Investigation of Workers' Exposures to Vibrations Produced by Portable Shakers

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ABSTRACT

Herein note focussed the attention on the vibration levels issued by two portable shakers models build in different and subsequent times by the same building company, which present different design and constructive solutions for both the handles.

The two tools were used, during tests, by a single operator, expert in the use of this typology of tools due to his job activity during the olives harvesting campaigns; the measurements were carried out respecting the indications contained in the provisions UNI EN ISO 5349-1 (2004) and UNI EN ISO 5349-2 (2004).

A different dynamic behaviour of the two tools emerged from the tests. The results point out, in a particular way, the high values of acceleration transmitted to the hand-arm system produced by the examined portable shakers: the vibration values are greatly higher than the limit ones laid down in the Italian law in force.

Keywords: Olive harvesting, safety, transmitted vibration

1. INTRODUCTION

The exposure of human body to mechanical vibrations can, as it is well known, be source of pathologies of different nature and entity, even if the levels (intensity, spectrum content, daily and total exposition duration) which determines the above-mentioned injures is not exactly known (ENAMA, 2005; ISPESL, 2001; UNI EN 12096, 1999).

The whole problems connected to the transmission of the vibrations to man can be divided according to two essential typologies: - vibrations of the whole body; - vibrations of the hand-arm system, meaning, with the first, a stress of oscillatory nature which involves the whole human organism; with the second, instead, a mechanical stimulation, also of oscillatory origin, which propagates through the hands and the arms and that gradually decrease.

The transmission of the vibrations through the hand-arm system is consequent to the use of tools equipped with handles through which the operator makes the job; it is a rather complex phenomenon because involves other factors which interact with the intensity of the vibration and its way of introduction and propagation in the organism (UNI EN ISO 5349-1, 2004; UNI EN ISO 5349-2, 2004). Has to be remembered that, in most cases, the handles represent the support device of such tools which are equipped with an internal combustion or electric engine that transmits the motion to the working utensil (Monarca et al., 2003; Monarca et al., 2003).

Through the handles the operator reacts to strengths and moments which spring between utensil and piece during the harvesting. At least, the entity of the vibrations transmitted through the hand-arm system and the consequent effects are affected strongly by the prehensile and/or pressing strength of the operator which, obviously, changes in function of the hands and wrists position during the harvesting, in function of the finish level requested by the harvesting itself and in function of the simultaneous use of the two hands.

Herein note focussed the attention on the vibration levels issued by the portable shakers which are always more used in the Apulia region olives production for the harvesting operations of the olives by the trees first of all for the greater investment and exercise economy with respect to the traditional taken or self-moved shakers.

In particular, the results of the tests on two portable shakers models build in different and subsequent times by the same building company, which presents different design and constructive solutions for both the handles are reported.

2. MATERIALS AND METHODS

The experimental tests have been carried out in an olives tree field located nearby the Agricultural Research Council (CRA-ISMA) in Monterotondo (Rome) and have been made on two brand new and actually produced models of portable shakers, both equipped with an internal combustion engine produced by TEKNA s.r.l. in Ostuni (BR): Vibrotek TK 650 e Vibrotek TK 5000 (Table 1).

Table 1. Technical characteristics of the tested portable shakers.

Model	Engine	Fuel tank capacity l	Vibration system	Reduction	Rod stroke mm	Frequency vibration stroke/min	Weight machine kg
Vibrotek TK 650	52 cc single-cylinder 2 stroke engine	1,7	Cam-rod system	Helical gears	60	till 1900	14,4
Vibrotek TK 5000					50		11

The choice fell on these models because, even though they are constructively similar, they present a substantial diversity in the arrangement and structuring of the handles.

In the Vibrotek TK 650 model, the command handle is mounted on an articulate quadrilateral support, in which torsion spring connected to the extremities to the two connecting rods, reacting to the vibrating stress recalls the system in the initial position. Instead, the auxiliary handle, runs, winning the recall spring's reaction, on a metal board mounted in the same direction of the vibrating rod (Fig. 1).

In the Vibrotek TK 5000 model both the handles are mounted on the same axis which is itself connected to the tool by an articulate parallelogram system, with the recall springs located in the anchoring points of the axis with the two connecting rods (Fig. 2).

Besides, both the tools, presents, downstream of the flywheel, a centrifugal clutch which, at the minimum regime, does not transmit the motion to the conic couple connected to the rod-lever mechanism which produces the alternative motion of the working rod.

The two machinery were used, during tests, by a single operator, expert in the use of this typology of tools due to his job activity during the olives harvesting campaigns. Furthermore, both the shakes have been equipped with two aluminium rods of different length: 325 cm (long rod); 225 cm (short rod).

The measurements were carried out respecting the indications contained in the provisions UNI EN ISO 5349-2 (2004).

Figure 1. Vibrotek TK 650
a – control hand-grip (1 – connecting rod, 2 – spiral spring), b – auxiliary hand-grip.

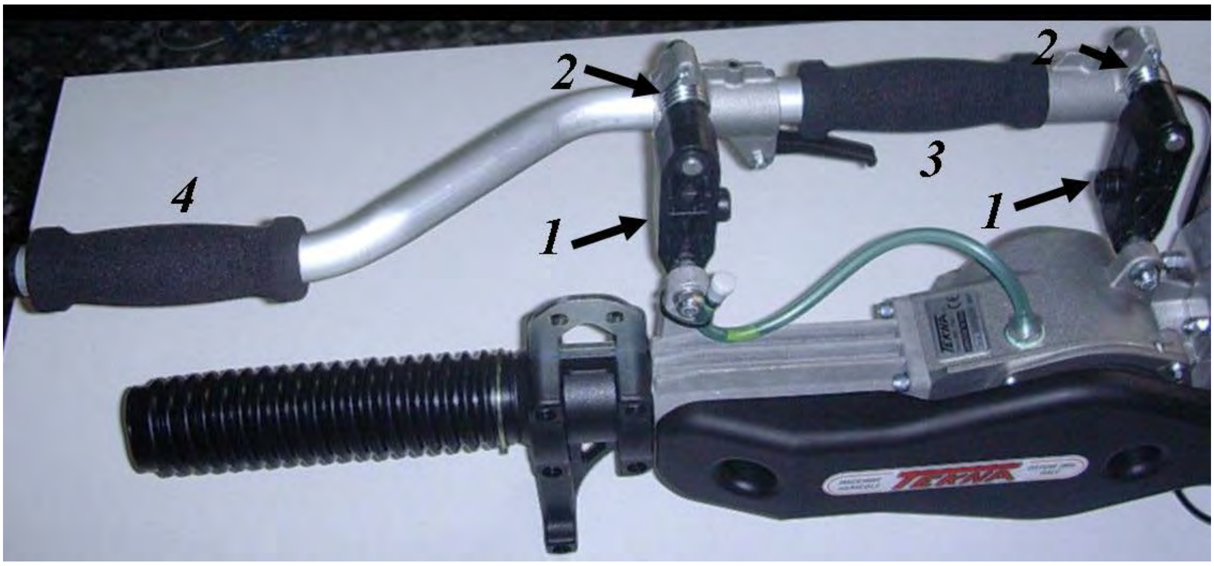

Figure 2. Vibrotek TK 5000
1 – connecting rod, 2 – spiral spring, 3 – control hand-grip, 4 – auxiliary hand-grip

The instruments and tools used were:

- Brüel & Kjær 4326 tri-axial accelerometer, with 0,320 mV/(m/s^2) sensitivity; 10 g mass; frequency response from 0,1 Hz to 13,3 kHz for x axis, from 0,1 Hz to 10 kHz for y axis and from 0,1 Hz to 16,6 kHz for z axis (linear response with a precision<10%);
- PCB SEN020 tri-axial accelerometer, with 0,100 mV/(m/s^2) sensitivity; 10 g mass; frequency response between 0,5Hz and 5 kHz, resonance frequency >25 kHz;

- Brüel & Kjær 2647 converter, used only for the B&K tri-axial accelerometer, used to convert the charge signals into continuous electrical signals;
- "SoundBook" data acquisition system made by a PC and a multi-analysis real-time interface (8 measurements channels);
- SoundBook™ "SAMURAI" operating system, used to configure acquisition system, to real-time monitor the measurements and to elaborate and present the obtained data;
- PCB 394C06 calibrator, characterized by a test signal of 9,835 m/s^2 (RMS), at the frequency of 159,2 Hz;
- aluminium supports, having 12 g of mass, used to fix the accelerometers to the handles of the shakers; these supports have been fixed with two plastic strip in order to ensure a perfect connection between accelerometers and tested machinery.

Particular attention was used during the fixing process of the accelerometers on the auxiliary and command handles, in order to have each axis oriented in the directions imposed by the provisions UNI EN ISO 5349-1 (2004) (basicentric coordinate system): y_h axis parallel to the axis of the handle; x_h perpendicular to the axis of the handle oriented by the back towards the palm of the hand and, at last, the z_h axis perpendicular to the plan formed by the two previous axis (Fig. 3)

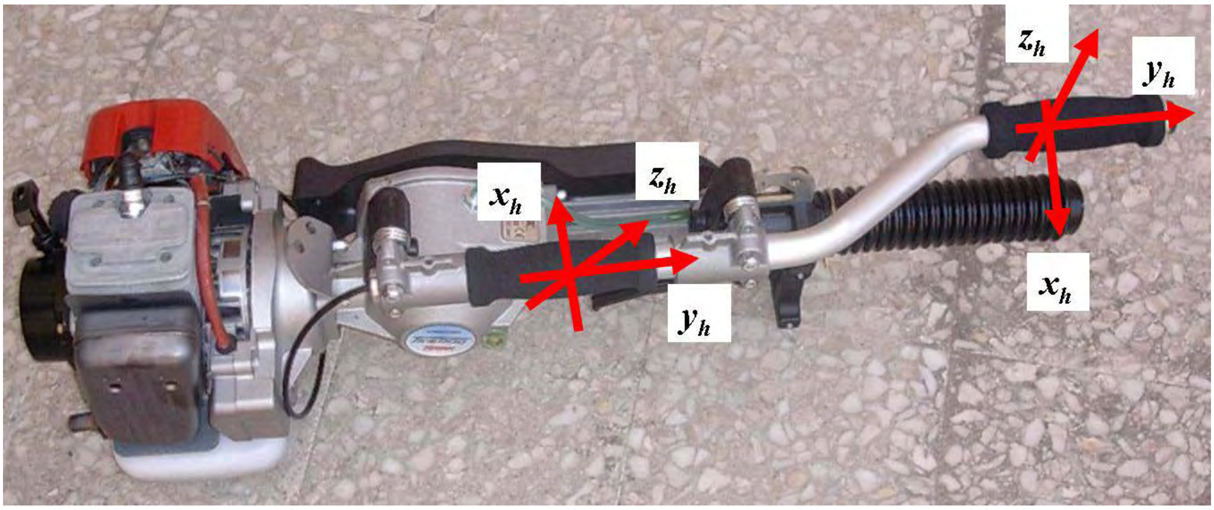

Figure 3. Basicentric coordinate system adopted for measurements.

The measure was set up using the optional software SoundBook HVMA which having, so, a class 1 testing instrument for the measure of the human exposure to the vibrations in conformity to the ISO 8041 (1990) and ISO/DIS 8041 (2003) and with digital direct weighing filters on the incoming signal. The analysed frequency spectrum, correspondingly to the actual provisions related to the hand-arm vibrations, was considered between 6,3Hz and 1250 Hz.

The equivalent accelerations weighed up in frequency on the single axis (a_{wx},a_{wy},a_{wz}) and total (a_{hv},), acquired simultaneously, were measured for the following modes of working of the tested shakers:

- at the minimum engine regime, that's to say ~2100 rpm (idle speed) with working rod stopped;
- during shaking work (full load);

- at the maximum engine regime, that’s to say ~9000 rpm (top speed).

The most significant mode of working is obviously the shaking one during the harvesting (full load), as in this condition of usage the hook of the rod hooks the branch and this represents the real dynamic behaviour of the shakers; the measurement time during this test mode were 300 s.
The idle speed mode is a working condition less onerous than the previous one because it takes place during the moves from a branch to another one of the same tree or of another tree and usually the worker reduce the prehensile strength of both the hands; the measurement time during this test mode were 20 s.

The top speed mode is not a standard operative condition and the worker rarely reaches this maximum running in order to prevent significant engine damage; the measurement time during this test mode were only 4 s.

On account of the aforesaid remarks, the measurements at idle speed and at top speed, made holding the shakers with both hands in a normal working position (working rod at ~60° on the horizontal plane), have been considered less important from the point of view of the evaluation of human exposure to hand-transmitted vibration and have been carried out with the only purpose to examine and compare the vibration emissions of the two machines. For this reason the measurements times related to these operative modes were short and in the case of top speed absolutely below the minimum time (8 s) advised by the above mentioned provisions. Furthermore these tests were carried out only on the shakers with the long working rod mounted which, being heavier than the short one, produces the highest dynamic lack of balance of the tools.

The full load working mode was made of several working phases: a) "hooking" of the branch with the engine to the minimum regime; b) operation of the accelerator, in order to open to the maximum value the valve of the carburettor; c) shaking of the branch exercising a constant strength on the handles; d) release of the accelerator, in order to take back the engine to the minimum regime; e) "unhooking" of the branch. The full load measurements were carried out with the shakers equipped with long working rod (full load -- long rod) and with the short one (full load – short rod)

The tests in each operating condition were repeated five times.

To monitor the data during the tests has been set up the real-time visualization of frequency analysis of the two accelerometers, of global value of the spectrum (axis x,y,z) and of a video capture using a web cam (Fig.4).

Before each test series and at the end of the series a calibration of the measurements instruments was carried out.

Figure 4. Signal analyses coming from the accelerometers displayed in real time.

3. RESULTS AND DISCUSSION

In the Tables 2 and 3, have been represented, respectively for the Vibrotek TK 650 and for the Vibrotek TK 5000, the frequency weighted accelerations along the axis and the total accelerations a_{hv}. The values a_{wx}, a_{wy} and a_{wz} are obtained, according to the previsions contained in UNI EN ISO 53491- (2004), as arithmetical average of the ones measured on the same axis (x, y and z) during the five repetitions made for each working mode of the shakers (idle speed, top speed, full load - long rod, full load – short rod); the total equivalent accelerations were calculated, how the same rule states vectorially adding the mean values concerning the three cartesian axis.

As aforesaid, the most significant values are obviously the ones measured during the harvesting tests (full load), as they represent the real use of the shakers; in these condition of usage the "intrinsic" characteristics of each shaker (rigidity, mass, rotating inertia of the individuals component and total), that define in an univocal way the natural frequencies and the ways of vibrating of the shaker, modify themselves at the moment in which the hook of the rod hooks the branch. This last one presents its intrinsic characteristics (rigidities, mass, etc.), moreover very much variables in function of its dimensions (length, diameter, etc.), that interacts with those of the shaker originating a quivering system, established by the branch-shaker system, of which it is difficult to foresee the dynamic behaviour. In this regard, it’s useful to observe that the total weighted acceleration a_{hv}, and the corresponding vibration emission, concerning the top speed mode, dependent just from the characteristics of the shaker, is different from that full load mode related, instead, to the characteristics of the branch-shaker system.

Table 2. Vibrotek TK 650. Average values of the frequency-weighted vibrations [m/s^2].

hand - grip	Test condition	a_{wx}		a_{wy}		a_{wz}		a_{hv}	
		average	St.dev	average	St.dev	average	St.dev	average	St.dev
control	idle speed	2,0	0,20	1,5	0,23	2,4	0,11	3,5	0,20
	top speed	12,9	1,2	14,1	3,2	19,2	2,20	27,2	2,7
	full load - long rod	9,7	1,1	10,4	0.9	4,0	0,4	19,5	2,0
	full load -short rod	10,6	0,9	14,5	1,6	3,1	0,4	18,2	1,9
auxiliary	idle speed	4,1	0,48	0,6	0,05	3,6	0,5	5,5	0,3
	top speed	15,2	3,6	27,5	9,1	17,42	3,16	36,1	9,6
	full load-long rod	12,2	1,4	11,8	2,0	11,3	1,8	20,4	2,5
	full load-short rod	13,3	1,7	12,4	1,8	14,5	2,1	23,2	3,0

For the Vibrotek TK 650 shaker, the usage of the long working rod or of the short working rod produce on both the handles weighted total acceleration values a_{hv} of the same magnitude (average 20,3 m/s^2). This tendency is the same for the x and y axis, while, on the z axis, the accelerations on the command handle are very much smaller (average 3,5 m/s^2); this behaviour is probably due to the constructive characteristics of this handle which evidently is more rigid in the z direction.

Table 3. Vibrotek TK 5000. Average values of the frequency-weighted vibrations [m/s^2].

hand - grip	Test condition	a_{wx}		a_{wy}		a_{wz}		a_{hv}	
		average	St.dev	average	St.dev	average	St.dev	average	St.dev
control	idle speed	4,5	0,1	1,3	0,1	3,3	0,1	5,7	0,1
	top speed	9,3	1,1	9,4	0,6	7,7	0,6	15,3	1,2
	full load - long rod	8,4	1,0	7,6	1.2	8,3	1,2	13,1	2,0
	full load -short rod	8,5	1,1	9,2	1,5	9,0	1,3	15,4	2,1
auxiliary	idle speed	6,8	1,0	0,9	0,1	2,6	1,2	7,4	1,4
	top speed	5,9	0,8	12,1	0,8	17,0	1,1	21,7	1,4
	full load - long rod	16,1	1,9	6,3	1,2	12,4	2,0	21,3	2,7
	full load -short rod	6,5	1,1	1,7	0,9	9,6	2,0	11,7	2,2

With regards to the Vibrotek TK 5000 shaker, the assembly of the two handles on a single axis, integral part of an articulate parallelogram system, has modified the dynamic behaviour of the shaker itself with respect to the other tested shaker. On the command handle the total weighed acceleration a_{hv} is reduced of 33% with the long working rod and of 15% with the short working rod with respect to the same value measured for the Vibrotek TK 650 shaker; on the auxiliary handle, considering the working condition with the short working rod, the a_{hv} value is reduced of 50%. On this handle, besides, the acceleration values are comparable between the two shakers only when they are both equipped with the long working rod.

In the Figures 5 and 6, are represented in the shape of bar diagrams, the frequency analyses for 1/3 octave bandwidth of the vibrations measured, respectively on the Vibrotek TK 650 and the Vibrotek TK 5000 shaker, during the mode full load -- long rod. These figures were obtained considering the vectorial sum of the linear accelerations measured on the three axes. From these figures the different dynamic behaviour of the two tools emerges in a clear way and, above all it is possible to notice the values meanly smaller of the accelerations measured on both the handles of the Vibrotek TK 5000 shaker. As we are dealing with the full load working mode, the regime of the engine is changed in a continuative way between 2100 and

9000 rpm, exciting the vibrating system in the correspondent range between 35 Hz and 150 Hz; to that has to be added the pulsating strength connected to the alternative movement of the working rod.

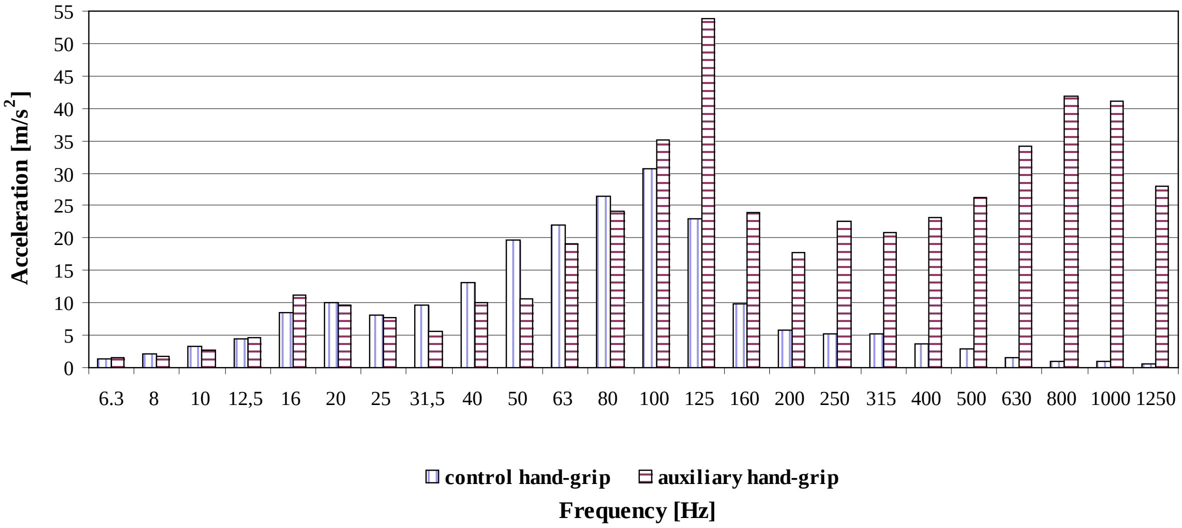

Figure 5. Vibrotek TK 650 equipped with long rod.
Average frequency spectrum of vibrations.

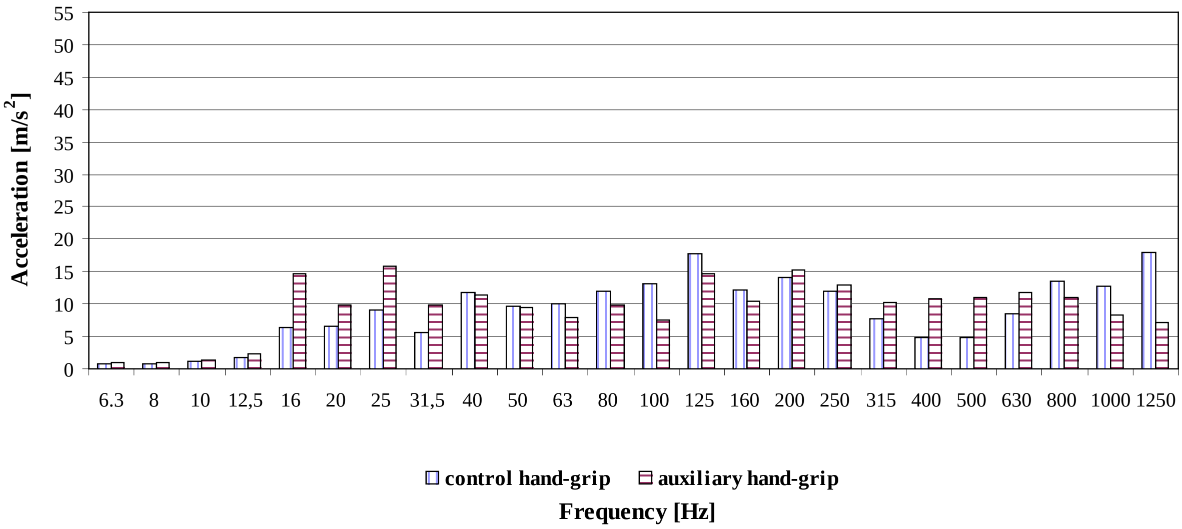

Figure 6. Vibrotek TK 5000 equipped with long rod.
Average frequency spectrum of vibrations.

4. CONCLUSIONS

The results of the carried outs tests, point out, in a particular way, the high values of acceleration transmitted to the hand-arm system produced by the examined portable shakers. In order to this it is necessary to remember that the Italian laws, with the object to evaluate of human exposure to hand-transmitted vibration, prohibit the overcoming the short period exposure limit value of 20 m/s^2 and impose a daily eight hours exposure limit value of 5 m/s^2. With regard to this, in the Table 4 has been represented, respectively for the Vibrotek TK 650 and for the Vibrotek TK 5000 the equivalent vibration total value related to 8 work hours, considering an average time of real daily exposure to vibration of 4,30 hours.

Table 4. Equivalent weighted acceleration related to 8 work hours [m/s^2].

hand -grip	test condition	Vibrotek TK 650	Vibrotek TK 5000
control	full load - long rod	14,6	9,8
	full load - short rod	13,7	11,6
auxiliary	full load - long rod	15,3	16,0
	full load - short rod	17,4	8,8

For both the examined shakers, the values are greatly higher than the limit ones laid down in the law in force.
The shoulder support device has not been object of the present study, but it is important to pay attention also to the weight of the tools so that can be avoided heavy physiological and muscular efforts.
The different dynamic behaviour of two devices which are structurally different only in the typology and disposition of the handles emerged from the tests; in purpose it is useful to remember that the limitation of the vibrations in design phase is one of the indication suggested by the current technical provisions [UNI/TR 11232-1 2007] to the tools manufacturers in order to increase the safety levels of the workers; in design phase, in fact, the in-depth study of some technical aspects allows an effective reduction of the effects of the exposure to damaging vibrations.

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