Optimization of quartz glass laser polishing parameters using the computational experiment planning method

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Abstract
This paper demonstrates the optimization of the laser polishing process of quartz glass. It was performed using the method of a complete factorial experiment with a two-level variation of factors and the parameters search method. After simulation, the laser polishing modes of quartz glass have been determined. These modes ensure the temperature set points in the processing zone at the minimum values of thermoelastic stresses in quartz plates.

Introduction
The quartz glass properties ensure its wide application in various technical fields. In this case, laser polishing is a promising method for processing quartz glass [1, 2]. The authors previously investigated the laser polishing process of quartz glass using finite element modeling and a complete factorial experiment by creating the appropriate regression model of the material laser processing [3, 4]. This research concentrates on optimizing the parameters of quartz glass laser polishing via the search method using finite element modeling and the method of planning computational experiments [5 – 7].

Numerical experiment
When using numerical simulation, the technique of a complete first-order factorial experiment was used with a two-level variation of factors (processing speed V, scanning pitch h, laser beam radius R) with output parameters (maximum temperature in the laser processing zone T and principal stress σ_1). The statistical model of the object for analysis was the response functions (T) and (σ_1), connecting the output parameters with the factors (V, h, R), which varied within the specified limits during numerical experiments. Table 1 was created after converting the independent variables in natural scale to dimensionless variables with coded values: -1, +1.

Table 1. Coded values of independent variables

Independent variables	Dimensionless variables	-1	+1
Processing speed, mm/s	X_1	2	4
Scanning pitch, mm	X_2	0.25	0.5
Laser beam radius, mm	X_3	1	2

Table 2 shows the numerical experiment results on quartz glass laser polishing, given for all values of the factors. According to the data presented in Table 2, the models were created. They determine the dependences T and σ1 on the processing parameters. The scanning pitch turned out to be a non-influencing parameter for the selected variation ranges of technological parameters.

After the appropriate calculations, the equations for T and σ_1 in the transition to actual values are as follows:

$$T = 2098.5 \cdot R - 163.25 \cdot V - (R - 1.5) \cdot (237.5 \cdot V - 712.5) + 159.75 ,$$

$$\sigma_1 = 104615000 \cdot R + 19697500 \cdot V + \\ + (R - 1.5) \cdot (38505000 \cdot V - 115515000) + 156272500 .$$

Table 2. Numerical experiment results

Factor combination number	T, K	σ_1, MPa
1	1813	7.0
2	1724	7.9
3	1813	7.0
4	1724	7.9
5	4149	73.1
6	3585	151.0
7	4149	73.1
8	3585	151.0

Results of modeling and their discussion

The optimization of the parameters of quartz glass laser polishing was carried out using the search method. This method is an alternative to the direct optimization method when solving extremum problems. In this case, the range of the temperature values T, required for effective polishing, was taken equal to 2000 – 2005 K. Then, the temperatures in the processing zone were calculated using the formula mentioned above. The speed varied in the range of 1 – 20 mm/s with a pitch of 1 mm/s, and the radius of the laser beam varied within 0.1 – 2 mm with a pitch of 0.1 mm. The stresses σ_1 were calculated after determining the parameters that ensure the formation of a given temperature in the laser processing zone (table 3).

Table 3. Calculated parameters of the quartz glass laser polishing

№	V, mm	R, mm	T, K	σ_1, MPa
1	5	1.2	2004	45
2	8	1.5	2001	160
3	17	0.3	2004	400

As Table 3 shows, the formation of temperatures in a given range is carried out when choosing three settings of speed and radii of the laser beam. In this case, critically high stresses are formed in the processing zone in the third setting.

Conclusion

The numerical experiment resulted in establishing the optimal parameters of laser polishing of quartz plates. These plates provide the minimum values of thermoelastic stresses at temperature set points. The technique proposed in this research can be used to optimize quartz glass laser processing.

References

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