Development of a Low-Cost System to Evaluate Coupling Forces on Real Power Tool Handles

Pierre Marcotte[1], Surajudeen Adewusi[2], and Subhash Rakheja[2]

[1] Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), 505 de Maisonneuve West, Montréal, Québec, Canada, H3A 3C2

[2] CONCAVE Research Center, Concordia University, Montréal, Québec, Canada, H3G 1M8

1. INTRODUCTION

Risk assessment of hand-arm vibration is currently performed following the guidelines of the ISO 5349-1 (2001) standard, by applying a frequency weighting on the measured tool handle acceleration. However, it is known that the health risks associated to hand-arm vibration also depend on the static coupling forces such as the push and grip forces applied on the handle. Indeed, several studies have shown that vibration absorbed and/or transmitted to the hand-arm system depends upon the static coupling forces exerted between the hand and tool handle (Adewusi et al., 2010; Burstrom, 1997; Dong et al., 2004; Kihlberg, 1995; Marcotte et al., 2005). To take into account the effect of the coupling forces when assessing hand-arm vibration exposure, it has been suggested to add a coupling factor to the frequency weighted acceleration (Reidel, 1995). Lemerle et al. (2008) have proposed a system based on a pressure mat to measure the pressure distribution at the hand-handle interface. From the pressure distribution, the static push/pull and grip forces are calculated as defined in the ISO 15230 (2007) standard. In this paper, it is proposed to use a low cost system based on two rigid thin film pressure sensors located on two sections of the handle between the operator hand and the tool handle. It is hypothesized that the grip and push forces can be estimated using two single distributed force sensor elements: one positioned between the palm and the handle and the other between the finger and the handle. The preliminary design and validation for such a system will be presented.

2. METHODS

The proposed system is made of two custom *FlexiForce®* sensors from *Tekscan Inc*. These sensors act as single distributed force sensors and can be trimmed to the desired shape and size. Each sensor is connected through a signal conditioner/amplifier. The sensors are positioned to partially cover the finger and palm sides of the handle, as shown in Figure 1. The coverage of the handle can be optimized in order to maximize the force measured in the axial direction (z_h-axis in this case) while minimizing the force measured in the tangential direction (x_h-axis). Let us define F_1, the force measured by the finger sensor (Sensor 1), and F_2, the force measured by the palm sensor (Sensor 2) It can be shown that the grip (F_g) and push forces (F_p) can be estimated using the following equations:

$$F_p = F_2 - F_1 \quad (1)$$

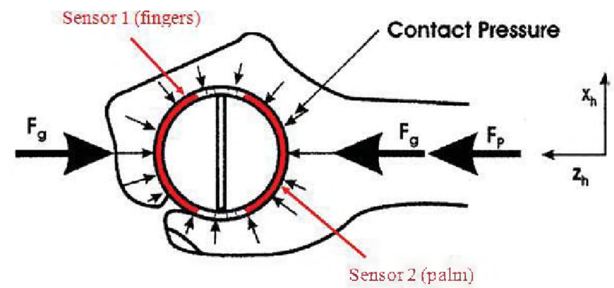

Figure 1. Schematic of the proposed system to measured the grip and push forces.

$$F_g = ½ (F_1 + F_2 - | F_2 - F_1 |) \quad (2)$$

Where | A | denotes the absolute value of A. A negative value for F_p indicates a pulling rather than a pushing force.

2.1. Calibration of the Sensor on a Flat Surface

The sensors with its amplifier were first calibrated on a flat surface by applying a force distributed over its entire area. The static forces were applied with a digital force gauge to values between 20 and 200 N with increment of 10 N. Three loading and unloadings were performed in order to evaluate the linearity and repeatability of the sensor.

2.2. Validation of the Sensor on an Instrumented Handle

The second test was performed on a split cylindrical handle having a diameter of 40mm. The handle is mounted on a shaker and is instrumented to measure the grip and push forces (Marcotte et al., 2005). Two *Flexiforce* sensors were attached to the handle with double sided tape as in the configuration shown in Figure 1. Four male subjects were asked to apply grip force to the handle from 10 to 80 N, with increment of 10 N. Each subject repeated the measurements three times. The process was then repeated for push forces applied to the handle from 10 to 80 N, with increment of 10 N. The grip and push forces were measured by the force sensors integrated in the instrumented handle.

3. RESULTS

3.1. Calibration of the Sensor on a Flat Surface

The outputs of the sensor, as a function of the force applied on the pressure sensor on a flat surface, are shown in Figure 2 for three trials in loading conditions (applied force is gradually increased). Linear correlation coefficients

(R^2) slightly above 0.99 were obtained for each of the three trials, confirming the linearity of the sensor. Similar results were obtained while unloading the sensor (not shown here) suggesting minimal hysteresis.

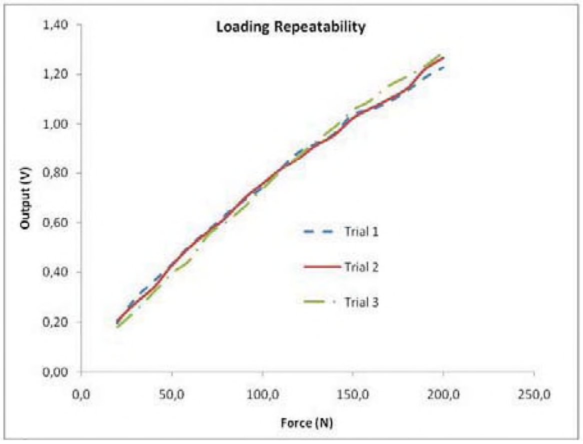

Figure 2. Output signal from the sensor as a function of the applied force: loading on a flat surface.

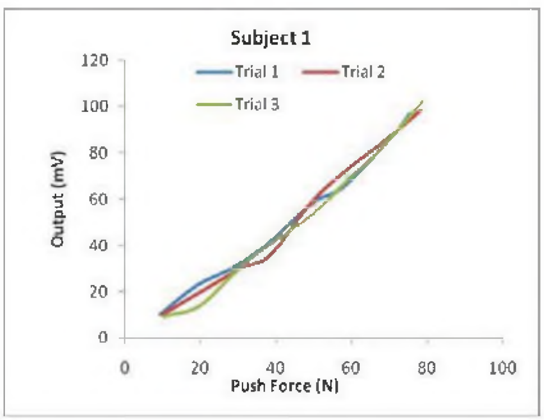

Figure 3. Output signal from the sensor on the palm side as a function of the measured push force on the handle.

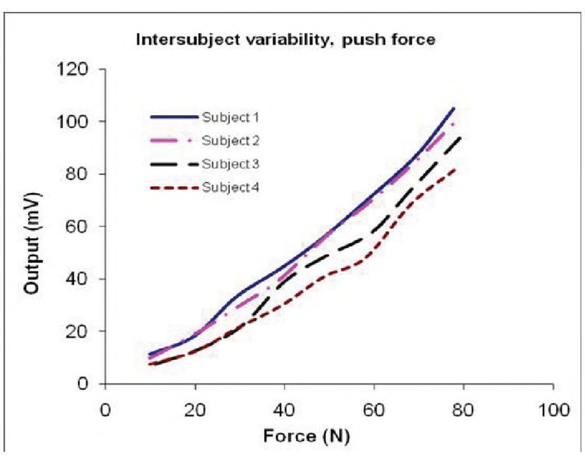

Figure 4. Intersubject variability for the push force measurement.

3.2. Validation of the Sensor on an Instrumented Handle

Figure 3 shows the palm sensor responses, as a function of push force applied by one of the subjects for three different trials. Linear correlation coefficients slightly above 0.98 were achieved for all three trials. However, some subjects have achieved lower linear correlation coefficients (0.93 and above). Similar results were obtained for the grip force (not shown here), using the finger sensor.

For each subject, the data of the three trials were averaged and are shown in Figure 4 for the push force. The Figure shows limited inter-subject variability for the push force. Similar results were obtained for the grip force (not shown here). These results suggest the proposed sensor could be of interest to estimate the grip and push forces on real handles.

4. DISCUSSION AND CONCLUSIONS

A low cost sensor based on thin *FlexiForce®* sensors has been proposed and validated. Preliminary results suggest that the new sensor is suitable to estimate the grip and push force on a cylindrical handle.

REFERENCES

Adewusi, S. A., Rakheja, S., Marcotte, P., and Boutin J. (2010). "Vibration transmissibility characteristics of the human hand-arm system under different postures, hand forces and excitation levels," J. Sound Vib., **329**(14), 2953-2971.

Burström L. (1997). "The influence of biodynamic factors on the mechanical impedance of the hand and arm," Int. Arch. Occup. Environ. Health, **69,** 437–446.

Dong, R. G., Welcome, D. E., McDowell, T. W., Wu, J. Z. (2004). "Biodynamic response of human fingers in a power grip subjected to a random vibration," J. Biomechanical Eng., **126**(4), 447-457.

ISO 5349-1 (2001). *Mechanical vibration and shock – Measurement and evaluation of human exposure to mechanical vibration – Part 1: General requirements* (International Organization for Standardization, Geneva).

ISO 15230 (2007). *Mechanical vibration and shock – Coupling forces at the man-machine interface for hand-transmitted vibration* (International Organization for Standardization, Geneva).

Kihlberg S. (1995). "Biodynamic response of the hand-arm system to vibration from an impact hammer and a grinder," Int. J. Ind. Ergon., **16,** 1-8.

Lemerle, P., Klinger, A., Cristalli, A., and Geuder, M. (2008). "Application of pressure mapping techniques to measure push and gripping forces with precision," Ergonomics **51**(2), 168-191.

Marcotte, P., Aldien, Y., Boileau, P.-É., Rakheja, S., Boutin, J. (2005). "Effect of handle size and hand-handle contact force on the biodynamic response of the hand-arm system under zh-axis vibration," J. Sound Vib., **283**, 1071-1091.

Reidel, S. (1995). "Consideration of grip and push forces for the assessment of vibration exposure," Central European Journal of Public Health, **3,** 139-141.