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– Abstracts –

A Comparison of Three Bucking Bar Handles: Vibration Measured at the Tool Interface and Transmitted to the Hand, Forearm and Shoulder

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Introduction

Aircraft production is central to meeting transportation, governmental and military needs; however, manufacturing airplanes does not come without consequences because each airplane requires an intensive amount of manual labor. Some of the manufacturing processes require riveting and bucking bar work, which produces impulsive vibration exposures, which are transmitted into the hands, forearms and shoulders. Performing bucking and riveting tasks every day may expose workers to potentially harmful levels of vibration, therefore both administrative and engineering controls are needed to reduce the risks for vibration-related injuries to the upper extremities.

The objective of this study was to instrument a bucking bar with three different handles and measure the vibrations transmitted from the handle of the bucking bar to the operators' hands, forearms and shoulders. The goal was to determine whether there were differences in vibration exposures across the three different bucking bar handles, and whether there were handle-related differences in the amount of acceleration transmitted through the operators' upper extremities. In addition, a wrist-worn device was used to characterize vibration exposures. This wrist-mounted device was designed to capture and estimate the tool-born exposures occurring at the hand.

Methods

Testing was conducted using the automated test bench located in the Boeing Advanced Research Center (BARC) located on the University of Washington campus in Seattle, Washington. Using two experienced mechanics, who were both right handed, three bucking bar handles were evaluated: 1) a typical 0.14 Kg plastic bucking bar handle (P), 2) similarly designed 0.66 Kg handle with a steel core and a built-in spring (SS), and 3) a similarly designed 0.29 Kg handle with an aluminum core and the same built-in spring as the steel-core handle (AS). These handles were affixed to a 4140-steel bucking bar with a 5 x 5 cm square face, that was 17.8 cm long and weighed 2.8 kg. This was a representative bucking bar used in plane fuselage riveting.

The BARC automated test bench was used to hold the rivet gun (Model AC-10P; Atlas Copco, Stockholm, Sweden) and controlled factors such as rivet gun position, trigger pull duration, and push force. On the other side of the test bench, the mechanics used the bucking bars to form a series of rivets with each of the three bucking bar handles. To replicate riveting, a 15.2 x 28.1 x 5 cm thick rectangular sheet of 2325-T-39 fuselage aluminum, with twelve evenly spaced 0.55 cm holes, was used to receive the 12 rivets.

To measure the bucking bar handle vibrations, a ±5000 g, 2 - 4000 Hz, triaxial accelerometer (Model SEN040, Larson Davis; Depew, NY) was rigidly affixed to the bucking bar handle and collected the vibration at 20K Hz. To measure the vibrations transmitted through the operators' right arms, 3.4 x 2.2 x 0.9 cm triaxial inertial measurement units (IMUs) were mounted to the back of the hand, middle of the forearm and middle of the upper arm with a double-sided medical tape. The battery powered IMUs (Model AX-3; Axivity Ltd; Newcastle upon Tyne, UK), had 512 Mb of internal memory, a ±16 g's measurement range, a bandwidth of 0 – 1000 Hz and collected the vibration data at 3200 Hz. Finally, a wrist-worn accelerometer device (HavWear, Reactec, Edinburgh, UK) was secured to the right wrist of the subjects. This wrist-mounted device, through the use of a transfer function, was designed to capture and estimate the ISO 5349-1 [1] tool-born exposures occurring at the hand.

With the exception of the HavWear device, all the acceleration data were analyzed employing the *Wh* filter as outlined un the ISO 5349-1 standard [1]. For the rivets formed with each bucking bar and handle, the twelve, short 0.6 to 1 second riveting episodes were analyzed, subject averages were calculated from the twelve riveting episodes and the group averages were calculated for each handle condition. The HavWear device, using its proprietary transfer function, calculated the vibration exposure based on the vibration data collected between the start and end of each riveting task. The operators would scan an RFID chip HavWear device to indicate the beginning and end of using each bucking bar handle. With all the devices, the tool averages were based on the mean of the two subjects. Due to the small sample size, no inferential statistical analyses were performed and general trends were compared across the bucking bars and measurement locations.

Results

As shown in Table 1 there were differences in the vibration magnitudes measured across the three bucking bar handles. In addition, the differences in the vibration magnitudes measured across the bucking bar handles were consistent and present across the three locations measured from the right arm. The plastic bucking bar handle (P) had the highest vibration magnitudes, the aluminum-core bucking bar handle with the spring (AS) had intermediate vibration magnitudes, and the steel-core bucking bar handle with the spring (SS) had the lowest vibration magnitudes.

Table 1 also shows that there was a relatively good correspondence between the vibration magnitudes measured at the bucking bar handle and the tool-measured vibration magnitudes estimated by the wrist mounted HavWear device.

Table 1: Mean (standard error) vector sum accelerations in m/s^2 measured at the various locations using the three different bucking bar handles. (n = 2)

Handle Type	Bucking Bar	Hav Wear	Hand	Fore-Arm	Upper Arm
P	23.6 (1.0)	26.6 (5.6)	17.9 (1.1)	16.5 (3.2)	11.3 (0.5)
AS	19.1 (3.2)	21.7 (4.8)	13.8 (2.9)	12.0 (2.2)	7.2 (1.8)
SS	14.5 (2.4)	14.8 (4.8)	10.5 (2.0)	8.8 (0.7)	4.8 (0.3)

Table 2 shows the percentage of the vibration exposure measured at the bucking bar handle transmitted through the upper extremities. As shown in Table 2, the bucking bar with the plastic handle (P) transmitted a greater percentage of vibration through the upper extremities when compared to the spring-loaded bucking bar handles (AS and SS). In addition, a fair amount of vibration energy from the bucking bar handle was transmitted through the right arm. Ranging from 72 - 77% transmitted through the hand to 34 – 49% transmitted to the upper arm.

Table 2: Mean (standard error) percentage of bucking bar measured vibration transmitted through the upper extremities. (n = 2)

Handle	Bucking Bar	Hand	Fore-Arm	Upper Arm
P	1.00	0.77 (0.01)	0.71 (0.11)	0.49 (0.00)
AS	1.00	0.72 (0.03)	0.63 (0.01)	0.37 (0.03)
SS	1.00	0.72 (0.02)	0.62 (0.05)	0.34 (0.03)

Discussion

Based on the initial results from this small pilot study, the preliminary results demonstrated that different bucking bar handle designs may affect the amount of vibration transmitted into the hand and through the arm of the bucking bar operator. Relative to the bucking bar with the plastic handle (P), on average, the aluminum-core bucking bar handle with the spring (AS) reduced the amount of vibration reaching in the handle of the tool by 19%, and the spring-loaded bucking bar handle made out of steel reduced the vibration measured in the handle by 39%. These handle-related reductions in vibration transmissibility were relatively consistent across the other locations measured from the operators' right arms.

The results also demonstrated that a fair amount of the tool-measured vibration was transmitted through the right arm. On average, 74% of the tool-measure vibration energy reached the back of the hand, 65% of the energy was reached the middle of the forearm and 40% of the energy reached the mid upper arm. Finally, the vibration exposure estimates from the wrist-mounted HavWear device corresponded relatively well with the magnitudes and exposure trends measured from the bucking bars; however, the between subject variability measurements (standard errors) were larger with the HavWear device.

Altering the bucking bar handles to contain a spring to absorb vibration appears to be an effective engineering control to reduce the vibration exposures the tool operators experience in the right hand, arm and shoulder. The vibration exposure levels measured were high and an overestimate of the true exposures. This was due to the analysis focusing on the riveting episodes only, and not accounting for the idle time between rivets. During actual manufacturing, there would be a greater amount of idle time between riveting episodes and the calculated vibration exposures would be lower. A limitation was all devices were evaluated with only two subjects, and studying a larger group of subjects would be merited to have greater confidence in the measurements and trends observed in this pilot study

Besides engineering controls, administrative controls are likely to be of utility for reducing and/or balancing out hand-arm vibration exposures across workers. In addition, vibration is not the only physical agent that may be contributing to these vibration-related disorders. There are high forces with bucking bar and riveting activities and characterizing these forces with load cells on the tools and/or using electromyography to measure muscle activity in the upper extremities may be merited.

Finally, based on this preliminary analysis of bucking bar activity, the HavWear device seemed to be relatively accurate in estimating characterizing the bucking bar-born exposures. This fairly non-invasive tool can be used to estimate full day and multi-day, longitudinal exposures across groups of workers. With the relatively inexpensive and minimally invasive capture of full day, longitudinal vibration exposures across large groups of workers, this device may have the potential to better estimate and/or determine the causality of tool-related vibration-induced injuries, and potentially be used as an administrative tool to measure and distribute exposures across a group of workers.

Conclusions

Different bucking bar handle designs may affect the amount of vibration transmitted to the hands and through the upper extremities of bucking bar operators. Both engineering and administrative controls should be pursued to reduce and more efficiently distribute vibration exposures across groups of workers

References

[1] International Organization for Standardization. (2001), ISO 5349-1:2001 Mechanical vibration -- Measurement and evaluation of human exposure to hand-transmitted vibration -- Part 1: General requirements

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