UNIVERSITY OF NIŠ
The scientific journal **FACTA UNIVERSITATIS**
Series: **Mechanical Engineering** Vol.1, N° 6, 1999 pp. 711 - 719
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ENDURANCE TEST OF MICRO PUMPS FOR BEARINGS LUBRICATION IN THE TURBOJET ENGINES

UDC 621.176, 62-728

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Abstract. *This paper presents the procedure for an endurance test conducted on the micro pumps for bearings lubrication in turbojet engines. The endurance test was carried out on the test rig installation using a procedure for a working regime simulation of the micro pumps. Analysis and evaluation of the investigation results are performed on the basis of the mathematical statistics methods.*

Key words: *Turbojet engine, lubrication system, micro pumps, endurance test.*

1. INTRODUCTION

Endurance investigations are usually conducted in the development phase of new equipment, or when materials or production technology are changed. The preconditions and load spectra used in the investigation are defined by the designer. He prescribes a duration time of investigations, which are usually conducted up to the failure of the component (damage appearance), or accomplished through a number of equivalent cycles defined in the program investigations.

This paper presents a procedure and part of the results of an endurance test of the micro pumps for bearings lubrication in turbojet engines. Investigations were permfored under laboratory conditions using a test device for simulation working regime of the micro pumps. The test lasted 1000 hours.

2. LUBRICATION SYSTEM

The lubrication system is self-contained with the engine and comprises a pressure and scaving system. The pressure system comprises two distinct circuits: the main pressure circuit which is supplied by the main oil pump to serve the front bearing, bevel gear box

Received December 28, 1998

and the accessory drive gearbox. In addition to this a separate (metered) circuit is supplied from the main system and delivered as a measured quantity from each of two micro pumps, one to supply the rear bearing and one the centre bearing (Fig. 1). This oil is finally burned in the jet pipe.

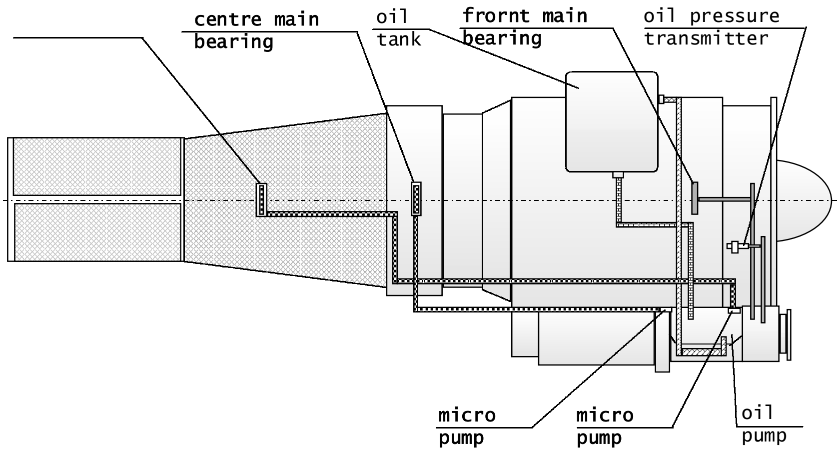


Fig. 1. Schematic representation of the oil lubrication system

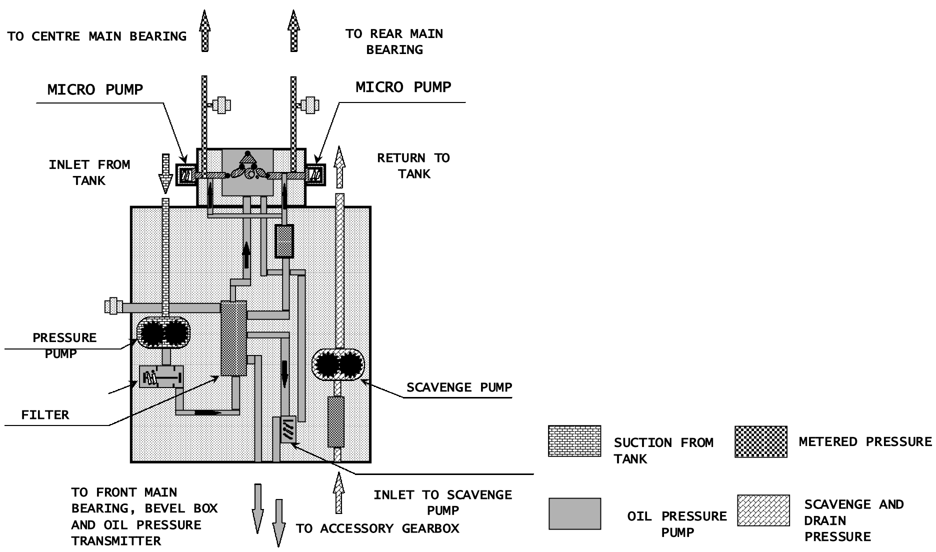


Fig. 2. Schematic view of the oil pump.

The oil pump is located on the accessory gearbox at the base of the air intake casing. The main oil pump unit (Fig. 2) comprises a separate gear type pressure and scavenge pump. A poppet type static sealing valve fitted adjacent to the pressure pump outlet, closes the pump delivery port when the engine is stationary to prevent oil seepage into the engine. A spring loaded piston type relief bypasses oil back to the pressure pump inlet to maintain the supply pressure at the required level.

Micro pumps are mounted on the oil pump cover. Essentially each pump (Fig. 3) consists of a positively driven pumping piston and spring loaded metering piston. Movement is transfered to the pumping piston by a yoke that is actuated by a cam. The metering piston located opposite each pumping piston is spring loaded and housed within a common ported cylinder and is operated by the force transmitted through the oil to uncover the delivery port.

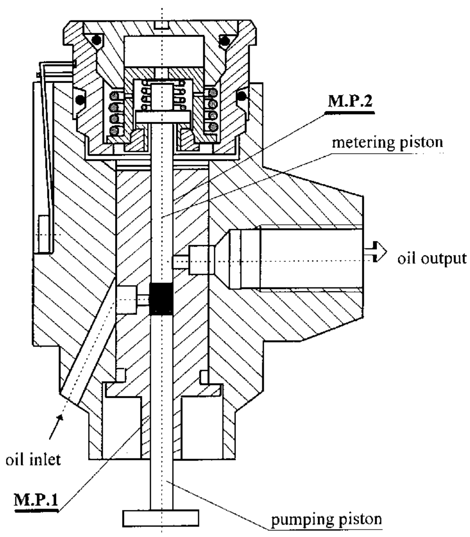


Fig. 3. Cross-section of micro pump

3. INVESTIGATION PROGRAM

The investigation program was performed on the basis of aircraft "flight profile" and contained working regime simulation of the micro pumps for three flight sortie patterns: low-low, high-low and training mission. Investigation is conducted in two phases on two arbitrarily selected micro pumps. Each phase lasted 500 hours.

During the test the value of certain parameters was adjusted: speed of the oil pump driving shaft, inlet and outlet micro pumps pressure and regime duration time for each of the mentioned missions. Total duration time testing for all three missions is presented as one cycle. Flow checking is permfored after each of 10 cycles, after first phase of 500 hours, before starting the second phase and at the end of the test (after second phase).

Special attention is paid to prevent oil leakage on the outside of the micro pumps surface during testing. Outlet pressure of 3 ± 0.5 bar of the micro pumps was achieved by closed valve (item 16 and 17 on the Fig. 4) at 2.07 bar inlet pressure and 65 ± 5^{0}C working fluid temperature.

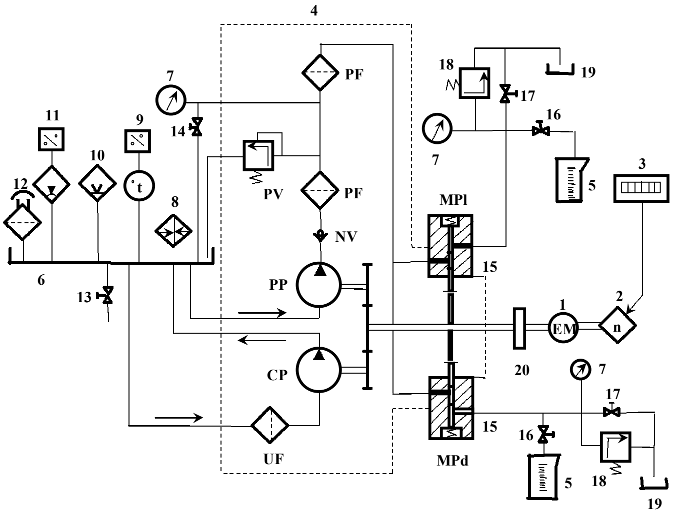


Fig. 4 - Shematic view of test device

1 – electromotor, ZIM 250 MKK , !S, type, r.p.m = 50 to 3260 min^{-1}, 2 – electromotor r.p.m gauge, 3 – digital r.p.m indicator, 4 – oil pump (PP-pressure pump, CP-scavenge pump, PV-relief valve, NV-non-return valve, UF-suction fir, PF-outlet pressure filter), 5 – gauge, V = 10 cm^3, 6 – oil supply tank, 7 – pressure gauge, 0 to 10 bar, class 1,160, 8 – heater, 2×1 kW, 9 – contact thermometer, 10 – level indicator, 11 – electric level, 12 – filler hole, 13 – draining valve, 14 – ball valve, 15 – micro pump (MPl-micro pump left, MPd-micro pump right), 16 – ball valve, 17 – adjustable valve for small flows, 18 – safety valve 744-0300, 19 – oil tank, V = 2 dm^3, 20 – multiplication gearbox, MR 2.010, i = 2, type

Dimensional checking of selected parts and subassemblies of the micro pumps after accomplished a fixed number of cycles was defined in the test procedure.

4. ENDURANCE TEST

Before beginning the investigations, a dimensional inspection of particular parts was permfored and the functional characteristics of the micro pumps was checked. The dimensional inspection consisted of disassembling and measuring characteristic dimensions of particular items and subassemblies of the micro pumps. Fig. 2 presents only two measured places (points M.P.1 and M.P.2) which are most interesting for analysis in this investigations. After accomplishing satisfactory values according to regulation on desired micro pumps quality, the endurance test started. In table 1 are given prescribed values of clearance at the points M.P.1 and M.P.2 and measured values during investigation. The functional relationship between a flow and realised clearance will not be considered in detail here.

A schematic view of the test device specially designed for this investigation, is presented in Fig. 4. For investigation synthetic engine oil MOBIL JET OIL II was used according to MIL-L-23699B. Oil temperature during investigation is controlled between 65^0C to 70^0C.

Table 1. Clearance values at the measure points M.P.1 and M.P.2

Measured points clearance	Prescribed values	Measured values (All dimensions in [mm])					
		Before beginning of investigations		After first phase of 500 hours		After second phase of 500 hours	
		Pump No1	Pump No2	Pump No1	Pump No2	Pump No1	Pump No2
M.P.1	0,002–0,005	0,004	0,004	0,004	0,004	0,005	0,005
M.P.2	0,002–0,005	0,004	0,004	0,004	0,004	0,004	0,005

The simplest measured parameter, and at the same time, the most reliable indicator of work and behaviour of the pumps during investigation was a flow. By measuring the flow, and dimensionally checking particular parts of the micro pumps at a fixed number cycles, the investigator was able to controll all the investigation process.

For practical reasons, here we shall present polygon flow distribution (Fig. 5) and parameters which defined its distribution.

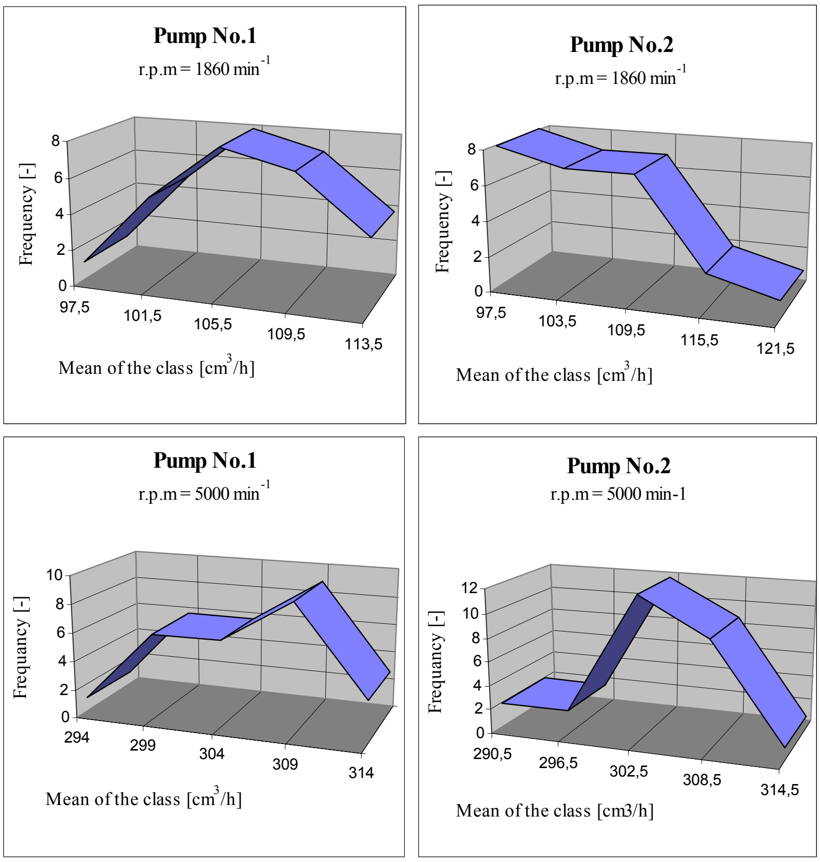


Fig. 5. Polygon of empirical flow distribution

5. MATHEMATICAL CALCULATIONS USING STATISTICAL METHOD

By using mathematical statistics method the main parameters which defined flow distribution are calculated. By well known procedure for statistical data processing measured values of the flow are classified into classes. The table 2 presents values of the delivery flow and frequencies for two characteristic speeds n = 1860 rpm and n = 5000 rpm.

Table 2.Delivery flow and frequencies

Pump No.1			Pump No.2		
Delivery flow [cm^3/h]	Mean of the class (arithmetic mean) x_i[cm^3/h]	Frequency [−]	Delivery flow [cm^3/h]	Mean of the class (arithmetic mean x_i [cm^3/h]	Frequency [−]
Driving speed n = 1860 rpm					
96 – 99	97,5	1	95 – 100	97,5	8
100 – 103	101,5	5	101 – 106	103,5	7
104 – 107	105,5	8	107 – 112	109,5	7
108 – 111	109,5	7	113 –118	115,5	2
112 – 115	113,5	4	119 – 124	121,5	1
Driving speed n = 5000 rpm					
292 – 296	294	1	288 – 293	290,5	1
297 – 301	299	6	294 – 299	296,5	2
302 – 306	304	6	300 – 305	302,5	12
307 – 311	309	9	306 – 311	308,5	9
312 – 316	314	3	312 – 317	314,5	1

To process the results statistically, let us denote with the $x_1, x_2, \cdots, x_n$, flow values noted during investigation and with $f_1, f_2, \cdots, f_n$ frequencies of its appearance. ($f_1 + f_2 + \cdots + f_n = N$ is measuring number).

From parameters representing centre distribution, we quote here the arithmetic mean, empirical dispersion and standard deviation.

The arithmetic mean $\bar{x}$ and empirical dispersion s^2can be, respectively, presented in following form:

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{n} x_i f_i$$

$$s^2 = \frac{1}{N}\sum_{i=1}^{n} f_i (x_i - \bar{x})^2$$

Positive square root from dispersion, known as standard deviation σ (for great values of N, according to law of great numbers, S is a little different from σ).

For a detailed description of flow frequency distribution are introduced according to [2,3,4] moment coefficient of skewness $\overline{K}_A$ and moment coefficient of kurtosis $\overline{K}_E$ in form:

$$\overline{K}_A = \frac{\overline{\mu}_3}{s^3}, \quad \overline{K}_E = \frac{\overline{\mu}_4}{s^4} - 3$$

where $\overline{\mu}_r = \frac{1}{N}\sum_{i=1}^{n} f_i (x_i - \bar{x})^r$, $(r = 3,4)$

are central moments of higher order (the third and the fourth order).

For comparison of dispersions of the different statistical assemblies, a coefficient of variation $\overline{K}_V$ is introduced, as relative dispersion characteristics in form:

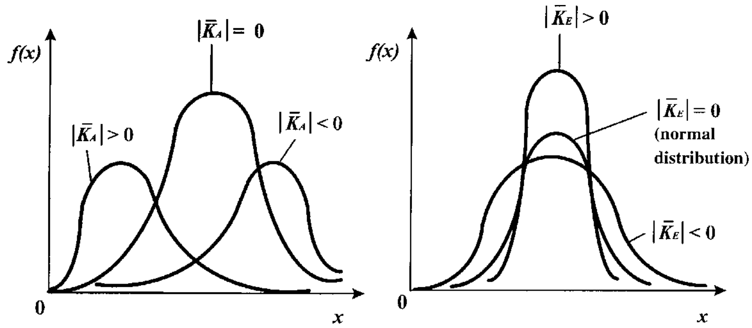
$$\overline{K}_V = \frac{s}{\overline{x}} = 100\frac{s}{\overline{x}}\%$$

Calculated parameters of dispersion centre for both investigation phases are presented in table 3.

Table 3. Parameters of centre dispersion

Parameters of centre dispersion	pump No.1		pump No.2	
	n = 1860 rpm,	n = 5000 rpm	n =1860 rpm,	n = 5000 rpm
Arithmetic mean $\overline{x}$	106,78	305,40	104,94	304,58
Empirical dispersion s^2	18,84	29,04	44,00	17,43
Standard deviation σ	4,34	5,39	6,63	4,17
Moment coefficient of skewness $\overline{K}_A$	1,42	2,00	1,49	1,52
Moment coefficient of kurtosis $\overline{K}_E$	– 0,76	– 0,87	– 0,36	– 0,24
Coefficient of variation $\overline{K}_V$	4,06	1,76	6,32	1,37

In order to better understand the investigation results, a graphical illustration of coefficients $\overline{K}_A$ and $\overline{K}_E$ is given in the Fig. 6.



Moment coefficient of skewness Moment coefficient of kurtosis

Fig. 6. Graphical illustration of coefficients K_A and K_B .

At symmetrical distribution $\overline{K}_A = 0$. If the moment coefficient of skewness is negative ($\overline{K}_A < 0$), the frequency curve is skewed to the left. If moment coefficient of skewness is positive ($\overline{K}_A > 0$), the frequency curve is skewed to the right. It is obvious, that distribution is more asymmetrical, if the absolute value of the moment coefficient of skewness is greater.

If $0 < |\overline{K}_A| < 0{,}1$, no asymmetry $0{,}1 < |\overline{K}_A| < 0{,}25$, asymmetry is small

$0{,}25 < |\overline{K}_A| < 0{,}5$, asymmetry is medium $0{,}5 < |\overline{K}_A|$, asymmetry is strong.

6. Analysis of Investigation Results

State of the parts and subassemblies was satisfactory, without visible damage trails. Only usual small wear is noticeable out moving parts as consequence of long-term pumps operations. This wear did not change the pumps' functional characteristics. Measured flow values remained within permissible boundaries during all investigation time. Clearance at the end of investigations, measured on the checking points M.P.1 and M.P.2 remained also in prescribed boundaries. At both micro pumps, there was evidently strong asymmetry of flow curve because coefficient ($|\overline{K}_A| > 0{,}5$) (see [2]).

Asymmetry at the pump No.1 is somewhat greater ($|\overline{K}_A| > 2{,}00$) than asymmetry at the pump No.2 ($|\overline{K}_A| > 1{,}52$) with speed of 5000 rpm. At both micro pumps, moment coefficient of kurtosis is negative. At pump number No.2, absolute value of the moment coefficient of kurtosis is something smaller than at pump No.1, that the curve is more near to normal (Gaussian curve) distribution ($\overline{K}_E = 0$). On the basis of coefficient of variation $\overline{K}_V$ it can be concluded that if speed is higher (n = 5000 rpm), at both pumps it is evidently greater homogeneity of flow values ($\overline{K}_V = 1{,}76$ i 1.37) than at smaller speed (n = 1860 rpm) ($\overline{K}_V = 4{,}06$ and $6{,}32$).

7. Conclusion

By using mathematical statistics methods, the main parameters which represented flow distribution during micro pumps testing can be calculated. The distribution type is most probably Erlang's as a special case of exponential distribution. Coefficients and this distribution can be permfored on the basis of further pumps investigations using presented procedure up to failure pumps appearance or on the basis of failures number during life of the pumps.

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TEST IZDRŽLJIVOSTI MIKRO PUMPI ZA PODMAZIVANJE LEŽAJEVA TURBOMLAZNIH MOTORA

Dragoljub Vujić

Rad prikazuje proceduru testa izdržljivosti sprovedenu na mikro pumpama za podmazivanje ležajeva turbomlaznog motora. Test izdžljivosti izvršen je u laboratorijskim uslovima, na ispitnom uređaju, simuliranjem režima rada mikropumpi. Analiza i ocena rezultata ispitivanja izvršena je na osnovu metoda matematičke statistike.

Ključne reči: *Turbomlazni motor, sistem za podmazivanje, mikro pumpe, test izdžljivosti.*