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Pressure sensor matrix for indirect measurement of grip and push forces exerted on a handle

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ABSTRACT

To date, a large part of workers is exposed to vibrations (23% in Europe) which can negatively impact on their health. This work discusses the importance of measuring grip and push forces in the context of hand-arm vibration tests, bearing in mind the state-of-art of current standards. It proposes a method for indirect measurement of coupling forces using a matrix of polymeric pressure capacitive sensors and discusses the model used for defining these quantities. The matrix of pressure sensors is wrapped around the tool handle and the acting forces, exchanged with the handle, are derived from the pressure values measured by the matrix. Calibration is presented and the effect of curvature is discussed. The work continues with the experimental validation of the model proposed for push force measurements carried out through lifting tests using known masses with a cylindrical handle. An experimental correction coefficient is defined in correlation to the type of grip. The method for measuring the push force, thus corrected, is assessed by means of push force tests on an instrumented handle. Finally the experimental data are analysed in order to assess the uncertainty of the proposed method for measuring the push force, highlighting the contribution of the different sources of uncertainty. The proposed measurement method allows to measure the push and the grip force (known influencing quantities for the measurement of the hand-arm vibration) during tool test and without modifying the handles.

1. Introduction

> *"... It is reasonable to assume that the biological effects depend to a large extent on the coupling of the hand to the vibration source. It should also be noted that the coupling can affect considerably the vibration magnitude measured. ... Forces between hand and gripping zone should be measured and reported.", "... It is possible that future vibration standards will require these forces to be determined."*
>
> [from standard ISO-5349-1]

This paper was motivated by these considerations, taken from current standards, and aims to make a contribution to the comprehensive ongoing discussion in the scientific community regarding the measurement of tool vibrations and the hand-arm system.

The measurement of vibrations which the whole body or the hand-arm system are exposed to is an extremely interesting issue because of the important aspects it involves regarding safety and health at the workplace. In particular, exposure to vibrations of the hand-arm system is an important factor in the use of hand-held power tools. On the basis of the findings of the 5th European Survey on Working Conditions 2010 [1] from the European Foundation for Improvement of Living and Working Conditions it is possible to observe how the exposure to

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vibrations of European workers is substantially unchanged between 1991 and 2010. Statistical data show that about 23% (33% men and 10% women) of the workers in Europe are exposed to mechanical vibrations (about 35,000 subjects), highlighting the extent and the importance of this issue [1].

In order to monitor and reduce the incidence of vibration-caused pathologies, the international community has adopted specific standards for the assessment of exposure to vibrations at the workplace. The current series of standards ISO 2631 [2] deal with the whole body while the arm-hand system is covered by the series ISO 5349 [3,4]. These standards require measurements to be performed on the tools in operating conditions which reflect those of real use. In line with the same objectives, various types of tests, such as those described in the series ISO-28927 [5], are available for measuring the vibration levels of different tools; these are useful for assessing the performance of tools in repeatable laboratory conditions. In addition, standard ISO 8041 [6] defines the specific measuring tools and the quantities to be measured.

Most of these standards, regardless of the specific features associated with the single piece of machinery and the relative measuring conditions, require measurement of the root mean square (rms) values of the accelerations, suitably weighted with frequency filters, to be carried out by means of a tri-axial accelerometer on those parts of the machine which are in direct contact with the body (generally handles and seats). It is well-known that the influence of numerous modifying or interfering inputs, as well as parametric variations, may reduce the repeatability and reproducibility of these tests. Of these, in hand-arm vibration measurements, the *push force* and the *grip force* are of undoubted importance and largely cited in literature [7–9].

The grip force definition has been debated for long time; its measurement trough an instrumented handle has been the standard approach [8,10–12] for many years. This implicitly treats the grip force as a vector with the direction depending on the structure of the instrumented handle. Some authors [13,14] defined the grip force as the integral of the spatial distribution of the contact pressures, that is to say as a scalar, which is useful for a better quantitative description of the entity of the forces distributed over the whole hand and handle contact surface. This explains why inverted commas are used for the term "grip force" in this paper, with reference to the definition proposed and discussed in detail below.

The maximum values of exposure to vibrations transmitted to the hand-arm system, the quantities which must be measured and the measuring conditions are defined at international level by the standard ISO 5349-1, 2001 [3]. The characteristics of the coupling between the hand and the handle and, consequently, the levels of energy exchange between the two systems, are indicated in the abovementioned standard as significant factors for the evaluation of biological effects. In particular, for the evaluation of the energy exchanged between these systems, the *grip pressure* generated and the *static force* are generally indicated as the quantities to be monitored during the tests. It is explicitly stated in ISO 5349-1 [3] that any modifications in the coupling of the hand with the handle may have a significant impact on the vibration measurement. Some standards, regarding tests for hand-held vibrating tools, require the measurement of the push force and recommend the assessment of the grip force in order to control operating condition, although there are no simple methods for measuring the latter on real tools without modifying the tool handle.

Coupling actions are indeed considered as influencing inputs to be monitored and kept under control when performing vibration tests. These forces are time-varying; since the hand-arm system reacts mainly at a low frequency, the components of the forces in the range up to 10 Hz are those which are of interest in the tests according to ISO-5349, ISO-28927, ISO-8662 and ISO 15230 [15]. Components at higher frequencies are certainly of interest for studying the mechanical impedance of the system. This paper, aimed at measuring the coupling actions in tests conducted in accordance with ISO-5349, ISO-28927 and ISO-8662, will be restricted to the measurement of the quasi-static components of the push force and the "grip force".

To date push force is normally measured by means of load cells or instrumented platforms which provide respectively the action or reaction forces which are exchanged between the system comprising the operator/tool and an object being worked in controlled conditions [12]. These procedures for measuring the push forces are widely used for laboratory tests on dedicated test benches, while it is often difficult to make use of them for field test.

If the grip force is considered, the problem of its measurement has not been univocally resolved [10–12]. In fact, in order to measure the grip force that a hand exerts on a cylindrical handle, standard ISO-10819 [16] indicates an example of a handle instrumented with a strain gauge load cell to measure the force generated by the hand on two semi-cylinders which are separated by an elastic element. If measured in this way, grip force is a vector whose direction is determined by the geometry of the measuring tool used. In reality, it would of course be possible to hold this type of instrumented handle in such a way as to obtain a null "grip force" measurement. This can be done by gripping with the fingers and the thumb in the direction which is orthogonal to the measurement direction, defined by the normal to the plane which separates the two semi-cylinders. This shows that the definition proposed does not describe exhaustively the interaction which occurs between the hand and the handle when grip is exerted. However it should be noted that this definition of grip force and the instrument described were conceived for use in laboratory conditions, with the main aim of performing tests on anti-vibration gloves according to standard ISO-10819. An instrumented handle of this type cannot be used for field tests and is not applicable for real tools, unless radical modifications are made to their mechanical structure. Therefore, in field and in laboratory type-tests on real tools, it is impossible to perform grip force measurements according to that method.

The International Organization for Standardization (ISO), in collaboration with the European Committee for Standardization (CEN), has published the ISO 15230:2007