11TH INTERNATIONAL CONFERENCE ON HAND-ARM VIBRATION

INDUSTRIAL TRIALS OF A SYSTEM FOR MEASUREMENT OF COUPLING FORCES

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Abstract

Within the "VIBTOOL" project[1)] sponsored by the European Union, a system was developed by means of which the magnitude and distribution of the coupling forces can be measured and analyzed. The BGIA assumed responsibility within the project for conducting practical trials in plant operation. The performance and the results of this part of the project are presented here. The trials were conducted on typical manually guided tools. The particular features of the tools studied and the issues identified during performance of measurement are presented, together with examples for their resolution. The limitations of the measurement system are described, and proposals stated for further optimization.

[1)] The project was led by the Politecnica Ancona (Italy) with the participation of the following test institutes: the Istituto per le Macchine Agricole e Movimento Terra (CNR, Italy), the Institut National de Recherche et de Sécurité (INRS, France) and the University of Southampton (UK), together with Novel GmbH (Germany).

1. Introduction

The magnitude of the coupling forces of the hand-arm system on vibrating equipment has considerable influence upon the vibration and strain to which the operator is exposed [1]. The effect of grip and coupling forces under vibration exposure upon the biodynamic vibration behaviour, the skin temperature and the vibration perception threshold have been described in numerous publications. The forces were defined as grip and feed forces in DIN 45679 as early as 1998, and a measurement and analysis method set out. The relationship between the coupling force and consideration of the "correction" of the vibration exposure is shown in figure 1.

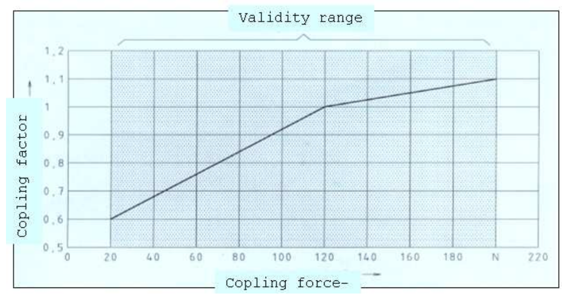

Figure 1 - Influence of the coupling forces to DIN 45679

The coupling-dependent measurement value can be obtained by multiplication of the frequency-weighted measured acceleration value by the coupling factor.

ISO/DIS 15230 [4] describes more far-reaching definitions of the forces; these also embody the principle of measurement of the pressure distribution on the surface of the handle.

2. Methods

2.1 Selection of typical tools and workplaces

The selection of typical tools takes account of the influencing variables and particular features: size and geometry of the handle, and gripping arrangements; requisite feed and grip forces; mode of operation and function (e.g. rotating or hammer-action); type and power of the drive; and switch position and working direction. Figure 2 shows the tools at different scales.

Figure 2 - Selection of suitable tools

2.2 Performance of measurements

The studies were limited to the testing of the “finger matrix” sensor. This sensor is an improved version of a simple pressure sensor matrix, and was developed by the

Polytechnic University of Marche together with Novel GmbH in order to permit mounting on the handles of actual tools.

The measurement strategy was based upon the vibration measurement standards ISO 5349 [3] and ISO/DIS 15230 [4] and upon DIN 45679 [5], the German standard governing the measurement and evaluation of the gripping and pull/push forces.

Two measurement systems were employed, enabling the coupling forces to be measured in parallel on both hands. Where permitted by the location of the acceleration sensors and the "finger matrix", the coupling force and vibration were measured simultaneously. Each series of measurements was performed with five repeat measurements and in some cases on several different test persons.

Prior to performance of each series of measurements, a static force measurement was performed for examination of the measurement chain at the site of use and for measurement of the feed angle. For this purpose, the test person stood on a force measurement platform and applied pressure to the tool in a typical working position (see Fig. 3). The measurement platform serves as a reference measurement system in this instance.

Figure 3 - Use of a reference measurement chain for examination of the measurement system

2.3 Particular issues and problems

Modification of the handles was necessitated by the mechanical sensitivity of the sensors on tools such as the angle grinder (shown in figure 4), on which the actuator of the switch was originally integrated into the handle, or the rammer (shown in figure 5).

For this purpose, the switch was locked in position and the handle, including switch, was encased by thin matting. Figures 6 and 7 show the handles modified in this way. For safety reasons, the tools concerned were operated by a foot-operated switch, and equipped in addition with an emergency-stop switch.

Figure 4 - Main handle of the angle grinder with integrated switch

Figure 5 - Rammer handle with switch

Figure 6 - Modified handle of the angle grinder

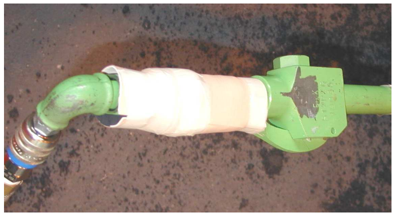

Figure 7 - Modified handle of the stamp hammer

A further problem is that of fitting the “finger matrix” to limited areas on handles, such as the auxiliary handle of the angle grinder (see Fig. 8). Owing to the susceptibility of the “finger matrix” to bending and buckling, the arrangement for attachment of the handles was modified as shown in figure 9. An alternative solution would be a number of sensor mats differing in their size and geometry. The width of the individual sensors would also have to be variable in this case.

Figure 8 - Auxiliary handle of the angle grinder

Figure 9 - Fitting the “finger matrix” to the auxiliary handle of the angle grinder

3. Results

3.1 Influence of different software

Conversion of the force distribution from the measured pressure distribution and calculation of the grip force and the feed force are based upon ISO/DIS 15230 [4]. Software developed in parallel by the INRS and the University of Ancona was available for these analyses of the measurement data. The results of the vibration measurements were analyzed by BGIA software in accordance with DIN EN ISO 5349 [3].

The influence of the different software applications was tested randomly. For this purpose, the same measurement data records were processed in both program versions. The results are summarized in table 1 as mean value and scatter. They exhibit only minor deviations, which may arise from rounding errors or differences in definition of the handle geometry.

Table 1 - Comparison of the results produced by the different software applications

	University of Ancona software	INRS software
Rammer		
Feed force	40 ± 9.0	40 ± 9.0
Grip force	44 ± 11.5	64 ± 13.2
Angle grinder		
Feed force	56 ± 2.6	56 ± 2.6
Grip force	55 ± 14.0	52.8 ±10.9

3.2 Influence of the handle geometry

The angular location of the sensor elements on the handle surface must be known for calculation of the coupling forces. Since the handles of the tools are generally virtually cylindrical in form, the programs assume a cylinder for calculation purposes. For estimation of the influence of calculation based upon a cylindrical handle geometry upon the actual handle geometry, precise measurements were taken of the handle with the greatest deviation (an electric breaker).

Table 2 - Influence of the handle geometry upon the measurement results [6]

	Cylindrical handle geometry [N]	Exact handle geometry [N]
Grip force	135 ± 13.0	112 ± 11.7
Feed force	210 ± 26.5	130 ± 13.4

The results of the comparison between the different handle geometries used are summarized in table 2 in terms of mean value and scatter. Use of a cylindrical handle geometry for approximate calculation yields higher measured values, namely: +20% for the feed force and +61% for the grip force.

3.3 System-induced limits and scope for correction

The system-induced limits of the measured forces become clear during measurement and analysis of the rammer. The feed forces exerted by the user can be measured by means of a measurement platform, but not by means of the measurement sensors on the handle. The pull and push forces measured by the system are tool guidance forces. During horizontal guidance back and forth of the tool, a push force and a pull force alternate on opposite hands (Figure 10).

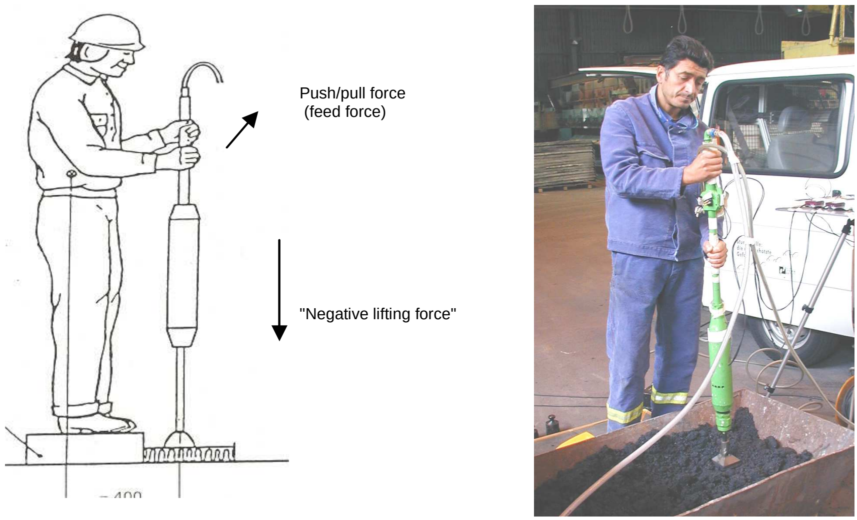

Figure 10 - Constraints upon recording of the feed forces

These special cases would necessitate synchronous measurement at the two measuring points and recording by the software of the resulting forces on the respective sides of the handles in the same axis of movement. On tools on which the working direction and the position of the hand or its angle to the handle changes during the working process, the reference values (angles) for calculation of the grip and feed forces also change. This fact was taken into account in the University of Ancona's software, and the measured data analyzed in addition with consideration for the axis of the feed force. Table 3 shows the measured values analyzed according to both methods for the rammer, presented as mean values with scatter for the tool in question.

Table 3 - Calculation method with consideration for the axis of feed force

Tool	Point of measurement	ISO 15230 [N]	UNIVPM software With consideration for the axis of the feed force
Rammer	Main handle		
	Feed force	37 ± 16.1	42 ± 16.2
	Grip force	101 ± 19.8	63 ± 9.9
	Auxiliary handle		
	Feed force	25 ± 4.9	37 ± 6.3
	Grip force	93 ± 20.4	85 ± 12.9

3.4 Measurement results

In accordance with ISO/DIS 15230, the grip and feed forces may be added together to form a coupling force for the purpose of data reduction. For illustration of the measured data gained under field conditions, the coupling forces are shown in graphical form for each tool in figure 11.

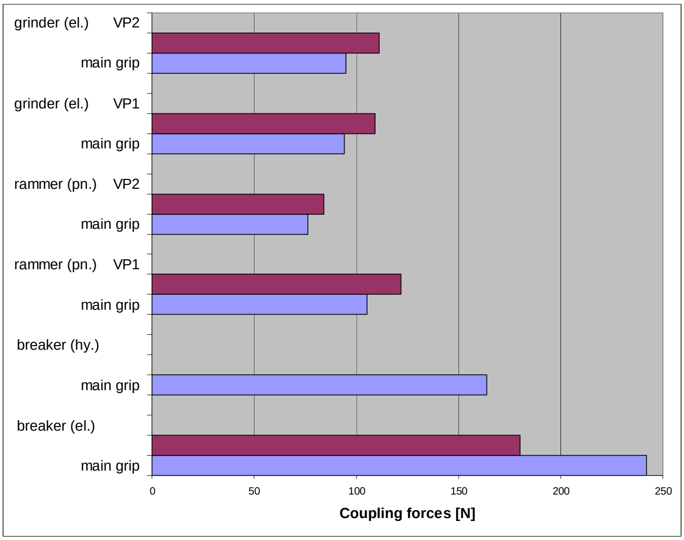

Figure 11 - Coupling forces of the tools studied

The vibration measurement results analyzed in accordance with ISO 5349 are summarized separately in table 4 according to the discrete axes of measurement and measurement points. The mean value and the scatter are indicated for the discrete axes of measurement, together with the total vibration value, which is computed from all axes of measurement.

Table 4 - Frequency-weighted acceleration of the tools studied

Tool		ahw [m/s²]			
		X	Y	Z	V
Breaker (electric)	Main handle	6.9 ± 0.72	5.5 ± 0.78	5.6 ± 0.76	10.5 ± 1.21
	Auxiliary handle	3.3 ± 0.14	3.9 ± 0.23	5.9 ± 0.29	7.8 ± 0.33
Breaker (hydraulic)	Main handle	6.3 ± 0.67	4.5 ± 0.51	13.3 ± 1.11	14.4 ± 1.09
Rammer (pneumatic)	Main handle	2.0 ± 0.14	12.1 ± 0.77	2.1 ± 0.15	12.8 ± 0.73
Angle grinder (electric)	Main handle	2.2 ± 0.28	3.6 ± 0.16	3.1 ± 0.31	5.3 ± 0.13
	Auxiliary handle	5.3 ± 0.16	3.2 ± 0.09	5.1 ± 0.16	8.1 ± 0.09

4. Summary

The measurement system involving the “finger matrix” and two alternative software applications for calculation of the coupling forces was trialled on typical tools which were relevant to the hazard analysis. A number of optimizations were implemented even during the trial phase, with the result that a suitable measurement system is available for a further area of application with which measurements can be performed in accordance with ISO/DIS 15230. Measurement and consideration of the handle geometry is absolutely essential for non-cylindrical handle surfaces.

In addition to software developments for error compensation, extension of the scope of use also requires improvements to the sensor matrix with regard to its mechanical robustness and its flexible adaptation to ergonomic handle geometries.

References

[1] Scheffer, M., Kaulbars, U., “Forschungsbericht Hand-Arm-Schwingungen III. Wirkung von Greif- und Andruckkraft unter Schwingungsbelastung”, published by: Hauptverband der gewerblichen Berufsgenossenschaften, Sankt Augustin, June 1992

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[3] ISO 5349-1, 2001-05, “Mechanical vibration — Measurement and evaluation of human exposure to hand-transmitted vibration” — Part 1: General requirements, Part 2: Practical guidance for measurement at the workplace

[4] ISO/DIS 15230, (draft standard), 2005-09, “Mechanical vibration and shock — Coupling forces at the machine-man interface for hand-transmitted vibration”

[5] DIN 45679, 2005-09, “Mechanical vibration — Measurement and evaluation of the grip and feed forces for assessing the exposure of the hand-arm system to vibration”

[6] Kaulbars, U., “Measurement of hand forces on vibrating tools: influence of the handle geometry upon calculation of the coupling forces”, ESM- emed scientific meeting 2006