Applied Ergonomics 43 (2012) 1051–1057

Contents lists available at SciVerse ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Ergonomic analysis of fastening vibration based on ISO Standard 5349 (2001)

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ARTICLE INFO

Article history:
Received 3 February 2010
Accepted 16 March 2012

Keywords:
Fastening
Vibration
Posture

ABSTRACT

Hand-held power tools used for fastening operations exert high dynamic forces on the operator's hand-arm, potentially causing injuries to the operator in the long run. This paper presents a study that analyzed the vibrations exerted by two hand-held power tools used for fastening operations with the operating exhibiting different postures. The two pneumatic tools, a right-angled nut-runner and an offset pistol-grip, are used to install shearing-type fasteners. A tri-axial accelerometer is used to measure the tool's vibration. The position and orientation of the transducer mounted on the tool follows the ISO-5349 Standard. The measured vibration data is used to compare the two power tools at different operating postures. The data analysis determines the number of years required to reach a 10% probability of developing finger blanching. The results indicate that the pistol-grip tool induces more vibration in the hand-arm than the right-angled nut-runner and that the vibrations exerted on the hand-arm vary for different postures.

1. Introduction

Fastening is one of the major operations on any manufacturing or assembly plant's shop floor. Due to the poor design of the workplace or of the fastening tool itself, the operator is often at risk of getting injured. These injuries, which are mostly musculoskeletal in nature, can lead to both direct and indirect losses to companies. It is well known that an injured worker will not be able to contribute optimum performance, thus, quality and productivity losses will be experienced. The direct losses are a result of man-hours lost due to the injured worker as well as material losses due to faulty jobs. The indirect losses are incurred due to inspection costs and worker compensation.

Ergonomic injuries can be caused by a variety of factors that fall into two categories: work related and non-work related (Griffin, 1990). Work-related factors include tool vibrations (Brammer, 1986; Griffin, 1990, 1994), external forces applied on the operator's hand-arm (Lin et al., 2003; NIOSH, 1997), repetition of the operation, and awkward body postures (NIOSH, 1997). Non-work-related factors include personal habits, such as smoking and sport activities. In the case of fastening operations, the impact delivered to the operator's hand-arm due to a part of the fastener shearing-off when the fastener reaches the end of its travel can cause significant vibration. The tools used in normal assembly operations are prone to inducing vibrations in the hand-arm of the operator (Griffin, 1990, 1994; Pelmear and Wasserman, 1998). Additionally, the forces generated by the operator's body in response to the externally imposed forces and those required for controlling the tool at uncomfortable postures make the operator susceptible to various injuries. Postural discomfort can also be attributed to the poor design of workplaces. The high repetition associated with fastening operations due to the large number of fasteners being installed further aggravates the problem of ergonomic injury. It takes millions of fasteners to assemble an aircraft, and it is estimated that nearly 1500 fasteners are installed daily, on average, by an automobile worker (Van Bergeijk, 1991).

Previous tool vibration studies have determined the effect of hand-transmitted vibrations on the human body by using transmissibility (Pyyko et al., 1976; Reynolds and Angevine, 1977) and modeling the response of the hand-arm system using measured compliance/impedance (Reynolds and Falkenberg, 1984). Studies by various researchers have led to the development of the ISO-5349 Standard (Brammer, 1986; Mishoe and Suggs, 1977), which defines the procedure for collecting data on the human body as well as categorizing the vibration effects in terms of susceptibility to development of vibration white finger (VWF), also called Raynaud's disease (ISO-5349, 2001a, b). In general, the vibration response can be categorized using the frequency, amplitude, direction, time of exposure and grip-force (Sorensson and Lundstrom, 1992).

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0003-6870/$ – see front matter
doi:10.1016/j.apergo.2012.03.005

Vibrations transmitted to the hand-arm caused by the use of power tools in fastening operations have been studied before. However, these studies were mostly limited to high-impact operations using tools such as impact wrenches (Bovenzi et al., 1997) and rivet-guns (Burdof and Monster, 1991; Dandanell and Engstrom, 1986; Jorgensen and Muthukurappan, 2005; Kattel and Fernandez, 1999). Typically, these tools have high vibration inputs of about 12 m/s^2 in daily exposure (Burdof and Monster, 1991). However, to our knowledge there has not been any study that analyzed the vibration effects of power tools used for fastening common types of fasteners such as the ones used in this study. There is no vibration data available for an ergonomic analysis of such fasteners as lock nuts, lock bolts and hi-lock bolts used in the aerospace industry.

The present paper describes an investigation of the ergonomic effects of using power tools for fastening operations commonly used in aircraft assembly. The paper describes the experiment for measuring vibration and the analysis used to determine the number of years taken to develop a 10% probability of finger blanching, following the ISO-5349 Standard. The amounts of hand-transmitted vibrations at different postures are measured and compared.

2. Data collection

An experiment was performed with two tools used for fastening shearing-type fasteners. Vibrations were measured at the tool–hand interface in three orthogonal directions using a tri-axial accelerometer at 6 different postures. The experimental setup was built so that vibrations entering the subject's hand-arm at various postures could be measured.

The experimental setup shown in Fig. 1 consists of a fixture rigidly attached to the wall. The fixture was an assembly of two parts, one attached to the wall and the other slid on top of the fixed part. A pre-drilled test plate was mounted on the movable part. A tri-axial accelerometer for vibration measurement was mounted on the tool handle close to the tool–hand interface, as shown in Fig. 2, which indicates the position and orientation of the accelerometer. The position of the accelerometer was in accordance with the ISO-5349 Standard-I (ISO-5349, 2001a).

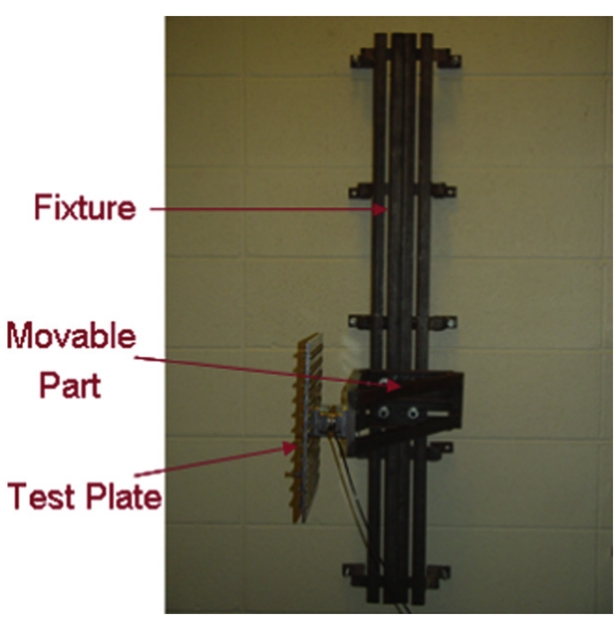

Fig. 1. Experimental setup.

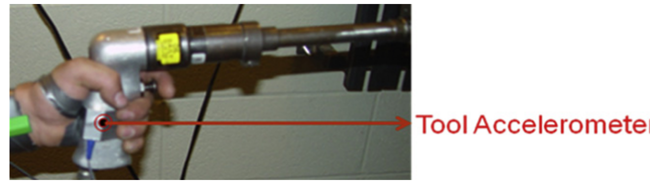

Fig. 2. Position of the accelerometer on the pistol-grip tool.

A twin-axis goniometer measured the angular movement of the wrist joint in flexion–extension and abduction–adduction, a torsiometer measured the twisting of the forearm, and a single-axis goniometer measured the rotational motion of the elbow joint as shown in Fig. 3. For data collection, the accelerometer, goniometers and torsiometer were connected through datalog and datalink units provided by NexGen. The datalink units were connected to a PC, and data acquisition was performed using Matlab software. The vibration data was sampled at 5000 Hz. Each subject performed 6 trials for each tool–posture combination.

Three Missouri S&T students participated in the study as subjects. The two tools used in the study were power tools commonly used for fastening shearing-type fasteners. When fastening these types of fasteners, the collar shears off from the pin at the end of the fastening operation, generating an impact to the subject's hand-arm. The experiment was performed with two tools and 6 postures, as shown in Figs. 4 and 5, respectively.

3. Data analysis

The acceleration data collected as a measure of vibration entering the hand-arm system was analyzed. The root mean square (RMS) acceleration value was calculated, and the obtained RMS value was then frequency weighted to compute the daily vibration exposure. The values of RMS acceleration at different postures for the two fastening tools were compared.

3.1. Root mean square acceleration

Following the ISO-5349 Standard, the RMS value of acceleration was computed for examining the extent of vibration entering the hand-arm system from each tool. The vibrations measured in the three orthogonal directions were combined into a single value using

$$a_{RMS} = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (1)$$

In order to assess the effects of different frequencies on the hand-arm, the RMS acceleration value was frequency weighted according to the ISO-5349-I Standard (SO-5349-I, 2001a). The measured acceleration was first filtered using a band-limiting filter. The lower and upper cut-off frequencies for the filter were 6.3 Hz and 1250 Hz, respectively. The filtered signal was then weighted using the weighting function shown in Fig. 6, which depicts the relative importance of different frequencies in causing vibration-related injuries. The band-limiting filter is given by the transfer function

$$H_b(s) = \frac{4\pi^2 s^2 f_2^2}{\left(s^2 + \frac{2\pi f_1 s}{Q_1} + 4\pi^2 f_1^2\right)\left(s^2 + \frac{2\pi f_2 s}{Q_1} + 4\pi^2 f_2^2\right)} \quad (2)$$

where $f_1 = 6.31$ Hz, $f_2 = 1258.9$ Hz and $Q_1 = 0.71$.

The frequency weighting function is provided by the transfer function