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Vibration reduction of pneumatic percussive rivet tools: Mechanical and ergonomic re-design approaches

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ABSTRACT

This paper presents a systematic design approach, which is the result of years of research effort, to ergonomic re-design of rivet tools, i.e. rivet hammers and bucking bars. The investigation was carried out using both ergonomic approach and mechanical analysis of the rivet tools dynamic behavior. The optimal mechanical design parameters of the re-designed rivet tools were determined by Taguchi method. Two ergonomically re-designed rivet tools with vibration damping/isolation mechanisms were tested against two conventional rivet tools in both laboratory and field tests. Vibration characteristics of both types of tools were measured by laboratory tests using a custom-made test fixture. The subjective field evaluations of the tools were performed by six experienced riveters at an aircraft repair shop. Results indicate that the isolation spring and polymer damper are very effective in reducing the overall level of vibration under both unweighted and weighted acceleration conditions. The mass of the dolly head and the housing played a significant role in the vibration absorption of the bucking bars. Another important result was that the duct iron has better vibration reducing capability compared to steel and aluminum for bucking bars. Mathematical simulation results were also consistent with the experimental results. Overall conclusion obtained from the study was that by applying the design principles of ergonomics and by adding vibration damping/isolation mechanisms to the rivet tools, the vibration level can significantly be reduced and the tools become safer and user friendly. The details of the experience learned, design modifications, test methods, mathematical models and the results are included in the paper.

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1. Introduction

The rivet hammer and bucking bar are a set of power tools commonly used for aircraft, ship, and heavy vehicle construction. During the operation, high vibration levels are generated by repetitive movements of a piston, and are transmitted to the operator's hand–arm system. Transmitted vibration could lead to upper-extremity disorders, commonly called, hand–arm vibration syndrome (Taylor et al., 1975; Taylor, 1982; Farkila, 1980; Radwin and Armstrong, 1985; Griffin, 1990; O'Connor and Lindquist, 1990; Pelmear et al., 1992). Impulsiveness of vibration of rivet tools is another factor that plays a key role in the development of vibration-related syndromes (Engstrom and Dandanell, 1986; Yu et al., 1986; Nelson and Griffin, 1989; Dart, 1946; Taylor et al., 1974; Starck and Pyykko, 1986).

The operation of the percussive rivet hammers is very different from the operation of compression riveters or other pneumatic hand tools, such as chipping-hammers or grinders. The riveting task is accomplished by pressing the rivet set of the rivet hammer against the tail side of the rivet while the bucking bar is pressing on the head of the rivet as shown in Fig. 1, where the installed instruments are also presented. As the trigger of the rivet hammer is pressed, the rivet set is continuously hit by a reciprocating piston within the rivet hammer. The duration of this operation lasts from less than 0.5 to 1 s depending on the diameter of the rivet, the length of the rivet and the type of the rivet hammer.

Two common design techniques to reduce vibration transmissibility of vibrating tools are (1) designing tools with damping mechanism, and (2) designing anti-vibration gloves or vibration absorbing handles (ILO, 1998). The results of the studies on glove design are somewhat conflicting. Some researchers reported significant vibration attenuation (Goel and Rim, 1987; Huuton et al., 1993; Klinenberg et al., 1994), while others reported none or little changes (Rens et al., 1987), even an increase in transmissibility (Griffin et al., 1982; Rens et al., 1987). Hence, tool

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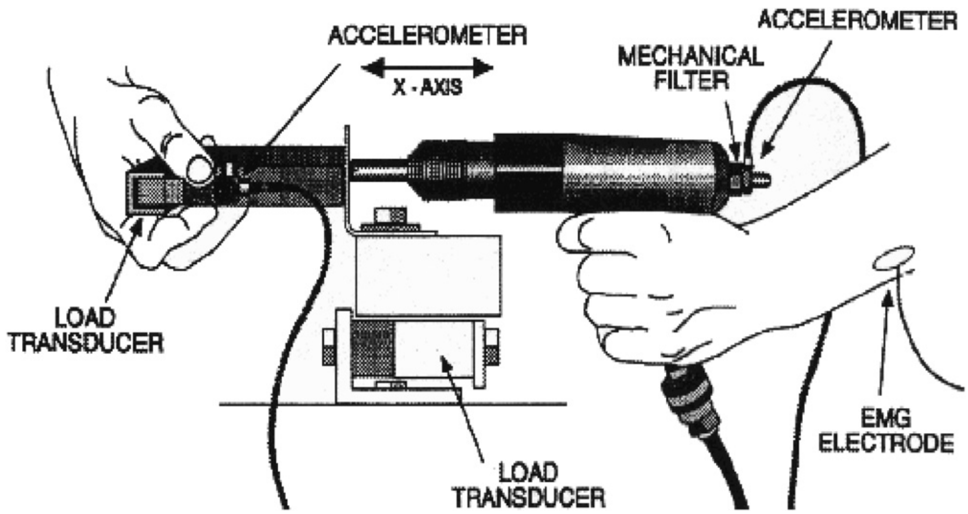

Fig. 1. Schematics of riveting operation.

manufacturers recently intensified their efforts on designing 'vibration-damped' rivet hammers and bucking bars.

It has been found that very little work has been done in the tools' mechanical aspects such as the design of percussion mechanism, the mathematical optimization of the tool, force and acceleration modeling, etc. Therefore, the objectives of the present study were to

1. investigate the possibility of reducing the vibration of rivet tools by applying the principles of vibration isolation, damping, and ergonomic design;
2. develop mathematical models to simulate the hammering forces and the bucking bar;
3. optimize the design parameters of the rivet hammer using design of experiment method such as Taguchi method; and
4. validate the re-designed rivet hammers and bucking bar both in laboratory test and field evaluation.

2. Operation characteristics and measuring method

The vibration generated by rivet tools is a series of periodic impulsive accelerations as shown in Fig. 2. Both signals from the rivet hammer and the bucking bar are sharp impulsive oscillations and the duration was less than 0.4 s in a 0.5 s time record window.

These highly impulsive and short-duration vibration signals present quite a challenge for proper data acquisition and spectral analysis. The signal diminished before the end of time block window, which generates large leakage errors, are not acceptable for an accurate measurement. A post-transient window should be used to reduce the leakage to the minimum as shown in Fig. 3.

ISO Standard 5349 (1986) requires that the measured acceleration be weighted and analyzed in a one-third octave spectrum from 0 to 1250 Hz as given in the following equation:

$$\text{Averaged acceleration} = \sqrt{\sum_{i=1}^{n}(\omega_i a_i)^2}, \tag{1}$$

where n is the number of one-third octave bands, ω_i is the weighting factor for the frequency and a_i is the acceleration at the one-third octave frequency.

In order to resolve the low resolution in low frequency for converting from FFT (fast Fourier transform) spectrum to one-third octave spectrum, two FFT analyzers in parallel should be used. One analyzer is set at 400 Hz with frequency resolution at 0.5 Hz and the other one is set at 1600 Hz with frequency resolution at 2 Hz. After the conversion of both the spectra, the two converted spectra are combined into a complete one-third octave spectrum from 0 to 1250 Hz.

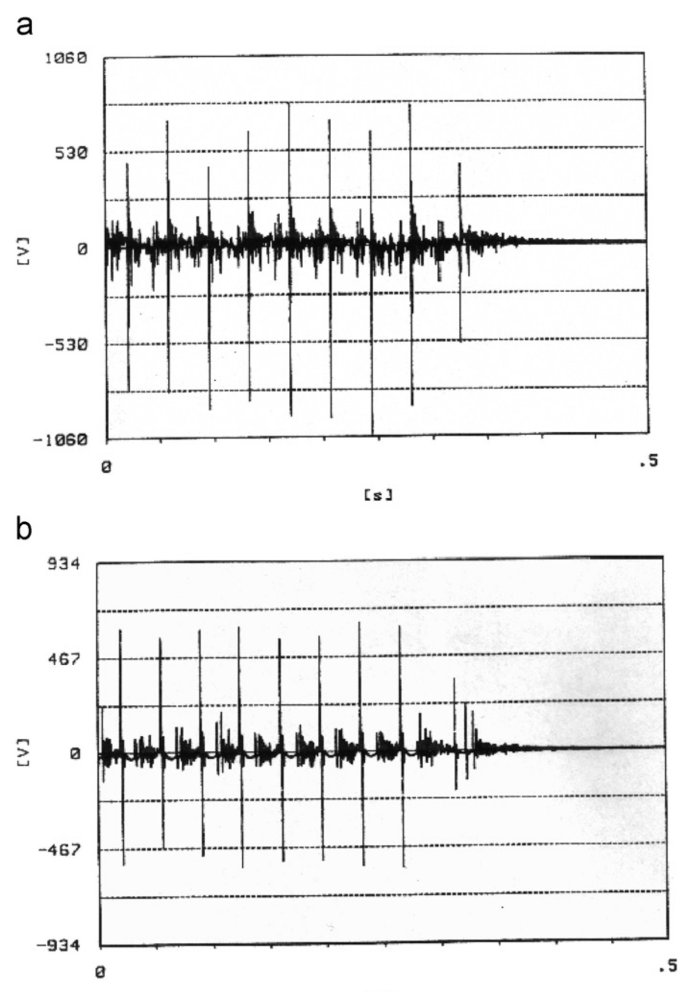

Fig. 2. Time signals of rivet hammer and bucking bar. (a) Time Signal of a Rivet Hammer and (b) Time Signal of a Bucking Bar.