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APPLICATION OF MACHINE LEARNING METHODS FOR MODELING THE QUALITY AND STABILITY OF THE TURNING PROCESS

The reliability of aircraft engine components directly depends on the quality of their surfaces, which is determined during the machining stages. The application of modern machine learning (ML) methods complements time-tested traditional approaches by providing tools for finer tuning of cutting parameters and finding the optimal balance between quality and productivity. However, an analysis of scientific works [1–3] shows that most studies focus on predicting only the average roughness value, whereas for critical parts, process stability and repeatability are no less important.

The aim of this work is to develop a methodology that allows for the simultaneous modeling of two criteria: average roughness and process stability, characterized by the spread of roughness values. The study is based on the open dataset of the MaRoReS project [4], which contains the results of 68 experiments on the turning of high-strength 42CrMo4+QT steel. Two approaches were compared: an empirical power-law model based on linear regression and a Random Forest machine learning model.

As a result of the regression analysis, the following empirical formula was obtained for predicting the average surface roughness Ra :

$$Ra = 24.824 \cdot r^{-0.456} \cdot d^{-0.1811} \cdot v^{-0.5643} \cdot f^{0.7435}, \quad (1)$$

where r - tool nose radius; d - cutting depth; v - cutting speed; f - feed rate.

The machine learning model demonstrated better prediction accuracy ($R^2 = 0.590$ versus 0.531 for regression) and revealed the dominant influence of feed rate on average roughness, while cutting depth had a minimal effect.

Additionally, a model was developed to assess process stability, which allowed for the identification of unstable operating conditions. It was found that the process becomes unstable at low cutting speeds ($v < 95$ m/min) and extreme feed rates. It was also found that a larger tip radius $r = 0.8$ mm (versus 0.4 mm) reduces roughness variability by more than 60%.

The robustness of the proposed ML approach was further verified on an independent dataset [5]. Testing confirmed that the “RandomForest” model is capable of identifying useful patterns ($R^2 \approx 0.5$) even under conditions where classical regression models prove practically ineffective ($R^2 < 0.1$).

Conclusions. A methodology for predicting the quality and stability parameters of turning operations based on the “Random Forest” algorithm has been developed and validated. The superiority of machine learning models over classical regression methods in terms of prediction accuracy and the ability to identify hidden process patterns has been demonstrated. Factor analysis showed that feed rate is the main parameter determining surface roughness, while process stability depends primarily on cutting speed and tool geometry, particularly the radius of its tip.

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