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A machine-learning based solution for chatter prediction in heavy-duty milling machines

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Abstract

The main productivity constraints of milling operations are self-induced vibrations, especially regenerative chatter vibrations. Two key parameters are linked to these vibrations: the depth of cut achievable without vibrations and the chatter frequency. Both parameters are linked to the dynamics of machine component excitation and the milling operation parameters. Their identification in any cutting direction in milling machine operations requires complex analytical models and mechatronic simulations, usually only applied to identify the worst cutting conditions in operating machines. This work proposes the use of machine-learning techniques with no need to calculate the two above-mentioned parameters by means of a 3-step strategy. The strategy combines: 1) experimental frequency responses collected at the tool center point; 2) analytical calculations of both parameters; and, 3) different machine-learning techniques. The results of these calculations can then be used to predict chatter under different combinations of milling directions and machine positions. This strategy is validated with real experiments on a bridge milling machine performing concordance roughing operations on F-114 steel with a 125 mm diameter mill fitted with nine cutters at 45°, the results of which have confirmed the high variability of both parameters along the working volume. The following regression techniques are tested: artificial neural networks, regression trees and random forest. The results show that random forest ensembles provided the highest accuracy with a statistical advantage over the other machine learning models; they achieved a final accuracy of 0.95 mm for the critical depth and 7.3 Hz for the chatter frequency (RMSE) in the whole working volume and in all feed directions, applying a 10x10 cross validation scheme. These RMSE values are acceptable from the industrial point of view, taking into account that the critical depth of this range varies between 0.68 mm and 19.20 mm and the chatter frequency between 1.14 Hz and 65.25 Hz. Besides, random forest ensembles are more easily optimized than artificial neural networks (1 parameter configuration versus 210 MLPs). Additionally, tools that incorporate regression trees are interesting and highly accurate, providing immediately accessible and useful information in visual formats on critical machine performance for the design engineer.

Keywords: Random Forest, regression trees, milling, vibrations, chatter, polar diagrams