III INTERNATIONAL SCIENTIFIC CONFERENCE “**SUSTAINABLE AND EFFICIENT USE OF ENERGY, WATER AND NATURAL RESOURCES” - SEWAN-2021** ”

APPLICATION OF MULTIVARIATE ANALYSIS IN TECHNICAL SYSTEMS

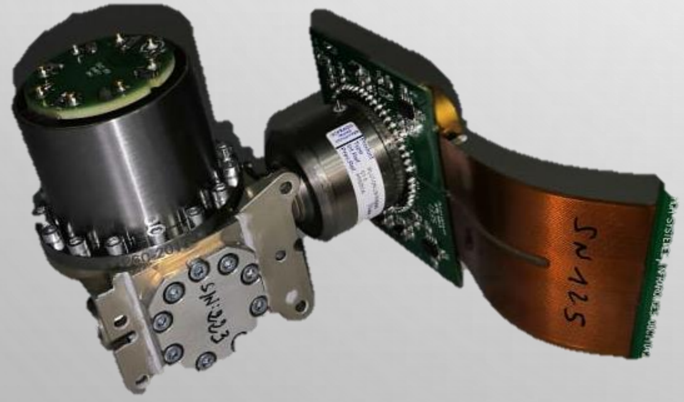
Authors: Natalia E. SHISHOVA
Ivan A. ARHAROV
Ekaterina C. NAVASARDYAN

ИСПОЛЬЗОВАНИЕ МНОГОФАКТОРНОГО АНАЛИЗА В ТЕХНИЧЕСКИХ СИСТЕМАХ

Авторы: Н.Е. Шишова
И.А. Архаров
Е.С. Навасардян

Saint-Petersburg, 19-24 April, 2021

THE STRUCTURE OF MULTIVARIATE ANALYSIS FOR ASSESSING OF THE EFFICIENCY INDICATOR



Multivariate Analysis in technical system

The statistical estimate of the influence of factors on the selected efficiency indicator of the technical system

Independent factors *i=1..n*

Formation of a module of initial data for each component of the technical system and testing samples under specified conditions

Multivariate ANOVA

Formation of the matrix **«FAILURE» x «COMPONENT»** for each independent factor for each component

Failure cause

Matrix «FAILURE» x «COMPONENT»

Components of the technical system

Dependent factors 1..j

Optimization of technical system components

Determination of the parameters of the Weibull distribution law for each component of the technical system

Assessment of the complex efficiency indicator

APPLICATION OF MICROCRYOCOOLERS

Special application of microcryocoolers:

- ✓ In cryostatting systems for PC – thermal imaging equipment in weapon sights and night vision devices;
- ✓ In thermal imaging channels of air defense systems (warning systems) and other guidance systems and fire control systems of armored combat vehicles (AFV);
- ✓ In aircraft protection systems;
- ✓ In coast guard systems;
- ✓ As part of onboard cooling systems for infrared surveillance spacecraft;
- ✓ In Mega pixel format FPAs systems of matrix photodetectors;
- ✓ In cryostatting systems for photosensitive elements of infrared receivers;
- ✓ In security systems high-density urban areas;
- ✓ In security system for airoports, military facilities and research institutions;
- ✓ In UAV control systems;
- ✓ In tracking antenna systems.

General technical systems:

- ✓ Medical equipment;
- ✓ Telecommunication equipment;
- ✓ Superconducting and scientific products;
- ✓ Non-destructive testing systems;
- ✓ Gas leak detection systems;
- ✓ PC spectrophotometers;

REVIEW OF METHODS FOR DETERMINING THE OPERATING TIME (MTTF – MEAN TIME TO FAILURE) OF VARIOUS MANUFACTURERS OF MICROCRYOCOOLERS

Methods for predicting the reliability of microcryocooler manufacturers: «Thales Cryogenic» (Sweden, France) and «Ricor» (Israel):

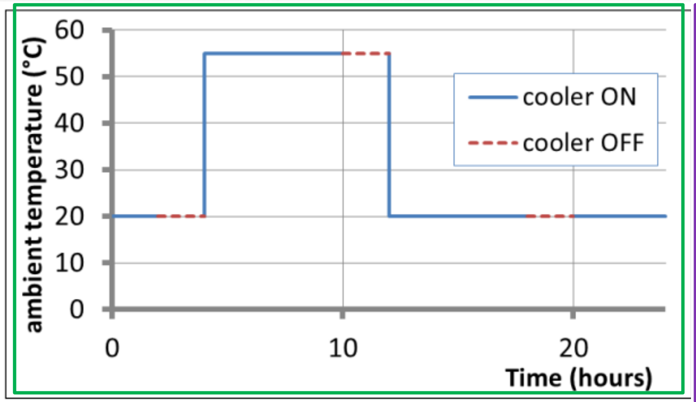


Fig.1 Standard tests of MTTF (at 20 ºC)

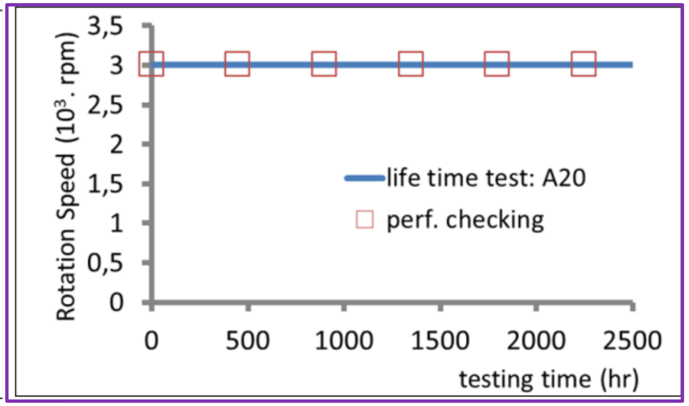


Fig.2 Accelerated tests A20 n=3000 rpm

$$f(x,\beta,\eta)=\frac{\beta}{\eta}\left(\frac{x}{\eta}\right)^{\beta-1}e^{-(x/\eta)^{\beta}}$$

β – shape factor;
η – scale factor.

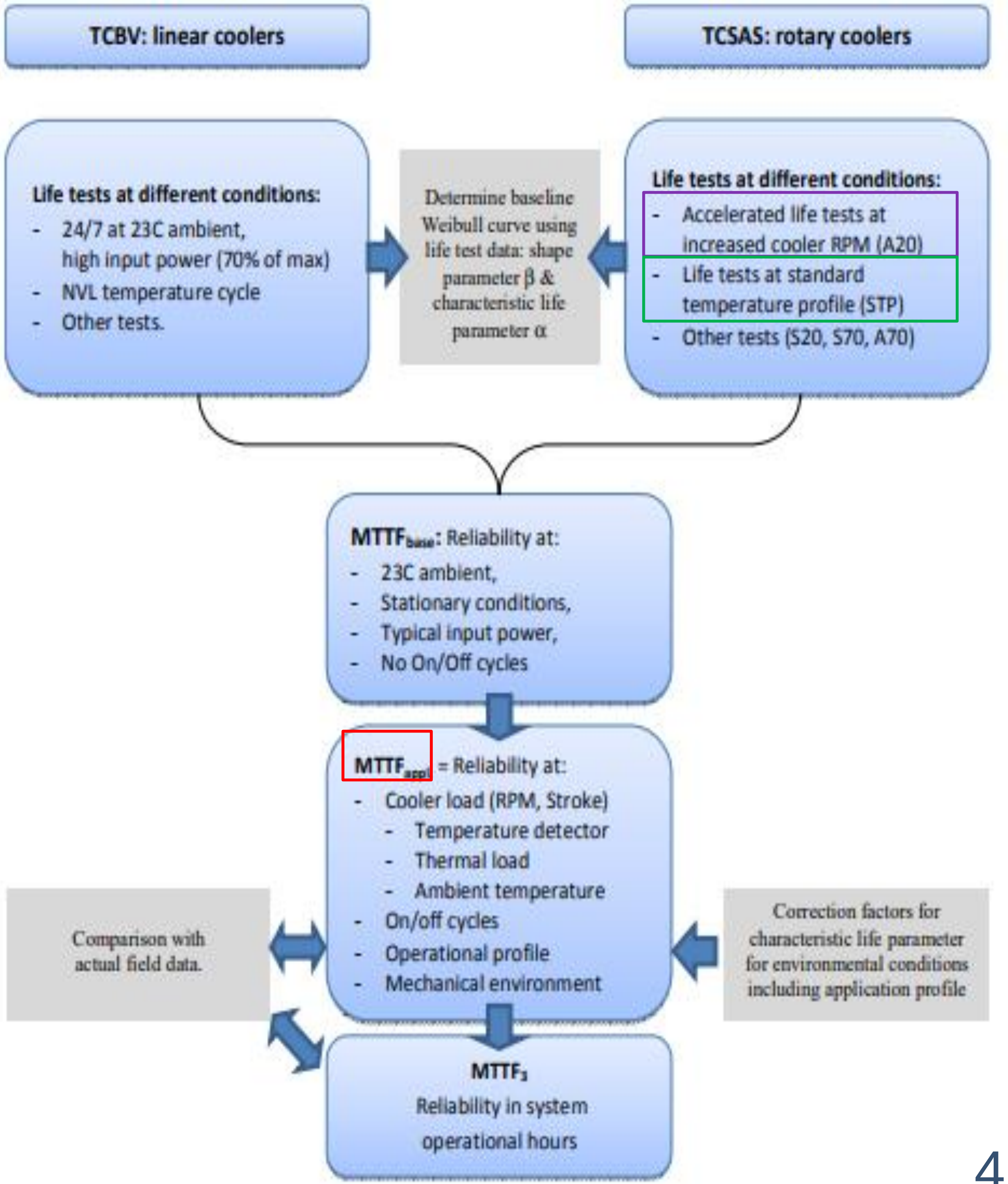
$$MTTF=\sum_{i=1}^{n}\frac{t_i}{m}$$

ti – time to failure;
n – number of tested machines;
m – number of failures.

Determination of the MTTF value taking into account the field of application:

$$MTTF_{\alpha n}=\left(\frac{RPM_{A20}}{RPM_{T\alpha n}}\right)^{1,5}MTTF_{A20\ test\ Weibull}\,C_{1\alpha n}$$

!



REVIEW OF METHODS FOR DETERMINING THE OPERATING TIME (MTTF – MEAN TIME TO FAILURE) OF VARIOUS MANUFACTURERS OF MICROCRYOCOOLERS

«BAE System» (Great Britain)

Predicition of the MTTF (reliability) is estimated in Watt-hours:

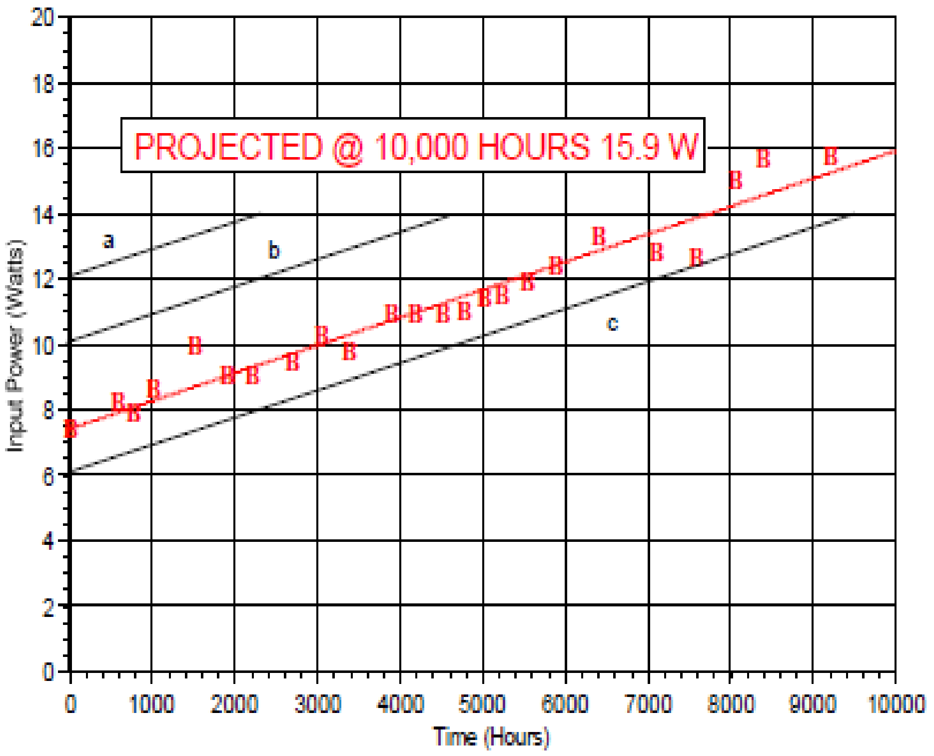


Fig.3 Power consumption: a -12W, b-10W, c – 8 W

Advantage of the «BAE System» method:

Prediction the mean time to failure under different operating conditions of the MTTF of the same series.

Disadvantages of the presented methods:

- a large number of tests;
- prediction of the operating time of the microcryocooler assembly and the impossibility of separately assessing the operating time of units and parts included in the assembly;
- applicability of the method only to manufactured equipment;
- predicting reliability with a probability of 63,2%**!!!**

IDENTIFICATION INDEPENDENT & DEPENDENT VARIABLES

➢ **INDEPENDENT VARIABLES**

- **External factors:**
  - Ambient temperature (-60…+60°C);
  - Ambient pressure (1…10 bar).
- **Design solutions:**
  - Design and porous of the regenerator;
  - Change working substance;
  - The size of clerance between the piston-cylinder (2…14μm).
- **Technical features:**
  - Filling pressure (2,5..4,0 MPa);
  - Rotation speed (1600…3000 rpm).

➢ **DEPENDENT VARIABLE**

- **Cooling capacity ≤ 500mW**
- **Power Comsumption ≤ 20W**
- **COP**
- **Cooling temperature ≤ 77K**
- **MTTF** (Mean Time To Failure)

Table №1. The Input data for the analysis of the influence on the dependent factor of the main independent factors A, B, C, D

Factor - A	Factor - B	Factor - C			
		Value 1		Value ... n	
		Independent factor- D		Independent factor- D	
		Value 1	Value k	Value 1	Value k
Value 1	Value 1	$R1_{11}$	$R7_{k1}$	$R13_{11}$	$R19_{k1}$
	Value j	$R2_{1j}$	$R8_{kj}$	$R14_{1j}$	$R20_{kj}$
...	Value 1	$R3_{11}$	$R9_{k1}$	$R15_{11}$	$R21_{k1}$
	Value j	$R4_{1j}$	$R10_{kj}$	$R16_{1j}$	$R22_{kj}$
Value i	Value 1	$R5_{11}$	$R11_{k1}$	$R17_{11}$	$R23_{k1}$
	Value j	$R6_{1j}$	$R12_{kj}$	$R18_{1j}$	$R24_{kj}$

t_1 ... t_{36k} – the values of the dependent factor (operating time of the tested samples of the microcryocooler)

Table №2. Experimental operating time values of a microcryocooler *t* (hour), grouped for multivariate analysis of variance

T ambient, ˚C	Filling pressure, bar	The size of the clearance between the piston and the cylinder, μm			
		δ=6		δ=10	
		Rotor speed n, rpm		Rotor speed n, rpm	
		n=1600	n=3000	n=1600	n=3000
Plus 60	32	t_{1k}, $k=1…m$	t_{10k}, $k=1…m$	t_{19k}, $k=1…m$	t_{28k}, $k=1…m$
	35	t_{2k}, $k=1…m$	t_{11k}, $k=1…m$	t_{20k}, $k=1…m$	t_{29k}, $k=1…m$
	40	t_{3k}, $k=1…m$	t_{12k}, $k=1…m$	t_{21k}, $k=1…m$	t_{30k}, $k=1…m$
Plus 20	32	t_{4k}, $k=1…m$	t_{13k}, $k=1…m$	t_{22k}, $k=1…m$	t_{31k}, $k=1…m$
	35	t_{5k}, $k=1…m$	t_{14k}, $k=1…m$	t_{23k}, $k=1…m$	t_{32k}, $k=1…m$
	40	t_{6k}, $k=1…m$	t_{15k}, $k=1…m$	t_{24k}, $k=1…m$	t_{33k}, $k=1…m$
Minus 60	32	t_{7k}, $k=1…m$	t_{16k}, $k=1…m$	t_{25k}, $k=1…m$	t_{34k}, $k=1…m$
	35	t_{8k}, $k=1…m$	t_{17k}, $k=1…m$	t_{26k}, $k=1…m$	t_{35k}, $k=1…m$
	40	t_{9k}, $k=1…m$	t_{18k}, $k=1…m$	t_{27k}, $k=1…m$	t_{36k}, $k=1…m$

The statistical estimate of the degree of influence of independent factors on the selected microcryocooler efficiency indicator (MTTF - mean time to first failure) in STATGRAPHICS©Centurion XVI

The results of calculating P-value when assessing the influence of independent factors:

- filling pressure (**3,2..3,5..4,0МПа**),
- ambient temperature (**+65 ºC, +20 ºC, -60 ºC**),
- clearance between the piston and the cylinder **δ** (**6 и 10μm**)
- rotor speed (**1600 rpm & 3000 rpm**)

Multifactor ANOVA - Operation time to failure

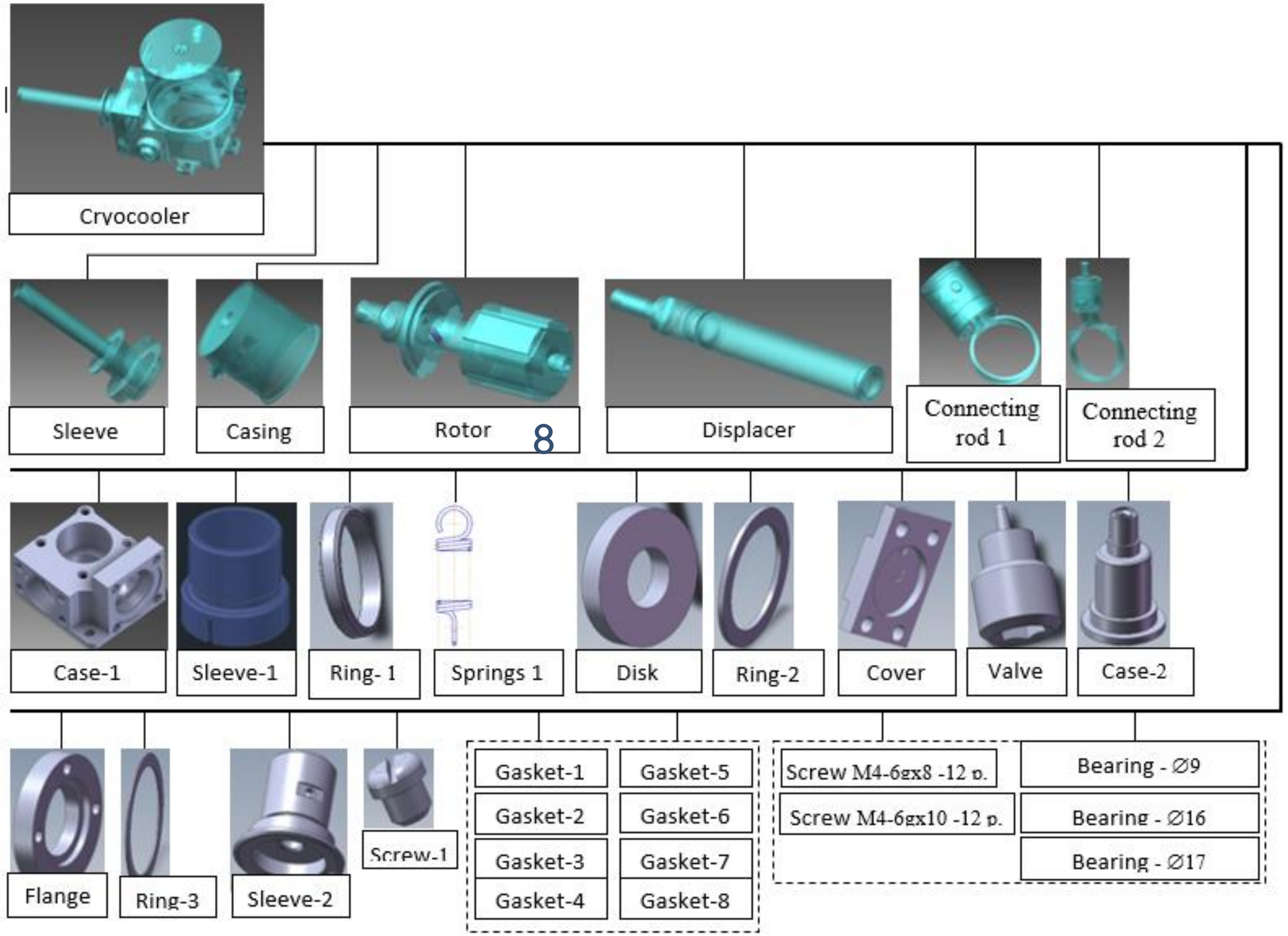
Analysis of Variance for Operation time to failure - Type III Sums of Squares

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:Filling pressure	171349,	2	85674,3	416,20	0,0000
B:Ambient temperature	528345,	2	264173,	1283,35	0,0000
C:Rotation speed	246636,	1	246636,	1198,15	0,0000
D:Clearance	34,7222	1	34,7222	0,17	0,6816
INTERACTIONS					
AB	83224,1	4	20806,0	101,08	0,0000
AC	999,299	2	499,649	2,43	0,0902
AD	5,21528	2	2,60764	0,01	0,9874
BC	830,84	2	415,42	2,02	0,1349
BD	242,528	2	121,264	0,59	0,5555
CD	129,337	1	129,337	0,63	0,4287
RESIDUAL	55166,9	268	205,847		
TOTAL (CORRECTED)	1,08696E6	287			

P ≤ 0.05 –ambient temperature, filling pressure, rotor speed have a decisive influence on the resource of the microcryocooler !

P ≥ 0.05 – the size of the clearance does not have a significant effect on the resource of the microcrycooler in the range from 6 to 10 μm

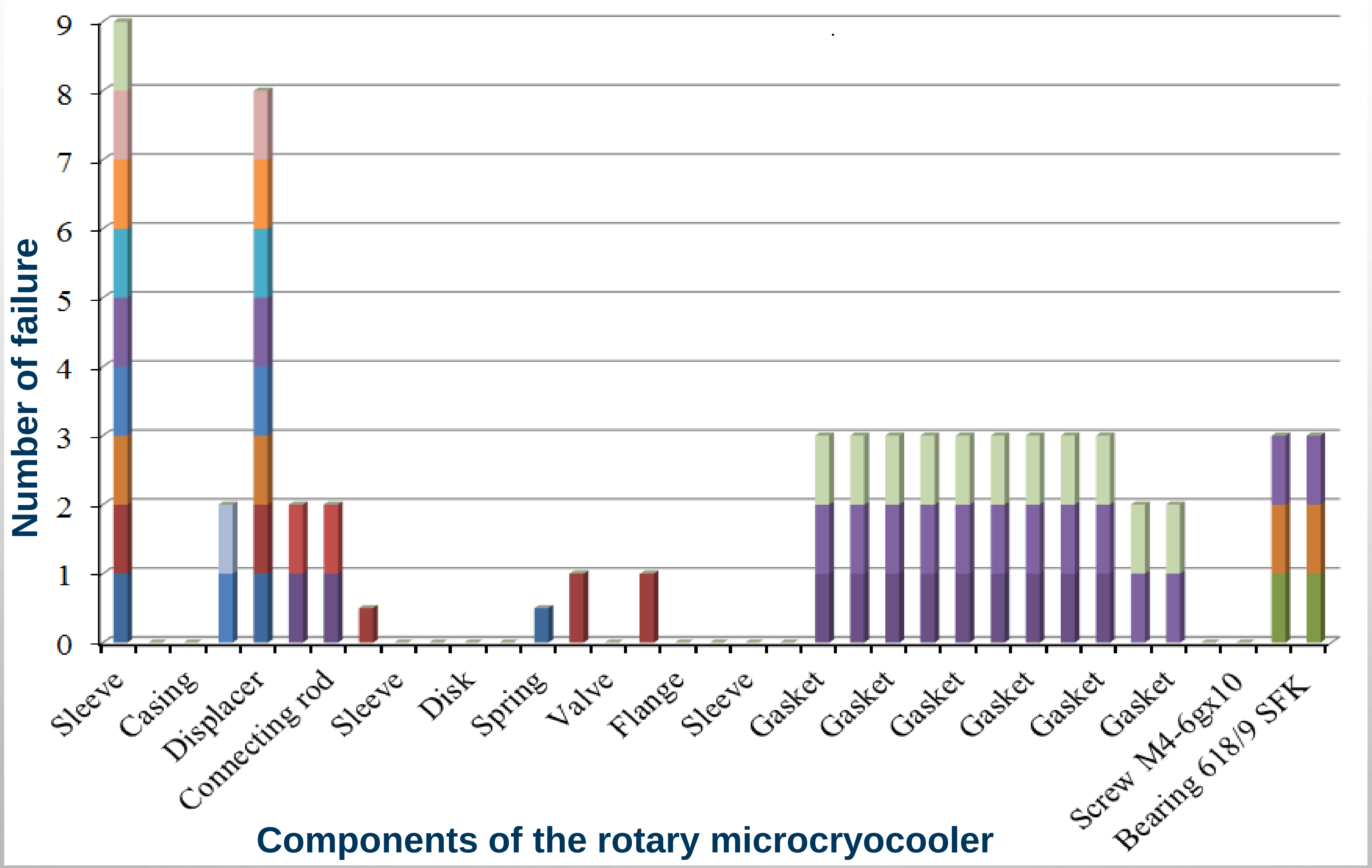
Sample of filling the Matrix «FAILURE» x «COMPONENTS» for rotary-type of the microcryocooler



Component «C»	COMPONENT	Destruction	Corrosion	Fatigue	Crack	Jamming and scuffs	Human factor	Disturbance due to stress	Wear	Critical growth in power consumption	Critical increase in the hydro-resistance of the regenerator	Vibration critical	Cryostation temperature rise	Leakage of working substance
Component/ Failure		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
C1	Sleeve (Assembly)	0	0	0	0	1	1	0	1	1	1	0	0	1
C2	Stator (A)	0	0	0	0	0	0	0	0	0	0	0	0	0
C3	Casing (A)	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	Rotor (A)	0	1	0	0	1	1	0	1	0	0	1	0	0
C5	Displacer (A)	0	1	0	0	0	0	0	0	0	0	0	1	0
C6	Connected rod 1	0	0	0	1	0	0	1	0	0	0	0	0	0
C7	Connected rod 1	0	0	0	1	0	0	1	0	0	0	0	0	0
C8	Case-1 (Detail)	0	1	0	0	0	0	0	0	0	0	0	0	0
C9	Sleeve-1 (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C10	Ring-1 (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C11	Disk (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C12	Ring-2 (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C13	Springs-1 (D)	1	0	0	0	0	0	0	0	0	0	0	0	0
C14	Cover (D)	0	1	0	0	0	0	0	0	0	0	0	0	0
C15	Valve (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C16	Case-2 (D)	0	1	0	0	0	0	0	0	0	0	0	0	0
C17	Flange (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C18	Ring-3 (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C19	Sleeve-2 (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C20	Screw-1 (D)	0	0	0	0	0	0	0	0	0	0	0	0	0
C21	Gasket-1(D)	0	0	0	1	0	0	0	1	0	0	0	0	1
C22	Gasket-2(D)	0	0	0	1	0	0	0	1	0	0	0	0	1
C23	Gasket-3(D)	0	0	0	1	0	0	0	1	0	0	0	0	1
C24	Gasket-4(D)	0	0	0	1	0	0	0	1	0	0	0	0	1
C25	Gasket-5(D)	0	0	0	1	0	0	0	1	0	0	0	0	1

COMPONENTS -Vector «C»
FAILURE – Vector «F»

The overall FAILURE DIAGRAM for each component in the microcryocooler



CONCLUSION

1. **Multivariate analysis in the technical systems allows**:

- To identify the factors that have the greatest impact on the efficiency indicator and on a frequent cause of failure;
- to determinate the depth and sequence of improving units and parts included in the assembly;
- to design equipment for the given operating conditions at the design stage;
- To predict of resource.

2. **Matrix «FAILURE» & «COMPONENT»** is informative because it shows the most loaded components when there is **no test data**.

3. **The combination of independent factors** that have the greatest impact on the resource **is basis for further optimization** of units and parts of the **technical system** for the specified operating conditions.

THANK YOU

QUESTION?

Natalia E. Shishova

Bauman Moscow State Technical University
nshishova@bmstu.ru

Saint-Petersburg, 19-24 April, 2021