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DESIGN OF EXPERIMENT AND TAGUCHI METHOD APPLICATION IN ANALYSIS OF GEAR OIL PUMP FLOW CAPACITY

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ABSTRACT

Application of experiment planning mathematical model in industrial conditions testing of gear oil pump at company "Pobjeda", Tešanj is shown in this paper. This paper is supplement to experimental research of gear pump flow capacity.
The experiment was conducted on a testing engine board specially designed for gear pump performances measuring. Optimizations of construction and exploitation factors are very important factor which influences on gear pumps quality and on functional utilization of these pumps. The investigation is realized under exactly established plan with using statistical methods of results treatment with application of regression analyse. The theory of experiment design through the models of the first and second order was applied here to obtain a functional relationship between following parameters: revolution speed, pressure, oil temperature and gear normal pressure angle on the one side and flow capacity on the other side.
The application of this form gives enough precisely results in practice. This paper's goal is to show that application of design experiment is successful in solving these and similar problems. Also, the application of Taguchi method (L16 experimental plan) in industrial conditions determination of firm "Pobjeda", Tešanj is shown in this article.

1. INTRODUCTION

Oil gear pumps belong in group of rotary pumps. The main characteristics of oil gear pumps are simplicity, compactness and long life over 5000 working hours.
Necessity of exactness theoretical determination of gear pump flow capacity is limited with their wide operating range and also with constant increasing capacity. Theoretical calculation of flow capacity of gear pump with external toothing is very difficult because it include influence a lot of various factors. Also, we need detailed mathematical treatment to calculate volume of gear gap.
Determination of flow capacity of gear pump with appropriate result analysis in the aim of establishing functional relation between revolution speed, pressure, oil temperature and gear normal pressure angle, is presented. The investigation was carried out on 61319 221 type of oil gear pump. This pump is a single stage pump with following original toothing characteristics:

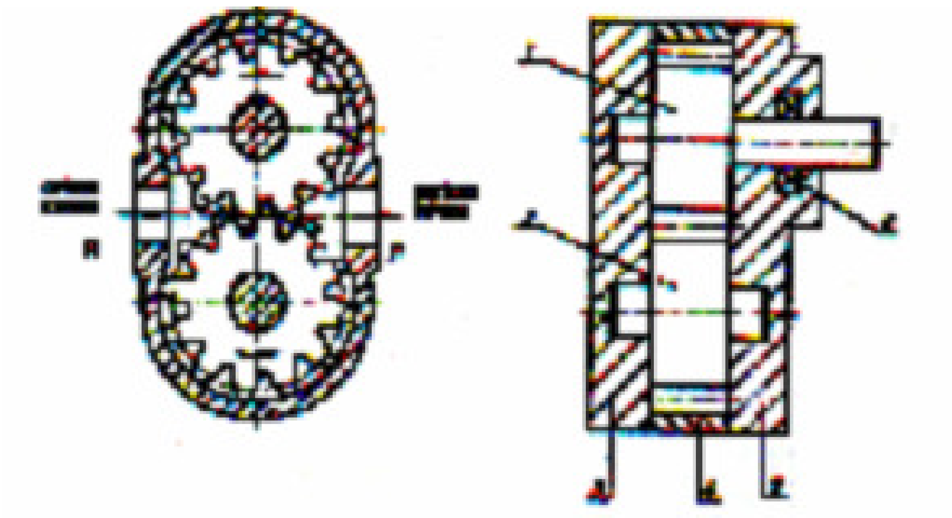

Figure 1. Section of gear pump.

• *Number of teeth*	z	8
• *Normal module*	m_n	6,5
• *Pitch diameter*	d_o	52
• *Root diameter*	d_f	$38{,}3_{-0{,}3}$
• *Base diameter*	d_b	47,128
• Tip diameter	d_e	66 h7
• Face width	b	28 h8
• Normal pressure angle	α	25º
• Centre distance	a	$52{,}75_{\pm 0{,}02}$
• Number of teeth of meshing gear	z_1	8

Also, in experiment we were used gear's with value of normal pressure angle: $\alpha_{(II)}$=27º and $\alpha_{(III)}$=29º . Theoretical value of flow capacity of oil gear pump is given by equation as follows [1]:

$$Q = \frac{2 \cdot z \cdot b \cdot A \cdot n}{2 \dfrac{\eta}{\cos\left(\dfrac{\beta}{\pi \cdot 180^{\circ}}\right)} \cdot 10^{6}} \qquad \ldots (1)$$

where is:

- *z -Number of teeth;*
- *b -face width, mm;*
- *A -cross section of gear gap, mm^2;*
- *n -revolution speed (rpm), min^{-1};*
- *η -efficiency of pump (in this case η=0,8);*
- *β -helix angle (in this case β=0), $^{\circ}$.*

Experiment was performed on a testing engine board (see figure 3) specially designed for these pumps testing with small resistance.

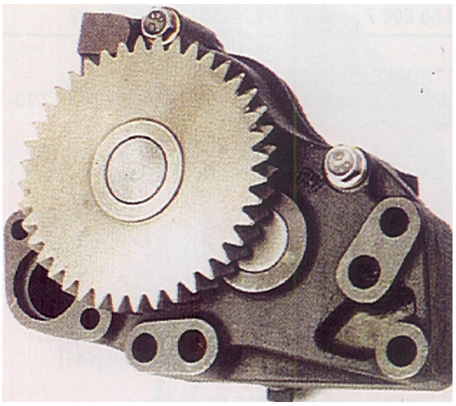

Figure 2. Oil gear pump 61319 221 type.

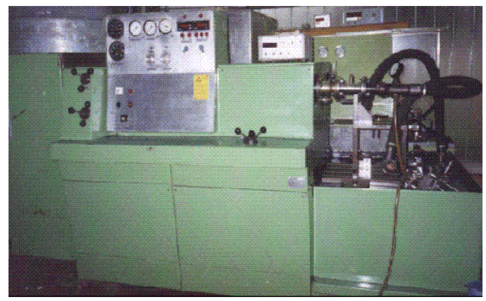

Figure 3. Test engine board for testing gear pumps.

2. EXPERIMENTAL DESIGN

Within experimental investigation of relationship (1) there have been assumed dependences of flow capacity (Q) upon oil pressure (p), rpm (n), oil temperature (t) and gear normal pressure angle (α) in the form of regression polynomial of the first order:

$$Y = b_0x_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{123}x_1x_2x_3 + b_{134}x_1x_3x_4 + b_{234}x_2x_3x_4 + b_{1234}x_1x_2x_3x_4 \quad \dots (2)$$

where:
b_0, b_1,… b_{1234}, are parameters or coefficients of regression and
x_1, x_2, x_3, x_4, are coded value of model.

In order to eliminate the influence of other factors upon the flow capacity, planned experiment is performed on oil gear pump of type 61319 221.Clearly, design (α) and exploitation (p, n, t) characteristics of gear pump will be varied experimentally by manufacturing sample gear pump 61319 221, and then the gear pump flow capacity will be examined. Testing the flow capacity will be performed on the test engine board, specially designed for these pumps performances measuring in the company "Pobjeda", Tešanj, B&H.
Characteristics of test engine board are as follows: Flow indication, from 5,6 to 200 dm^3 (maximum flow by section 400 dm^3); Pressure indication, from 0 to 2,5 MPa; Vacuum indication, from -1 to 0 MPa; Maximum power of electric motor 70 kW; Maximum pressure loss by normal flow, to 0,1 MPa; Temperature indication, from 0 to 120 °C; Revolution speed (rpm) indication, from 100 to 4000 rpm; Force moment of variable speed hydraulic governor, 0,8 Nm; Volume of oil tank, 80 dm^3.
Also, characteristics of working fluid, oil SUPER HD SL. (grade SAE 30, producer INA, Croatia), are: Specific weight, γ=0,898 kg/dm^3;Viscosity by 50 °C, ν=65 mm^2/s;Viscosity index, IV=95; Flash point by Marcusson, 200° C; Freezing point by ASTM, -20° C [2].

Table 1. Levels of model factor in natural and coded values.

FACTOR		Lower level	Basic level	Upper level	Interval of variation
pressure	*p, 10^{-1} MPa*	*2*	*4*	*6*	*2*
	x_1	*-1*	*0*	*+1*	
rpm	*n, min^{-1}*	*1000*	*1750*	*2500*	*750*
	x_2	*-1*	*0*	*+1*	
oil temperature	*t, °C*	*80*	*84*	*88*	*4*
	x_3	*-1*	*0*	*+1*	
normal pressure angle	*α, °*	*25*	*27*	*29*	*2*
	x_4	*-1*	*0*	*+1*	

In the Table 1, coded and natural values of model factor are shown, while in the same time equations of transformation are in the shape:

$$x_i = \frac{X_i - X_{oi}}{w_i} \qquad \dots (3)$$

where:
x_i, is coded value of model factor;
X_i, is natural value of model factor;
X_{oi}, is basic level of model factor, and
w_i, is interval of variation.

Table 2. Plan-matrix and results of investigation

No	x_0	x_1	x_2	x_3	x_4	$x_1 \cdot x_2$	$x_1 \cdot x_3$	$x_1 \cdot x_4$	$x_2 \cdot x_3$	$x_2 \cdot x_4$	$x_3 \cdot x_4$	$x_1 \cdot x_2 \cdot x_3$	$x_1 \cdot x_3 \cdot x_4$	$x_2 \cdot x_3 \cdot x_4$	$x_1 \cdot x_2 \cdot x_3 \cdot x_4$	$\overline{y}$	$\hat{y}$
1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	131,5	132,332
2	+1	-1	+1	+1	+1	-1	-1	-1	+1	+1	+1	-1	-1	+1	-1	133,8	134,92
3	+1	+1	-1	+1	+1	-1	+1	+1	-1	-1	+1	-1	+1	-1	-1	47,6	48,72
4	+1	-1	-1	+1	+1	+1	-1	-1	-1	-1	+1	+1	-1	-1	+1	53,7	54,532
5	+1	+1	+1	-1	+1	+1	-1	+1	-1	+1	-1	-1	-1	-1	-1	133,1	133,932
6	+1	-1	+1	-1	+1	-1	+1	-1	-1	+1	-1	+1	+1	-1	+1	135,1	136,22
7	+1	+1	-1	-1	+1	-1	-1	+1	+1	-1	-1	+1	-1	+1	+1	51,3	52,42
8	+1	-1	-1	-1	+1	+1	+1	-1	+1	-1	-1	-1	+1	+1	-1	55,5	55,994
9	+1	+1	+1	+1	-1	+1	+1	-1	+1	-1	-1	+1	-1	-1	-1	147,7	148,82
10	+1	-1	+1	+1	-1	-1	-1	+1	+1	-1	-1	-1	+1	-1	+1	150,2	151,37
11	+1	+1	-1	+1	-1	-1	+1	-1	-1	+1	-1	-1	-1	+1	+1	56,6	57,432
12	+1	-1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1	+1	+1	-1	60,3	61,42
13	+1	+1	+1	-1	-1	+1	-1	-1	-1	-1	+1	-1	+1	+1	+1	149,5	150,62
14	+1	-1	+1	-1	-1	-1	+1	+1	-1	-1	+1	+1	-1	+1	-1	151,6	152,432
15	+1	+1	-1	-1	-1	-1	-1	-1	+1	+1	+1	+1	+1	-1	-1	57,7	58,532
16	+1	-1	-1	-1	-1	+1	+1	+1	+1	+1	+1	-1	-1	-1	+1	62,3	63,42
17	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99,4	99,57
18	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102	99,57
19	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99,8	99,57
20	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98,6	99,57
21	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	105,4	99,57
22	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	103	99,57
23	+1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104,4	99,57

Multy-factor complete orthogonal first order plan $N=2^k + n_0$, with replication in central point n_0 times is used for function form Q = f (p, n, t, α).In our case (four factors), *number of replication of experiment in central point is n_0 =7. Therefore, the number of experimental points is: $N=2^k + n_0 = 2^4 + 7 = 23$. By regression analysis of data from the Table 2, regression model of first order in coded values has been obtained:*

$$\hat{Y}= 99,57-1,719\cdot x_1+42,969\cdot x_2-0,919\cdot x_3-5,894\cdot x_4+ 0,606\cdot x_1\cdot x_2-0,106\cdot x_1\cdot x_3-0,106\cdot x_1\cdot x_4+0,156\cdot x_2\cdot x_3-2,294\cdot x_2\cdot x_4-0,131\cdot x_3\cdot x_4+0,019\cdot x_1\cdot x_2\cdot x_3-0,169\cdot x_1\cdot x_3\cdot x_4+0,169\cdot x_2\cdot x_3\cdot x_4+0,181\cdot x_1\cdot x_2\cdot x_3\cdot x_4 \quad ...(4)$$

Using the transformation equations (3) and model (4) is transformed into model with natural values:

$$Q=\hat{Y}=217,004-83,094\cdot p+0,021\cdot n-2,464\cdot t-7,067\cdot \alpha+0,034\cdot p\cdot n+0,979\cdot p\cdot t+3,078\cdot p\cdot \alpha+0,001\cdot n\cdot t+0,001\cdot n\cdot \alpha +0,082\cdot t\cdot \alpha-0,0004\cdot p\cdot n\cdot t-0,001\cdot p\cdot n\cdot \alpha-0,037\cdot p\cdot t\cdot \alpha-0,000003\cdot n\cdot t\cdot \alpha+0,00002\cdot p\cdot n\cdot t\cdot \alpha \quad ...(5)$$

By disperse analysis of model (4) it has been shown that following parameters of the model $b_{0,}$ b_1, b_2, b_4 and b_{24} (b_0=99,57, b_1=-1,72, b_2=42,97, b_4=-5,89, b_{24}=-2,29) are significant, because numerical values of Student t-test (t_{b0}=333,46, t_{b1}=4,01, t_{b2}=100,11, t_{b3}=2,14, t_{b4}=13,73, t_{b24}=5,34) greater than table value or critical value t_t= 2,447 for α=0,05 and ν=6 degrees of freedom. Checking of model (4) adequacy has showed that model is adequate, because numerical value of Fishers test F_r=0,921 is smaller the table or critical ones F_t=4,00 for the α=0,05 and ν_1=12 and ν_2=6 degrees of freedom.

Accordingly, final first order polynom for proper describing dependence of flow capacity of examined oil gear pump upon significant factors of model is:

$$\hat{Y}=99,57-1,719\cdot x_1+42,969\cdot x_2-5,894\cdot x_4-2,294\cdot x_2\cdot x_4 \quad ...(6)$$

or, applying transformation equation (3), in natural values:

$$Q=214,004-83,094\cdot p+0,021\cdot n-7,067\cdot \alpha+0,001\cdot n\cdot \alpha \quad ... (7)$$

3. ANALYSIS OF THE EXPERIMENTAL RESULTS

- Flow capacity phenomena can be adequately presented by application of experiment design;
- Significance analysis of model (6) was shown that factors as follows: x_1 (pressure), x_2 (rpm) and x_4 (normal pressure angle) are significant. Also, this analysis was shown that only factor x_3 (oil temperature) are not significant and doesn't have any significantly influence to flow capacity value in this case;
- Adequacy analysis was shown that model (6) correctly describe researched process, and coefficient of correlation has a very high value R=0,99;
- Comparation between theoretical and model value of flow capacity are presented on figure 4. From this figure, you can see that the main influence on flow capacity has rpm value;
- Optimization of dependence between flow capacity on the one hand, and rpm, pressure, and normal pressure angle on the other hand, is presented on the figure's 5 and 6;
- The importance of this experiment is in the fact that it shows how on the fast and

simple way, with the use of the methods of the experimental design, the expressions which describe more complex processes can be obtained with the sufficient precision.

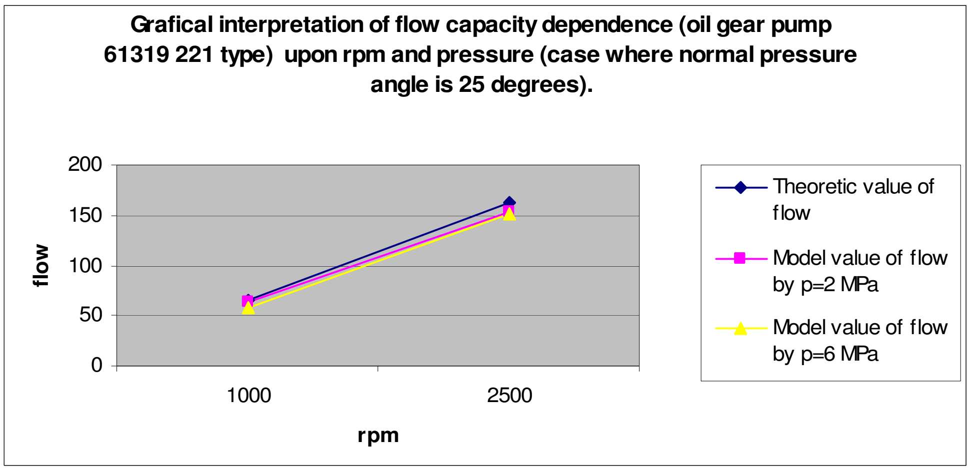

Figure 4. Grafical interpretation of flow capacity dependence of gear oil pump 61319 221 type.

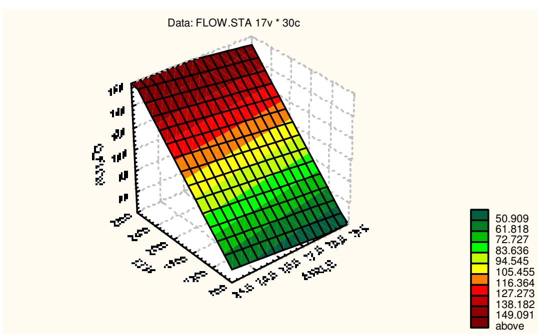

Figure 5. Influence optimization of rpm and normal pressure angle (α) on flow capacity.

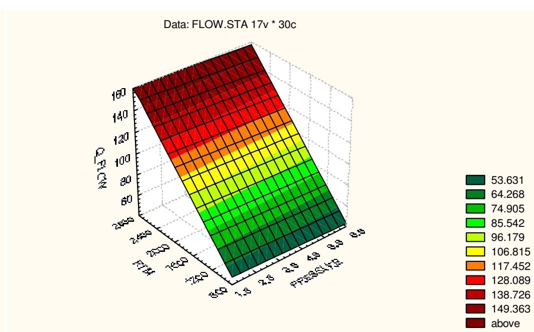

Figure 6. Influence optimization of rpm and pressure on flow capacity.

4. APPLICATION OF TAGUCHI METHOD

The Taguchi method is based on statistical design of experiments and is applied at the parameter design stage to establish optimum process settings or design parameters.
The basic concept of the Taguchi Method through application example in order to determine flow capacity of gear oil pump is presented in this article. This article is supplement to experimental research of gear pump flow capacity. Combination of working pressure, revolution per speed, working oil temperature, normal pressure angle as design characteristic of gear pump and type of oil has essential influence on achievement of flow capacity as output characteristic of gear oil pump. All above five factors were used for the experiment.

The experiment was carried out using a standard Taguchi's experimental plan with denotation L16 (2^{15}). The S/N calculations are based on larger the better S/N ratio. The experiment was conducted on a testing board specially designed for gear pump performances measuring. Application of Taguchi method in industrial conditions determination of flow capacity of gear oil pump in company "Pobjeda", Tešanj is shown in this article. Obtained test results are of practical importance, especially in the field of gear pumps design.

The experimental plan has two levels. There are 13 degrees of freedom regarding the number of levels of control factors and number of desired interactions between control factors. The experiment was performed according to Taguchi experimental plan with designation L_{16} (2^{15}). An orthogonal array with arranged control factors and their interaction to columns is presented in table 2. Where designations 1 and 2 mean 1st and 2nd level of each control level. According to that we have made 16 experimental runs at control factors' level like it is determined by the orthogonal array.

Table 3. The levels of the factors.

Factor	Designation	1st level	2nd level	Degrees of freedom
pressure, p [10^{-1} MPa]	A	2	6	1
rpm, n [min^{-1}]	B	1000	2500	1
oil temperature, t [$^{\circ}$C]	C	80	88	1
normal pressure angle, α [°]	D	25	29	1
oil type (producer of oil)	E	INA	Castrol	1

The Larger-the-Better approach of Taguchi method has been used for analysis of experimental results. The Signal-to-Noise (S/N) ratio is calculated according to the equation:

$$\eta = S/N = -10\log_{10}(\sum_{i=1}^{n} y_i^2) \qquad \text{… (8)}$$

Each measurement of flow capacity has been repeated three times, as can be seen from table 3.

Table 4. Plan of an experiment and results based on L15 experimental plan.

No	C	E	CxE	B	CxB	BxE	AxD	A	AxC	AxE	BxD	A x B	DxE	CxD	D	Measured flow capacity, Q[dm^3]			S/N
i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Q_1	Q_2	Q_3	η_i
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	62,4	62,3	62,4	45,44148
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	51,3	51,3	51,1	43,73349
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	135,2	135,1	135,2	52,15982
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1	149,6	149,7	149,6	53,04299
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	55,4	55,6	55,6	44,43351
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1	57,7	57,8	57,8	44,77597
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1	151,6	151,6	151,6	53,15641
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2	133,2	133,2	133,3	52,03468
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	53,7	53,6	53,8	44,14192
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	56,4	56,6	56,6	44,58853
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1	150,3	150,3	150,3	53,08160
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2	131,7	131,5	131,4	51,92315
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1	60,4	60,4	60,3	45,15837
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2	47,5	47,5	47,6	43,08239
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2	133,6	133,7	133,8	52,06505
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1	147,8	147,8	147,7	52,93396

Control factors and their interactions are sorted in relation to the difference values. The all control factors and their interactions are shown in table 4. We can see that the strongest influence is exerted by control factors B (rpm), D (normal pressure angle) and interaction AxB. All other control factors and interactions have a weak influence on the S/N ratio of the considered flow capacity.

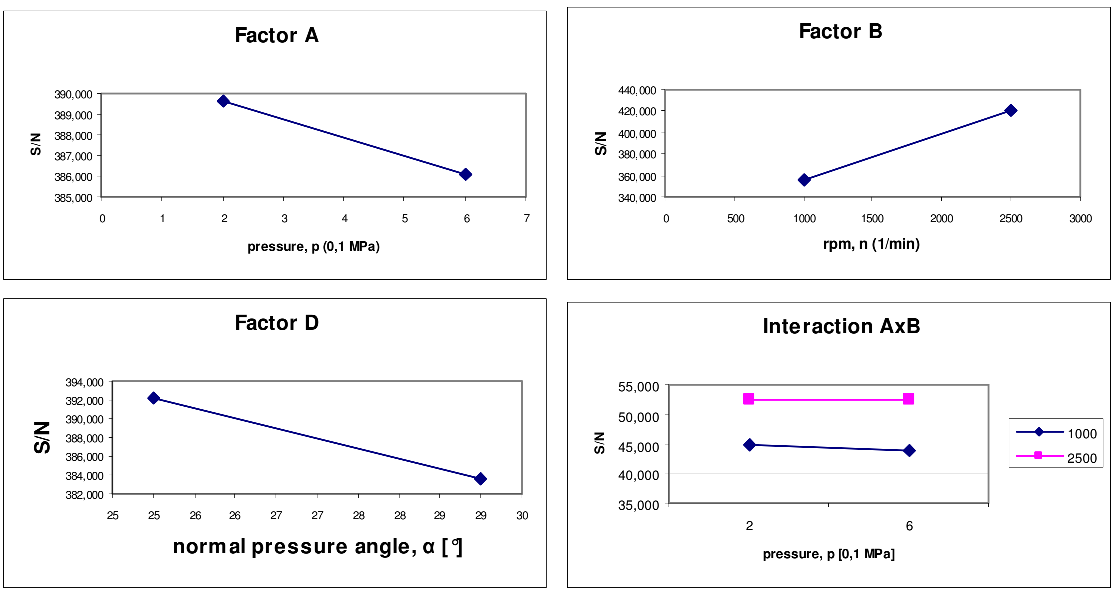

Figure 7 Signal-to-Noise Ratio response graphs for significant control parameters and their interactions.

Table 5. Signal-to-Noise ratio response table.

	C	E	CxE	B	CxB	BxE	AxD	A	AxC	AxE	BxD	AxB	DxE	CxD	***D***
L1	388,778	388,113	387,618	355,356	388,388	388,096	387,612	389,638	387,719	387,652	388,147	389,110	387,770	387,629	***392,179***
L2	386,975	387,640	388,136	420,398	387,365	387,658	388,142	386,115	388,034	388,102	387,606	386,643	387,983	388,124	***383,574***
Delta	1,803	0,473	0,518	65,042	1,023	0,438	0,530	3,523	0,315	0,450	0,541	2,467	0,213	0,495	***8, 605***

According to the table 5, we can determine which control factors and their interactions have a very strong influence on the flow capacity of the oil gear pump. Optimal input working conditions of these control factors can be very easily determined from S/N response graphs in figure 7. The best flow capacity value is at the higher S/N values in the mentioned response graphs. Expected value of S/N ratio was calculated by following expression:

$$\eta = \overline{Q} + (\overline{B_2} - \overline{Q}) + (\overline{D_1} - \overline{Q}) + |(\overline{A_1 B_2} - \overline{Q}) - (\overline{A_1} - \overline{Q}) - (\overline{B_2} - \overline{Q})| \qquad ...(9)$$

$$\eta = \overline{A_1}\,\overline{B_2} + \overline{D_1} - \overline{A_1} = 55{,}18 \qquad ...(10)$$

The η value derived from expression (9) was used to calculate flow capacity Q according to expression:

$$\eta = 10^{\frac{\eta}{20}} = 10^{\frac{55,18}{20}} = 579,78 \text{ dm}^3/\text{h} \qquad \ldots (11)$$

The calculated flow capacity is 579,8 dm^3/h, this value is very close to the value calculated by expression (1) Q=583,15 dm^3/h. The analysis of variance ANOVA of S/N ratios is shown in figure 8.

Figure 8. Analysis of variance using QI Macros.

Anova	Factor and Interactions	df	SS	MS	F	Effect	Contrast
C	oil temperature, t [°C]	1	86	86	-0.03	-1.8875	-45
E	oil type (producer)	1	3	3	-0.001	-0.370833	-9
CE	oil temperature x oil type	1	2	2	-8E-04	0.304167	7
B	rpm, n [min-1]	1	177452	177452	-62.49	85.9875	2064
CB	oil temperature x rpm	1	2	2	-8E-04	-0.304167	-7
BE	rpm x oil type	1	2	2	-7E-04	-0.2875	-7
AD	pressure x normal pressure angle	1	1	1	-4E-04	0.204167	5
A	pressure, p [10-1 MPa]	1	284	284	-0.1	-3.4375	-83
AC	pressure x oil temperature	1	1	1	-6E-04	0.2375	6
AE	pressure x oil type	1	2	2	-7E-04	0.2875	7
BD	rpm x normal pressure angle	1	503	503	-0.177	4.579167	110
AB	pressure x rpm	1	40	40	-0.014	-1.2875	-31
DE	normal pressure angle x oil type	1	0	0	-1E-05	0.0375	1
CD	oil temperature x normal pressure angle	1	2	2	-7E-04	0.2875	7
D	normal pressure angle, α [°]	1	3363	3363	-1.184	-11.8375	-284
	Error	32	-90872	-2840			
	Total	47	90872				

5. CONCLUSION

Based on presented experimental research and results analysis, following can be concluded:

- Systematically, by applying theory of experimental design, dependence of oil gear pump flow capacity value upon the revolution speed, pressure, oil temperature and gear normal pressure angle, has been investigated;

- Experimental investigation has been performed on a testing engine board specially designed for these pumps performances measuring in industrial conditions at company "Pobjeda", Tesanj, Bosnia and Herzegovina;

- For the purpose of reliable predicting the flow capacity value of mentioned oil gear pump can be used experimentally obtained polynomial dependence of the first order:

$$Q = \hat{y} = 217,004 - 83,094 \cdot p + 0,21 \cdot n - 7,067 \cdot \alpha + 0,001 \cdot n \cdot \alpha$$

- Theoretical value of flow capacity of oil gear pump is given by one of following equations [3], [4], [5], [6], [7], [8], [9], [10] :

$$Q_t = 2\pi b n m^2 (z+1) 10^{-6} \qquad \ldots (12)$$

$Q_t=2\pi bnm^2(z+2k_1+0,276)10^{-6}$ ...(13)
$Q_t=6,5bnm^2z10^{-6}$ ...(14)
$Q_t=7bndm10^{-6}$ ...(15)
$Q_t=\pi bna(d_k-a)10^{-6}$ ...(16)
$Q_t=(\pi/4)\ bn(d_k^2-d_f^2)10^{-6}$ ...(17)
$Q_t=0,785\ bn(d_k^2-d_f^2)10^{-6}$ ...(18)
$Q_t=\pi bnd_oh10^{-6}$ ...(19)
$Q_t=0,875\ bn(d_k^2-d_f^2)10^{-6}$ ...(20)
$Q_t=(31,4/60)bn(d_k^2-d_f^2)10^{-6}$ ...(21)
$Q_t=(47/60)bn(d_k^2-d_f^2)(1/\cos\beta_o)10^{-6}$ ...(22)
$Q_t=(\pi/2)bn[d_k^2-a^2-(d_b^2\pi^2/3z^2)]10^{-6}$ ...(23)
$Q_t=2A_zbnz10^{-6}$ ...(24)
$Q_t=2A_mbnz10^{-6}$ ...(25)
$Q_t=2\pi bn[r_k^2-r_o^2-k(t_0/12)]10^{-6}$ ...(26)
$Q_t=2\pi bnm^2[z+1-(\pi^2\cos^2\alpha)/12]10^{-6}$ ...(27)
$Q_t=2\pi bn[m^2(z+1)-(l^2/12)]\ 10^{-6}$ ...(28)
$Q_t=2\pi bn[[r_k^2-r^2-m^2\cos^2\alpha]\ 10^{-6}$ ...(29)

Deviation limits between mentioned equations and obtained equation of the first order are as follows: -4% and +7%;

- Based on performed experiment, can be concluded most influence factors on flow capacity of gear oil pump are as follows:

-design of gear, housing of pump and cover of pump;
-radial and axial clearance;
-type and temperature of fluid and
-gear tooth profile.

- The experiment has been performed on oil gear pump of type 61319 221, and because of that, stated conclusions can not be applied for the other types of these pumps, but the same methodology of design experiment can be used for other types of these pumps.

- In this article, the way of optimisation of input working characteristics in order to determine of flow capacity of oil gear pump, using the Larger-the-Better Taguchi method approach, is shown. Using the Taguchi method, the flow capacity of gear oil pump was optimised. An L16 orthogonal array was used to accommodate the experiments. Analysis of the result of experiment obtained information regarding the most influencing factors on flow capacity. The results revealed that the rpm, the normal pressure angle, and the interaction between rpm and pressure could significantly affect the flow capacity. By consideration of technical effects, the optimal levels were chosen to be A1, B2, C1, D1 and E1, corresponding to pressure of 0,2 MPa, rpm of 2500 min^{-1}, oil temperature of 80°C, normal pressure angle of 25° and oil type of INA producer.

Finally, it can be concluded that according to the experimental results, Taguchi method approach used for determination of flow capacity of oil gear pump, makes possible to obtain good quality of pump output characteristic, which is very close to the value calculated by theoretical expression (1). Finally, it can be concluded that according to the experimental results, Taguchi method approach used for determination of flow capacity of oil gear pump, makes possible to obtain good quality of pump output characteristic, which is very close to the value calculated by theoretical expression (1).

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