation, i.e. in exploitation regime, is a very actual problem.

Today, diagnosis of the faults, wear and integrity of the gears is usually carried out in static condition. In dynamic regime, spectral method of vibration signal analysis has found a wide use. These signals are received from the controlled mechanism. But spectral method of diagnosis has several serious disadvantages. Diagnosis of the signal envelope specter is quite difficult for physical explanation of gear teeth catching and it usually require good theoretical preparation of the vibration diagnostician or presence of the specialized computer expert system in his technical equipment [13].

Figure 5. Appearance of the experimental stand

Non-contact radio wave method [14,15] was suggested for exploitation control and working condition diagnosis. This method is based on the on-line treatment of the signals, received after detection of the microwave radiation reflected from the gear teeth. Parameters of information signals are compared correspondingly with reference signal received at gear exploitation start. This method allows to obtain information directly about wearing degree of every exact tooth and fault occurrence in it in dynamic regime. Parameters of monitoring signals are determined by geometric parameters of the teeth and technological configuration of thee control zone. Microwave radiation can exist in oil media where gears operate. Advantages of this method are lack of high number of sensors and necessity of their precise adjustment. There is also lack of the necessity of frequent maintenance of sensor operating in quite harsh environment.

Several types of the tooth destruction are separated: tooth crash, spalling, teeth faces damaging, abrasive wear, crack occurrence, peeling and deep contact destruction of the material [13]. Several information parameters are separated during diagnosis from the signal of reflected monitoring signal converted to electric signal. Only teeth crack cannot be diagnosed by aforementioned method if they are not located on the researched area. Experimental unit was developed to carry out the tests and reference gear was manufactured with given tooth geometry. Upper part of the unit has an possibility to mount and regulate location of the modified wave emitter.

Results of theoretical and experimental researches show that received reflected signal after detection has a quasi-bell form of impulse [15]. Estimation of the steam compressor gear wear degree is based on information parameters which include signal amplitude, normalized duration of signal front, lack of signal. Every type of wear influences certain information parameters separated from reflected signal. For example, lack of signal means tooth crash. Teeth spalling influences signal amplitude and normalized signal duration. Abrasive teeth wear predetermines such information parameters as normalized duration of the signal, signal amplitude and normalized duration of the signal fronts.
Modified wave-guide emitter represents waveguide-coaxial transition and wave-guide with dielectric filling, for example, as quartz glass. Modified wave-guide emitter is screwed directly in the shell of multiplier system perpendicularly to pinion ring of controlled gear mechanism. Application of dielectric filling allows to decrease wave-guide dimension at constant wave length. Dielectric filling also helps to avoid oil splash inside the wave-guide and carbon deposit occurrence. Design of such primary converter is presented on figure 6. The proposed system for monitoring the working state of the gear wheels of energy-loaded multipliers can be used for diagnostics in operation in any dynamic modes. Ultimately, the proposed system allows to automate the control process, objectively evaluate and record its current operating state, and reduce the number of device preparations. The monitoring system generates a pre-emergency signal of the torque multiplier and thereby significantly reduces the probability of failure of a complex and responsible mechanical system and ensures operation of the torque multiplier of the steam compressor based on its actual technical state.

4. Conclusions
Suggested method allow to maintain non-contact control of working condition of some elements of the steam compressor for desalination plant. These elements include impeller of the compressor itself and gear mechanism for the multiplier. Both methods assume utilization of specially developed software. Described control systems allow to detect deviations equal to 1-2% from initial condition. Application of such systems gives the opportunity to improve fault diagnosis and maintenance in 2-3 times.

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