Design of an innovative olive picking machine

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Abstract: This work describes the complete design of an olive picking machine especially conceived for secular olive plants with the purpose of increasing the mechanization level of the harvest operation and permitting the production of high quality oil; the design is made considering all the mechanical, agronomical and economical aspects involved in this issue. Once defined the picking technique, the first step consists in the design of the shacking device used for the separation of the olives from the plant, the next step is the design of the support structure, including the arms and the frame; finally there is a description of the hydraulic plant that drives the moving parts of the machine; in order to increase the flexibility of the machine, it is adapted also for other works, like pruning, that can be performed outside the harvest season. Starting from the principal characteristics of the cultivations the design of the machine and its implementation is realized considering all functional features, including verifications of resistance according to the current standards; finally the economic aspects are hinted to confirm the marketing appeal of the machine.

Keywords: Olive picker, mechanical harvest, olive oil, secular olive trees

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1 Introduction

The picking operation of olives (Deboli et al., 2014) requires, like in other cultivations, a high mechanization level in order to reduce the production costs of high quality olive oil (Mirzabe, Khazaei, Chegini, & Rostami Nejad, 2013; Sola-Guirado et al., 2014).

To realize a high quality product (Di Giovacchino, Sestili, & Di Vincenzo, 2002) the direct picking from the tree is necessary avoiding the gather from the ground. In fact, in ground gathering, the detachment time of the single fruit cannot be controlled, because it be dropped from the plant several days before its harvest (González-Montellano, Baguena, Ramírez-Gómez, & Barreiro, 2014). In this time period the fermentation can lead to a degeneration of the organoleptic properties increasing, for example, the acidity that determines the reduction of oil quality; for the same purpose, the time between the detachment of the fruit from the tree and its transfer to the oil mill for pressing must be minimized.

In the last decades there has been a great diffusion of picking machines for young olive plants that realize the detachment of the olive fruit by vibrations transmitted to the tree trunk.

All the developed systems are especially made for small trees whose trunks do not exceed the diameter of 20-30 cm; the picking operation on secular plants is a demanding problem because they have a trunk diameter which can measure even more than a meter thus vibrations can damage stem and roots; the only accepted harvesting is carried out manually with sticks or small shakers but brings very low yields, leading to production costs unable to withstand the international competition.

The machine presented in this article works realizing the vibration on the foliage having a direct contact with

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the olives and is characterized by an operation method that allows to have lower and more competitive production costs than in actual processes. For the same reason self-propelled machinery is avoided in favor of a machine pulled by tractor, whose costs are much lower (the tractor is an equipment usually present in a farm).

Then this work describes the most important aspects considered during the design of the machinery, showing the general arrangement drawings of the its functional subassemblies and reporting, as examples, some computations made in order to dimension the components of the machine.

2 The olive tree and its cultivation

2.1 Characteristics of the plants

The olive tree is a characteristic plant of the Mediterranean region cultivated for the production of the oil extracted from its fruits, the olives (Mirzabe et al., 2013; Rababah, Feng, Yang, Eriefej, & Al-Omoush, 2011); it is one of the most longeval trees and can exceed 2000 years of age; it prefers a warm and dry climate, therefore we can find the oldest ones were the climate remained stable over the centuries, mostly near the sea. Table 1 shows the data of to the oil production in the year 2009.

Table 1 World production of olive in 2012 (thousands of tons) according to FAO, where the symbol * means that it is estimated by FAO

Country	Production
Spain	3627
Italy	3018
Greece	2081
Turkey	1820
Morocco	1316
Syrian Arab Republic	1050
Tunisia	963
Egypt	465 *
Algeria	394
Portugal	390
Argentina	175 *
Jordan	156
United States of America	145
Libya	135 *
Albania	125
Lebanon	95 *
Peru	93
Occupied Palestinian Territory	80 *
Australia	75 *
Chile	74 *

Modern farms that produce oil are characterized by super intensive cultivation, widespread in Spain, which consists in planting young trees keeping them very small during their life with a look more like bushes than trees in order to allow the mechanization of all the operations required during the year. Thanks to the regularity of the implantation the harvest operation is made in a continuous way by a machine that realizes at the same time the detachment and the harvesting of the fruits; this provides a highly competitive price of oil, however implying a remarkable water demand due to the shallowness of the roots of plants; this has repeatedly caused serious shortages of water during the dry season in regions like Andalusia. Moreover, the type of implantation facilitates and accelerates the spread of fungal diseases or biological damages caused by insects, obliging to make frequent treatments based on dangerous chemicals in order to prevent this troubles; therefore few varieties of olive trees can be cultivated according to this technique.

There are also cultivations with trees not older than 30 years and an average trunk diameter of 20-30 cm; these sizes allow the mechanical harvesting using a shaker acting on the trunk and able to detach the olives due to vibrations transmitted to the branches; the fruits can be collected by hand in a traditional way using nets or can be conveyed by a “reverse umbrella” down in a collection tank; this kind of cultivation permits a high level of mechanization, but lower than the super intensive one, leading to an increase of production costs; an advantage is the lower water demand and the greater resistance to diseases of the trees.

Another type of cultivation with secular olive trees is characterized by an average trunk diameter of 50-60 cm, up to 1 m and more in some cases; with this size the olive cannot be detached with a trunk shaker due to the high stiffness of olive wood, thus the vibration is induced directly on the foliage in order to avoid serious tree damages; now the harvesting operation on these trees is made sometimes in a complete manual way, sometimes with the help of vibrating pneumatic or electric rakes (Figure 1) carried by hand.

Figure 1 Vibrating pneumatic rake

As reported in Table 1, Italy is the second producer of olive; in contrast to Spain is characterized by a great number of small farms; this implies that the investment possibilities are lower and make it difficult to convert the actual plants, mostly composed by secular trees, to a modern super intensive system.

Another reason, in addition to the higher environmental sustainability compared with the other plants, that lead to prefer the maintenance of the current crop is the fact that the ancient olive trees represent the distinctiveness of the landscape of southern Italy and are important elements of the ecosystem.

The main oil production in Italy (almost 40%) is made in the Apulia region that is suitable for mechanization of the collecting operation, presenting an almost entirely flat territory; the machine developed is especially conceived for these characteristics.

As mentioned, an important economic factor differentiates the various cultivation types due harvesting costs; these are listed in Table 2 (Vieri, 2005) as ratio to a complete manual operation.

Table 2 Costs of different harvesting types as ratio to a complete manual operation

Harvesting type	Intensive plants	Traditional plants
Manual	1	1
With manual vibrator	0.5	0.7
With mechanical shaker and nets	0.3	0.6
With mechanical shaker and reverse umbrella	0.2	0.5
Continuous	0.1	-

A type of harvesting can be evaluated also in terms of productivity: the amount of product picked by each operator, the number of treated plants in one hour and the total number of workers involved; Table 3 (Vieri, 2005) shows these data for the principal harvesting categories.

Table 3 Productivity of different harvesting types

Machinery used	Productivity (kg/h x operator)	Work capacity (trees/h)	Operators involved
None (manual harvesting)	10-15	-	1
Manual vibrator	25-50	4-8	3
Mechanical driven shaker and nets	70-100	16-22	12
Self-propelled shaker and reverse umbrella	400-500	20-25	1

2.2 Characterization of the picking technique

Picking technique is fundamental for different fruits and crops and innovative automatic techniques are always emerging in literature (Lu, Peisong, Caiyun, & Pan, 2011; Oduori, Mbuya, Sakai, & Inoue, 2012).

The picking technique is fundamental for a good result of the harvest, both for the amount of product and for the time spent in this operation.

The olive fruit is characterized by a very light weight and high resistance to detachment, thus a high mechanical energy is necessary for removing a fruit from the tree.

The technique adopted is the tangential picking, (Figure 2): a helical movement around the tree is set to the implement from the highest to the lowest part of the foliage with a machine that moves around the tree. In this way, a horizontal displacement is realized, while a vertical component of displacement is commanded by the up or down movement of the supporting arm; the angle α is function of various parameters (Equation (1)), including the tractor speed (v), the diameter of the foliage (d) and the density of the olives in the foliage (q):

$$\alpha = f(v; d; q) \quad (1)$$

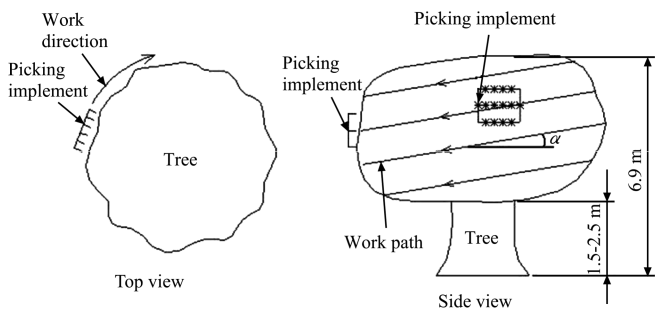


Figure 2 Tangential picking technique

This technique minimizes the idle time, that is the movement and positioning between a tree and the other, increasing in this way the performance of collection and contributing to the reduction of production costs.

3 Design of the machine

An important design target is lightness, that influences the maneuverability of the machine and the conveyable load of harvested olives. A material suitable for this purpose is aluminum (Solazzi, 2010), or composite materials (Solazzi & Scalmana, 2013). Then the design optimization (Borboni, Bussola, Faglia, Magnani, & Menegolo, 2008) must be performed on the entire machine (Solazzi, 2012), but the loading conditions and the dynamical effects are associated to the action of the shaker and of the arm of the machine (Polizzotto, 2012). Basing on these considerations and on economic aspects, the adopted material is structural steel for the carpentry parts and heat treated steel for the rotary elements. An admissible stress field verification is then performed; a reliability approach cannot be employed because reliability parameters will be known after the realization of the prototype with experimental tests (Donzella, Matteazzi, & Solazzi, 2005). The determination of the applied mechanical (static and dynamical) actions allows the next step of the design procedure: the fatigue dimensioning and verification evaluating stresses with finite element analysis and comparing results with admissible stresses of the adopted material. This verification is associated to a determination of an adequate safety coefficient. A functional parameter is the stiffness of the structure that can be adequately designed to ensure the shaking action of the olive branches.

The entire design process was performed adopting the software Solidworks@ for the 3D modelization and the software Abaqus@ for the finite element analyses.

3.1 Design of the picking implement

The picking implement has to perform the detachment of the highest number of olives from the tree; to achieve this target the device is composed by two vibrating panels that move in opposite phase in order to eliminate the effect of vibrations on the support structure.

The panels are moved by an eccentric shaft that transmits the motion through two connecting rods which take the power from a hydraulic motor; the total angular excursion of the panels is equal to 8°.

On each panel are mounted about 40 polymeric cylindrical rods (Figure 3) with dimensional characteristics (length and diameter) computed in order to have the natural frequency ω_n of oscillation suitable to transmit sufficient energy forth detachment of the olives (about 8 Hz) (Equation (2)):

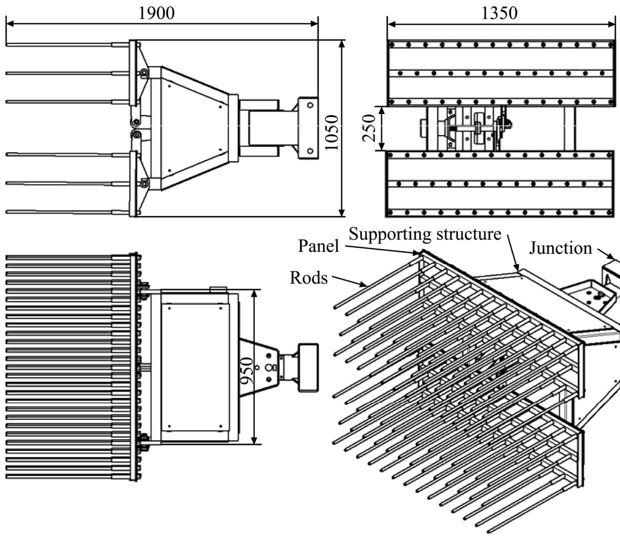


Figure 3 Mechanical design of the picking implement (dimensions in mm)

$$\omega_n = \beta_n^2 \cdot \sqrt{\frac{E \cdot J}{\rho \cdot A}} \quad (2)$$

where, E is the elasticity modulus of the material; J is the moment of inertia of the cross section of the rod; ρ is the density of the material; A is the cross-sectional area of the rod. β_n is a coefficient computable using Equation (3):

$$\beta_n = \frac{\alpha_n}{L} \quad (3)$$

where, L is the length of the rod and α_n is a value dependent of the considered mode of vibration solving the characteristic equation of frequencies for this configuration:

$$1 + \cos\alpha \cdot \cosh\alpha = 0$$

The implement is supported by a junction which permits its angular displacement (±90°), needed to realize the tangential picking; for security reasons, protections are added to enclose the structure and to prevent the operator to come into contact with moving parts.

The choice of material of the rods was carried out by checking the flexural fatigue behavior with experimental tests performed on a workbench; the first material to be tested was the fiberglass, which has a high elastic modulus (about 74 GPa); during the tests, this material showed a good response for high frequency excitation, but the fatigue resistance was very bad, as known from literature (Kordatos, Dassios, Aggelis, & Matikas, 2013), bringing to a delamination (Figure 4a) after a small number of cycles (500).

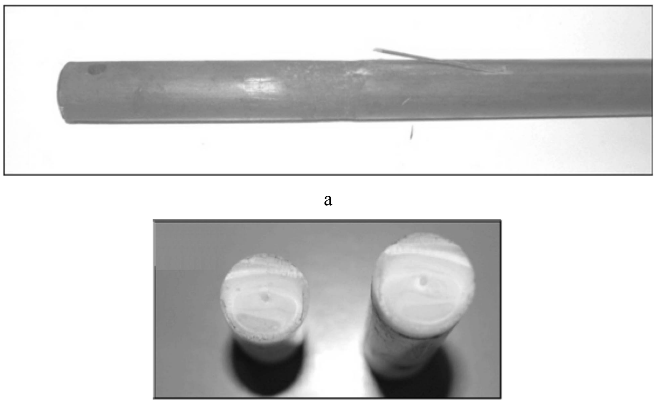


Figure 4 Aspect of the fiberglass rod after 500 cycles (a) and of the fracture surface of the plastic rod (b)

The second category of tested rods is composed by two kinds of polymeric material; the first is a semi-crystalline polyester, the second is an acetalic resin; the test is performed in a similar way as for the glass fiber and any sign of deterioration has not recognized due to fatigue in the second one, but a failure has occurred in the polyester rod caused by a sharp rise of the temperature in the most stressed zone in proximity to the constrain, showing a typical fatigue fracture (Figure 4b).

The lack of polymeric materials (compared with the fiberglass) is the low stiffness that brings to a lower frequency response and also to a lower energy transmittable to the foliage; to overcome this problem the length of the rods was reduced and the cross section was increased.

The supporting structure is composed by tubular welded square section 60 mm×60 mm×4 mm made of S355JR (UNI EN 10025-1) structural steel, which give the required stiffness to the structure.

Particular attention has been paid to the choice of "Steel Community", and in particular in the joints (bolted and welded) because often olive plantations are close to the sea thus in a corrosive and potentially damaging environment forth steel structures (Fazal, Haseeb, & Masjuki, 2011; Solazzi, Scalmana, Gelfi, & Vecchia, 2012).

Resistance checks are carried out on the structure both analytical and numerical in order to prevent failures and to size the drive system; first method was used to determine the forces during the rotation of the panel, schematizing the structure as shown in Figure 5.

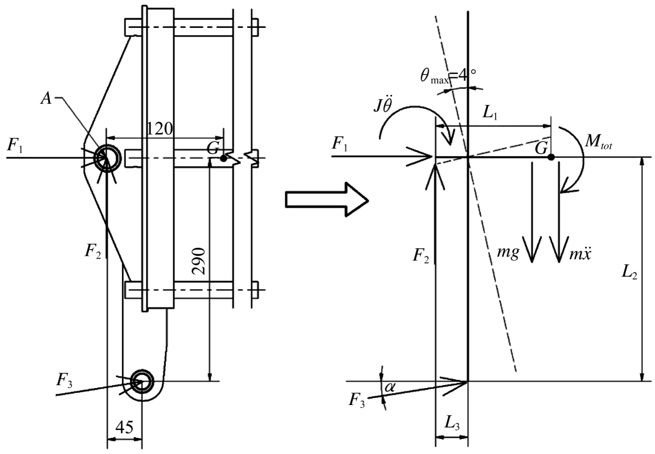


Figure 5 Schematization of the considered structure (dimensions in mm)

The forces F_1 and F_2 are those exchanged between the panel and the supporting structure, the force F_3 is transmitted to the panel by the connecting rod, G is the center of gravity of the structure, the forces $J\ddot{\theta}$ and $m\ddot{x}$ are the inertial components generated by the motion of the panel; mg is the gravity force due to the mass of the panel; M_{tot} is the total moment generated by the maximum deflection of the booms; remembering that Equation (3):

$$F_i + f_i = m_i \ddot{a}_i \qquad i = 1,2,\ldots,N \tag{3}$$

where, F are the generalized forces; f are the reaction forces; $\ddot{a}$ are the accelerations of the i-th mass m.

We can also write Equation (4):

$$F_i + f_i - m_i \ddot{a}_i = 0 \qquad i = 1,2,\ldots,N \tag{4}$$

The equilibrium equations (Equation 5) can now be applied to the structure for the rotation around the center in A:

$$F_3 = [J_{tot}\ddot{\theta} + M_{tot} + (mg + m\ddot{x}) \cdot L_1] / [\cos\alpha \cdot L_2 + sen\alpha \cdot L_3] = 3298\,\text{N} \tag{5}$$

For the translation along the vertical direction:

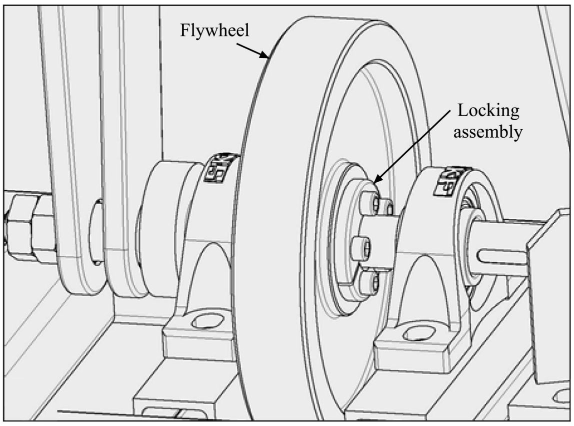
$$F_2 + F_3 \cdot sen\alpha - mg - m\ddot{x} = 0 \Rightarrow F_2 = 1381\,\text{N}$$

For the translation along the horizontal direction:

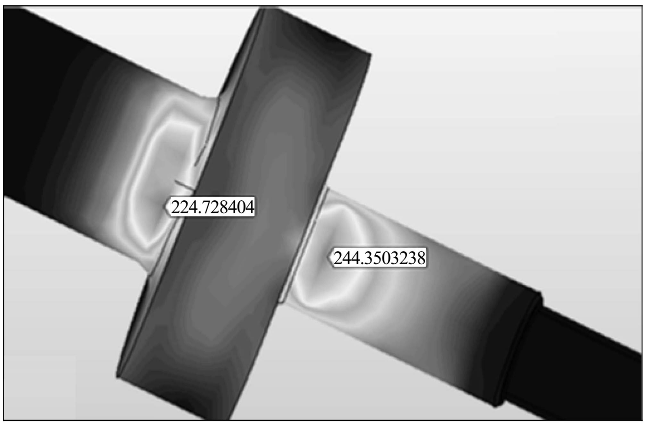
$$F_1 + F_3 \cdot \cos\alpha = 0 \Rightarrow F_1 = -3257\,\text{N}$$

These results are also used to verify the resistance of the involved components, like the connecting rods/pins and the transmission shaft; the first ones have no problems, ensuring a high safety factor; for the shaft, realized in 39NiCrMo3 (UNI 7845) with a form able to minimize notch the situation is more delicate and suggests to use a finite elements method to verify the stresses, as shown in Figure 6b.

The boundary conditions on the shaft are two compliant supports constraining the vertical displacements with a surface constraint. The compliance of the supports is associated to the plummer block housing and to the inserted bearings. Horizontal displacements are constrained with a point constraint also at the right side of the shaft (according to Figure 6).



a



b

Figure 6 View of the driving assembly (a) and stresses (MPa) in the transmission shaft (b)

The stresses computed are also used for fatigue verification with the Gough-Pollard method, obtaining a safety factor equal to 1.9; this is an acceptable value, enough to ensure the resistance of the component even in case of an unexpected increase of the forces, possible during the intended use because of the high variability of external conditions. A shot peening was realized in the fillet neighborhood to generate a compressive stress state that increments the fatigue resistance of the component (Donzella, Pola, Solazzi, & Marconi, 2000).

To avoid irregularities in the motion of the panels, a flywheel is connected to the drive shaft by a locking assembly shown in Figure 6a, which allows a good centering, avoiding at the same time a notch in the shaft structure.

3.2 Design of the platform

The designed platform can be exchanged with the picking implement and used for the ordinary maintenance operations of the plants, like pruning: this solution increments the flexibility and the economical convenience of the machine. The component (Figure 7) is dimensioned for one operator and the required equipment (1,000 N), respecting all the security prescriptions contained in standard EN 280:2001, is made by a welded tubular structure, having a door for operator access and the possibility to connect the commands of the hydraulic circuit.

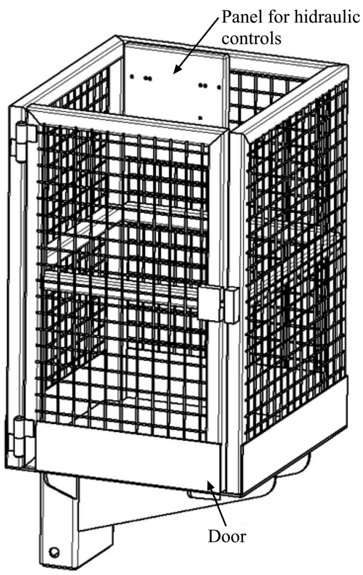
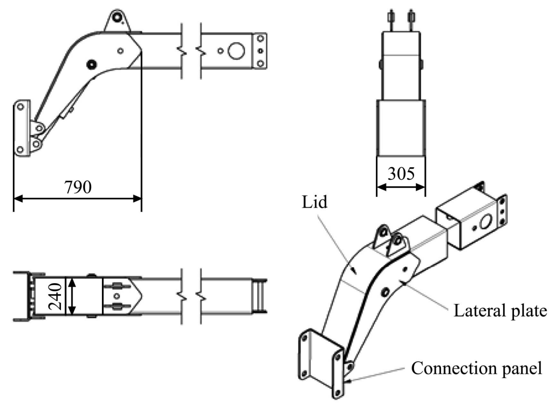


Figure 7 View of the platform

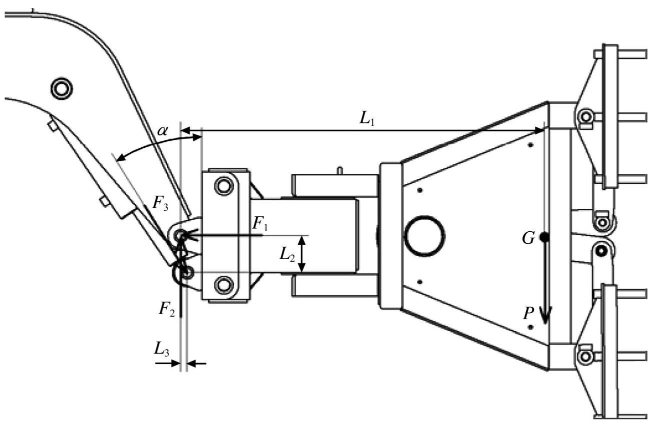
3.3 Design of the support structure

This part of the machine performs the supporting function of the implement and its handling; in order to allow the required movement of the implement, the machine is equipped with two supporting arms made by S355JR (UNI EN 10025-1) structural steel: the first is connected to the rotating column and the second telescopic one is able to scroll through pads and rollers, driven by a hydraulic cylinder.

The first step is the design of the structure that allows the connection of the picking implement with a special linkage driven by a hydraulic cylinder composed by a lid and two lateral plates (Figure 8a); the position of the holes coupled with the cylinder and the connection panel influences the realized rotation.



a



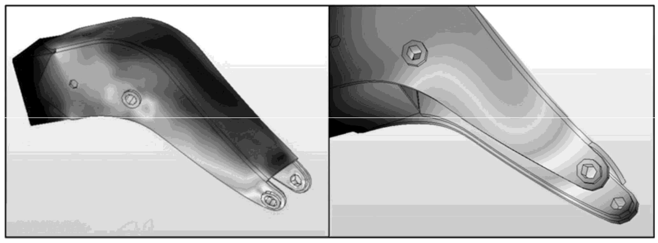
b

Figure 8 Views of the linkage between the picking implement and the arms (a); scheme utilized for the computation of the forces on the support structure (b) (dimensions in mm)

Sizeable forces are generated due to the proximity of the connecting hinges and their magnitude was calculated with analytical methods as shown in Figure 8b.

A magnifying factor of 1.5 is used, as for the other computations, in order to consider the dynamic effects acting on the structure during its utilization on rough terrain.

The part in question are analyzed with a finite element method because of the high value of the applied forces and the complex geometry; some reinforcements are inserted in the structure to bring the stress value within an acceptable range; the patterns represented in Figure 9a and Figure 9b are obtained with the final geometry for stresses and displacements respectively, showing values well below the required limits.



a b

Figure 9 Performance of stresses (a) and displacements (b) in the linkage part (max. stress 70 MPa, max. displacement 0.2 mm)

The following results are obtained, from the equilibrium equations for the system in Figure 10.

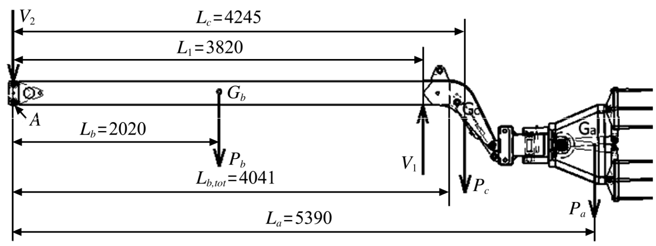


Figure 10 Example of the schematization of the arm structure during a load cycle (in this case the first arm, dimensions in mm)

$$F_1 = 42 \text{ kN} \qquad F_2 = 63 \text{ kN} \qquad F_3 = 73 \text{ kN}$$

The correct scroll of the internal arm is permitted by rolls and sliding pads; the first ones are applied were the forces are higher, because they prevent the wear and also the frequent replacement of components thanks to the rolling friction, the second ones are applied where the forces are low or where there is not much space; both components are realized in a plastic material.

A lot of stress analyses are performed on the arms in order to prevent dangerous failures considering all the main load cycles supported by the structure during its life. These operations are made using analytical methods, schematizing the arms like de Saint Venant beams, as shown as example for one position of the second arm in Figure 10. Here, to increment safety, a comparison was done with the stresses determined by experimental analysis on components which have a very similar working mode.

The local effects induced by the interactions between the elements are fundamental, i.e. the bending of beams that are reflected on the values of the transmitted forces.

The forces considered in this analysis are vertical, deriving from the weight of the structure and horizontal, deriving from the inertia generated by the rotation of the turret; only the first ones are increased by a dynamic coefficient experimentally evaluated on similar structures, their values are significantly higher than those provided by the corresponding standard due to the frequent oscillations occurring in the operating terrain, which can be very irregular.

Once estimated the stresses in various working conditions, the highest and the lowest value (Solazzi, 2004a) are considered for a fatigue damage computation.

3.4 Design of the rotating castle

The rotating castle is the part of the machine which has to:

- permit the connection of the arms and of the hydraulic cylinder;
- give the required stability to the structure, thanks to the ballast filled with inert material (sand);
- allow to reach the required angular position, thanks to the rotation permitted by the ball-bearing fifth wheel on which the turret is assembled;
- give the possibility to accommodate the operator with the hydraulic controls necessary to the handling of the machine;
- offer the place to assembly the diesel motor.

The dimensioning of the ballast is made considering the worst possible situation that occurs during the shaking work, when the arms are horizontal and the stabilizers are not used.

The main frame of the castle is made by welded sheet metal, the cabin for the operator is designed respecting the dimensions provided by the corresponding standard and is reinforced by a tubular structure in order to protect the person in the case of an overturning of the machine; the geared motor that drives its rotation is also mounted on the castle (Figure 11).

3.5 Design of the main frame

The main frame is the part of the machine that has to:

- permit the assembling of the fifth wheel, on which is mounted the turret;
- allow, thanks to a towbar and two wheels, the connection of the machine with the tractor and its transport;
- permit the housing of the stabilizers.

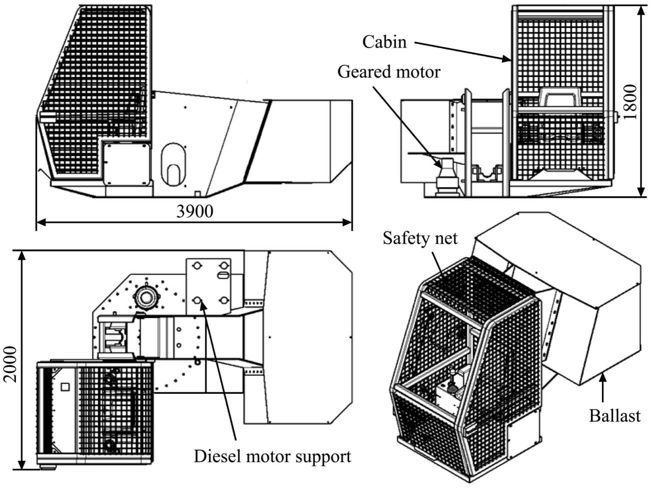


Figure 11 Views of the turret (dimensions in mm)

The supporting structure of the frame is made by UPN welded beams composed by S355JR (UNI EN 10025-1) structural steel; the support for the fifth wheel and the stabilizers are assembled on the same part; two independent wheels are mounted in order to permit the movement of the machine; due to the low speed reached with the machine there are no suspensions even to give the structure a greater stiffness; the views of the complete supporting frame are shown in Figure 12.

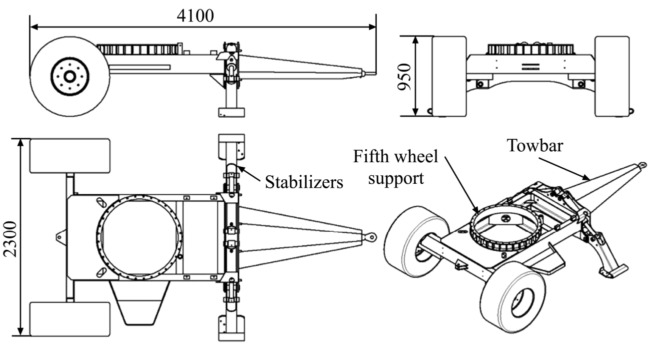


Figure 12 Views of the complete supporting frame (dimensions in mm)

Specific stress analyses were not performed on the main frame structure, as in the turret because its components are generally over-sized. The views of the machine with its functional groups are shown in Figure 13.

3.6 Design of the hydraulic plant

The hydraulic plant is the part devoted to the transfer of the mechanical power to the hydraulic drives of the machine; it is composed by a pump which takes the energy from a combustion engine and the appropriate hydraulic actuators, which can be linear (cylinders) or rotary (orbital motors).

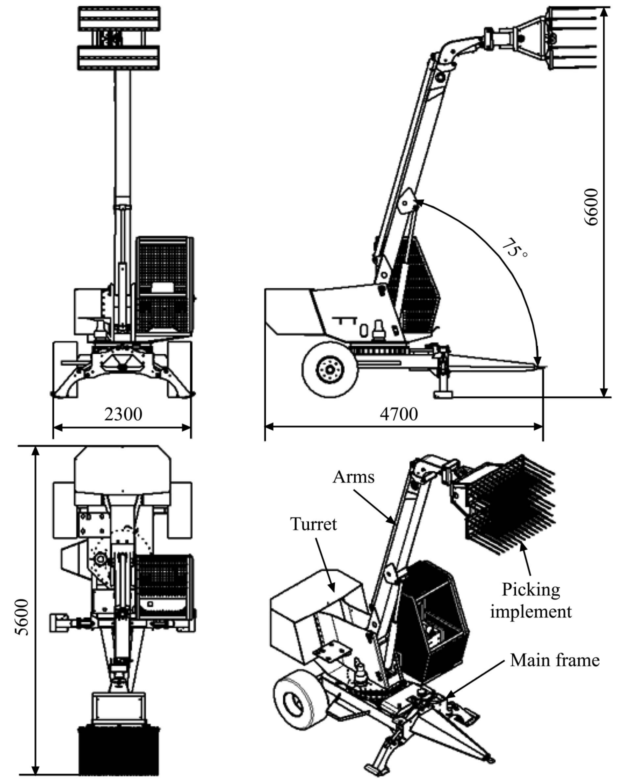


Figure 13 Views of the complete machine with the functional groups (dimensions in mm)

The linear cylinders are designed considering the maximum force that they have to support, increased by a factor equal to 2; in addition the buckling resistance of the piston rod is verified.

The orbital motors are dimensioned considering the maximum flow required for their operation.

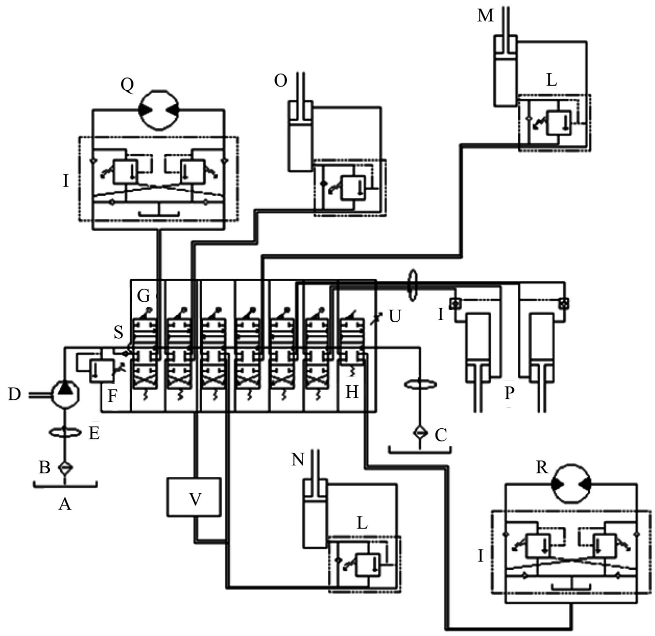
The control of the actuators is made by directional control valves; a rotary collector with the needed number of lines is necessary because of the rotation of the turret to prevent the kinking of the connecting pipes.

Different types of valves are necessary for the correct behavior of the plant the use of:

- simple non-return valve, which prevents the reversion of the oil flux;
- controlled non-return valve, which prevents also the dislodgement of the oil from the cylinders when not in use;
- maximum pressure valve, which allows to discharge the oil from the actuators in case of excessive pressure;
- controlled block valve, which has both features of the previous two components;
- valve utilized for the actuators, which has to prevent shocks and cavitation, has to guarantee the block of the motor when not in use and control its rotation;
- restrictor, utilized for the regulation of the flow.

In order to synchronize the motion of the lift and the overturn actuator, a compensator is added and it has the task of controlling the amount of oil entering in the cylinders, to maintain the parallelism of the final implement with the ground during the lift motion of the arms.

All the parts which compose the hydraulic plant are shown in Figure 14.



A. Oil tank B. Suction filter C. Exhaust filter D. Pump E. Six ways collector F. Maximum pressure valve G. Three positions, five ways directional control valve H. Two positions, three ways directional control valve I. Shockproof, block, anticavitation, rotation control valve L. Controlled block valve M. Lift actuator N. Overturn actuator O. Telescoping actuator P. Stabilizing feet actuator Q. Rotation motor R. Picking implement motor S. Simple non-return valve T. Controlled non-return valve U. Restrictor V. Compensator

Figure 14 Hydraulic plant

4 Feasibility study

The first step, in order to evaluate the economical convenience of the machine, is the determination of total production costs; to do this, the components are divided in two categories: the first composed by the ones produced in the factory or bought as semi-manufactured; the second composed by the ones bought from outside companies; all costs are subjected to a variance considered about ±5%.

The determination of the component costs of the first category is valued starting from the material of each one and its processing cycle, which includes the type of machines, the number of workers and the time involved in the realization.

Then the estimation of the costs of the welded assemblies is made considering also the mounting costs; finally, the assembly costs of the entire machine are estimated with the same technique.

The cost of the components of the second category are the purchase prices of each one supplied by the dealer; the last considered costs are those of painting for the entire machine.

The expected gain for the company, including the VAT, is considered to determine the selling price that can be about €25,000.

Once calculated the production costs the suitability for a typical medium-size farm situated in the south of Italy is considered. The machine was conceived for a number of plants equal to 1,000; the productivity of the machine is estimated at 12 plants per hour and the harvest of the fallen olives (estimated at around 70% of the total quantity on plants) is performed by three persons using nets; two operators are provided for the handling of the machine.

The selling price for the oil is considered equal to 7 €/kg (about 6.4 €/L), due to the high quality of this kind of oil (the price depends also on the area of sale, it can rise up to 15 €/kg and more).

In addition to the purchase cost of the machine was considered even the maintenance costs of the machinery and the plants as well as all the other costs involved: squeeze of the olives, marketing, bottling and transport of the product; the payback period resulting from the purchase of the machine amounts to about four years.

5 Conclusions

This work proposed the realization of an innovative machine that aims to improve the picking phase of the olives from secular trees increasing the degree of mechanization, prerequisite for the reduction of production costs; the next step after the realization of the machine is to make a set of tests observing the behavior of the machinery in order to evaluate any possible improvement and to perform the pruning technique used for secular olive trees.

For the design of the most stressed mechanical parts, a good safety factor is preferred to prevent failures caused ban unexpected rise of the forces, especially for the components that can cause physical damage to involved operators.

The hoped target is to allow a profitable farming of secular olive trees, helping to preserve a unique environment, preventing the replacement of old cultivations with modern plants and severely limiting in this way the use of chemical products indispensable in super-intensive fields.

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References

Borboni, A., Bussola, R., Faglia, R., Magnani, P. L., & Menegolo, A. 2008. Movement optimization of a redundant serial robot for high-quality pipe cutting. *Journal of Mechanical Design, Transactions of the ASME,* 130(8): 0823011-0823016.

Deboli, R., Calvo, A., Gambella, F., Preti, C., Dau, R., & Casu, E. C. 2014. Hand arm vibration generated by a rotary pick-up for table olives harvesting. *Agricultural Engineering International: CIGR Journal,* 16(1): 228-235.

Di Giovacchino, L., Sestili, S., & Di Vincenzo, D. 2002. Influence of olive processing on virgin olive oil quality. *European Journal of Lipid Science and Technology,* 104(9-10): 587-601. doi: 10.1002/1438-9312(200210)104:9/10<587::aid-ejlt587>3.0.co;2-m

Donzella, G., Matteazzi, S., & Solazzi, L. 2005. Experimental and numerical analysis of the body of a refuse collecting vehicle. *International Journal of Computer Applications in Technology,* 24(2): 89-97.

Donzella, G., Pola, A., Solazzi, L., & Marconi, G. P. 2000. Effect of shot peening on carburized surfaces. *International Journal of Materials and Product Technology,* 15(1): 117-130.

Fazal, M. A., Haseeb, A., & Masjuki, H. H. 2011. Effect of different corrosion inhibitors on the corrosion of cast iron in palm biodiesel. *Fuel Processing Technology,* 92(11): 2154-2159. doi: 10.1016/j.fuproc.2011.06.012

González-Montellano, C., Baguena, E. M., Ramírez-Gómez, A., & Barreiro, P. 2014. Discrete element analysis for the assessment of the accuracy of load cell-based dynamic weighing systems in grape harvesters under different ground conditions. *Computers and Electronics in Agriculture,* 100, 13-23.

Kordatos, E. Z., Dassios, K. G., Aggelis, D. G., & Matikas, T. E. 2013. Rapid evaluation of the fatigue limit in composites using infrared lock-in thermography and acoustic emission. *Mechanics Research Communications,* 54, 14-20. doi: 10.1016/j.mechrescom.2013.09.005

Lu, L., Peisong, D., Caiyun, Y., & Pan, L. 2011. Design of a new type of maize harvesting header. *International Agricultural Engineering Journal,* 20(1): 62-65.

Mirzabe, A. H., Khazaei, J., Chegini, G. R., & Rostami Nejad, M. H. A. P. 2013. Determination of some physical properties of virgin olive fruits. *Agricultural Engineering International: CIGR Journal,* 15(1): 201-210.

Oduori, M. F., Mbuya, T. O., Sakai, J., & Inoue, E. 2012. Kinematics of the tined combine harvester reel. *Agricultural Engineering International: CIGR Journal,* 14(3): 53-60.

Polizzotto, C. 2012. A gradient elasticity theory for second-grade materials and higher order inertia. *International Journal of Solids and Structures,* 49(15-16): 2121-2137.

Rababah, T. M., Feng, H., Yang, W., Eriefej, K., & Al-Omoush, M. 2011. Effects of type of packaging material on physicochemical and sensory properties of olive oil. *International Journal of Agricultural and Biological Engineering,* 4(4): 66-72.

Sola-Guirado, R. R., Castro-García, S., Blanco-Roldán, G. L., Jiménez-Jiménez, F., Castillo-Ruiz, F. J., & Gil-Ribes, J. A. 2014. Traditional olive tree response to oil olive harvesting technologies. *Biosystems Engineering,* 118(1): 186-193.

Solazzi, L. 2010. Design of aluminium boom and arm for an excavator. *Journal of Terramechanics,* 47(4): 201-207.

Solazzi, L. 2012. Applied research for weight reduction of an industrial trailer. *FME Transactions,* 40(2): 57-62.

Solazzi, L., & Scalmana, R. 2013. New design concept for a lifting platform made of composite material. *Applied Composite Materials,* 20(4): 615-626.

Solazzi, L., Scalmana, R., Gelfi, M., & Vecchia, G. M. L. 2012. Effect of different corrosion levels on the mechanical behavior and failure of threaded elements. *Journal of Failure Analysis and Prevention,* 12(5): 541-549.