

A PRELIMINARY STUDY OF THE RELATIONSHIP OF HAND GRIP AND PUSH FORCES TO TOTAL COUPLING FORCES

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Abstract

The coupling force at the hand-handle interface is measured using a capacitive thin-film pressure-sensing grid. The measured data acquired for a 40 mm diameter handle and 12 male subjects under different combinations of grip and push forces are analyzed to derive relationships between the coupling, grip and push forces. The measured data are also analyzed to study the variations in the effective contact area as a function of the grip and push forces. The results suggest that the hand-handle contact force can be expressed as a linear combination of grip and push forces, where the contribution of the grip force is considerably larger than that of the push force. The variations in the contact area can be approximated by an exponential function of the grip force. The results of the study suggest that the hand-handle contact force can be conveniently estimated from the grip and push forces, which can be measured directly.

1. Introduction

The variations in coupling force at the interface between the hand and a vibrating tool handle may influence the nature of hand-transmitted vibration, and the stresses imposed on the anatomical structure. Many studies have suggested that the coupling force between the hand and a tool handle affect the severity of exposure to the hand-transmitted vibration and hand-wrist cumulative trauma disorders (Pyykkö et al., 1976; Fransson and Winkel, 1991; Radwin et al., 1987). The coupling force may also have a synergistic effect with vibration exposure on anatomical structures, such as the vascular system, nerves, and joints. An increase in the coupling force has been related to increased biodynamic response of the hand and arm (Hartung et al., 1972), while the increase in electrical activities of muscles has been related to increased grip or push forces (Gurram et al., 1995). The reduction in the peripheral circulation of fingers has also been related to application of high static and dynamic contact forces (Gurram et al., 1995, Miyashita et al., 1990).

The need to measure the hand-handle coupling force has thus been emphasised in many studies. The hand-handle interface forces are invariably measured in terms of grip and push/pull forces, using split handle designs and force plates, respectively. It has also been suggested that the coupling force can be considered as the sum of push/pull and grip forces, which can be measured directly (Kaulbars, 1996; ISO/WD 15230, 2000). The hand-handle coupling force, however, is a vector force that acts in all the directions around the handle surface, as shown in Figure 1. The grip and push/pull forces (F_G and F_P , respectively) represent only a fraction of the coupling force and thus do not fully characterise the coupling force at the hand-handle interface. The CEN-12349 (1996) and recent revision of the ISO-5349 (2001) emphasize the need for measurement of coupling force between the hand and

handle, but provide no guidance to the method of measurement. This is mostly attributed to the lack of reliable measurement methods.

Air or fluid bladders have been applied to measure the handgrip, wrist flexion and finger pinch forces (Tsaousidis and Freivalds, 1998). Many technical complexities, however, have been associated with these devices. These include the difficulties in calibration of such devices with reasonable degree of accuracy when applied to handles with complex geometry, strong influence of hand posture on the measurement sensitivity, variations in temperature, etc. Moreover, the occurrence of high contact pressure may squeeze out the entire air or fluid media between the enveloping layers in some localized areas. Matrices of thin-film resistive and capacitive sensors have also been applied for qualitative measurement of hand-handle interface pressure distributions (Gurram et al., 1995). The hand-handle contact force could be theoretically derived from the contact pressure distribution, while the application of the sensing grid in the field may lead to some difficulties due to delicate nature of the sensors, limited sampling rate and high cost. In this study, the feasibility and reliability of a capacitive sensing matrix is examined in the laboratory for realizing a direct measure of the hand coupling force. The measured pressure distributions, contact area, and grip and push force data are analyzed to explore relationship among the coupling, grip and push forces.

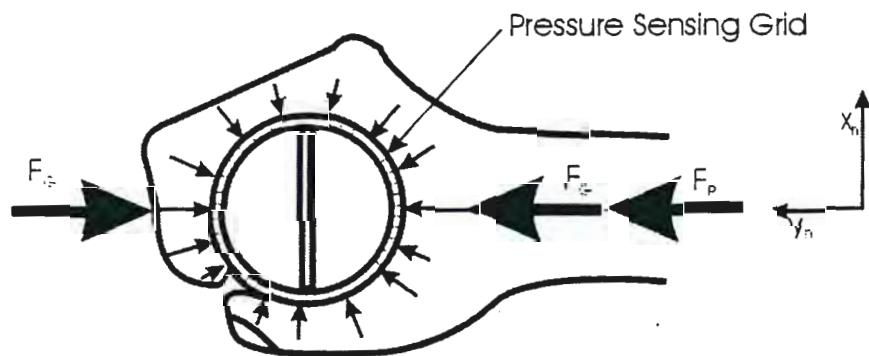


Figure 1. Definitions of grip, push/pull and coupling forces

2. Study Method

An instrumented handle developed on the basis of the design outlined in ISO-10819(1996) was employed in the study. The handle was installed on a shaker to measure the hand grip force, while the push or feed force was measured using a Kistler force plate. A capacitive thin-film pressure sensing system, developed by NOVEL Electronics, was applied to the handle for measuring the hand-handle interface pressure distributions as functions of grip and feed forces. The sensing system consisted of 16x11 (16 rows and 11 columns) pressure sensors encased within a 2 mm thick elastomeric mat. Each sensor was considered to cover an area of 0.766 cm^2 , including the spacing between the adjacent sensors. The sensing mat was calibrated under a pneumatic bladder in the 0 to 30 N/cm^2 range. The sensing mat was wrapped around the handle with an adhesive tape, as shown in Figure 2. The two of the rows of the sensing matrix were masked to ensure that overlapping of the sensors

does not occur. The sensing mat was connected to a computer through the Pliance Mobile data conditioning and acquisition system.

A total of 12 male subjects were employed in the study. Table 1 summarizes the age, height and hand sizes of the test population. In this preliminary study, the measurements were performed without the presence of handle vibration to study the relationship between static grip, push and contact forces. Although the handle diameter is expected to yield significant influence on the relationship between the forces, the preliminary measurements were performed using a 40 mm diameter handle. Each subject was advised to grasp the instrumented handle with his dominant right hand with a specified arm posture (elbow angle = $90^{\circ} \pm 10^{\circ}$), and specified grip and feed forces using the visual displays of the forces. Figure 3 schematically illustrates the experimental set-up. The measurements were performed with under different combinations of grip (0, 15, 30, 50 and 75 N) and feed (0, 25, 50 and 75 N) forces, and each measurement was performed twice.

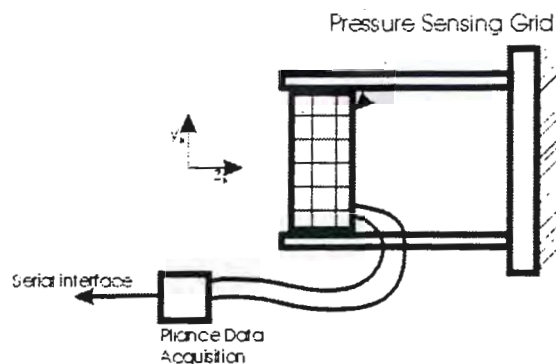


Figure 2. Instrumented handle wrapped with a capacitive thin-film pressure-sensing mat.

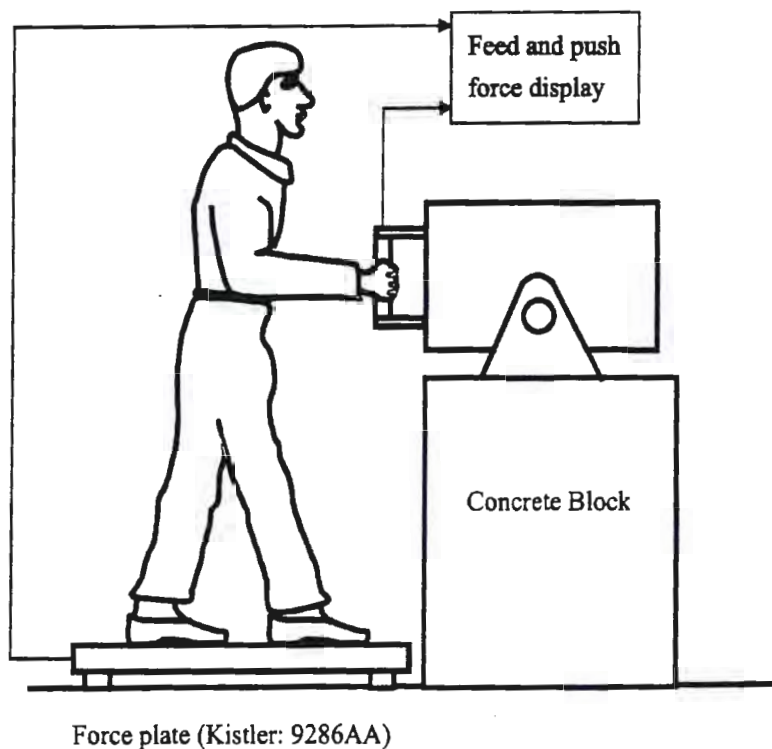


Figure 3. A schematic of the experimental set-up.

3. Results and Discussions

The EMED measurement system was used to acquire the pressure distribution at the hand-handle interface. The software provided the total contact force by integrating the pressure over the area formed by the contacting sensors. The contacting sensors were defined as those with pressure values exceeding a threshold value of 0.5 N/cm^2 . The effective contact area was thus also derived from the measured data. The measured pressure data was further analyzed to determine the peak contact pressure and its location. The contact condition of 0 N grip and 0 N push force was realized by placing the hand lightly on the mat covered handle, while monitoring the grip and push force displays. The sensing mat, in general, resulted in a contact force in the 2 to 15 N range under this condition. This was attributed to the hysteresis and offset of the sensing mat, and was treated as a bias in the measured signals. The measured values of the contact force corresponding to different combinations of grip and push forces were therefore adjusted for the measured bias.

Table 1: Age, height, weight and hand sizes of the test population.

	Minimum	Maximum	Mean	Std. Deviation
Age	18	60	29.5	14.8
Height (m)	1.73	1.90	1.83	0.05
Weight (kg)	64	127	84.2	17.8
Hand length (cm)	17.5	22.0	19.6	1.2
Hand circumference (cm)	20.5	25.0	22.3	1.4
Overall hand width (cm)	10.5	12.0	11.0	0.5
Hand thickness	4.5	5.5	4.9	0.4
Hand volume (cm ³)	345	525	424	55
Hand Size (EN 420)	9	10-11	9	-

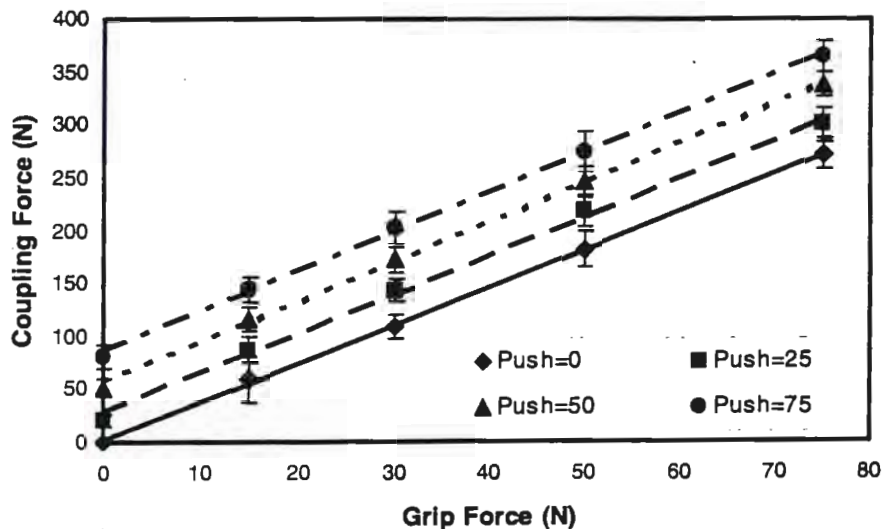
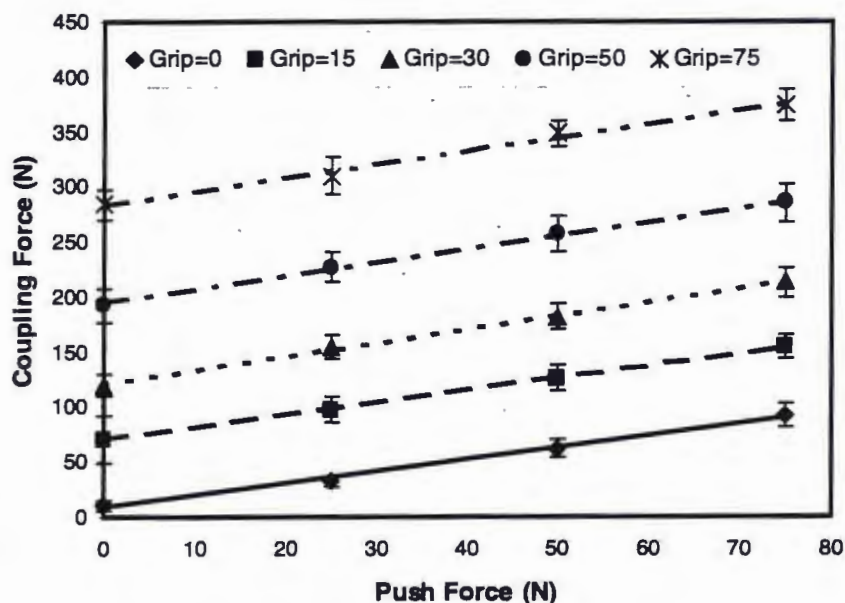


Figure 4. Relationship between the mean measured contact force and the grip force under different levels of constant push force.

The data acquired for 12 subjects and 2 trials were analyzed to derive the mean and standard deviation values corresponding to each grip and push force combination. Figure 4 shows the variations in the mean contact force as a function of the grip force corresponding to different constant magnitudes of the push force. The inter-subject variability was relatively low as demonstrated by the error bars, which denote the standard deviation of the coupling forces. The coefficient of variation of the measured data was observed to vary in the 6% to 18 % range. The results show linear relationship between the coupling force and the grip force, irrespective of the push force employed. The figure also illustrates the linear curves fitted to the mean measured data. The slope of the linear curves varies between 3.61 and 3.79, with R^2 values above 0.99 for the entire range of the push force.

Figure 5 illustrates the relationship between the mean coupling force and the push force corresponding to different levels of constant grip force. The figure shows the mean and standard deviations of the measured data. The results again show a linear relationship between the contact force and the push force, irrespective of the grip force employed. The slope of the linear curves fitted to the mean data varied from 1.1 to 1.25, with R^2 values in the order of 0.99.



Force 5. Relationship between the mean measured contact force and the push force under different levels of constant grip force.

The results presented in Figures 4 and 5 suggest linear relationships between the contact force and the grip and push forces. The grip force, however, has a stronger contribution to the overall coupling force. The contact force may thus be expressed as a linear combination of the grip and push forces in the following manner:

$$F_C = \alpha F_G + \beta F_P \quad (1)$$

The constants α and β may assume values in between 3.61 and 3.79, and 1.1 to 1.25, respectively. The above relationship is considerably different than those suggested by Kaulbars (1996) and ISO/WD 15230(2000). Considering nearly unity value of β for most of the grip forces considered, a modified coupling force may be defined as the total coupling force minus the input push force. Figure 6 illustrates this force as a function of the grip forces alone. The linear curve fitted to the mean of mean measured data resulted in a slope of 3.75 with a small intercept of 6.55 N. The value of the constant α may thus be taken as 3.75 for the range of push force considered in the study. The constants α and β , however, are expected to vary considerably with variations in the hand and handle sizes. These preliminary results can be considered applicable for hand size in the order of 9 and handle diameter in the order of 44 mm, including the thickness of the sensing mat.

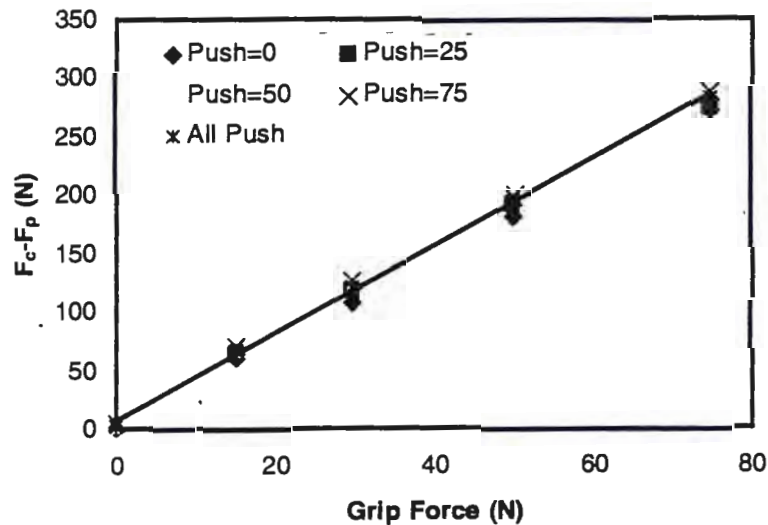


Figure 6. Modified coupling force as a function of the grip force.

Figure 7 illustrates the mean effective contact area derived from the measured data as a function of the grip and push forces. The results show exponential increase in the contact area when grip force is increased from a zero value, irrespective of the push force. The contact area, however, rapidly approaches a steady value as the grip force exceeds 30 N. From the regression analysis, the effective contact area may be expressed as an exponential function of the grip force:

$$A_C = \rho + \sigma(1 - e^{-\lambda F_G}) \quad (2)$$

where A_C is the effective contact area, and ρ , σ and λ are regression coefficients. The values of these constants for the present study were obtained as 56, 47.7 and 0.069, respectively, when the area is expressed in mm^2 .

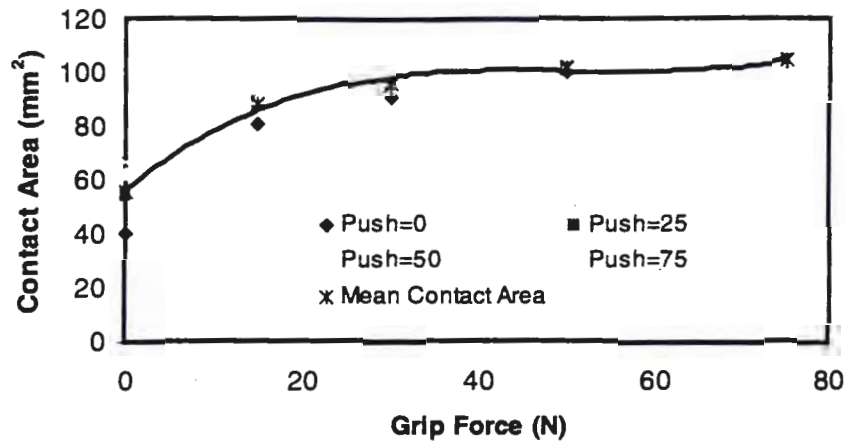


Figure 7: Variation in the mean contact area with grip force.

4. Conclusions

The contact force developed at the hand-handle interface is measured under different combinations of grip and push forces is measured using a thin-film capacitive pressure-sensing grid. The measured data is analyzed to identify relationships between the contact, grip and push forces. From the study it is concluded that the contact force and the contact area can be effectively measured using the pressure-sensing grid, developed by Novel Electronics. Its application in the field, however, may be limited due to its delicate construction and limited sampling rate when a large number of sensors are used. The laboratory measurements performed under static grip and push forces, however, provided a vital estimation tool to predict the hand-handle contact force from the directly measurable grip and push forces. The results suggested that the contact force could be derived from a linear combination of the grip and push forces, where the contribution due to grip force is considerably more significant. Further studies, however, are needed to quantify such relationships for different hand and handle sizes.

6. Refererices

- CEN-12349 (1996) Mechanical vibration - Guide to health effects of vibration on the human body. European Committee for Standardization.
- Fransson C and Winkel J (1991) Hand Strength: The influence of grip span and grip type. *Ergonomics*, 34(7), 881-892.
- Gurram R, Rakheja S and Gouw GJ (1995) A study of hand grip pressure distribution and EMG of finger flexor muscles under dynamic loads. *Ergonomics*, 38(4), 684-699.

Hartung, E., Dupuis, H. and Scheffer, M. (1993) Effects of grip and push forces on the acute response of the hand-arm system under vibrating conditions. *Occup. Environ Health*, 64, 463-467.

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

International Organization for Standardization (1996) Guide for mechanical vibration and shock - hand-arm vibration - method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand. International Standard, ISO-10819.

ISO/WD 15230 (2000) Definition and guidelines for the measurement of the coupling forces for operators exposed to hand-arm vibration. ISO/TC 108/SC 4/WG 3

Kaulbars, U. (1996) Measurement and evaluation of coupling forces when using hand-held power tools. *Centr. Eur. J. of Pub. Health*, 4(1), 57-58.

Miyashita, T., Miura, H., Futatsuka, M. (1990) Hand-arm vibration, noise, temperature and static load: an experimental study of peripheral circulation while operating chain saws. *Kurume Med. J.*, 37, 73-83.

Pyykko I, Fdrkkild M, Toivanen J, Kohonen O and Hyvdrinen J (1976) Transmission of vibration in the hand-arm system with special reference to changes in compression force and acceleration. *Scand. J. of Ebviron. & Health*, 2, 87-95.

Radwin RG, Armstrong TJ and Chaffin DB (1987) Power hand tool vibration effects on grip exertions. *Ergonomics*, 30(5), 833-855.

Tsaousidis N and Freivalds A (1998) Effects of glove on maximum force and the rate of force development in pinch, wrist flexion and grip. *Int. J. of Ind. Ergonomics*, 21, 353-360.

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