

**APPLICATION OF METHODS OF EXPERIMENT PLANNING THEORY
FOR ASSESSING THE ECONOMY OF A PNEUMO-ENGINE**

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The relevance of the work is to optimize the workflow of a pneumatic engine by conducting a full factorial experiment (FFE).

The impact of independent parameters (valve opening-closing angles) on its indicator air consumption was evaluated.

The purpose of the work is to conduct a full factorial experiment (FFE). Tasks: on the basis analysis of the literature, taking into account various factors to choose the experiment plan to construct graphical dependences of the factors influence (intake valves opening - closing angles) on the specific effective compressed air consumption in the pneumatic engine and determine their influence on the indicator air consumption.

The research object is the workflow of a piston pneumatic engine with valve air distribution.

The research subject is the workflow patterns and parameters of the car combined power plant pneumatic engine with valve air distribution.

This work using the central composite rotatable plan of a different order, offers Box and Behnken [1].

Previously, to reduce the number of experiments using the Placketts method and Burman [2] screening of insignificant factors was carried out. The factors varied on three levels.

Each of the experiments was conducted strictly for the combination of selected variables X_1, X_2, X_3, X_4 , factors given by the plan at three levels $(-1, 0, +1)$:

$$y=f(X_1, X_2, X_3, X_4) \quad (1)$$

where:

- X₁ - intake valve opening moment (-10, 0, 10);
- X₂ - intake valve closing moment (160, 170, 180);
- X₃ - exhaust valve opening moment (170, 180, 190);
- X₄ - exhaust valve closing moment (260, 270, 280).

When setting up an experiment to study the mutual influence of three factors, 18 experiments will be required. At the same time, except there will be even ones taken into account and everything and other types of correlations. Exit function of this FFE has probability minimization of compressed air effective consumption, which takes into account its quality change in the pneumatic engine workflow [3].

The main requirement for the model is the ability to predict the direction of further research and to predict with the necessary accuracy. In this, the experiment itself can be carried out both in a real object and with its mathematical models [4,5,6]. In the theory of experiment planning, requirements and conditions are formulated that must be taken into account when choosing dependent variables (feedback, outputs, objective functions) and independent variables. Dependable variable must be single, unambiguous, have a clear physical meaning, and be characterized by a number. Thus, it is necessary with the help of an experiment, which will be carried out with incomplete knowledge or unknown mechanisms phenomenon, build mathematical model, which is specific air consumption g_i defined by expression (2), with all the variables (factors) on which it depends.

According to the chosen plan, it was done, in randomized 18 studies. Each experience was repeated 3 times, for this a simulation mathematical model of the pneumatic engine operation was used, taking into account the constancy of the compressed air quality parameters, implemented in the MATLAB software product.

The mathematical model after the implementation of FFE experiments looks like this:

$$y = b_0 + b_1 x_1^2 + b_2 x_2^2 + b_3 x_3^2 + b_4 x_4^2 + b_{11} x_1 - b_{22} x_2 - b_{33} x_3 - b_{44} x_4 + b_{12} x_1 x_2 - b_{14} x_1 x_3 - b_{14} x_1 x_4 + b_{23} x_2 x_3 + b_{24} x_2 x_4 - b_{34} x_3 x_4 \quad (2)$$

where y is a output function; x_i, x_j, \dots, x_n – driving factors ; b_i, b_j, \dots, b_n - regressions coefficients.

To calculate the coefficients of this model, an extended matrix of planning and experimental results was built (Table 1).

Studying the obtained polynomial model (3), it is possible, on the basis of some mathematical assessment criteria, to fairly clearly judge their adequacy or inadequacy to its processes that are actually occurring.

Table 1 – Expanded matrix of 18 studies plan and results

Series tests	Factors				air cons. g_i , kg/(kW·h)		
	φ_{in_o}	φ_{in_cl}	φ_{ex_o}	φ_{ex_cl}	Repeated tests		Average value
	x_1	x_2	x_3	x_4	1	2	\bar{g}_{icp}
1	0	0	0	0	41.09	41.46	41.83
2	-1	-1	-1	-1	98.30	99.01	99.72
3	-1	+1	+1	+1	58.58	58.63	58.68
4	+1	-1	+1	+1	57.87	57.32	56.77
5	+1	+1	-1	+1	122.53	121.86	121.19
6	+1	+1	+1	-1	142.58	142.37	142.16
7	0	+1	-1	-1	72.76	71.88	71.00
8	0	-1	+1	-1	83.33	82.85	82.37
9	0	-1	-1	+1	64.59	63.30	62.01
10	+1	0	-1	-1	120.54	120.50	120.46
11	-1	0	+1	-1	72.43	71.11	69.79
12	-1	0	-1	+1	50.85	51.08	51.31
13	+1	-1	0	-1	101.98	101.85	101.72
14	-1	+1	0	-1	40.68	41.48	42.28
15	-1	-1	0	+1	104.16	103.99	103.82
16	+1	-1	-1	0	95.60	94.77	93.94
17	-1	+1	-1	0	34.36	33.92	33.48
18	-1	-1	+1	0	117.11	116.46	115.81

Such a model allows us to talk about the influence of individual factors on the system, as well as their mutual influence. The regression coefficients were calculated according to the following formula:

$$b_0 = \frac{1}{n} \sum_{j=1}^n \bar{y}_j; \quad b_i = \frac{1}{n} \sum_{j=1}^n x_{ji} \bar{y}_j. \quad (3)$$

As a result of the implementation of the three-level four-factor model of FFE and definition statistical significance all of 15 coefficients, the regression equation (4) became next form:

$$y = 9399,8871 + 0,26 + 0,18 + 0,057 + 0,03 + 2,6014x_1 - 62,9937x_2 - 19,9586x_3 - 15,9027x_4 + 0,2512x_1x_2 - 0,1x_1x_3 - 0,1x_1x_4 + 0,0044x_2x_3 + 0,002x_2x_4 - 0,0048x_3x_4 \quad (4)$$

Audit reproducibility experiment was conducted using Cochran's criterion, and the degree significance coefficients determined by Student's criterion on the basis of parallel experiments, showed significance everyone coefficients received equation.

At the same time adequacy hypothesis mathematical model by criterion Fisher's is not contradicted by Eq 5% significance.

We gave and obtained graphical dependences of the influence of varying factors on the compressed air specific effective consumption (Fig. 1).

Figure 1 presents the pneumatic engine characteristics of the specific indicator consumption as a function of the intake and exhaust valves opening-closing angles.

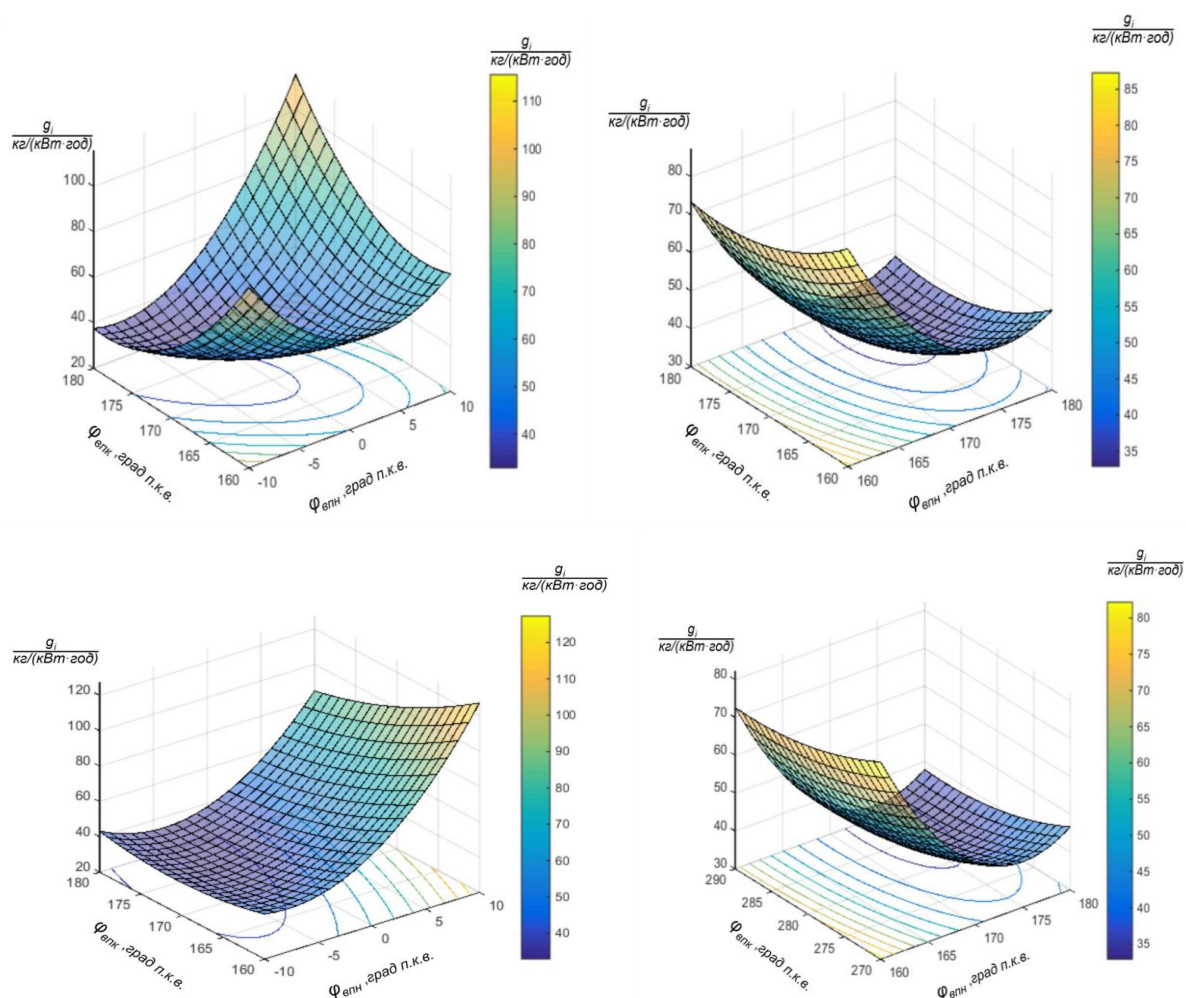


Figure 1 – Graphic dependencies impact factors (intake and exhaust valves opening-closing angles) of the pneumatic engine compressed air specific effective consumption.

Conclusions

The goal of the work was fulfilled, a full factorial experiment (FFE) was carried out. On the basis of the literature analysis, taking into account the variable factors, the task of the work is defined - the choice of the plan for conducting the experiment is carried out. Graphical dependences of the factors influence (valves opening - closing angles) of the pneumatic engine compressed air specific effective consumption were constructed and their influence on the indicator air flow rate was determined.

With given above dependences can be seen that compressed air specific effective consumption g_i is growing from increasing the closing of the intake valve (X_2) and increasing the closing of the exhaust valve (X_4). Increasing or decreasing the

opening angles of the intake (X_1) and exhaust (X_3) valves and the closing of the exhaust valve also leads to an increasing the pneumatic engine compressed air specific effective consumption.

Multifactorial optimization of pneumatic engine operation was carried out $D/S = 9.2/9.2$. As a result of the analysis of the calculations, the optimal parameters kW and kg/h were obtained.

Thus, to reduce pneumatic engine compressed air specific consumption as a whole possible development measures of a constructive nature aimed at modernization systems air supply by application of electrohydraulic valves drive.

Literature

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