

# IMPACT OF TECHNOLOGICAL OPERATIONS PARAMETERS ON MOEMS COMPONENTS FORMATION

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**Abstract** — In the paper the modeling results for the process of MOEMS functional surfaces shaping are presented. The significance and magnitude of factors that directly affect the shaping process of MOEMS functional surfaces were determined.

**Keywords** — component, MOEMS, shaping, optical switcher, micro mirror, grinding, polishing.

## I. INTRODUCTION

One of the many MEMS types is Micro Optical Electro Mechanical Systems (MOEMS). These are microchips with optical components integrated into their bodies. The ability to perform complex operations with the light beam (reflection, diffraction, modulation, spatial orientation) occurs due to the use of miniature optical elements and is one of the main advantages of MOEMS.

The fiber optical transmission systems performance properties depend on the quality of the components used. The required parameters can be guaranteed only with strict adherence to the technological process of their production, the use of high-precision quality control equipment and the use of effective data processing [1, 2].

One of the most important operations in the production process of reflecting MOEMS components is the shaping operation. Finishing operations in such a technological process are grinding and polishing of reflective surface.

This research work is devoted to the study of the parameters and factors that directly affect the functional reflective components shaping during the finishing operations. The value of the reflecting element surface roughness is the main shaping factor.

## II. FACTORIAL EXPERIMENT

### A. Factorial experiment planning

To simulate the influence of the finishing technological operations modes on the parameters of the MOEMS components formation, we use a full factor experiment. To conduct the experiment, it is necessary to perform the next:

- to obtain and analyze of a priori information;
- to select the input and output variables;
- to choose the mathematical model by which the experimental data will be presented develop;
- to determine the method of data analysis;
- to conduct an experiment;

– to check the statistical preconditions for the received experimental data;

– to process the results and interpret them, and to develop the recommendations of choosing the parameters values [3] for getting the planned parameters values of the finishing operations in the MOEMS component forming.

We will conduct a full factorial experiment in order to provide control over the shaping technological processes for the silicon substrates of reflection elements at polishing and grinding by various types of diamond grinding pastes (ACM 2/1, ACM1 4/10, ACM 0/28).

### B. Factors and their variation intervals selection

As is known [4-9], the most significant input factors of the finishing technological operations of shaping, which meet all the requirements of the factorial experiment, are the sample processing time –  $t$  (s), the lap rotation speed –  $v$  (rpm) and the graininess of the paste for polishing and grinding –  $z$  ( $\mu\text{m}$ ).

The pressure of the polishing tool on the sample is taken unchanged during the experiment.

We define the limits of factors variation: the maximum processing time of the material within  $t_{max} = 20$  minutes, and the minimum  $t_{min} = 10$  minutes, the lap rotational speed –  $v_{max} = 40$  rpm,  $v_{min} = 30$  rpm, the graininess of the paste –  $z_{max} = 32$  microns,  $z_{min} = 2$  microns. Variations of factors are listed in Table 1.

TABLE I. VARIATION CHANGES BORDERS AND DESIGNATION OF FACTORS

Factors	Processing time $t$ [min]	Rotation speed of a lap $v$ [rpm]	The graininess of diamond paste $z$ [ $\mu\text{m}$ ]	Roughness $Ra$ [ $\mu\text{m}$ ]
Value of factorial experiment	$x1$	$x2$	$x3$	$y$
Upper bound of values (1)	20	40	32	–
Basic level of value (0)	15	35	17	–
Lower bound of values (-1)	10	30	2	–

The planning of an experiment is preceded by the stage of determining the center of experiment and the intervals of factors variation. At the same time, ranges borders of factors definition are established by technical restrictions [3].

Based on the research [8-18] the factors that influent on resulting value of the material roughness  $Y$  ( $\mu m$ ) were chosen [3].

The general factors dependence is represented as (1):

$$Y = f(t, v, z) \tag{1}$$

where  $t, v$  and  $z$  are factors affecting on the magnitude  $Y$ .

The matrix of a full factorial experiment was constructed, and the results are presented in Table 2.

TABLE II. THE FULL FACTORIAL EXPERIMENT RESULTS

$N\bar{b}$	$t$	$v$	$h$	$x_1$	$x_2$	$x_3$	$x_1 \cdot x_2$	$x_1 \cdot x_3$	$x_2 \cdot x_3$	$x_1 \cdot x_2 \cdot x_3$	$x_{11} = x_1^2 - d$	$x_{22} = x_2^2 - d$	$x_{33} = x_3^2 - d$	$y$
1	20	40	32	1	1	1	1	1	1	1	0.2697	0.2697	0.2697	44.1
2	10	40	32	-1	1	1	-1	-1	1	-1	0.2697	0.2697	0.2697	20.6
3	20	30	32	1	-1	1	-1	1	-1	-1	0.2697	0.2697	0.2697	35.7
4	10	30	32	-1	-1	1	1	-1	-1	1	0.2697	0.2697	0.2697	17.9
5	20	40	2	1	1	-1	1	-1	-1	-1	0.2697	0.2697	0.2697	12.2
6	10	40	2	-1	1	-1	-1	1	-1	1	0.2697	0.2697	0.2697	5.8
7	20	30	2	1	-1	-1	-1	-1	1	1	0.2697	0.2697	0.2697	9.7
8	10	30	2	-1	-1	-1	1	1	1	-1	0.2697	0.2697	0.2697	4.5
9	24.308	35	17	1.2154	0	0	0	0	0	0	0.7469	-0.7303	-0.7303	28.4
10	7.846	35	17	-1.2154	0	0	0	0	0	0	0.7469	-0.7303	-0.7303	8.1
11	15	48.616	17	0	1.2154	0	0	0	0	0	-0.7303	0.7469	-0.7303	30.2
12	15	23.538	17	0	-1.2154	0	0	0	0	0	-0.7303	0.7469	-0.7303	14.7
13	15	35	38.8928	0	0	1.2154	0	0	0	0	-0.7303	-0.7303	0.7469	46.6
14	15	35	1.5692	0	0	-1.2154	0	0	0	0	-0.7303	-0.7303	0.7469	3.8
15	15	35	17	0	0	0	0	0	0	0	-0.7303	-0.7303	-0.7303	22.6

Since the true type of the basic function (2) is unknown, we will use the equation to describe the response surface, which is the decomposition of this function in a row [3]:

$$y = b_0 + \sum_{i=1}^n b_i x_i + \sum_{ij=1}^n b_{ij} x_i x_j + \sum_{i=1}^n b_{ii} x_i^2, \tag{2}$$

where  $x_i, x_j$  are variable factors at  $i = 1 \dots n, j = 1 \dots n, i \neq j$ ;  $b_0, b_i, b_{ij}$  are regression coefficients with corresponding variables whose values determine the response surface form.

Numerical values of regression coefficients are calculated and represented in Table 3.

The verification of the statistical significance of the regression equation parameters (regression coefficients) was performed according to the Student's  $t$ -criterion [3].

Numerical values of the regression equation coefficients dispersion are calculated and listed in the Table 3.

The regression equation (3) has the form:

$$y(x_1, x_2, x_3) = 20.33 - 5.17x_1 + 2.25x_2 + 9.21x_3 + 1.98x_3. \tag{3}$$

The statistical significance of the model using the F-criterion was tested.

The coded calculation values in accordance with the obtained regression equation were found.

The results of the encoded calculated experimental values of the function response are listed in the Table 4.

TABLE III. CALCULATION VALUES OF THE REGRESSION COEFFICIENTS

Regression coefficients	Estimated result				
	Numerical value	$S^2_{bi}$	$t_{bi}$	Tabular Value of Student's coefficient	Significance validation
$b_0$	20.33	0.418	31.456	1.886	Significance
$b_1$	5.17	0.572	6.839	1.886	Significance
$b_2$	2.25	0.572	2.975	1.886	Significance
$b_3$	9.21	0.572	12.177	1.886	Significance
$b_{12}$	0.46	0.783	0.520	1.886	Not
$b_{13}$	1.98	0.783	2.238	1.886	Significance
$b_{23}$	0.49	0.783	0.550	1.886	Not
$b_{123}$	0.30	0.783	0.339	1.886	Not
$b_{11}$	-1.22	1.435	1.016	1.886	Not
$b_{22}$	-0.39	1.435	0.325	1.886	Not
$b_{33}$	0.15	1.435	0.127	1.886	Not

TABLE IV. ENCODED CALCULATED EXPERIMENTAL VALUES OF THE FUNCTION RESPONSE

N	$Y_u, [\mu\text{m}]$	$Y_u, [\mu\text{m}]$
1	44.1	38.9
2	20.6	24.6
3	35.7	34.4
4	17.9	20.1
5	12.2	16.6
6	5.8	10.2
7	9.7	12.1
8	4.5	5.7
9	28.4	36.6
10	8.1	14
11	30.2	23.1
12	14.7	17.6
13	46.6	31.5
14	3.8	9.1
15	22.6	20.3

### III. DETERMINATION OF THE FACTORS EFFECT ON MOEMS COMPONENTS FORMATION

To get the response surface, each of the three factors was fixed to zero level:  $t=15 \text{ min}$ ,  $v = 35 \text{ rpm}$ ,  $z = 17 \mu\text{m}$ .

The regression equations were decoded and three equations with two factors, substituting these values, were obtained [3].

To decode the Eq. 4-6 we replaced  $x_i$  with the natural values:

$$x_1 = \frac{t-15}{5} = 0.2t - 3. \quad (4)$$

$$x_2 = \frac{v-35}{5} = 0.2v - 7. \quad (5)$$

$$x_3 = \frac{z-17}{15} = 0.057z - 1.13. \quad (6)$$

Performing Eq. 3 decoding, we obtain the next model:

$$y(t, v, h) = 20.33 + 5.17(0.2t - 3) + 2.25(0.2v - 7) + 9.21(0.057z - 1.13) + 1.98(0.2 - 3)(0.005z - 1.13). \quad (7)$$

After performing the transformations and shortening, we obtain the Eq. 8-11:

$$y(t, v, h) = 0.58652 \cdot 15 + 0.45v + 0.1635z + 0.0198tz - 14.6251 \quad (8)$$

$$y_{t=15}(v, z) = 0.45 \cdot v + 0.4605 \cdot z - 5.8273 \quad (9)$$

$$y_{v=35}(t, z) = 0.58652t + 0.1635z + 0.0198tz + 1.1249 \quad (10)$$

$$y_{z=17}(t, v) = 0.92312 \cdot t + 0.45 \cdot v - 1.1249 \quad (11)$$

### IV. RESEARCH RESULTS

Responses surfaces are presented graphically in Fig. 1 (two-dimensional version), Fig. 2-4 (three-dimensional version) and built on the obtained Eq.4-11.

By the obtained graphs the estimation of each factors influence (or the factors combination) on technological operations of MOEMS components shaping parameters was conducted.

The values and combinations of factors were determined to obtain the planned roughness of the sample.

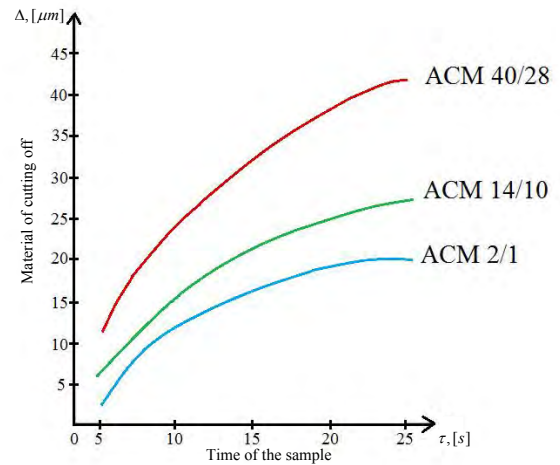


Fig. 1. Dependence of the material cutting off rate on the processing time

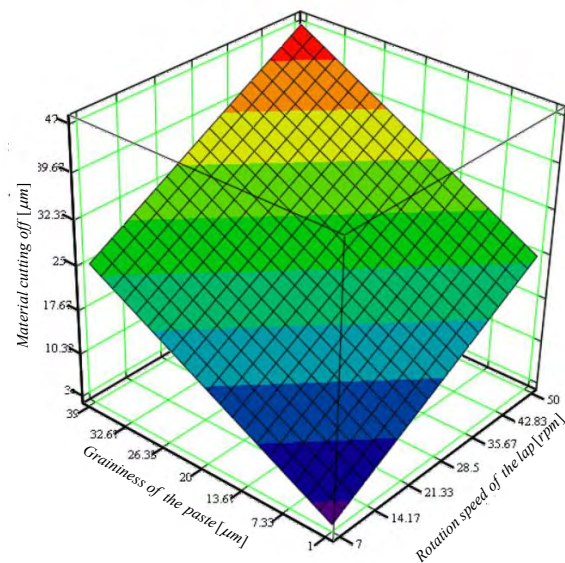


Fig. 2. Responses surface at constant processing time

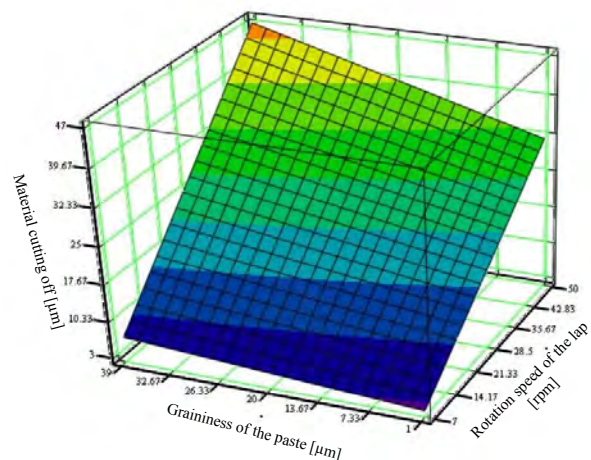


Fig. 3. Response surface at constant lap rotation speed

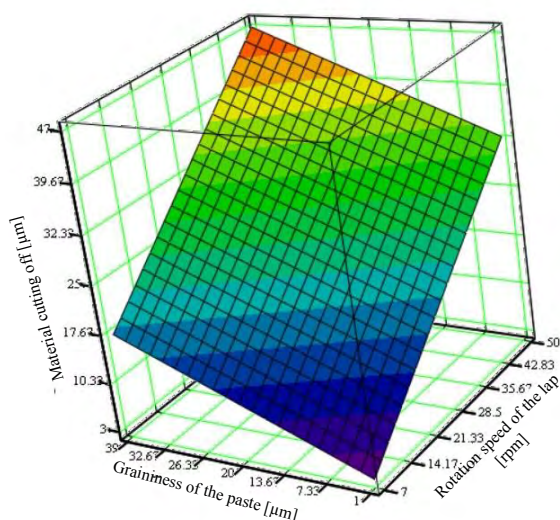


Fig. 4. Responses surface when diamond grinding pastes value is constant

## V. CONCLUSIONS

The article represents the result of research the impact of the parameters of the grinding and polishing finishing technological operations on the MOEMS-components shaping parameters.

Simulation allows to determine the set and magnitude of the input parameters to obtain the specified values of the output sample roughness.

The simulation results can be useful in planning the technological processes of functional reflective MOEMS-elements production. This research will make it possible to determine the exact values of the shaping parameters of the components, for example, mirrors, for micro-optoelectromechanical switches.

The results can later be used also for the control operations of such components.

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