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DEPENDABILITY ANALYSIS OF GAS COMPRESSION UNITS

The paper puts forth the main findings of dependability analysis of gas compression units (GCU) operated by Russian gas transmission companies. The authors examine the key design and functionality features of GCUs, as well as the matters of dependability in the gas industry. The paper presents the structural and functional GCU dependability model (SFDM) that was developed based on the results of GCU dependability research.

Keywords: *gas compression unit, dependability, failure, probability of no-failure.*

A gas compression unit is a complex power facility designed for compression of natural gas arriving to a gas compression station (GCS) via a long distance pipeline [1]. Gas compression units are the primary production facilities of gas compressions stations that enable regular gas transportation operations of a long distance pipeline. The gas compression unit of a gas compressor station consists of a centrifugal pump and a drive. Gas turbines (stationary, aeroderivative or marine) and electric motors are primarily used as drives.

One of the key operational characteristics of a gas compression unit is its dependability. As per GOST 13377-75, dependability is defines as the ability of a facility to perform the specified functions while preserving in time the specified performance indicators within the limits set for specific modes and conditions of operation, maintenance, storage and transportation. The dependability of the unit is generally defined by the dependability of its components, the systems that service it and the nature of their interaction.

The matters of dependability are especially relevant in the gas industry. The bulk of the power equipment stock of Russian gas transportation enterprises was commissioned in 1980 – 1990's and a major part of it is beyond the standard operation time specified by the manufacturer. That situation inevitably affects the reliability of power utilities operation. Evidence of that is the fact that 30% of the total number of power utilities malfunctions are related to equipment tear and wear [2].

GCU dependability depends on the solution of a number of scientific, technical, economic and organizational tasks at all stages from the design to the operation. The solution of the dependability problems depends on the development of the dependability theory that is based on the applied mathematics methods, i.e. probability theory and mathematical statistics [3].

The theory and practice of dependability is closely connected with such concepts as equipment operability and failure. Operability is the condition of a facility capable of performing certain functions while maintaining the values of parameters within the limits set forth in norms and specifications. A failure is an event consisting in the disturbance of operability and requiring the unit to be stopped.

Dependability calculation is based on methods of probability theory and mathematical statistics [4-8] that are also applicable to GCU dependability models. The failure of a unit in operation and its recovery are two opposite random events. In practice, operations are performed with random variables. A variable is deemed random if it can assume any value unknown in advance.

Currently, the evaluation of GCU dependability in pipelines is performed using a system of indicators based on the definition of the time the unit operating in a certain condition:

– total operating time of the unit T_O over the reporting period T_{RP};

– total standby time of the unit T_{STB};

– total scheduled repair operation time of the unit T_{SR};

– forced downtime T_{FDT}.

Normally, a calendar year is taken as the reporting period:

$T_{RP} = T_O + T_{STB} + T_{SR} + T_{FDT} = 365$ days.

The unit's dependability indicators are identified by comparing the above temporal conditions. The probability of fault-free operation *P(t)* is the primary dependability indicator that shows the probability of failure not occurring within the set time period *t* (or within the specified operation period).

Evaluation and prediction of GCU operational dependability can be based on the GCU structural and functional dependability model (SFDM). The structural and functional dependability model is the probability of fault-free operation (PFFO), a composite indicator of longevity that comprehensively characterizes the dependability of complex technical systems. The GCU structural and functional dependability model reflects the integrated dependability indicator (DI) trough structural and functional decomposition of GCU, causes and nature of failures, rational nomenclature of output parameters, operability model, structure and type of the input information regarding dependability of GCU components, as well as operation times, operation modes, maintenance system, operation guidelines and conditions. SFDM to the fullest extent characterizes the dependability of the researched object, reflects its main design and functional features, operating modes, causes and nature of the failures. Based on the results of the comprehensive GCU dependability research, the structural and functional GCU dependability model takes the following form:

$P_{FFO}(t_\sum) = F_1 [Y_i (T_O, T_{STB}, T_{SR}, T_{FDT}); Zj (T_O, T_{STB}, T_{SRP}, T_{FDT}); Xk (T_O, T_{STB}, T_{SR}, T_{FDT}); [Yi]; [Zj]; [Xk]; R_1; \eta; \varepsilon; \zeta] * F_2 [\lambda_{1\mu} (T_O, T_{STB}, T_{SR}, T_{FDT}); \lambda_{2\mu} (T_O, T_{STB}, T_{SR}, T_{FDT}); \lambda_{3\mu} (T_O, T_{STB}, T_{SR}, T_{FDT}); r] * F_3 [\lambda_{4v} (T_P, T_{STB}, T_{SR}, T_{FDT}); \rho] * F_4 [t_{MO}, n_{TO}, t_{sr}, n_{sr}, t_{elim}, m, t_3, n_3]$.(1)

In formula (1):

• $P_{FFO}(t_\sum)$ is the probability of fault-free operation of GCU as an integrated facility, a composite index of unit dependability over the operational period under consideration $(t_\sum)$;

• $F_1 [Y_i (T_O, T_{STB}, T_{SR}, T_{FDT}); Z_j (T_O, T_{STB}, T_{SR}, T_{FDT}); X_k (T_O, T_{STB}, T_{SR}, T_{FDT}); [Y_i]; [Z_j]; [X_k]; R_1; \eta; \varepsilon; \zeta]$ is the operator that defines the probability of the system ensuring operability in the given operational conditions and GCU operating modes depending on operation time and working conditions. Taking into consideration the influence and dispersion of the following values:

○ Y_i is the generalized GCU output parameters (level of noise in the machine room, general vibration condition of the unit, gas accumulation in the shop or GCU shed, gas pressure at the output of the compression station, gas temperature at the output of the compression station, etc.);

○ Z_j is the output parameters of individual subsystems (temperature, pressure and level of oil; level of vibration of the electric motor, multiplier and compressor; compressor surging protection; power restriction, cosφ of electric motor, network voltage, etc.);

○ X_k is the output parameters of individual components of the unit (temperature of electric motor bearings, oil pressure in compressor seals, axial shift of compressor rotor, temperature of electric motor stator coils, electric motor insulation spacers resistance, diametric gap between spindles and bearing pads, axial play of multiplier wheel shaft, etc.); the number of output parameters Y_i, Z_j, X_k in formula (1) depends on the essence of the problem to be solved, design features of the specific GCU and operating mode. Parameters may correlate.

○ $[Y_i]$, $[Z_j]$ and $[X_k]$ are ranges of allowable values of output parameters that in general depend on the time and conditions of operation;

○ R_1 is the set of real numbers that includes all possible and allowable values;

○ T_O, T_{STB}, T_{TM}, T_{FDT} is the GCU operation time in time units in different modes during the operation period (time of unit operation, time of stand by, maintenance and forced downtime);

○ η; ε; ζ is the number of Y_i, Z_j, X_k output parameters that characterize GCU operability.

Operator $F_1 (Y_i (); Z_j (); X_k (); ...)$ defines the probability P_n of the GCU ensuring operability for given parameters depending on the allowable limits in given operation mode and time: $P_n = \{Y_{1\in}[Y_1]; Y_{2\in}[Y_2]; \ldots\ldots Y_{i\in}[Y_i]; \ldots\ldots Z_{j\in}[Z_j]; \ldots\ldots X_{k\in}[X_k]\}$. Operator F_1 virtually defines the parametric dependability.

• $F_2 [\lambda_{1\mu} (T_O, T_{STB}, T_{SR}, T_{FDT}); \lambda_{2\mu} (T_O, T_{STB}, T_{SR}, T_{FDT}); \lambda_{3\mu} (T_O, T_{STB}, T_{SR}, T_{FDT}); r]$ is the operator that characterizes the way the GCU dependability is affected by minor design and manufacturing defects that are not covered by operator F_1, as well as the influence of the quality of maintenance. Taking into consideration the influence and dispersion of the following values:

○ $\lambda_{1\mu}$; $\lambda_{2\mu}$; $\lambda_{3\mu}$ are the failure rates of μ-th GCU subsystem due to minor design, manufacturing and maintenance defects over the operation period respectively;

○ r is the number of μ-th subsystems the GCU is arbitrarily divided into for evaluation of dependability indicators.

• $F_3 [\lambda_{4v} (T_O, T_{STB}, T_M, T_{FDT}); \rho]$ is the operator that takes into consideration the effects of violations of GCU operation rules on its dependability. Taking into consideration the influence and dispersion of the following values:

○ $\lambda_{4v} (T_O)$; $\lambda_{4v} (T_{STB})$; $\lambda_{4v} (T_{SR})$; $\lambda_{4v} (T_{FDT})$ are the violation rates of the ν-th rule of GCU operation depending on the operating mode, time of operation;

○ ρ is the number of operation rules recommended for application.

• $F_4\ [t_{MO}, n_{MO}, t_{sr}, n_{sr}, t_{elim}, m, t_3, n_3]$ is the operator that characterizes the total effect of current failures and the adopted GCU preventive maintenance system on its availability. Taking into consideration the influence and dispersion of the following values:

○ t_{MO}; t_{sr}; t_{elim} is the average duration of maintenance (M), average duration of scheduled GCU repairs and average failure elimination time;

○ m; n_{MO}; n_{sr} is the expected number of failures, maintenance operations and scheduled repairs over the specified period of time t of GCU operation respectively;

○ t_{WO} is the time of work order delivery;

○ n_{WO} is the expected number of work orders.

Operator $F_4\ [t_{MO}, n_{MO}, t_{sr}, n_{sr}, t_{elim}, m, t_3, n_3]$ is essentially the GCU utilization coefficient.

In order to calculate the components of the utilization coefficient, we use the preventive maintenance system according to which:

$T_{\Sigma pto} = n_1 t_{MO} + n_p t_p$; $T_{\Sigma nto} = m t_{elim}$; where:

○ n_{MO}, n_p, m is the number of maintenance operations (MO), scheduled repairs and failures over the specified operation period;

○ t_{MO}, t_p, t_{elim} are respectively average time expenditure of a maintenance operation, scheduled repairs and failure elimination.

SFDM can be used as the foundation of evaluation and analysis of GCU dependability at all stages of design, manufacture, commissioning tests and operation. It enables an integrated and organized approach to dependability analysis by the designer, process engineer, tester, customer and operating personnel, which allows generating a universal database for dependability forecasting and increases the probability of finding the real cause of failure.

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