

The Use of a Capacitive Sensor Matrix to Determine the Grip Forces Applied to the Olive Hand Held Harvesters

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ABSTRACT

The hand held olive harvesters increase the work productivity but they submit the operator's hand arm system to high vibration level values and to relevant efforts to drive them through the tree branches. Many scientific works demonstrate that a correlation exists among the intensity of vibration, their direction and the grip force applied by the operators' hands. It is not easy to measure these parameters, unless instruments which permit the measurement in an objective way are available. Aim of the work is to present the results of the application of a measurement instrument that allows to detect the operator's hands grip force applied to drive the olive harvesting shaker. This device is done using a capacitive sensor matrix that can be wrapped around the machine handlebars. The matrix is thin (approximately 0.9 millimetres of thickness): for this reason its presence does not modify the operator's behaviour and allows to obtain measures of the pressure dynamic contact distribution and its time history. In this way we have the grip forces applied by the operator's hand over the machine handlebars. This matrix has been fixed over olive harvesting machine handlebars and the grip forces time histories have been recorded. The tests have been carried out in a laboratory simulating the olive harvesting operations by means of the arms movements towards to targets positioned at different heights. Obtained results should permit to appreciate both the grip force time history and the spatial force application: with the spatial and temporal applied force values, more ergonomic solutions and implementations could be possible for olive hand held harvesters.

Keywords: Vibration, olives, shaker, capacitive matrix, grip force

1. INTRODUCTION

One of the major expenses of olive production is the manual detaching of the fruits from the branches: in the little farms the cost may reach the 50-70% of the obtained cultivation revenue, with a productivity that is not higher than the 15 kg/h for each operator. In this situation it is convenient to use olive hand held harvester such as pneumatic or electric olive harvester, shakers with knapsack engine, etc ...

The hand held olive harvesters are operators' brought machines, which cause the fruit pick up by means of impacts produced by vibrational tools driven by little i.c. engines or electric motors. The hand held olive harvesters, shaker type, have an hook at the top of the rod. The i.c. engine produces an alternative motion of the rod and therefore of the hook. During the work, the operator clasps the olive branch with the machine, which moves the branch with high frequency, detaching the fruits.

These machines increase the work productivity, doubling the manual one, but they tire the operator. They submit the operator's hand arm system to high vibration level values and to relevant efforts to drive them through the tree branches.

Other than the vibratory stress, many other bio-mechanical factor may contribute to the etiopathogenesis of the osteoarticular injuries in the operators using vibrating tools, such as the articular overload, the intense muscular strain and the discomforting postures. Many scientific works demonstrated that a correlation exists among the intensity of vibration, their direction and the grip force applied by the operators' hands. Exposure to hand-arm vibration is one of the main physical risks for workers involved in the agro-forestry field. The prolonged use of hand held vibrating power tools like chain saws and hand-held shakers can lead to the hand-arm vibration syndrome (HAVS) that can interest the muscle-skeletal, nervous and vascular peripheral structures of the upper limb (Bovenzi, 1998). The hand-arm vibration damage depends on multiple factors: the stimulus intensity, the propagation direction, the exposure duration, the operators' grip forces on the tool's handles (Bovenzi *et al.*, 2000). While the first parameters are easily determined by accelerometers positioned over the handlebars, the grip force behaviour is more difficult to measure (Deboli *et al.*, 2006), unless instruments which permit the measurement in an objective way are available. The use of new transducers in hand-arm vibration experimental set-up has been recently improved (Scalise *et al.*, 2007).

Aim of the work is to present the results of the application of a measurement instrument that allows to detect the operator's hands grip force applied to drive the olive harvesting machine shaking tool. This device is done using a capacitive sensor matrix that can be wrapped around the machine handlebars, allowing to obtain measures of the pressure dynamic contact distribution and its time history. The matrix is thin (approximately 0.9 millimetres of thickness): for this reason its presence does not modify the operator's behaviour. The tests have been carried out in two laboratories simulating the olive harvesting operations by means of the arms movements towards to targets positioned at different heights, executing the same field movements of machine lifting, hooking and pulling, at different engine speeds. At the same time acceleration values were measured, both over the handlebars (front and rear) and over the hook.

2. MATERIALS AND METHODS

Tests have been carried out in two different laboratories: the first was at the IMAMOTER-CNR institute, the second was at an olive shaker manufacturer. Aim of the test at the IMAMOTER institute was to determine a methodology to verify the data repeatability of the matrix and to simulate the operator behaviour during the effective olive harvesting process by means of the matrix positioning over the handlebars.

In the second laboratory static and dynamic test have been carried out, both with the engine off and at the idling, racing and full load speed. At the idling state the engine speed is at the minimum and the rod is stopped, the racing state corresponds to an engine speed of 133% of the speed at maximum engine power, while the full load is equivalent to the maximum engine power.

The matrix has been wrapped around the handlebars of one shaker (figure 1a), while the acceleration measurements have been revealed over six olive shakers. Two operators drove the shakers during the tests: the first was skilled, 1.68 m tall and 70 kg weight, whereas the

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second was not skilled, 1.73 m tall, 75 kg weight. To simulate the field operation, a device has been built, using a fork lift with wrapped elastic rope bound at the fork (figure 1b): in this way the ‘tree branch’ height was variable.

2.1 Operative Conditions

At the IMAMOTER laboratory, the olive shaker has been tested with the engine off, to appreciate the operator’s gestural expressiveness during the machine lifting, swinging, hooking and the tree branch pulling.

At the manufacturer laboratory different operative conditions have been carried out. For the grip force analysis and the hand-arm vibration measurements, the operative conditions have been the following:

- machine at the idling state (normal condition during the operator transfer among the olive trees) in the same phases described for the IMAMOTER laboratory;
- machine to simulate the operative condition (idling state during lifting and hooking, full load state during pulling).

All these tests have been conducted by a skilled operator.

The hook acceleration has been measured over three machines at the idling and racing state: in this case the acceleration was not frequency weighted. For acceleration measurements the experiments were conducted according with ISO 22867.

210 tests have been executed: 34 for the grip force, 176 for the vibration measurement.



Figure 1a. Matrix wrapper around the front olive shaker handlebar (left)

Figure 1b. Device simulating olive tree branches (right)

2.2. Measurement Chain

The utilized matrix “Fingermat” (by Novel GmbH, Munich - Germany) is composed of 156 square capacitive pressure sensors arranged in 2 different areas: 144 sensors (12 per 12) for

the palm and fingers and 12 (4 per 3) for the thumb area. Each sensor has a surface of 1.094 cm², it means that the total available surfaces are 12.55 per 12.55 cm for the palm-fingers and 4.18 per 3.14 cm for the thumb. Three cuts divide the finger area in 4 strips (figure 2). The matrix is connected to the electronic signal conditioning equipment. It consists of conditioning circuit, analog multiplexer and 8 bit analog to digital converter that scans each capacitive sensor sequentially at a frequency of 20 kHz.

The acceleration chain for the machine was composed by two tri-axial accelerometers placed both on the front shaker (left hand) and rear (right hand) handlebars (figure 3), a rpm meter and a digital data acquisition recorder. A dual channel frequency analyzer Bruel&Kjaer type 2133 was used to investigate the acceleration data along the x, y and z directions and a personal computer was devoted to investigate on pressure distributions on the two handlebars.

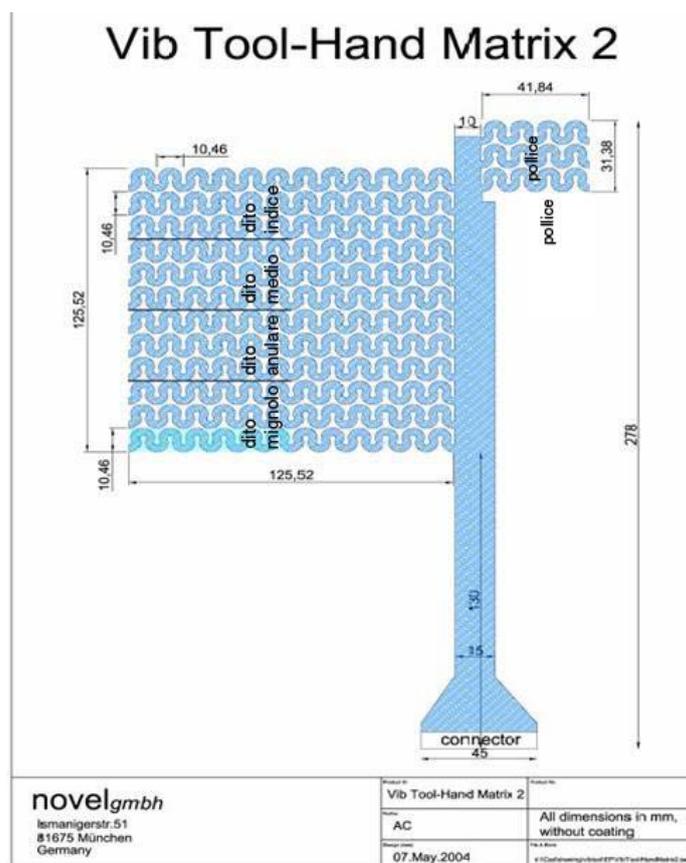


Figure 2. Matrix layout

Accelerometers were both calibrated before test session using a on-field mono-frequency calibrator. Output signals of accelerometers have been weighted using the ISO 5349-1 filters.



Figure 3. Accelerometers positioned over the olive shaker handlebar

2.3 Machines Characteristic

Six olive shaker have been tested (one for the grip force analysis, six for the emitted vibration, table 1): one of them was equipped with an experimental handlebar.

Table 1. Main features of the used olive shakers

Machine	Displacement (cm ³)	Speed (r/min)		Weight (kg)
		idling	racing	
A (experimental rear handlebar)	52	3600	11300	17
B	52	3600	11300	11
C	52	3600	10200	10.9
D	52	3600	10200	11
E	52	3600	11300	17
F	42	3600	10600	11

3. RESULTS

3.1 Grip Force Time History. IMAMOTER Laboratory

All the executed tests demonstrate an high repeatability inside each group (lifting, swinging, hooking and pulling).

Graph 4a. 0 rpm. Hooking and pulling. Test 2 Graph 4b. 0 rpm. Hooking and pulling. Test 4

Figure 4. Two of the four hooking and pulling test conducted at the IMAMOTER laboratory

In figure 4 it is possible to appreciate both the operator handling and the grip force repeatability detected in the same operative conditions: at the beginning the olive shaker is positioned over the simulated tree branch, after around 9 seconds the operator starts to hook the machine and after 14-16 seconds he pulls the handlebars toward the ground. In both of the cases the grip force augments from 60-80 N at the initial phase until 150-180 N during the hooking, decreasing again to 60-80 N in the pulling phase. The grip force time history permits to understand the operator's behavior and to quantify the grip force in the different situations.

3.2 Grip Force Time History. Manufacturer Laboratory

Graph 5a and 5c report the force time history at the same operative condition (lifting) with the engine off (5a) and idling (5c); graph 5b and 5d, instead, are the same variable representation at the hooking and pulling operative conditions with the engine off (5b) and idling (5d).

In these last graphs it is possible to appreciate the different operation phases: for the around firsts two seconds the hooking phases are present (with an highest grip force), while after the pulling state appears. At the same operative condition, the grip force increase when the engine is running in the idling state: only in graphs 5b and 5d in the pulling state (after around two seconds) the grip force stay around 200 N, both with the engine off and idling. In the graph 5b it is possible to notice when the operator ends to pull (at the 7th second).

Graph 5a. 0 rpm. Lifting

Graph 5b. 0 rpm. Hooking and pulling

Graph 5c. 3600 rpm. Lifting

Graph 5d. 3600 rpm. Hooking and pulling

Figure 5. Lifting, hooking and pulling tests conducted at the manufacturer laboratory

The grip force time history is very different when the operator simulates the effective field operation (hooking at the idling state and pulling at the full load, figure 6): the grip force is averagely high during the hooking phase (400 N, from 2nd to the 4th second), while in the pulling phase it is evident the operator's difficulty to maintain the handlebar control (from 300 to 500 N after the 5th second). The high grip force values recorded in this figure are due to the handlebar hits against the operator's hands: the first peak during the hooking phase is caused by the hook which knocks against the branch, the second one is the result of the very high machine vibration level (the operator feels the machine to escape and grippes the handlebar).

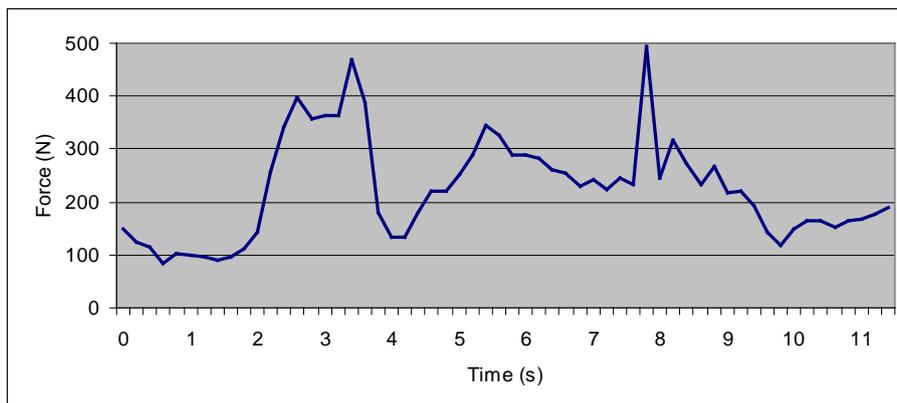


Figure 6. Hooking (3600 rpm, 3 seconds) and pulling (11300 rpm, 6 seconds)

Another matrix feature is to see the pressure spatial distribution, to understand if there are more solicited hand palm parts. In figure 7 the left hand pressure map of the maximum grip force registered during the simulated field operative condition is shown: from the map it is possible to understand the highest pressure values (red coloured and circled, from 20 to 30 N/cm^2), corresponding to the fingertips of thumb, index and medium.

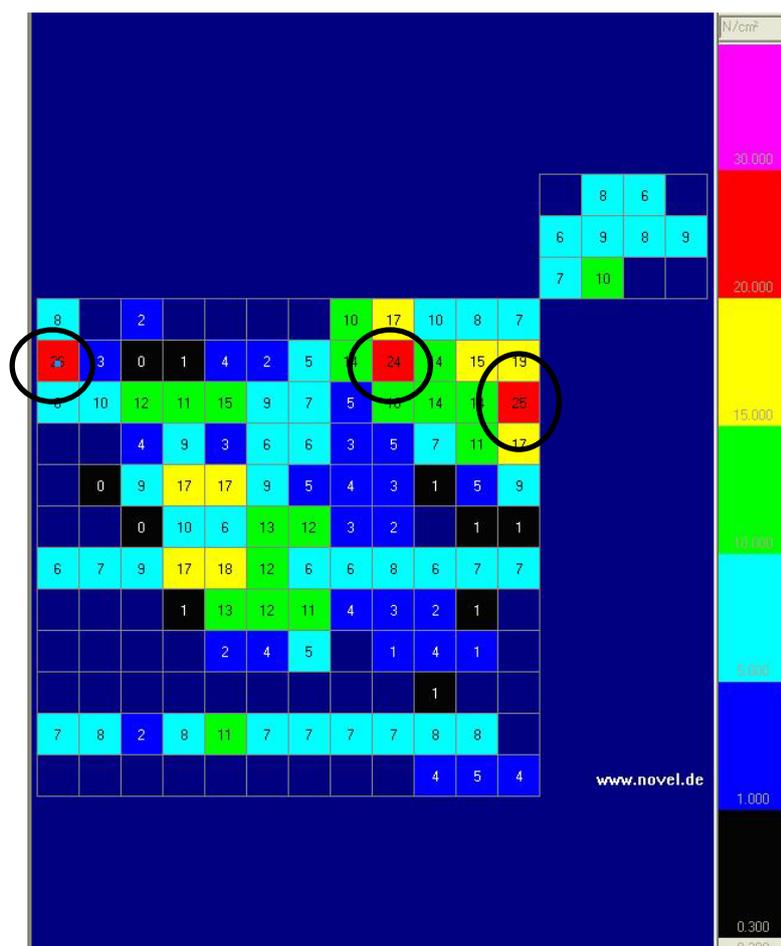


Figure 7. Left hand pressure map of the maximum grip force registered during the simulated field operative condition

3.3 Acceleration values

The recorded acceleration vary both amongst the machines, the handlebar (front or rear) and the engine state. The results are shown in table 2.

Table 2. Shaker handlebars' accelerations (hooking and pulling)

Machine	Engine condition	Front m/s ²	Rear m/s ²	Hook acceleration (not frequency weighted) m/s ²	
				Off-hook	On-hook
A	idling	3.3	3.8	24.5	
A	full load	22.5	15.5	840	800
B	idling	7.9	7.2	12.5	
B	full load	29	32	825	800
C	idling	11	4.6		
C	full load	20	26	n. r.	n. r.
D	idling	n.r.	n.r.		
D	full load	30.7	22.5	n. r.	n. r.
E	idling	n.r.	n.r.		
E	full load	20.6	17.3	n. r.	n. r.
F	idling	n.r.	n.r.	39.3	
F	full load	71	51	1020	1040

Because of the machines characteristic, the acceleration values are always quite high, especially in the full load engine condition (normally more than 20 m/s², with one machine over 50 m/s²): it is however interesting to notice the lowest vibration data (15.5 m/s²) in the rear experimental handlebar of the machine A. On the other hand, the hook accelerations were so high that not all the machines have been measured, because there was the serious possibility to damage the measure instrumentation (values higher than 800 m/s² at the full load state).

4. CONCLUSIONS

The matrix used in this work permits to appreciate both the grip force time history and the spatial force application, while in the past it was only possible to determine an average applied force with a dynamometer which also modifies the handlebar structure. With the spatial and temporal applied force values, more ergonomic solutions and implementations are possible.

Also if the machines are well balanced, the physical effort to insert the hook on the branch is high, especially in the simulated field condition: probably in the real field, with slippery and uneven ground the grip forces are higher. If to the physical effort we add the vibration values, the load intensity to the upper limbs is significantly high.

The olive shaker acceleration values are high and reflect the actual situation for this kind of machines, but engineering proposal to modify handlebars seem to give good results, as shown in table 2, machine A.

5. Acknowledgment

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