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HAND-ARM VIBRATION MEASUREMENTS BY LASER VIBROMETRY AND CAPACITIVE SENSOR MATRICES

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ABSTRACT
A new hand-arm vibration measurement technique has been proposed and applied in order to characterise hand held machine vibrating parts/components usually coming into contact with the operator (hydraulic breaker handles, agricultural/earth-moving machine steering-wheel and levers). The purpose consisting on identifying machine structural modifications aimed at reducing vibrations and improving in parallel operator comfort/working conditions, this way taking into account also ergonomic aspects. The measurement technique proposes a parallel application of: a) laser vibrometry b) capacitive sensing element matrixes.

1 - INTRODUCTION
From a recent study by the European Committee of Standardization, released last october, emerges the problem of the high uncertainty and the scarce repeatability and reproducibility of the vibration measurements, necessary to certify the machines vibrating emission. The reason for such unsatisfactory results is particularly due to the inability to fully control the operator, using the measurement techniques currently prescribed.
Furthermore, the vibration level registered on the handle by means of piezoelectric accelerometers does not estimate the dose transmitted to the operator and the risks of danger which could be incurred (*HAVS: Hand arm vibration syndrome*).
The use of no contact laser vibrometer avoids many measurement problems due to the presence of transducers on the hand and/or the vibrating surface. Moreover, the laser beam scanning characteristics allow fast and spatially detailed data acquisition.
The scanning laser Doppler vibrometry, used along with capacitive sensing element matrixes, has been proposed as a new measurement technique for a more accurate estimation of the vibration dose absorbed by the operator and machine vibration characteristics.
The contact pressure distribution at the operator's hand/machine handle interface has to be known, indeed, in order to evaluate hand-arm vibration transmission. Moreover, the global grip force applied by the operator turns out to be an important parameter to be considered. On this purpose, capacitive sensors matrixes have been developed and optimised to fit the different test applications.
By means of this technique the impedance of the hand-arm system can be determined. This measurement can be useful from a medical point of view in order to gather information on the local correlations between cause and effect, as the transmitted power and damages to the operator are linked to the impedance. Moreover a system dynamic model has been developed as a planning instrument to optimise constructing choices of shock-absorbing devices.

The proposed measurement technique represents the topic of an European Community funded project in the Framework IV, SMT programme. The results shown in this work are those till now achieved in conclusion of the second year of activity of the project itself.

2 - EXPERIMENT AND ANALYSIS

Tests were initially carried out on a standard test bench (Figure 1) with an instrumented handle (designed according to EN ISO 10819-1986) and an electrodynamic shaker, in order to obtain comparative measurement results by means of laser and accelerometers [1]. The capacitive sensing element matrix (Figure 1) has been introduced in a following series of acquisitions. In a first phase the laser carried out a scanning on seven points on the back of the hand while the accelerometer simultaneously measured the handle vibration.

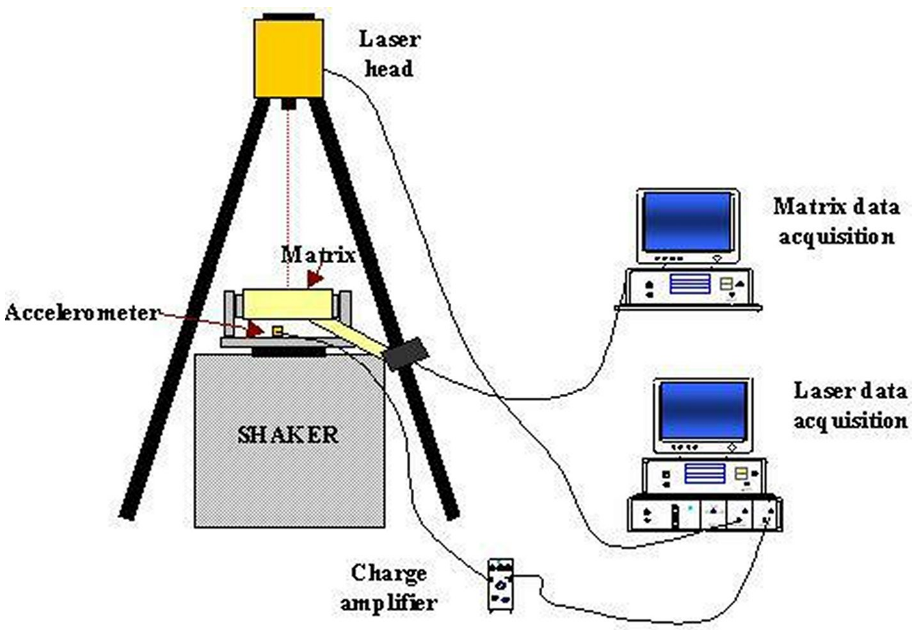

Figure 1: Test bench with accelerometer, scanning laser Doppler vibrometer and capacitive sensing element matrix.

Table 1 shows the vibration values (m/s^2) relevant to different operators and frequencies.

	Subjects						
Freq [Hz]	**ro**	**ni**	**gi**	**je**	**Mean value**	σ	σ%
16	4.38	4.12	4.78	4.35	4.41	0.27	6.19
31.5	4.40	4.15	4.55	4.2	4.35	0.17	3.93
63	3.92	3.64	3.69	4.32	3.89	0.31	7.96
125	3.81	3.50	3.74	3.24	3.57	0.26	7.26
250	2.85	3.25	2.67	2.76	2.88	0.25	8.84
500	3.45	2.70	2.89	3.67	3.18	0.45	14.45

Table 1: Vibration values (different operators and frequencies).

The standard deviations are plotted around respective average values (Figure 2). The influence on the vibration output by the various adopted grip procedures and results dispersion caused by the impossibility of controlling the grip can be reduced by calculating the average velocity, relative to all the scanning points on the back of the hand, as declared test vibration level.
The standard deviation values to be referred to our tests (Figure 2) do not exceed 15%, compared with the limit of 30% declared in the document CEN/TC 231/WG 2 N 204, regarding a series of round robin tests carried out on principal vibrating machines by means of traditional instrumentation.
The measurement results obtained by the scanning laser Doppler vibrometer proved to be consistent. Impedance curves show trends similar to those found in literature [2] (Figure 3).

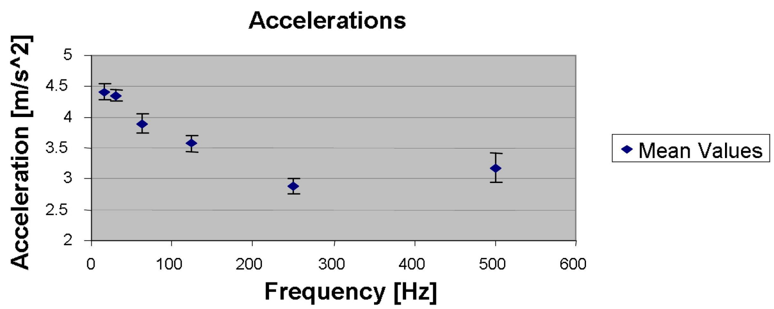

Figure 2: Acceleration deviation values.

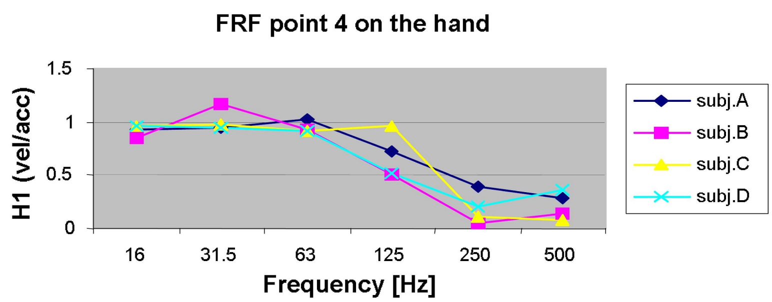

Figure 3: Impedance curves.

Moreover the velocity spatial distribution on the back of the hand can be displayed by means of the laser vibrometer. The measurement requires that the grip by the operator is always constant and the simple control of the total static force applied does not assure repeatability.
Therefore another series of tests has been carried out. By applying a capacitive sensing element matrix around the handle (Figure 1), monitoring the distribution of the contact force at the hand-handle interface turned out to be feasible.
Figure 4 shows the correlation between velocity and pressure fields for a subject at a specific frequency (30 Hz). Minimum velocity corresponds to maximum pressure.

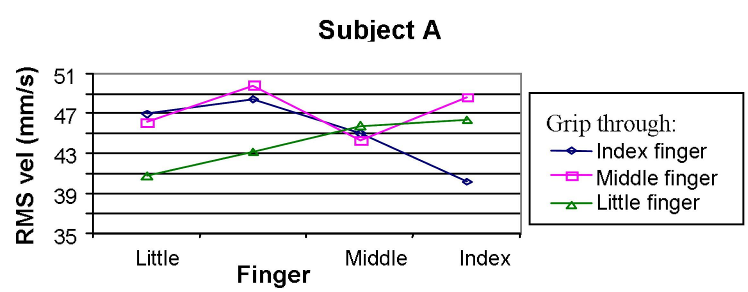

Figure 4: Correspondence between minimum velocity and maximum pressure (gripping finger).

This result has been obtained by a series of tests in which the subjects had to alternate the use of only one finger (index, middle or little finger) in order to obtain a total grip force of 50 N. Pressure maps acquired relevant to various test subjects showed that the correlation above is verified only in case of good control of the grip force by the operator.
Figure 5 displays a map of velocity and pressure relative to a grip correctly applied using the index finger (minimum velocity indicated by the green area on the strip above the knuckles, maximum pressure represented purple below).
Similar tests have been carried out using different kind of handles and/or machine components (hydraulic breakers handle, agricultural steering-wheel and levers). Capacitive sensing element matrixes of different shape and characteristics have been designed and made in order to fit the various applications.
Static and dynamic characterisation of the sensors used has been carried out and the effect of contact surface analysed [3]. The results show that the sensing element has to be calibrated directly onto surface using an appropriate gauge to generate the reference pressure.

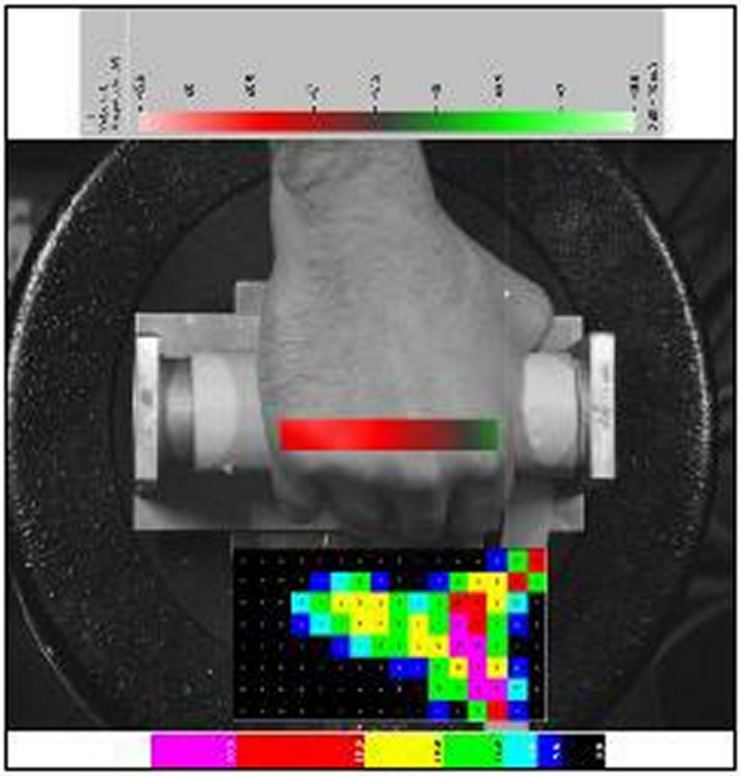

Figure 5: Map of velocity and pressure relative to a grip correctly applied.

3 - CONCLUSIONS AND FUTURE DEVELOPMENTS

In conclusion of the second year of activity of an European Project, the application of the no contact measurement technique based on the laser vibrometer has been successfully validated. This measurement technique turned out to be an efficient tool in order to evaluate vibrations on hand held machines and on operator's hand-arm system. The use of a sensor matrix is necessary in order to measure the grip force between operator's hand and machine.

Future planned activity foresees, on the one hand, the methodology application directly on hand held machine and steering instrumentation vibrating parts/components, on the other hand, identifying machine structural modifications aimed at reducing vibrations and improving operator working conditions.

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