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The effects of feed force on rivet bucking bar vibrations

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ABSTRACT

Percussive riveting is the primary process for attaching the outer sheet metal “skins” of an aircraft to its airframe. Workers using manually-operated riveting tools (riveting hammers and rivet bucking bars) are exposed to significant levels of hand-transmitted vibration (HTV) and are at risk of developing components of hand-arm vibration syndrome (HAVS). To protect workers, employers can assess and select riveting tools that produce reduced HTV exposures. Researchers at the National Institute for Occupational Safety & Health (NIOSH) have developed a laboratory-based apparatus and methodology to evaluate the vibrations of rivet bucking bars. Using this simulated riveting approach, this study investigated the effects of feed force on the vibrations of several typical rivet bucking bars and that transmitted to the bucking bar operator's wrist. Five bucking bar models were assessed under three levels of feed force. The study results demonstrate that the feed force can be a major influencing factor on bucking bar vibrations. Similar feed force effects were observed at the bucking bar operator's wrist. This study also shows that different bucking bar designs will respond differently to variations in feed force. Some bucking bar designs may offer reduced vibration exposures to the bar operator's fingers while providing little attenuation of wrist acceleration. Knowledge of how rivet bucking bar models respond to riveting hammer vibrations can be important for making informed bucking bar selections. The study results indicate that, to help in the appropriate selection of bucking bars, candidate bar models should be evaluated at multiple feed force levels. The results also indicate that the bucking bar model, feed force level, or the bucking bar operator have no meaningful effects on the vibration excitation (riveting hammer), which further suggests that the test apparatus proposed by NIOSH researchers meets the basic requirements for a stable vibration source in laboratory-based bucking bar vibration assessments. This study provides relevant information that can be used to help develop a standardized laboratory-based bucking bar evaluation methodology and to help in the selection of appropriate bucking bars for various workplace riveting applications.

Relevance to Industry: Because the feed force level can affect HTV exposures to bucking bar operators, the feed force required for specific riveting operations should be an important consideration when selecting bucking bar models. This study provides useful information about bucking bar responses to riveting hammer vibrations; this knowledge can improve bucking bar selections.

1. Introduction

In the aerospace industry, percussive riveting is the primary process for attaching the outer sheet metal “skins” of an aircraft to its airframe during assembly and maintenance. Millions of rivets are required to attach the skin sections of a large continental aircraft; even a small, regional airplane or fighter aircraft requires hundreds of thousands of rivets (Campbell, 2006; Xi et al., 2013). Some aircraft riveting is accomplished using automated and semi-automated riveting machines, but due to the size and restricted maneuverability of these robotic devices, such automated processes are usually limited to large, flat substructures (Xi et al., 2013). For access to tighter spaces and for more complex sub-assembly shapes, a manual riveting process is often used. In the typical manual riveting process, metal rivets are individually-inserted into sheet metal with pre-drilled and countersunk holes. An operator uses a riveting hammer to sequentially set each rivet as it is driven against a metallic bucking bar held by a second tool operator positioned on the opposite side of the airframe (see Fig. 1). Even in this age of advanced robotics and innovative materials, this manual process still represents the principal method for fastening sheet metal skins to the frames of commercial and military aircraft throughout the world (Jorgensen and Viswanathan, 2005; Campbell, 2006; Cheraghi, 2008).

Workers using manually-operated riveting tools are exposed to significant levels of hand-transmitted vibration (HTV), and exposures to percussive HTV among riveters has become a major occupational health concern. Studies have shown that pneumatic percussive riveting

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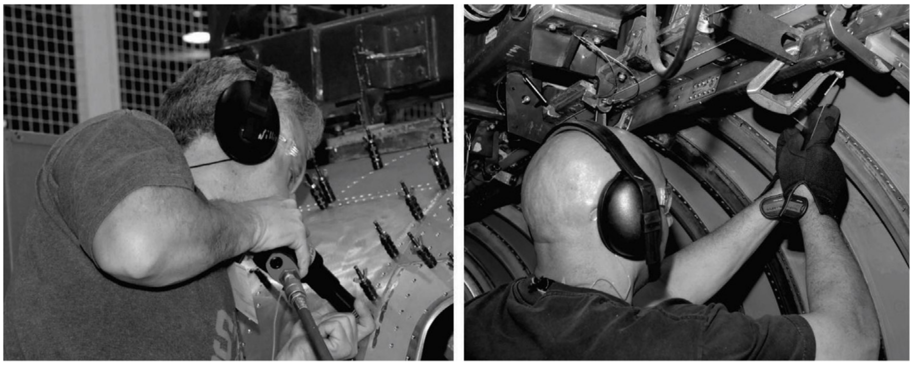

Fig. 1. Manual percussive riveting of aircraft sheet metal skins requires two riveting tool operators; one worker operates the riveting hammer (left) on the exterior surface of the assembly, while a second worker operates the bucking bar (right) on the interior of the airframe. The riveting hammer delivers a rapid series of impacts while the bucking bar supplies the opposing force. The metal rivet is mechanically deformed and work-hardened between the two riveting tools to securely fasten the sheet metal to the airframe.

hammers can produce high vibration magnitudes (Dandanell and Engstrom, 1986; Burdorf and Monster, 1991; McDowell et al., 2012). This percussive vibration can be effectively transmitted to the hands and fingers of the riveting hammer and bucking bar operators (Kattel and Fernandez, 1999). Riveting-induced HTV has been associated with the development of components of hand-arm vibration syndrome (HAVS) such as vibration white finger (VWF) (Yu et al., 1986; Burdorf and Monster, 1991). It has been reported that in some occupational environments, perhaps more than 50% of riveting tool operators could exhibit symptoms of HAVS within the first decade of their careers (Engström and Dandanell, 1986; Burdorf and Monster, 1991). Combinations of intensive HTV exposures, forceful exertions, repetitive actions, and awkward hand and finger postures may leave bucking bar operators especially vulnerable (McKenna et al., 1993; Fredericks and Fernandez, 1999). These ergonomic factors could also be connected with increased incidences of carpal tunnel syndrome and other hand and wrist musculoskeletal disorders among sheet metal workers (Burdorf and Monster, 1991; NIOSH, 1997). The underlying biomechanics involved in the development of HAVS are largely unknown, but several studies have implicated percussive HTV in the etiology of the syndrome. In a study using a rat-tail model, Govinda Raju et al. (2011) concluded that percussive vibrations designed to simulate rivet bucking bar HTV exposure may cause severe nerve damage. Krajnak et al. (2013) also reported that impact vibration may adversely affect peripheral nerves. Percussive HTV has also been associated with damage to joint cartilage (Gemne and Saraste, 1987). Exposures to rivet bucking bar vibrations have also been linked to acute vascular effects in workers (McKenna et al., 1993). Further, impulse vibrations have been shown to cause damage to red blood cells in vitro (Ando et al., 2005).

Because of the strong association between percussive HTV exposures and the above-mentioned health concerns, it has become accepted practice at many workplaces to develop HTV exposure control strategies in efforts to help minimize the potential for harm. In many parts of the world, employers are required by law to implement HTV exposure control programs (EU Directive, 2002). Guidelines and/or requirements for HTV control programs are found in national and international standards for assessing and controlling occupational HTV exposures; most of these HTV exposure standards incorporate aspects of the International Organization for Standardization (ISO) standards for measuring and assessing HTV exposures (ISO 5349-1, 2001a; ISO 5349-2, 2001b). In the European Union, EU Directive 2002/44/EC on human vibration exposure requires that HTV exposure assessments be conducted in accordance with these ISO standards (EU Directive, 2002). The EU Directive also specifies a daily Exposure Action Value (EAV) and a daily Exposure Limit Value (ELV). These values represent the upper boundaries on the daily HTV exposure values normalized to an 8-h work shift. In the U.S., provisions of the EU Directive including the EAV and ELV are repeated in the U.S. HTV exposure standard (ANSI S2.70, 2006).

Responsibility for HTV exposure control typically falls on the employer, and the above-mentioned national and international standards form the foundation for most employer's HTV control programs. The standards instruct employers to first focus on reducing HTV at the source (EU Directive, 2002; ANSI S2.70, 2006), so it is typical for employers to implement practices for identifying and selecting powered hand tools that generate reduced HTV exposures. The SAE International Aerospace Standard AS6228 (SAE, 2014) provides technical guidance for power hand tool selection which includes evaluations of life-cycle cost, productivity, and safety/health factors, including HTV exposures. In order to compare tool models based on their vibration emissions, the tools should be assessed while they are challenged under comparable operating conditions. Ideally, the tools should be assessed while being operated during the actual work tasks for which they are intended to be used. However, it is usually very difficult to maintain consistent trial-to-trial tool loading conditions in workplace environments. Such systematic workplace tool vibration assessments may also be time-consuming and expensive; obtaining statistically-reliable tool model comparisons usually requires many tool operators due to potentially-large intra-operator and inter-operator variations. The costs increase substantially when multiple tool models are involved in the tool assessments. Alternatively, tool vibration comparisons can be conducted in a laboratory using a simulated workstation whereby different tools can be tested under comparable tool loading conditions. While not suitable for assessing workplace vibration exposures, laboratory testing can be used for initial screenings to predict which tool models might be expected to produce lower vibration exposures in the workplace. To standardize such tool assessments and to make inter-laboratory results directly comparable, the ISO has developed the ISO 28927 series of laboratory-based tool vibration testing standards. These standards are intended to be used for comparing tools according to their tool handle vibrations. These standards prescribe the postures and loading conditions under which the tools will be evaluated. For example, Part 10 of this series (ISO 28927-10, 2011) pertains specifically to chipping hammers and riveting hammers. Researchers at the U.S. National Institute for Occupational Safety & Health (NIOSH) found that ISO method is acceptable for identifying riveting hammers that could be expected to exhibit lower vibrations in workplace environments (McDowell et al., 2012). Unfortunately, there is no standardized method for comparing rivet bucking bars in terms of their vibration exposures. To that end, a recent NIOSH study included the development of a laboratory-based method for evaluating bucking bar vibrations (McDowell et al., 2015). That study found that the NIOSH test method shows promise for identifying rivet bucking bar designs that may reduce workplace HTV exposures to sheet metal workers, but the bucking bar test method is in need of some refinements.

One refinement to the bucking bar test being explored requires an examination of the effect of feed force on the measured vibration. The level of hand forces applied to a vibrating tool by the tool operator has been shown to affect the HTV exposure, so the control of feed force has traditionally been included in standardized laboratory-based tool vibration assessments (e.g., ISO 8662-2, 1992; ISO 8662-7, 1997). Many studies have indicated that increasing the hand forces applied to a tool