V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
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METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL ELEMENTS OF DEVICES AND SYSTEMS

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ABSTRACT

Features of the application of standards for evaluation (predict) the reliability of mechanical and electromechanical devices and systems are considered. The main characteristics of the models of operational failure rate of mechanical components and provides recommendations for their use are given. The use of software tools that implement the methods for calculating reliability, can cause significant difficulties with the reliability of initial data.

1. INTRODUCTION

Handbook "Reliability ERP" is the main source for the calculation of reliability indices of elements of sensors, devices and systems at the present time in Russia. The handbook is an official document of the Ministry of Defence of Russian Federation in accordance with standard (RDV 319.01.20-98 1998). Mathematical models of the operational failure rate electro-radio-products (ERP) and the numerical values of the coefficients are given in it. The survey provides data not only for performance reliability of electronic devices, such as integrated circuits, semiconductor devices, etc., and of electromechanical components (such as electrical machines of small capacity) and the purely mechanical components (connections, circuit boards, etc.).

Since the range of such elements is limited, so in practical calculations the reliability of the elements that are missing in the Handbook "Reliability ERP", not included and considers them an "absolutely reliable". However, this approach can lead (and leads) to a significant overestimation of the reliability of systems (Markin et al. 2010), primarily of test containing primary transducers (sensors). Evaluation of reliability of such systems requires taking into account not only the reliability of the electronic devices, but also a wide class of mechanical components (connections, details, etc.).

2. MODELS RELIABILITY OF MECHANICAL COMPONENTS

Mathematical models of operational failure rates are given in article (Shavykin & Petruhin 2006) for the following classes of mechanical connections, components, assemblies and equipment manufactured in Russia:

- Non-demountable fasteners
- Threaded fasteners
- Demountable fasteners
- Nodes of transmission of motion
- Bearings
- Seals and Gaskets
- Bellows and tubular springs

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December

- Impeller flow sensors
- Membrane
- Pressure Gauges
- Vacuum gauges with tubular springs
- Springs, couplings, watch mechanisms

All these models are as follows:

$$\lambda_{э} = \lambda_0 \cdot \prod_{i=1}^{I} \alpha_i$$

where: $\lambda_{э}$ = operational failure rates of seals; λ_0 = base failure rate of seals; α_i = multiplying factors which considers the effect on the base failure rate; I = number of multiplying factors.

In addition to mathematical models (formulas) in article (Shavykin & Petruhin 2006) also shows a table containing the numerical values of their coefficients. The possibility of using these models due to the fact that they are full copies of the "Procedure…" (Shavykin et al. 1998) in terms of mechanical parts, which at present applies to ROSATOM.

As an example we will consider class "Seals and Gaskets". For this class in article (Shaykin & Petrukhin 2006) the following mathematical model of operational failure rate is resulted:

$$\lambda_{э} = \lambda_0 \cdot \alpha_1 \cdot \alpha_m \tag{1}$$

where: $\lambda_{э}$ = operational failure rate of seals; λ_0 = base failure rate of seals; α_1 = multiplying factor which considers the effect of service conditions and etc. on the base failure rate; α_m = multiplying factor which considers the effect of type of a material on the base failure rate.

In turn, the multiplying factor α_1 pays off on model:

$$\alpha_1 = k_{11} \cdot k_{12} \cdot k_{13} \cdot k_{14} \cdot k_{15}, \tag{2}$$

where: k_{11} = multiplying factor which considers the effect of service conditions, vibrating loadings and amortization on the base failure rate; k_{12} = multiplying factor which considers the effect of service conditions, shock loadings and amortization on the base failure rate; k_{13} = multiplying factor which considers the effect of type of a climate, presence of the conditioner, heating and premise hermetic sealing on the base failure rate; k_{14} = multiplying factor which considers the effect of a kind of equipment and quality of service on the base failure rate; k_{15} = multiplying factor which considers the effect of a kind of equipment and quality of manufacturing on the base failure rate.

Numerical values multiplying factors k_{11}-k_{15} are given in tables. Due to the limited size of the article yourself a table full list here are not going to give only their fragments (see Table 1-4).

Table 1. Values of multiplying factors k_{11} and k_{12}

Operating conditions	k_{11} (vibration)		k_{12} (strikes)	
	not amortized	amortised	not amortized	amortised
Lab, instrument-making enterprises, assembly plants	1,0	1,0	1,0	1,0
Marine conditions	3,0	1,0	1,2	1,0
…	…	…	…	…
The equipment of rolling mills, forging hammers, presses	10,0	3,0	15,0	5,0

Table 2. Values of multiplying factor k_{13}

Climate	air conditioning	Heated room		Not heated room	
		sealed	not sealed	sealed	not sealed
Cold	1,0	1,0	1,2	1,2	2,0
Moderate, middle band	1,0	1,0	1,2	1,0	1,3
…	…	…	…	…	…
marine subtropical	1,1	-	-	1,5	2,0

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December

Table 3. Values of multiplying factors k_{14} and k_{15}

Equipment	k_{14} (service)	k_{15} (production)
Household	5,0	2,0
Management of individual units	1,0	1,0
...	...	...
Process control	0,8	0,5

Table 4. Values of multiplying factor α_m

Material	Temperature				
	20 ^{0}C	40 ^{0}C	60 ^{0}C	80 ^{0}C	100 ^{0}C
Organic fibrous	1,0	1,5	2,0	4,0	8,0
Rubber	1,0	1,2	1,5	2,5	4,0
...	...	...	...	...	...
Fluoroplastic	1,0	1,0	1,0	1,0	1,2

Even a simple analysis of Tables 1-4 shows that the model (1) is of little use to solve practical problems of reliability. Indeed, the failure rate of the seals does not depend on their size, nor on the quantitative characteristics of the physical and mechanical properties of materials, etc.

For example, in the standard (TU 38 005 1166-98 1998) is defined more than 50 brands of rubber compounds with different physic-chemical properties and the calculation of the model (1) for all of them give the same failure rate (see Table 5)!

Fragment of the table the standard (TU 38 005 1166-98 1998) are as follows (see Table 5).

Table 5. Characteristics of rubber compounds

Mark rubber compound	Operating conditions		The main purpose of	Relative tensile strength, n/m		Elongation at break, % n/m	Hardness, Shore unit
	environment	T, ^{0}C		MPa	kgs/sm^2		
B-14 *HTA*	Air	-45...+100	Molded rubber and rubber parts and immobile joints operating under a static strain	10,8	110	160	72-92
	Oil *АМГ*-10	-60...+100					
	Ethanol	-60...+70					
B-14-1 *HTA*	Air	-45...+100	Molded Rubber and rubber parts and immobile joints operating under a static strain	11,8	120	150	78-85
	Ethanol	-60...+70					
...	...	...	...	...	...	...	...
ИРП-1354 *HTA*	Air	-70...+250	Shaped syringe electrical parts operating in the unstressed state, Amortisseur, Molded and non-sealing parts (rings, gaskets, etc.) for fixed joints	5,4	55	280	54-66
	Air with high ozone	-76...+125					
	The electric field	-60...+250					
	Lubrication *ВНИИ НП*-279	-60...+150					

In other words, if the resulting failure rate calculations seals (or any other elements) will be high, the number of possible ways to enhance their security in the use of model (1) is limited, and, consequently, the possibility of implementation of relevant activities is unlikely or will require a large material costs.

And the "Procedure…" (Shavykin et al. 1998), and the standard TU 38 005 1166-98 were published in the same year. But the data presented in "Procedure…" (Shavykin et al. 1998) almost entirely with the data of the Recommendation (RM 25 446-87 1987). From this it follows that the conduct of the calculation is based on data from 20-years old ago.

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December

From this point of view of greater interest are the models listed in the American standard (NSWC-98/LE1 1998), developed by experts Naval Surface Warfare Center, or rather, its latest edition (NSWC-06/LE10 2006).

The standard includes mathematical models of operational failure rate for the following classes of mechanical equipment:

- Seals and Gaskets
- Springs
- Solenoids
- Contactors
- Valve assemblies,
- Bearings
- Gears and Splines
- Actuators
- Pumps
- Fluid Filters
- Brakes and Clutches
- Compressors
- Electric Motors
- Accumulators, Reservoirs
- Threaded Fasteners
- mecanical Couplings
- Slider cranks mechanisms
- Sensors and Transducers.
- Shafts
- Belt and chain drivers
- Fluid conductors

To give an idea of the mathematical models of operational failure rates present a model for the class "Seals and Gaskets":

$$\lambda_{SE} = \lambda_{SE,B} \cdot C_P \cdot C_Q \cdot C_{DL} \cdot C_H \cdot C_F \cdot C_v \cdot C_T \cdot C_N, \tag{3}$$

where: λ_{SE} = failure rate of seals in failures/million hours; $\lambda_{SE,B}$ = base failure rate of seals, 2,4 failures/million hours; C_P = multiplying factor which considers the effect of pressure on the base failure rate; C_Q = multiplying factor which considers the effect of allowable leakage on the base failure rate; C_{DL} = multiplying factor which considers the effect of seal size on the base failure rate; C_H = multiplying factor which considers the effect of contact stress and seal hardness on the base failure rate; C_F = multiplying factor which considers the effect of seat smoothness on the base failure rate; C_v = multiplying factor which considers the effect of fluid viscosity on the base failure rate; C_T = multiplying factor which considers the effect of temperature on the base failure rate; C_T = multiplying factor which considers the effect of contaminants on the base failure rate.

Even simple comparison of models (2) and (3) shows that models of standard (NSWC-06/LE10 2006) more exact, than resulted in article (Shavykin & Petruhin 2006). Besides, factors of these models also represent functions of the geometrical sizes, physic mechanical properties of materials, etc. For example, the formula for calculating the factor C_H is shown below:

$$C_H = \left(\frac{M/C}{0,55} \right)^{4,3} \tag{4}$$

where: M = Meyer hardness, lbs/in^2; C = contact pressure, lbs/in^2.

It is obvious that application of models of standard (NSWC-06/LE10 2006) essentially increases labor input of "manual" calculations in comparison with article (Shavykin & Petruhin

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December

2006). Therefore along with formulas for calculation of factors in it corresponding monograms (**Figure 1** see) are resulted.
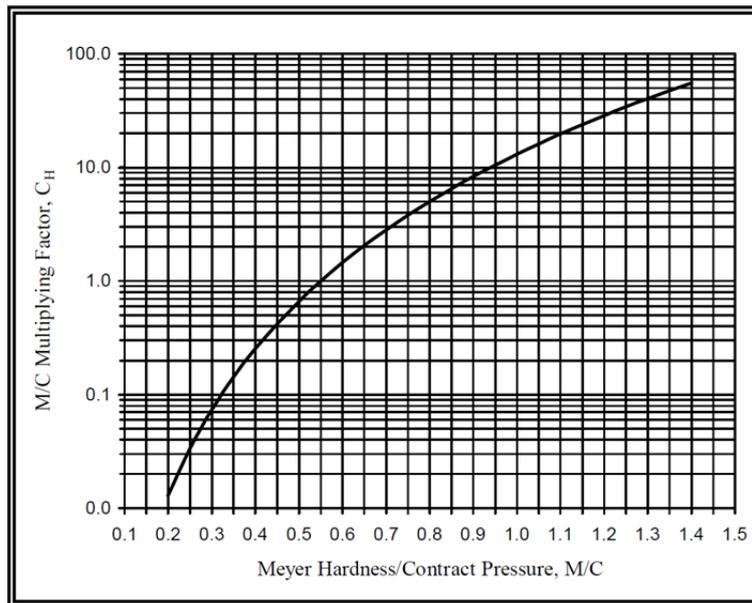

Figure 1. NSWC-06/LE10: Dependence of multiplying factor C_H on relation M/C.

These monograms may be helpful in justifying the choice of measures aimed at improving the reliability, because give a clear idea of the effect of each option on the magnitude of the coefficients and, consequently, the operational failure rate in general. However, these monograms rather to the tradition of information in handbooks on reliability than a means to facilitate the calculations, since with a large number of elements the complexity of calculations, even for simple models of article (Shavykin & Petruhin 2006) increases significantly.

Another feature of the standard (NSWC-06/LE10 2006) is that some elements are considered as a system. For example, the calculation of the failure rate of the electric motor is carried out according to the model:

$$\lambda_M = \lambda_{BE} + \lambda_{WI} + \lambda_{BS} + \lambda_{AS} + \lambda_{ST} + \lambda_{GR}, \tag{5}$$

where: λ_M = total failure rate of motor system, failures/million hours; λ_{BE} = failure rate of *bearings*, failures/million hours; λ_{WI} = failure rate of electric motor windings, failures/million hours; λ_{BS} = failure rate of brushes, failures/million hours; λ_{AS} = failure rate of the armature shaft, failures/million hours; λ_{ST} = failure rate of the stator housing, failures/million hours; λ_{GR} = failure rate of *gears*, failures/million hours.

As follows from (5), the calculation of the electric motor, you must first calculate the failure rate of the *bearings* and *gears*.

2. SOFTWARE FOR THE CALCULATION OF RELIABILITY

To automate the calculation of reliability of mechanical connections, parts, components and devices on models of article (Shavykin & Petruhin 2006) can be used system ASONIKA-K-ME, which is part of the software complex ASONIKA-K (Zhadnov et al. 2011). The main form of the interface of the user of system is resulted on **Figure 2**.

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December
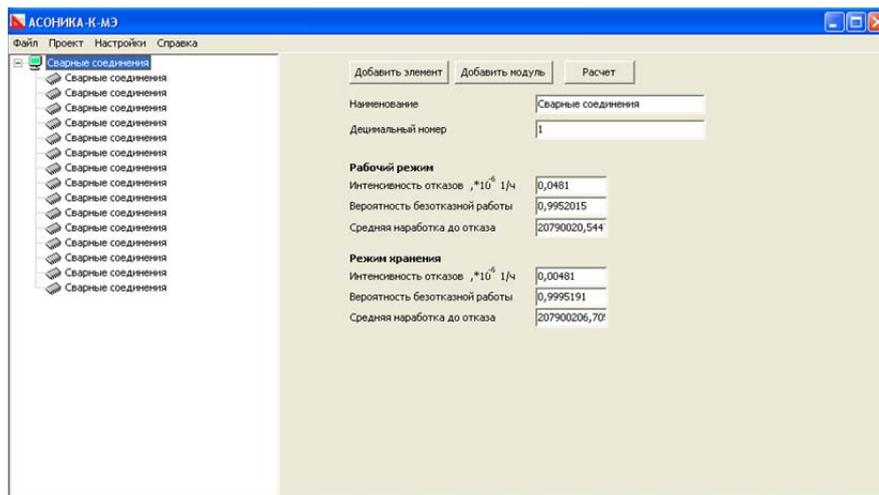
Figure 2. System ASONIKA-K-ME: the Interface of the user.

To automate the calculation of reliability of mechanical equipment on the models standard (NSWC-06/LE10 2006) developers provide a computer program MechReal (see **Figure 3**).
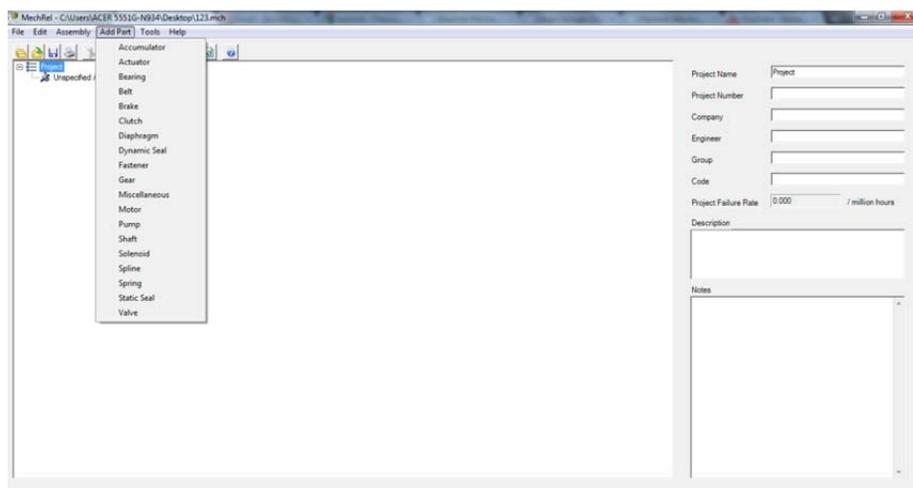
Figure 3. Program MechReal: the Interface of the user.

It is natural that models of this standard are included and into structure of software (modules of Reliability Prediction) well-known manufacturers, such as PTC Corporate Headquarters (Relex visual studio), ReliaSoft Corporation (Lambda predict), ALD Ltd. (RAM Commander), Etc. (Stroganov et al. 2007). And, many are constructed of them in such a manner that allow to consider in one calculation as electronic devices, and mechanical elements, unlike system ASONIKA-K-ME and programs MechReal.

On **Figure 4** is shown the interface of the user of program Lambda Predict of company ReliaSoft Corporation.

But practical application of these programs causes considerable difficulties that is connected not only (and not so much) with the English-speaking interface (**Figure 3, 4** see), how many with search of the initial information. Therefore in standard (NSWC-06/LE10 2006) tables with "typical" values of parameters are resulted.

For example, a fragment of the table "typical" values of is maximum-admissible working temperatures (T_R) of materials of Seal is shown below (see Table 6).

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December
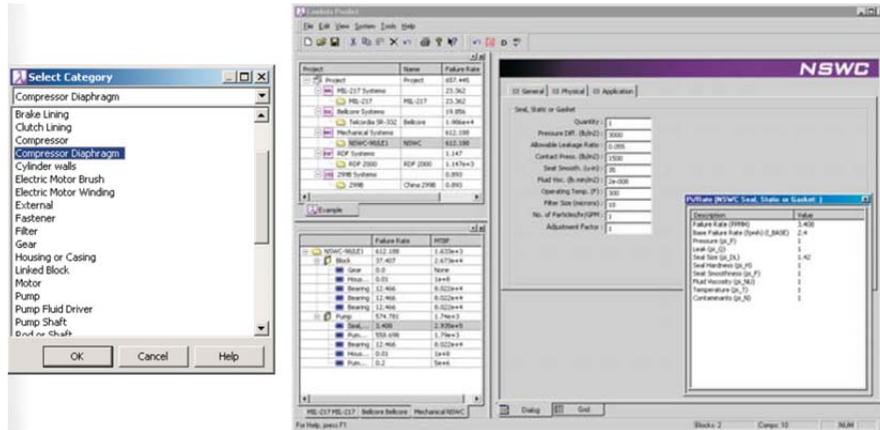
Figure 4. Program Lambda Predict: the Interface of the user.

Table 6. Typical values of is maximum-admissible working temperatures of materials of seal

Seal material	T_R, (^{0}F)
Natural rubber	**160**
Ethylene propylene	**250**
...	...
Impregnated poromeric material	**250**

Comparing the first columns of Table 4 and 6 it is easy to notice that search of values is carried out not to concrete marks of materials, and to the more general classification signs. Since these tables are standard (NSWC-06/LE10 2006) and placed in modules "Prediction of Reliability", as stated above, it is clear that, despite the adequacy of the model, calculations with the this data source will be little different from the calculations on model article (Shavykin and Petrukhin, 2006) for accuracy

Therefore for maintenance of accuracy of calculations creation of the database containing all necessary help given (characteristics of materials, maximum-permissible operating modes etc.) is necessary. For the decision of this problem in structure of a help part of a database of the system ASONIKA-K-SCh such database has been added. On **Figure 5** as an example the model of the data for a class "Bearings", created in Sybase PowerDesigner is resulted.

Feature of the developed base is that are stored in it not only numerical values, but also codes of mathematical models (formulas) on which calculation is carried out. In addition, the database stores brand materials and their characteristics are necessary for the calculation of the coefficients of models standard (NSWC-06/LE10 2006). For work with this database the system has been modified ASONIKA-K-SCh.

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In addition, in the system ASONIKA-K-SCh were added to the model, listed in article (Shavykin and Petrukhin, 2006). Thus, the new version of system ASONIKA-K-SCh allows the do calculation of mechanical elements on models of standard (NSWC-06/LE10 2006) and article (Shavykin and Petrukhin, 2006).

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December
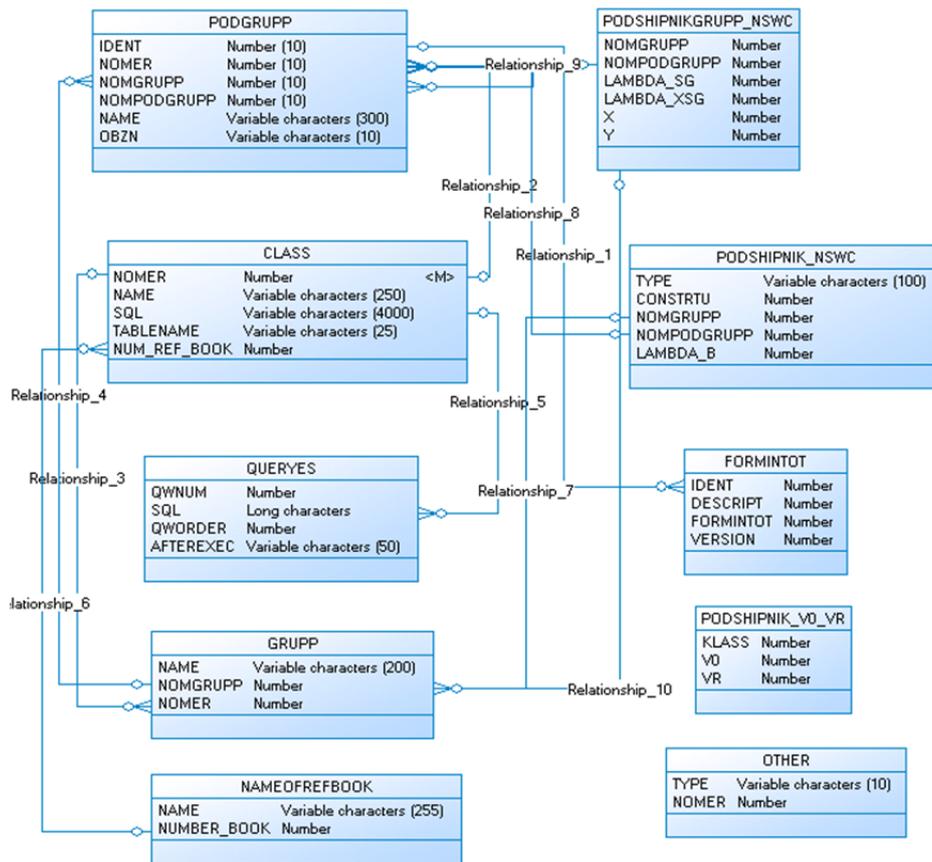
Figure 5. Class "Bearings": model of the data.
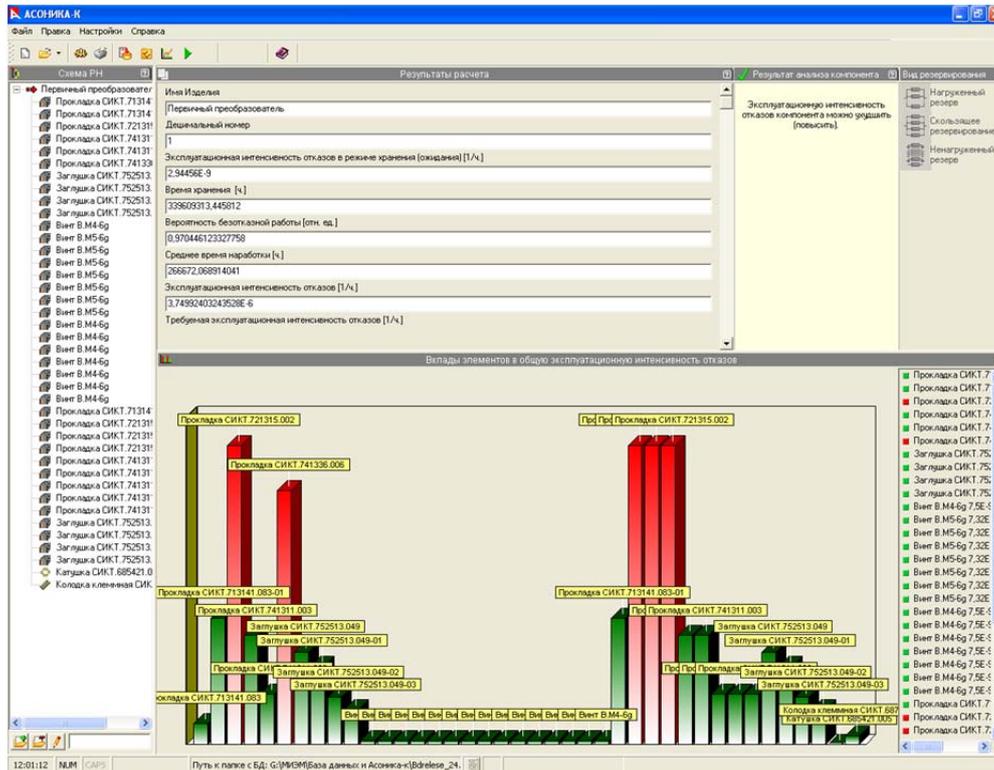
Figure 6. System ASONIKA-K-SCh: the Interface of the user.

V. Zhadnov – METHODS AND MEANS OF THE ESTIMATION OF INDICATORS OF RELIABILITY OF MECHANICAL AND ELECTROMECHANICAL
ELEMENTS OF DEVICES AND SYSTEMS

RT&A # 04 (23)
(Vol.2) 2011, December

3. CONCLUSION

In the conclusion it is necessary to note the following. Even creation of a database doesn't remove all problems with the initial information for calculations. In the model standard (NSWC-06/LE10 2006) enter the variable parameters, depending on the application (allowable leakage, size of gasket, the pressure on the gasket, etc.). Already in itself calculation of these parameters is not a trivial problem and, despite an abundance of software of modeling physical process (mechanical, hydraulic, etc.), that under force only to professionals in area of mechanics, resistance of materials, etc.

In other words, calculation of reliability of such products can be hardly spent one expert. However program realization of system ASONIKA-K-SCh in technology "client-server" allows to carry out calculation of one product from different workstations (i.e. to involve in calculations so much experts, how many it is necessary) that will help to remove the specified problem partly.

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