An artificial neural network approach to investigate surface roughness and vibration of workpiece in boring of AISI1040 steels

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Abstract In metal cutting, tool failure and surface roughness are the important aspects that affect product quality and production cost, and these are affected mainly by vibration of workpiece. Current techniques do not have a proper method to measure vibration of a rotating workpiece so as to use it as a parameter to replace a cutting tool at an appropriate time. The purpose of the present work is therefore to use of laser Doppler vibrometer (LDV) to measure the vibration of workpiece without interfering the machining. Subsequent to obtaining the workpiece vibration data, artificial neural network (ANN) method was adopted to predict surface roughness and root mean square (RMS) velocity of workpiece vibration. According to Taguchi design of experiments, 18 experiments were prepared with two levels of nose radius and three levels of cutting speed and feed rate. Experiments were conducted on CNC lathe to obtain data of surface roughness and RMS of workpiece vibration velocity in boring of AISI 1040. A multilayer feedforward ANN model was developed and trained with the experimental data using back propagation algorithm. Further, the ANN was used to predict surface roughness and RMS velocity of workpiece vibration. The predicted values were compared with the collected experimental data and percentage error was computed. Less percentage of error was found between the experimental and predicted values.

Keywords ANN · Surface roughness · Tool vibration · Acousto-optic emission · Tool wear

1 Introduction

Boring process is a difficult operation when compared with external turning process, and many variables affect the surface roughness. In boring process, tool vibration is the main factor that affects the tool life and surface finish. In boring operations, the length of boring bar is kept long, resulting in vibrations leading to tool failure, poor surface finish and chatter. Prasad et.al [1] stated that the texture of machined surface provides reliable information regarding the tool wear because tool wear affects the surface roughness dramatically. Machining error is one of the factors that is to be given attention to obtain good quality of work. Error in machining is wrong selection of cutting parameters that affect dimensional accuracy and surface quality. Chun and Tae [2] studied the effect of deflection of cutting tool, tool wear, depth of cut and thermal effects and machine tool errors on machining process. They found that deflection of tool and depth of cut are significant parameters affecting the surface quality and dimensional accuracy.

Chatter vibrations at high cutting speed can be measured accurately by laser Doppler vibrometer (LDV). Venkatarao et al. [3] and Balla et al. [4] also used LDV to observe vibration of workpiece and used a high-speed fast Fourier transform (FFT) preprocessor for generating features from online AOE signals to develop a database for appropriate decisions. The LDV is being used to observe high-frequency vibrations.
during machining process. In this present work, a LDV was used to observe vibration of workpiece and FFT was used to process the acousto-optic emission (AOE) signals. Length-diameter ratio (L/D) of boring bar is one of the important factors causing tool vibration. In the present work, the L/D ratio was taken as 3 in order to minimize vibrations of tool and workpiece [3].

Surface quality is one of the important characteristics to estimate functional quality and life of a machined product. Good surface quality is essential for manufacturers to improve functional and technical quality of any product. Quintana et al. [5] stated that the surface roughness is influenced by various factors like cutting parameters, cutting tool characteristics, workpiece properties and cutting phenomena. Julie and Joseph [6] conducted experiments using Taguchi design to optimize surface quality. In the Taguchi design, they used cutting parameters like feed rate, spindle speed, depth of cut and tool type. In the present study, the Taguchi design is made with cutting speed, feed rate and nose radius.

According to Chang [7], the surface roughness and tool wear are strongly affected by the vibration amplitude and frequency. Improper tool geometry and the nose radius will produce more vibrations than the depth of cut. Two different nose radii were taken in the present work to evaluate effects of vibrations on tool life and surface roughness. Venkatarao et al. [3] mentioned in their work that two types of vibrations may occur in machining, such as forced vibration and self-excited vibration. Forced vibration is associated with bad gear drives, unbalanced machine tool components, misalignment, motors and pumps etc. Self-excited vibration occurs due to chatter which is caused by the interaction of the chip removal process and the structure of the machine tool and results in disturbances in the cutting zone. Chatter always indicates defects in the self-excited vibration. Junyun Chen, Qingliang Zhao [8] stated that vibration between tool and workpiece is more credible to estimate surface roughness. They have developed prediction models using vibration signals to predict surface roughness. Zahia Hessainia et al. [9] have studied effect of tool vibration along with cutting speed, depth of cut and feed rate on surface roughness. They have used response surface methodology to find out and optimum cutting parameters for minimum surface roughness with less tool vibration. In the present work, effects of vibration signals on workpiece vibration and surface quality were studied.

Tool condition monitoring (TCM) is an important characteristic in the automated manufacturing industries to assess ability of cutting tools for high production rates and good quality. Proper tool condition monitoring reduces tooling cost, and it helps in the reduction of product cost. Various authors reported different methods for online assessment of tool condition, such as process monitoring based on manipulation of sensor measurements like acoustic emission, cutting forces, vibration, temperature, stress-strain, vision and main motor current etc. to determine the state of the process. Estimation of tool wear is required for good quality of product and higher productivity. New tool is to be replaced when it loses its

<table>
<thead>
<tr>
<th>Elements</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Carbon</td>
<td>0.37−0.44 %</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.05 % max</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.6−0.9 %</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.04 % max</td>
</tr>
<tr>
<td>Iron</td>
<td>Balance</td>
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<table>
<thead>
<tr>
<th>Tool geometry of DNMG150608 and DNMG150604</th>
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<tbody>
<tr>
<td>Cutting edge length</td>
</tr>
<tr>
<td>Cutting point angle</td>
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<tr>
<td>Thickness</td>
</tr>
<tr>
<td>Hole smallest dia</td>
</tr>
<tr>
<td>Side clearance</td>
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</tbody>
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Fig. 1 Workpieces

Fig. 2 Tool inserts