Prediction of cutting forces in drilling AL6082-T6 by using artificial neural networks

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Abstract. This research investigates the comparison of the thrust force (Fz) and cutting torque (Mz) predictive models based on artificial neural networks (ANN). The models were developed based on three-level full factorial design of experiments conducted when drilling of Al6082-T6 alloy material with cutting speed, feed rate and tool diameter as the process parameters. The predictive ANN models of thrust force (Fz) and cutting torque (Mz) were developed using a multilayer feed forward neural network, trained using an error back propagation learning algorithm. The developed models are shown capable of predicting them (Fz and Mz) to a great level. The confirmation experiments provided favorable results with accuracy of 4% and 4.5%, for the thrust force (Fz) and the cutting torque (Mz) respectively. Furthermore the R coefficient for the prediction model of the thrust force is 0.99608 and 0.9946 for the cutting torque. As a result they can be considered as very accurate and appropriate for their prediction. This study promotes the better machining quality and the sustainability of the process that are achieved at the same time

1. Introduction
Drilling is one of the most commonly used process in the machining of metals in today’s industry. The most product parts are designed in such a way that they should be processed on drilling machines in the stage of manufacturing [1-4]. Al6082-T6 alloy is very common in industry and is appeared as a good choice for many applications in the field of aerospace, aircrafts and automobile sector. It offers great finishing character and responds great to anodizing. There is no doubt that a lot of research implemented about the appropriateness of different predictive models during many cutting processes. According to the literature review, Artificial Neural Networks (ANN) has been used for modelling many manufacturing parameters. The Artificial Neural Network can be effectively used to determine the input-output relationship of a complex process and is considered as a tool in nonlinear statistical data modelling. Artificial Neural Network (ANN) is a learning system, while it has a simple structure, has the ability to learn and solve very complex and non-linear processes.

2. Methods

2.1. Technics of experiments
During this research, an aluminum workpiece with 140 mm X 100 mm X 30 mm size was tightly clamped in the vice. A combination of different cutting parameter such as Feed rate (f), Cutting
speed (Vc), and different cutting tool diameters (D), were used in order the experiment execution (table 1). Three different cutting speed of 50 m/min, 100 m/min, 150 m/min, and three feed rates of 0.15 mm/rev, 0.2 mm/rev and 0.25 mm/rev, were chosen. Simultaneously the combination of three cutting tools diameters of 8 mm, 10 mm and 12 mm were used for the creation of 27 drilled holes with 30 mm overall depth. Each hole was done by using a unique tool, manufactured by Marena S.L. and a cutting fluid was used every time a hole was drilled.

| Factors                  | Notation | I    | II   | III  |
|--------------------------|----------|------|------|------|
| Cutting speed (m/min)    | V        | 50   | 100  | 150  |
| Feed rate (mm/rev)       | f        | 0.15 | 0.2  | 0.25 |
| Tool diameters (mm)      | D        | 8    | 10   | 12   |

The CNC machine that used for the experiment was the HAAS VF1 machining center. The setup of the experiment consists of a piezoelectric drill dynamometer (Kistler type 9123), charge amplifier, an analog to digital converter and a computer for data acquisition. A specific software named Dynoware (type 2825D-02) was used for the recording and the analysis of the experimental values of the cutting forces. A simple means of documenting and exporting the data is provided also by the DynoWare software. The workflow of the research is depicted in figure 1.

![](Workflow.png)

**Figure 1.** The schematic diagram of the experimental setup.

The derived values during the experiment are depicted in figure 2. As showed by the results Fz and Mz values are increased, when the diameter of the tool increases. Additionally, the Fz and the Mz are increased, when the feed rate values are increased, respectively. Conversely, the cutting parameter of cutting speed doesn’t influence remarkably their values on both cases.
2.2. ANN modeling

According to literature review many studies have been done using Artificial Neural Network for the prediction of cutting parameters during manufacturing processes [5-7]. The drilling process is one of the most important [8,9]. In this study, an Artificial Neural Network with a back propagation neural network was used for the prediction of the thrust force (Fz) and cutting torque (Mz). Back propagation is used as a supervisor for the whole process. The output results of the network are compared to the experimental values and the weights in the network are recalculated with an aim the network’s response to be closer to the desired response [10,11]. The main ANN advantage is the ability to learn from the process and finally to present the desired output. During the training process there is a comparison between the calculated output and the experimental output and the mean square error is calculated. When the mean square error is more than the prescribed limiting value, then it is back propagated. The back-propagation training algorithms, the scaled conjugate gradient (SCG) and Levenberg–Marquardt (LM), are used for ANNs training.

Figure 2. Experimental values derived from Kistler 9123.

Figure 3. Architecture of ANN topology.
The structure of this network involves input, hidden and output layers as shown in figure 3. In this case, the selected input parameters are the cutting speed, feed rate and the drill diameter. In the hidden layer, the choices of the number of hidden layers and the number of neurons are the most important factors for the quality of the results. A large number of neural network topologies were tested in consequence of trials (3-6~11-1), and based on the convergence rate of the mean square error and the best network topology for the prediction of both the thrust force and cutting torque was the 3-8-1 architecture. The output layer receives all the necessary information from the network, and sends the results to an external collector. This layer consists of one neuron corresponding to one output variable Fz and Mz, respectively. Three layer network architectures were used to predict the thrust force and torque as shown in figure 3.

All of the original (27) experimental data were randomly divided into three data sets including a training, validation and testing. The 70% of the data was used for the training set in order to build the network, 15% to measure network generalization and 15% as a testing set of the neural network. Using the ANN methodology there are some criteria which measure its performance properly. The most important is the criterion of correlation coefficient (R-value) between targets and outputs of the neural network. It can be considered as a measurement of how well the variation in the outputs is clarified by the targets. The R-value takes a value between 0 and 1. When the value is close to 1, then there is a good correlation between targets and outputs, otherwise (close to zero) there is a poor correlation. In this study, for the case of Fz the R-value for the entire dataset (training, validation and testing) is 0.996, while for the case of Mz the R-value for the entire dataset is 0.994. Both represent high correlation, which means that the network achieves high accuracy (figure 4). Besides, the comparison between the measured with the predicted Fz values shows that the highest difference observed is 4% and for the case of Mz the highest difference observed is 4.5%.

![Plot Linear Regressions](image)

**Figure 4.** Neural network plot linear regressions for thrust force and torque (Fz-Mz).

3. Discussion
The neural network analysis was employed to develop the mathematical model for the thrust force (Fz) and the cutting torque (Mz) concerning cutting parameters such as cutting speed, feed rate, and cutting tools diameters. A comparison between experimental and predicted values of the developed models is presented in figure 5.
Figure 5. Comparison of the experimental values with the predicted values.

It is understandable that the predicted values from the ANN model catch up the experimental values. Additionally, the calculated percentage of error between experimental and predicted values, which can be considered as an extra criterion for the developed models accuracy (figure 6), shows that the accuracy achieved was 4% and 4.5% for both the thrust force and torque respectively.
4. Conclusions
The object of this research was the formation of mathematical models based on artificial neural network (ANN) for the prediction of the thrust force (Fz) and torque (Mz) in a sequence of drilling operations of Al6082-T6. Various process conditions such as different feed rates, cutting speeds (Vc), and cutting tool diameters were applied under experiment principles. The study shows that the experimental and predicted ANN model results are very much close matching small deviation observed. The ANN models achieved the accuracy of 4% and 4.5% for both the thrust force and torque measured. This strategy can be considered as appropriate in modelling and predicting thrust force and cutting torque when drilling is occurred. This research encourages the quality of the machining process while simultaneously promotes the sustainability that are achieved at the same time.

5. References
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