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Predictive Modeling for Power Consumption in Machining using Artificial Intelligence Techniques

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Abstract

The objective of this work is to highlight the modeling capabilities of artificial intelligence techniques for predicting the power requirements in machining process. The present scenario demands such types of models so that the acceptability of power prediction models can be raised and can be applied in sustainable process planning. This paper presents two artificial intelligence modeling techniques - artificial neural network and support vector regression - used for predicting the power consumed in machining process. In order to investigate the capability of these techniques for predicting the value of power, a real machining experiment is performed. Experiments are designed using Taguchi method so that effect of all the parameters could be studied with minimum possible number of experiments. A L_{16} (4^3) 4-level 3-factor Taguchi design is used to elaborate the plan of experiments. The power predicted by both techniques are compared and evaluated against each other and it has been found that ANN slightly performs better as compare to SVR. To check the goodness of models, some representative hypothesis tests *t*-test to test the means, *f*-test and Leven's test to test variance are conducted. Results indicate that the models proposed in the research are suitable for predicting the power.

1. Introduction

Energy efficiency and environment impact have become important benchmarks for assessing any industry both globally and domestically due to sustainability issues and manufacturing industry is no exception. The energy efficiency of machines tools is generally very low particularly during the discrete part manufacturing and users in the automotive industry demand more often an indication for new acquisitions of how much energy a machine tool will expectedly consume during operation. The factor energy efficiency is therefore important evaluation criterion for new investment in machinery and equipment in addition to the classical parameters accuracy, performance, cost and reliability. The large number of interrelated parameters (cutting speed, feed, depth of cut, tool geometry, work piece and cutting tool properties, etc.) that influence the power consumption during machining on a machine tool makes the development of an appropriate predictive model a very difficult task. As a result analytical, numerical and artificial intelligence methods have been developed for the power

consumption prediction. A lot of research has been done in last 60 years on the optimization of machining parameters for surface roughness, tool wear, forces, etc but a little research has been done to minimize the power consumption of a machine tool. Machine tools require power during machining, build-up to machining, post machining and in idling condition to drive motors and auxiliary equipments including compressed air in CNC machine tools. However, the design of a machine tool is based on the maximum power requirement during machining of material which may be very high as compared to average power requirement of the machine tool. This leads to higher inefficiency of energy in machine tools. The optimization of machining parameters for minimum power requirement is expected to lead to the application of lower rated motors, drives and auxiliary equipments and hence save consumption of power not only during machining but as well as during build-up to machining, post machining and idling condition.

The machining process is very complex and does not permit pure analytical physical modeling [1]. Predictive models that are developed using conventional approaches such

as the statistical regression technique (regression analysis, response surface methodology) may not describe the nonlinear complex relationship between machining parameters and machining performance [2]. Recently there has been a lot of interest to develop models for investigating the influence of machining parameters (cutting speed, tool geometry, etc.) on response parameters (cost, roughness, time etc.) using artificial intelligence techniques [3-10]. Therefore, this paper aims at predicting the power consumed in machining using artificial intelligence techniques: Artificial Neural Networks (ANN) and Support Vector Regression (SVR). Machine tools have efficiency less than 30% [11] and more than 99% of the environmental impacts are due to the consumption of electrical energy used by the machine tools in discrete part manufacturing machining processes like turning and milling [12]. Reduction in power consumption will improve the environmental impact of machine tools and manufacturing processes.

In the present study, ANN and SVR models are developed to predict power during turning operation of AISI 1045 steel. In the development of predictive models, machining parameters of spindle rpm, feed and depth of cut are considered as machining parameters. Taguchi's design of experiments is carried out to conduct experiments. Total 16 experiments are conducted to measure the power. The ANN and SVR are compared against each other using the relative error, descriptive analysis and hypothesis testing. The results of developed models are in close agreement to experimental results.

This paper is organized as follows. The experimental procedure to obtain the power values is presented in section 2. Section 3 and 4 presents the prediction of power using ANN and SVR respectively. The models proposed in section 3 and 4 are compared against each other in section 5. Finally the conclusions are highlighted in section 6.

2. Experimental Planning

The turning experiments are carried out in dry cutting conditions using HMT Lathe machine, which has a maximum spindle speed of 2300 rpm. The tool holder used is a Sandvik PTGNR 2020 K16 along with Tungsten Carbide Sandvik TNMG 16 04 12 inserts. The rake angle is $+7^0$ and the clearance angle is $+6^0$. The workpiece used is AISI 1045 steel having a diameter of 47 mm and length 365 mm. An indirect method of power measurement is used to measure the power consumed during machining. A Kistler Type 9272 4-component dynamometer is used to measure the cutting force. Dynamometer is connected to a multichannel charge amplifier (Type 5070A) by a highly insulated connection cable. The amplifier amplifies the electrical charges delivered from the dynamometer into proportional voltages and then the proportional forces are processed using Dynoware, a software package designed for this purpose. Experimental set up used in this study is shown in Fig. 1.

Experiments are designed using Taguchi method so that effect of all the parameters could be studied with minimum possible number of experiments. A L_{16} (4^3) 4-level 3-factor

Taguchi design is used to elaborate the plan of experiments with the factors.
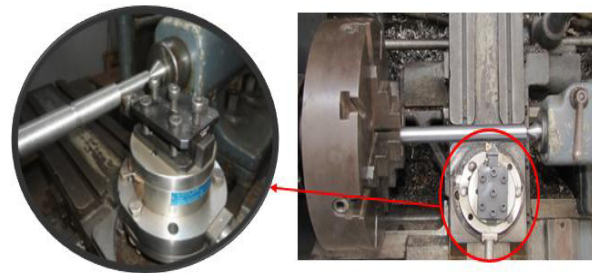

Fig. 1. Experimental setup used in this study

The choice of level is made by taking into account the capacity of the lathe and limiting cutting conditions. Three factors and their levels are given in the Table 1.

Table 1. Machining parameters and their levels

Factor	Symbol	Level 1	Level 2	Level 3	Level 4
Spindle speed (rpm)	n	700	910	1180	1540
Feed (mm/rev)	f	0.20	0.40	0.65	1.30
Depth of cut (mm)	d	0.6	1.0	1.4	1.8

The results obtained through a series of experiments for various sets of parametric combinations are listed in Table 2.

Table 2. Experimental design using orthogonal design and power results

Experiment No.	n (rpm)	f (mm/rev)	d (mm)	P (kW)
1	700	0.20	0.6	0.743
2	700	0.40	1.0	1.488
3	700	0.65	1.4	2.724
4	700	1.3	1.8	4.699
5	910	0.40	0.6	1.369
6	910	0.20	1.0	1.395
7	910	1.30	1.4	5.412
8	910	0.65	1.8	4.810
9	1180	0.65	0.6	2.515
10	1180	1.30	1.0	7.395
11	1180	0.20	1.4	1.589
12	1180	0.40	1.8	2.515
13	1540	1.30	0.6	4.311
14	1540	0.65	1.0	4.348
15	1540	0.40	1.4	4.004
16	1540	0.20	1.8	3.541