International Journal of Automotive and Mechanical Engineering
ISSN: 2229-8649 (Print); ISSN: 2180-1606 (Online)
Volume 16, Issue 3 pp. 7121-7132 Sept 2019

Analysis of Vibration Level for Power Tool Using Neural Network

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ABSTRACT

Power tool produced vibration when human use it for the activities of construction, repairing or finishing. Long-term mechanical vibration exposure of power tools causes worker's fingers to feel prickle and numbness, which lead to the phenomenon of hand arm vibration syndrome (HAVS). Thus, the vibration of power tool was studied and analysed in this study. First, the results of vibration level of pistol-grip corded drill were collected by using vibrometer, respectively to x, y and z-axis direction. Furthermore, to study the effect of mass on the vibration level, the vibrations results have been collected when mass attached to power tool are 1 kg and 2 kg respectively. To predict the vibration amplitudes, neural network was used to build the model from the collected experimental data and generated the required prediction results. MATLAB software has been used to analyse measurement results and predict new vibration results. Simulated vibration results have lower acceleration compared with measured vibration results, especially at the peak of vibration amplitude. The neural network model was developed in this study can be considered as reliable and applied in the design of mechanical and electrical component of power tool to reduce the vibration generated during its operating.

Keywords: Neural network; power tool; vibrometer; vibration level.

INTRODUCTION

Vibration is any movement that repeats itself after an interim of time. The vibration of a system involves the transfer of its potential energy (spring or elasticity) to kinetic energy (mass or inertia) and kinetic energy to potential energy, repeatedly [1]. Power tool such as pistol-grip corded drill produces vibration when human use it for drilling the screw hole and tighten the screw in the hinge on door. After long time experienced mechanical vibration, it causes worker’s fingers to feel tingling and numbness. This phenomenon is called hand arm vibration syndrome (HAVS) [2]. Exposure to hand-arm vibrations is related to a risk of damage in form of: vascular disorders, nerve malfunction, and effects on the musculoskeletal system [3]. There is a research study was conducted on 172 male Malaysian workers to study on hand-arm vibration syndrome (HAVS) between Malaysian workers. The results showed that about 25% of workers had the symptoms of finger numbness, tingling, and bluntness [4]. After long time use of the power tool, when the vibration level of power tool is high and not properly maintained, the internal components worn or loose parts, which increase vibration and the risk of workers suffer from HAVS. For instance, the vibration acceleration of poorly maintained grinders was higher than the vibration acceleration of new grinders significantly [5, 6].

Many researchers conducted the study to reduce the vibration level of power tools. Ko et al. investigated the vibration level of petrol driven grass trimmer by adding suspended handle on grass trimmer. The purpose of suspended handle design method is to minimize vibration transmissibility within the working frequency range of the machine according to machine vibration spectra [7]. Chen et al. (2017) investigated to avoid vibration-induced white finger among workers when they are grinding the golf club-heads. The solution is decreasing of machine vibrations by placing an anti-vibration device such as vibration absorber on the grinding machine [8]. Besides that, there is another study conducted by Kihlberg et al. to reduce the vibration of chipping hammer. They modified the internal components of chipping hammer and separated the springs and compressed air of tool body from the vibration source. Thus, the vibration readings produced by the tool had been reduced by half [9, 10]. In addition, it is very helpful to develop mathematical model of power tool by neural network using MATLAB software compared with the way of conducting experiment to obtain the desired vibration results. It save lot of the costs without producing a prototype and carrying out an experiment to obtain satisfied vibration results. Since there still lack of work regulations which can provide the solutions or guidance to blue-collar workers suffering from HAVS in Malaysia, thus it is important to have this study to reduce the vibration level of power tool. The aim of this study is to perform analysis on the vibration results of a pistol-grip corded drill, then applying neural network algorithm in MATLAB software to develop a mathematical model for the vibration level of power tool. At last, the developed mathematical model has been used to predict new vibration results of pistol-grip corded drill.

METHODOLOGY

Figure 1 shows the flow of this study. In this study, first, system identification on the power tool was carried out. Rated input power of this power tool is 450 W, while the range of rotational speed of power tool is from 0 to 3000 rpm. The vibration level of power tool was measured using vibrometer, respectively to x, y and z-axis direction. To investigate the effects of mass on the vibration level, vibrations results have been collected when 1 and 2 kg mass attached to the power tool. On the next stage, by using MATLAB software, mathematical model has been established to do analysis on measured vibration results. The mathematical model of neural networks has been used to predict new vibration results. When the percentage value of vibration reduction has achieved target value, this study is considered success. If not, it must tune the mathematical modelling until it obtains the desired vibration results.

Measurement of Vibration Level on Power Tool

Piezoelectric accelerometer has been attached on the pistol-grip corded drill by using double sided tape. The accelerometer was attached to the x, y and z-axis on the power tool. Figure 2 shows the manner of accelerometer attached to the x-axis on pistol-grip corded drill. Hence, to investigate the effect of mass on the vibration level, the measurement of vibration results has been repeated when mass of 1 and 2 kg are attached to power tool respectively. Figure 3(a) and 3(b) show the mass block of 1 kg and 2 kg are attached to the power tool.

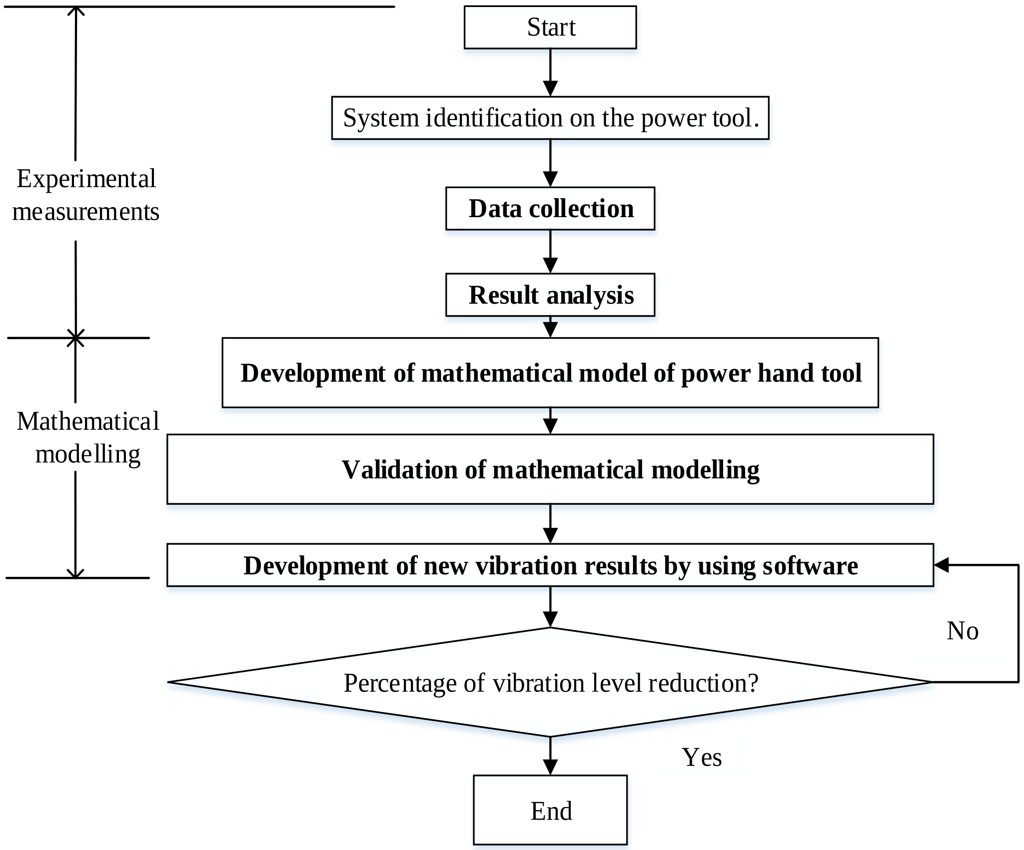

Figure 1. Flow of study.

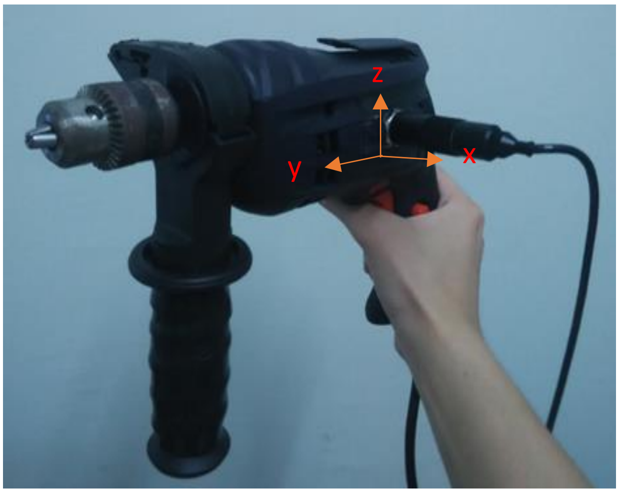

Figure 2. The accelerometer is attached to the x-axis on the surface of pistol-grip corded drill.

(a)

(b)

Figure 3. Power tool is attached with mass block (a) 1 kg and; (b) 2 kg.

Development of Mathematical Model of Power Tool

In this study, neural network has been established in MATLAB software to analysis the measurement results. A deep neural network combines multiple nonlinear processing layers, using simple elements working in parallel and inspired by biological nervous systems [11]. An artificial neural network (ANN) comprises many processing elements named neurons. A common ANN pattern consists of an input layer, an output layer, and the minimum number of one hidden layer [12]. The working principle of neural network has similarity to the inherent neural network in human body. A neural network is the computing system that consists of some uncomplicated and highly connecting processing units; the non-static response is handling and transfers the information to outer input [13]. Since that neural network is learn through previous case, it cannot be provided with coded instruction to carry out particular work [14].

Frequency, synchronous speed of motor and vibration acceleration which are the measurement results were input data of the mathematical model. Figure 4 shows the Feed-forward neural network model, which consists of 2 input data, 100 hidden layers, 1 output layer and 1 output results.

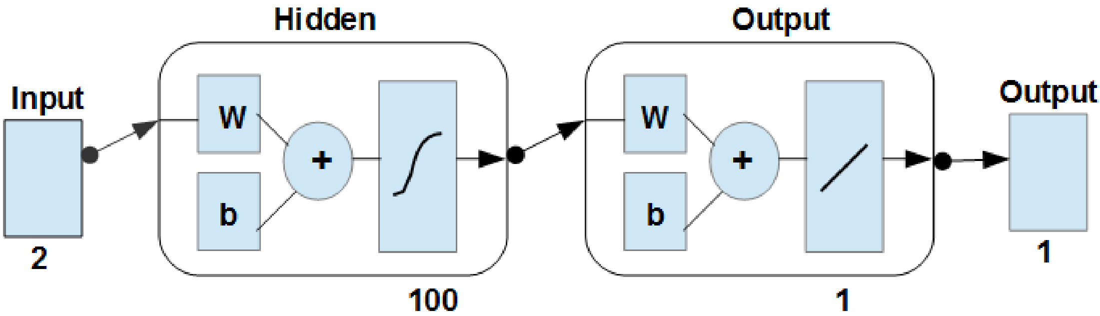

Figure 4. Feedforward neural network model [15].

The first layer contains inputs that are transfer to hidden layer using sigmoid function. Next, hidden layer initiates weight factor randomly and perform calculation on transfer function value from input layer to hidden layer, then hidden layer to output layer. The simulated results are calculated and compared with target value to obtain mean square error. The training of neural network has repeated and the searching range of weight factor becomes smaller. Depending on the results, the weight factor updated per iteration in neural network training. After inserting the input data in neural network model, it can predict new vibration results from the trained networks.

RESULTS AND DISCUSSION

This section presents the vibration measurement results of power tool, it has measure and collect the vibration acceleration reading when accelerometer has attached to x, y and z-axis on pistol-grip corded drill. Mass block with 1 kg and 2 kg was attached on the power tool to investigate the effect of mass on the vibration level. Study case 1 is without mass block attached to power tool, while study case 2 and 3 are the mass block of 1 kg and 2 kg attached to power tool respectively. For analysing vibration acceleration, neural network model has been developed in MATLAB software to analyse the measurement results. After simulations were done; new vibration results were predicted. The percentage of vibration reduction of measurement and simulated results has been calculated to determine which mass is the best choice to reduce vibration to greater extent.

Vibration Measurement

Figure 5 shows the vibration measurement results on x-axis when mass block is not attached to power tool. It is insignificant to reduce the amplitude of vibration for this case as the natural frequency is relatively high, that leads to low possibility that excitation frequency of drill equals to that particular natural frequency, and lead to the resonance. The second reason is the value of acceleration in the frequency range of 0 Hz until 12,000 Hz is relatively small; it is insignificant for vibration reduction for the x-axis. Therefore, vibration analysis of x-axis on power tool was not considered for the following analysis in this study.

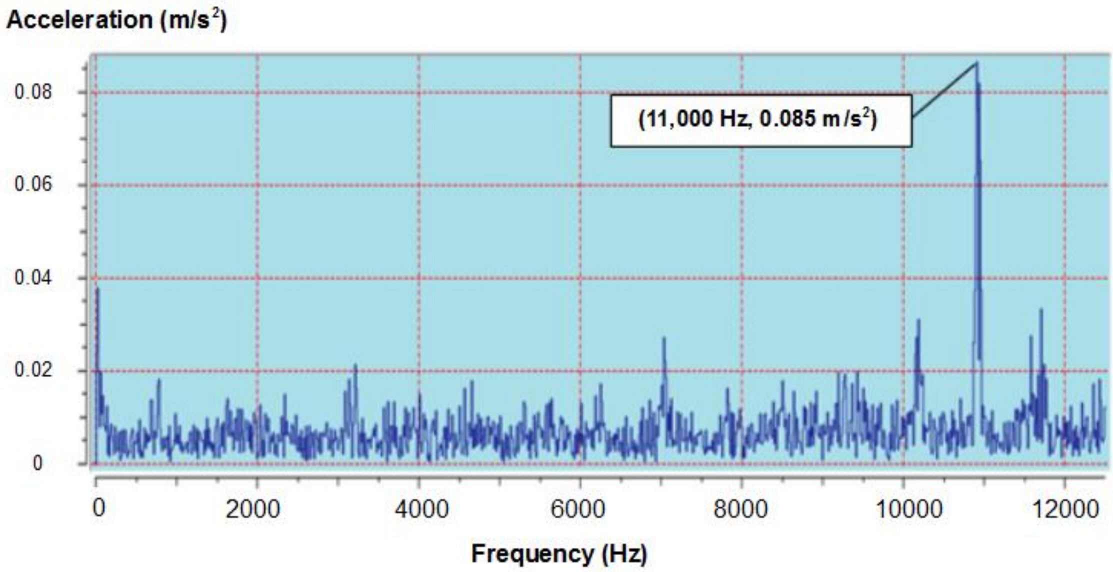

Figure 5. Acceleration as a function of frequency for vibration measurement results on x-axis (case 1).

In Figure 6, for z-axis direction, when mass of 1 and 2 kg are attached to power tool separately, the percentages of vibration reduction are 27 and 48.7 % respectively at frequency of 500 Hz. Besides that, in other natural frequency states, such as 964.46, 1257.15 and 1770 Hz, the vibration acceleration was decreased significantly when it has additional mass. Hence, to reduce the vibration experienced by worker when using power tool, it can improve the design of power tool by adding the mass of the internal components of power tool.

Based on Figure 7, for y-axis, when mass of 1 and 2 kg are attached to power tool respectively, the percentage of vibration reduction are 72.3 and 93.6 % respectively at frequency of 500 Hz. This calculated percentage value shows that the addition of mass has decreased vibration acceleration to the greatest extent. For the measurement results in case 1, it has other natural frequency; 1013, 1355, 1514 and 1855 Hz. When it has additional mass, the vibration acceleration at this few natural frequency state has decreased significantly, approximately equal to zero. Thus, increasing of mass of power tool is extremely effective way to decrease vibration acceleration on y-axis.

In previous research study [16], it was discovered that the electromagnetic forces and magnetostrictive forces are the main cause of electromagnetic vibration in small induction motor. For instances, magnetostriction of steel is change in the dimensions of steel, generated by alternating in the direction and degree of its magnetization, can cause electromagnetic vibration [16]. Furthermore, when the natural frequency of stator core is approximately equal to external excitation frequency, the resonance, which is higher level of vibration occur. Hence, in Figure 6 and Figure 7, when resonance occurred, it shows higher vibration reading in this few specific natural frequencies.

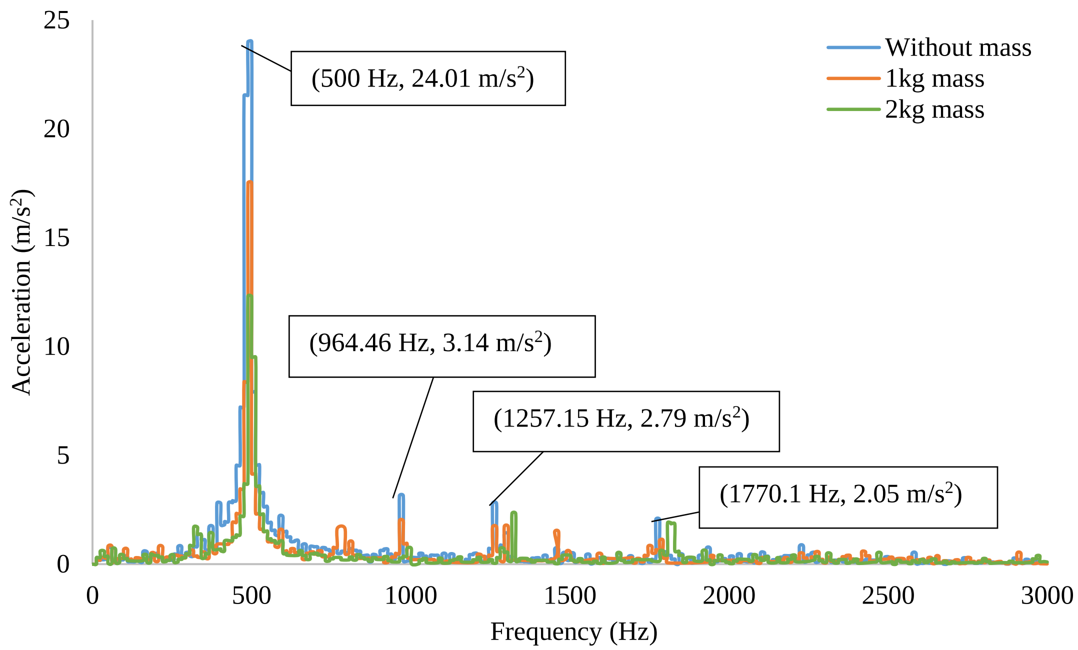

Figure 6. Acceleration vs frequency for measurement on z-axis in three different cases.

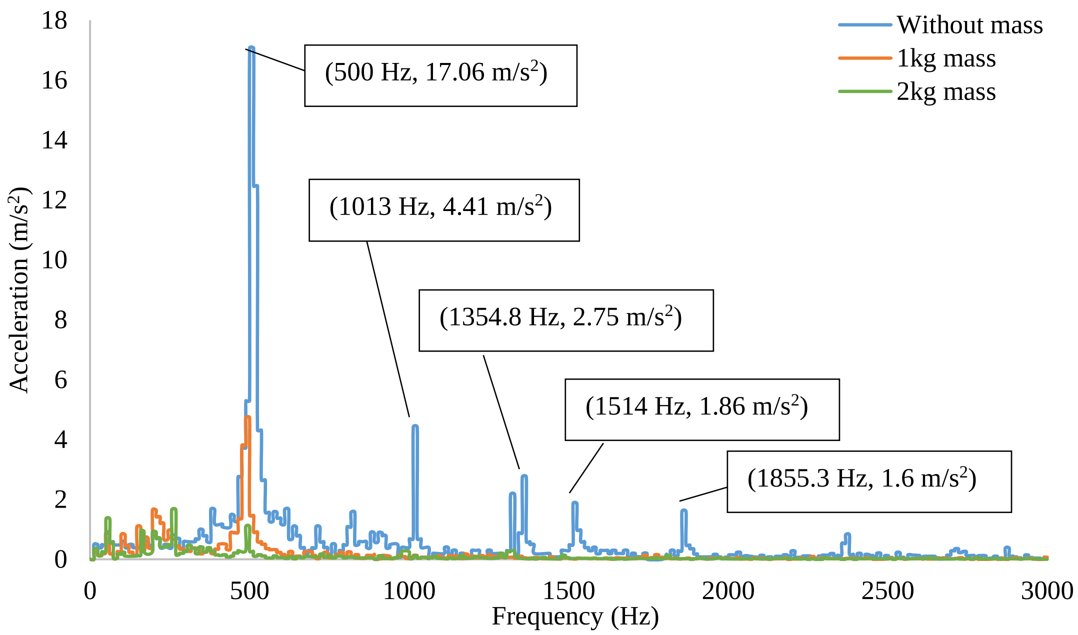

Figure 7. Acceleration vs frequency for measurement on y-axis in three different cases.

Simulated Vibration

In Figure 8, for case 1, the vibration acceleration at 500 Hz is low, which is 6.1 m/s^2 only compared with measurement results in Figure 6. At 500 Hz, for the mass of 1 and 2 kg that attached to power tool, the percentages of vibration reduction are 24.92 and 36.07 % respectively. Although it has other natural frequency state, all those vibration accelerations are low, which are around 1 to 1.32 m/s^2 only.

As shown in Figure 9, when the mass is not attached to power tool, at 500 Hz, the vibration acceleration is 5.05 m/s^2, it is close to vibration acceleration reading in Figure 8, which is 6.1 m/s^2. Hence, the user's hand is experience same vibration level on y and z-axis, which is not cause great impact on user's hands. At 500 Hz, when mass of 1 and 2 kg attached to power tool, the percentages of vibration reduction are 71.28 and 91.88 % respectively. It has decreased vibration acceleration to the highest extent. For case 1, apart from 500 Hz, it has other natural frequency state, but the range of vibration acceleration is from 0.35 to 1.34 m/s^2, which is low vibration level. Worker's hand is not experience higher vibration level though resonance happen at this few frequency state, thus can avoid them had hand arm vibration syndrome (HAVS).

Validation and Comparison of Vibration Measurement with Simulated Results

Acceleration vs frequency for vibration measurement result on y-axis for the second case is given in Figure 10. Based on Figure 10, for y-axis, the vibration acceleration results by simulation are in good agreement with the experimental measurement results. The simulated vibration curve is smoother than measurement vibration curve. Overall, it has lower acceleration compared to vibration measurement results, especially at the peak of vibration amplitude. Furthermore, measurement and simulated vibration results demonstrates that the resonance did not happen when external excitation frequency lower or higher than specific natural frequency.

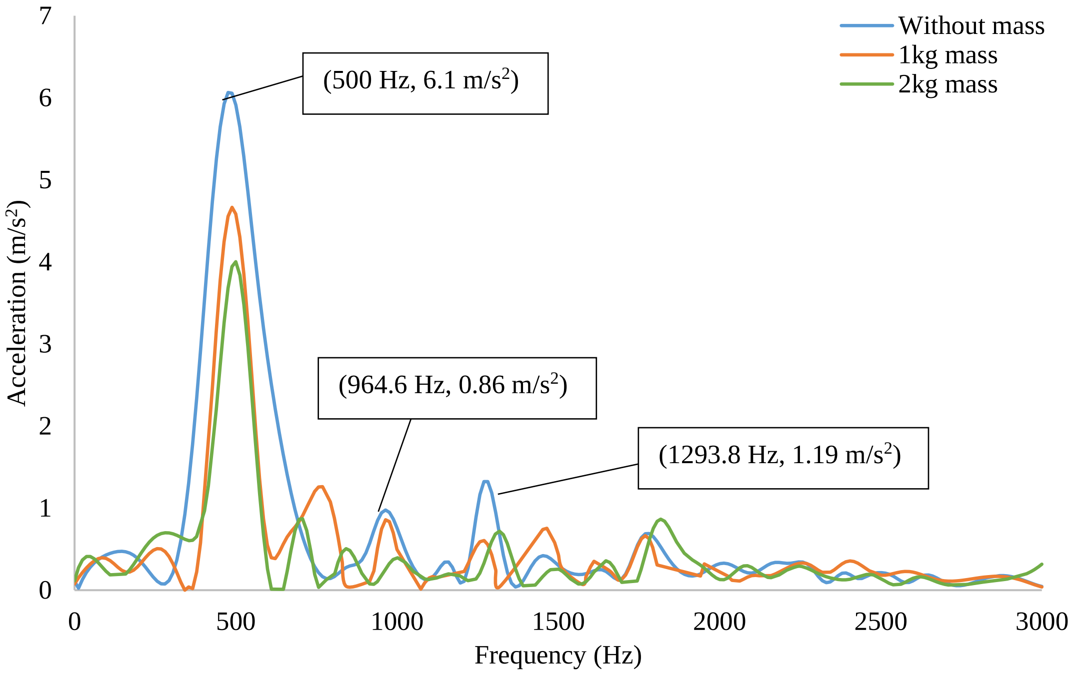

Figure 8. Acceleration vs frequency for simulation results on z-axis in three different cases.

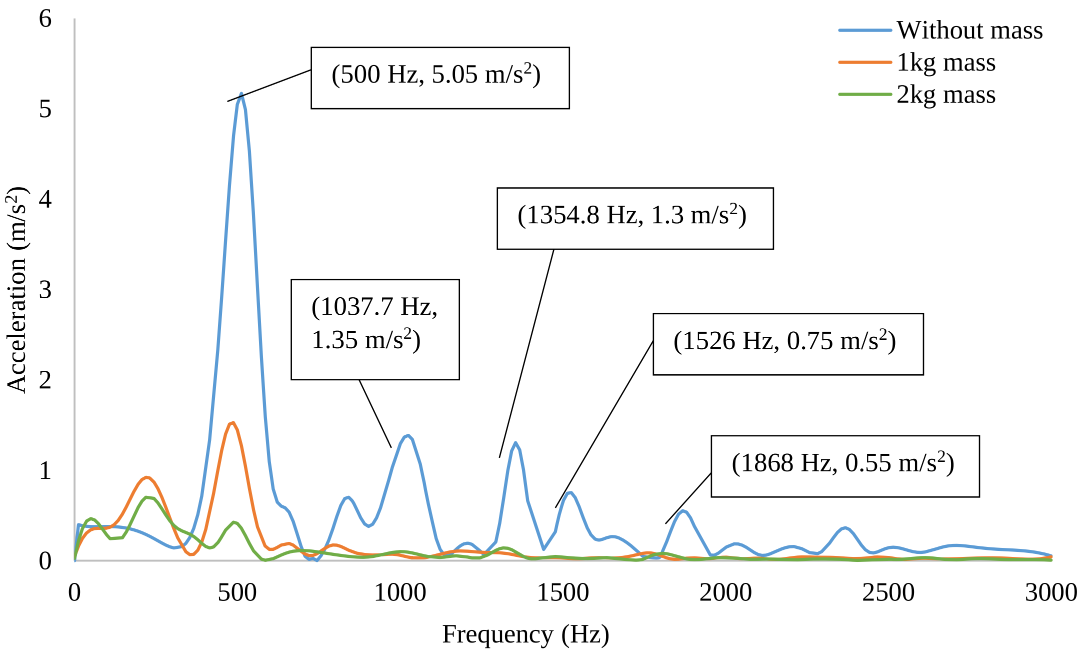

Figure 9. Acceleration vs frequency for simulated results on y-axis in 3 different cases.

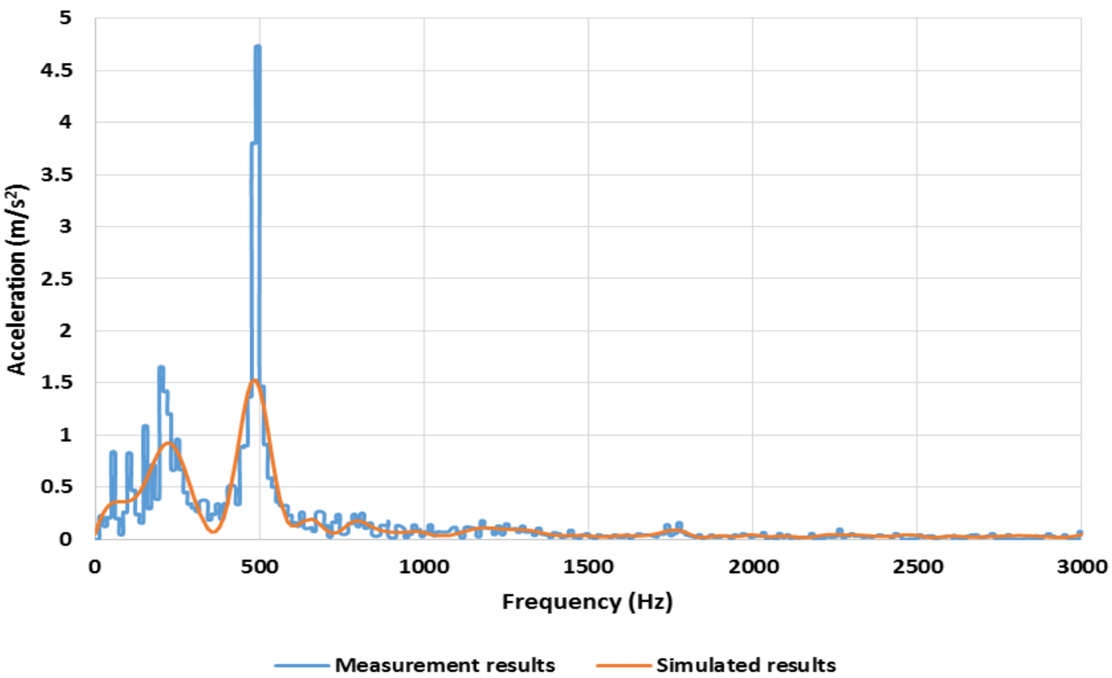

Figure 10. Acceleration vs frequency for measured and simulated vibration results on y-axis for case 2.

Study case 3 is the mass block of 2 kg attached to power tool. Figure 11 shows the acceleration vs frequency for measurement and simulated vibration results on z-axis for case 3, while Figure 12 shows the acceleration vs frequency for measured and simulated vibration results on y-axis for case 3. In case 3, when the mass attached to power tool is 2 kg, the value of Pearson Correlation Coefficient on z and y-axis still are higher positive number, that are 0.76 and 0.74 respectively. Since that value of Pearson

Correlation Coefficient are nearer to +1, which is positive correlation or strong positive relationship between measured and simulated vibration results [17]. It means that when the value of measured vibration acceleration increased, the value of simulated vibration acceleration also increased. Otherwise, when the value of measured vibration acceleration decreased, the value of simulated vibration acceleration also has decreased.

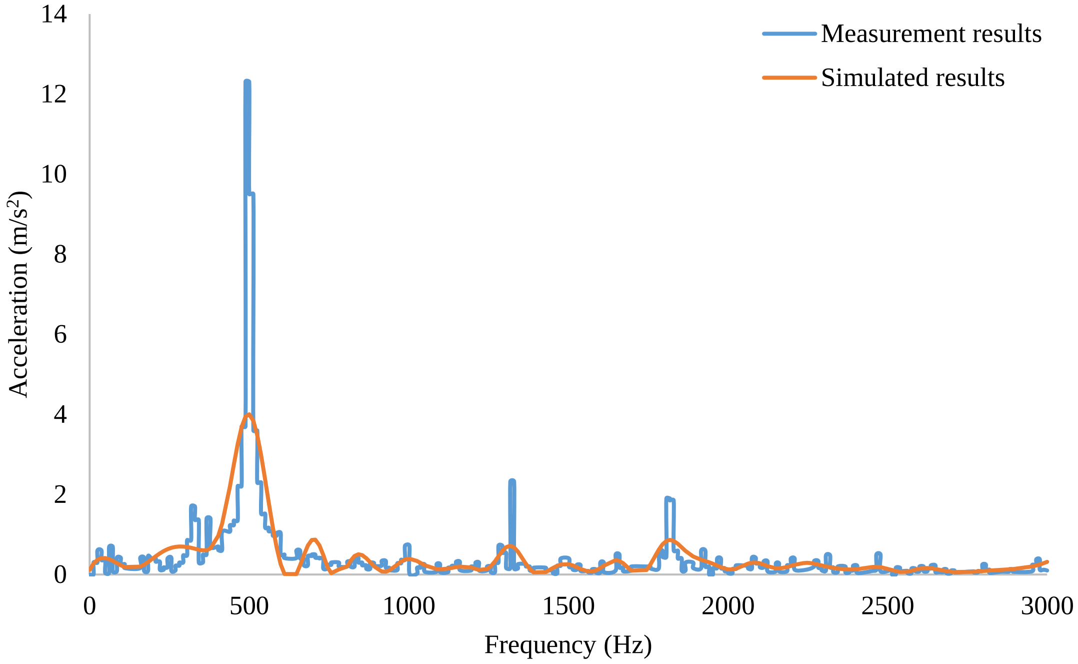

Figure 11. Acceleration vs frequency for measurement and simulated vibration results on z-axis for case 3.

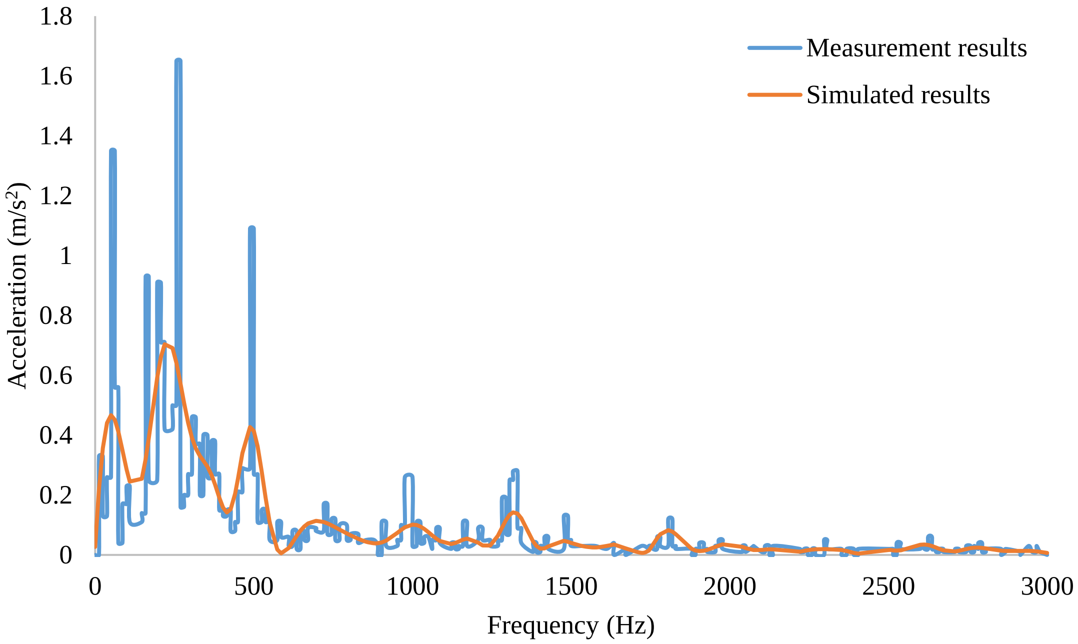

Figure 12. Acceleration vs frequency for measurement and simulated vibration results on y-axis for case 3.

CONCLUSION

In conclusion, the vibration level of power tool has been reduced after considering the effect of mass. When the mass is not attached to power tool, on z and y-axis, the value of peak acceleration at frequency of 500 Hz is found as the highest. Hence, the mass block has attached to power tool for decreasing the value of peak acceleration at 500 Hz. For z-axis, when mass of 2 kg attached to power tool, the percentage of vibration reduction is 48.7 % at frequency of 500 Hz. However, on y-axis, the percentage of vibration reduction is almost 100 % at frequency of 500 Hz. Thus, when manufacturing company is designing new power tool, they can increase the mass of internal components of power tool to reduce vibration level of power tool to greatest extent. However, the mass of power tool should not be high, because it is important to avoid worker had muscle fatigue when used power tool for longer period of handling the tool.

Furthermore, after collecting vibration measurement results, MATLAB software was used to predict new vibration results. After conducting analysis by using MATLAB software, new vibration results were predicted which is smoother than measured vibration results. On the whole, simulated vibration results gain lower acceleration amplitude compared to the measured vibration results. Besides that, measured and simulated vibration results show that the resonance did not happen when external excitation frequency lower or higher than specific natural frequency. Thus, this neural network model was developed in this study is considered reliable and can applied in design of mechanical and electrical component of power tool in future.

The simulation was validated with the measurement results through regression correlation method to evaluate the possible linear relationship between the two results. From all three cases, it appears that the Pearson Correlation Coefficient attained were ranging from 0.69 to 0.81, which was greater than 0.5. Thus, this proof a strong positive relationship between the measured and simulated vibration results existed.

ACKNOWLEDGEMENT

The authors grateful for the lab assistance, colleagues who are willing to share their opinion and School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP) for providing the equipment and environment during this research.

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