CHEMICAL ENGINEERING TRANSACTIONS
VOL. 58, 2017
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216
DOI: 10.3303/CET1758022

A Body Impedance-Based Safety System for Electrical Pruning Tools

Daniele Sarri[a], Stefano Gemignani[b], Riccardo Lisci[a], Marco Vieri[a]

[a] Department of Agriculture, Food production and Forestry management, Division Biosystems Engineering, University of Florence, Piazzale delle Cascine - 15 50144 Firenze, Italy.
[b] Flash Elettronica Via Valiano I 50065 Molino del Piano (FI)
daniele.sarri@unifi.it

The use of high productivity pruning shears led the market toward the development of electronic controlled pneumatic or electric tools, which improve the ergonomics and the effective field capacity. A vineyard worker can get to make up to 8-10.000 cutting shares per working day. Nevertheless, the high intensity and repetitiveness of the movements, which shall be added to the limitation of workspaces with the constrain of a high precision cuts, gives rise to main two issues i.e. the primary on the safety for the operator, the other related to the potential plant damage. Investigation concerning such tools provided by National Institute for Insurance against Accidents at Work - INAIL have highlighted for the agricultural sector, on average just under 200 accident per year of partial or sharp cuts of the phalanges. Similarly, a further problem which occurs during the pruning stages in vineyards, is the accidental cutting of trellis wires. On the market, are available some safety systems which, however, do not spread because the non-user-friendliness. After all, the innovations in electronic technology allow realizing devices that can discriminate at any instant and with great accuracy, what is touching the blade of the scissors and lock it if necessary. The present work relates the preliminary evaluation of a safety kit applicable to electrical portable tools with trigger activation or similar progressive regulators. It is made of a safety circuit that interacts with the electronic controller of the tools by using the natural body impedance measurements. An electrical control allows to immediately detecting the materials impedance that come into contact with blade. When accidentally the operator finger's is touching the blade, the impedance value go down quickly, consequently the voltage reading will drop towards a threshold value where a decision block will intervene to stop the closing movement of the blades. The preliminary tests carried out showed the high reliability of the safety stop system, which could represent a feasible active solution for every electrical supplied cutting tools employable in agriculture sector and not just.

1. Introduction

Winter pruning and canopy management are very important stages of the field activities because they are the actions that will guide the annual production toward the oenological goal. In the last five years, wine companies have rediscovered the influence of this step in determining the proper budding and in the long run, the vineyard's life (Sarri et al., 2015). Consequently, next to an industrial viticulture oriented to cost reduction it is developing a new management devoted to the implementation of agronomic basics and fruit growing more respectful of productive unit (Vieri et al., 2013). In this way, the cutting operations become a key point of the process for which the operators pose much attention to the execution of cuts using more and more electric tools to accomplish precise and quickly cuts. In cutting stage, the risk factors are linked to the constant repetition of movements, awkward postures, the projection of the cut material or contact with sharp objects, sharp or plant parts (elastic elements).
In a common vineyard with planting layout of 2.2 m between rows and 0.8 on the row, raised to cordon with four spurs, for a total of 5681 plants per hectare, are performed on average from 40,000 to 55,000 cuts depending on the budding degree and the magnitude of dead vines. A further factor that exposes workers at injuries is the difficulty to reach the proper cutting point and blades positioning. It follows that often the operator uses the free hand to move the branches that block access by entering it inside the blade range area

Please cite this article as: Sarri D., Gemignani S., Lisci R., Vieri M., 2017, A body impedance-based safety system for electrical pruning tools, Chemical Engineering Transactions, 58, 127-132 DOI: 10.3303/CET1758022

(i.e. a minimum of 0.4 m away from the blade). These conditions expose the operators to a high shearing risk which is, generally, of partial type with electric pruning shears since that they operate in progressive cutting mode, while of total type with pneumatic machines.
Surveys concerning such tools provided by National Institute for Insurance against Accidents at Work - INAIL (database from 2009 to 2011: Variable ESAW / 3 - 2/7 "mechanized hand tools for cutting, separating (scissors, shears, pruners)", have highlighted in the agricultural sector, on average just under 200 accident per year of partial or sharp cuts of the phalanges. Another problem related to electrical pruning shear is the accidental damage of plant trellis. The resulting economic damage to an accidental cutting of main trellis entail the complete substitution in young vineyards or whereas there are vines with wood structure that have not yet enclosed the wire or, where possible, the partial substitution with specific conjunction units.
To date, the available pruning shears safety devices are designed to safeguard the operators through passive or active system type, but none is able to protect, at the same time, also from accidental cutting of the support structures.
In the first case, they are represented in gloves of metallic mail, which can be heavy and not properly comfortable to use but above all, they prevent from stub wounds but not to the shearing. The available active solution include electronic control systems for stopping tools.

Figure 1: (Left) Active protection system based on conductive glove by Infaco (Bois de Roziès, France) company. (Right) Active electronic control systems for stopping tools based on remote detection via electromagnetic waves made Paterlini company (San Martino in Rio, RE, Italy).

The first devices, named Extra Electronic Safety System (DSES) made by INFACO patent FR 2712837 Figure 1 (Infaco, 2017) is an injury prevention system based on contact system. It consists of a conductive safety glove, worn in the free hand, connected to a pole of a protection electronic circuit that interact with the pruning shear supply line. The blade and the counter blade are joined to the same circuit thus with the other pole of battery. As a matter of fact, as soon as the cutting head and the conductive glove come into contact the circuit is closed, the closing of the blade is stopped immediately and it returns to the opening position. The blades can thus no longer close and the accident is prevented.
Another available active device is that designed by Paterlini to protect the operators that work with pneumatic equipment Figure 1. It is made of a pair of magnetic bracelets and an electro-pneumatic control valve. The two bracelets work one as transmitter of a magnetic field TX and the other as receiver RX through a set of three inductances that work like antenna detecting the signals in the xyz axes. The operational principle provides that, when the two hands are located apart 0,5 m to each other, it determine an electro-magnetic field's variation with generation of an electric signal that acts on the solenoid valve (normally closed). This entail the air inlet opening, so the deflecting the air flow outside of the pipeline, thereby preventing the actuation of the shears.
Once re-established the minimum distance between the limbs, the system it will re-activate automatically.
Currently, the proposed solutions are not able to avoid, at the same time, the cuttings injuries for workers and damaging to the installation components, such as vineyard support wires.
On the basis the aforementioned safety solutions and considering the possibility to effort the impedance measurement, i.e. the ability of a circuit to resist the flow of electrical current, a safety stop for electric cutting tool, was designed. The impedance measurements is widely utilized for the design of human health monitoring tools that currently are able to provide the bioelectrical impedance analysis (BIA) namely the body composition

in terms of fats, muscle, and water (Ellis, 2000, Lee & Gallagher, 2008). This is accomplished by cross the body from a known value of alternating current with an outer pair of electrodes while another inner pair of electrodes measure the voltage drop across the body so that the impedance is measured.
Therefore, the objectives of this first analysis were the development of a system based on impedance monitoring capable of protecting the operator, but also the trellis structure. In addition, it was evaluated the extent of the risk condition occurrence for the worker during the pruning steps in the vineyard.

2. Materials and methods

The safety stop system has been implemented as an intelligent protection circuit applicable to electric supply cutting equipments. It is able to distinguish, on the basis of the object impedance value, what is in contact with the conductive elements of the blade.

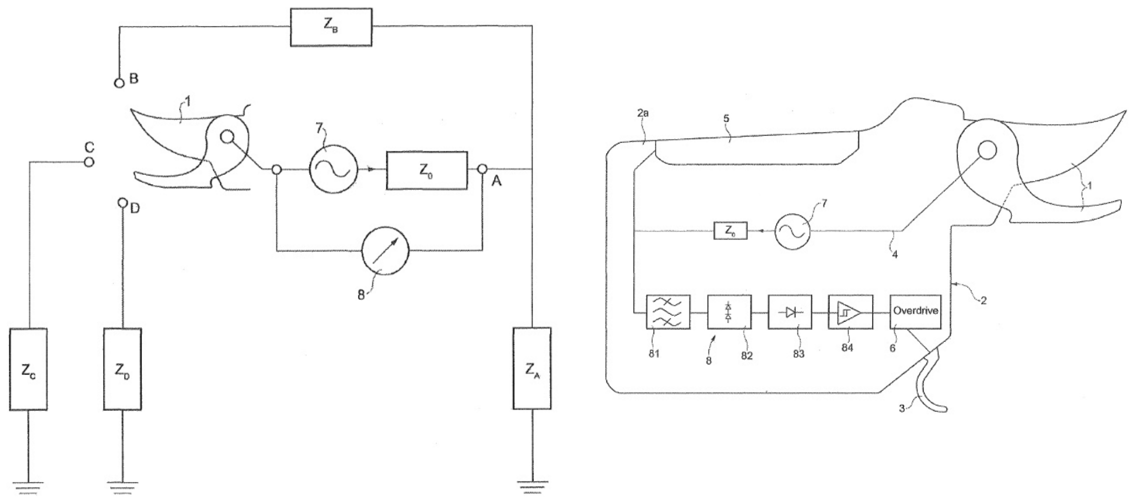

Figure 2: Schematic circuit representation of the related control system.

The main element that enables the intelligent management is an electric protection circuit that control and interprets the signal changes that occur between three main elements Figure 2:
(a) The blades of the shears;
(b) A metallic plate (5) made of electrically conductive material (metal with capacitance less than or equal to 100pF) located on the handle;
(c) The external object that meets the blade.
Specifically, when the circuit detects a variation value of less voltage than a predetermined threshold value V_T, the system blocks the blade closing action and starts the instantaneous opening by disconnecting the overdrive (6) connected to the trigger (3) of the shear drive. An alternating voltage generator (7) supplies the voltage VT in the control circuit, at low voltage 5V, with their relative known impedance value indicated as Z0 and a working frequency of 100Hz for ensuring measurement rapidity and invariance. These elements are placed on the line (4). The chain from 81 to 84 Figure 4, ensures the detection and measurement of the voltage drop on the line (4) with a programmable decision block (84). The latter, manages the override block (6) in response to the detection through the measurements made by the circuit (8). Three are the main measurements thus impedance values considered in relation to the events that may occur during the use of a pruning shears in the vineyard i.e. (A) contact among blades and user's free hand, (B) among blades and metal wire, (C) among blades and plant stem (material to be pruned).
This correspond to three-voltage variation thus impedance changing, caused by the accidental creation of circuit bridges hereinafter called Z_B, Z_C, Z_D. Furthermore, in order that the system allows a protection from wires damage is required a further conductive element with impedance Z_A, which fulfils the circuit closing. That element may be a conductive sock or a shoe that realize an electrical continuity between the hand that holds the pruning shears and the ground.
For the worker injury prevention scenario, the circuit setting comprises that the decision block (84) it is programmed with a threshold value V_T corresponding to the voltage generated when impedance Z_B reaches a value Z_T caused by the pressure of the blades in the skin causing injury. This impedance value and the corresponding threshold value can be determined by applying the follow equation (1):

$$V_T = V_0 - Z_0 \cdot \left(\frac{V_0}{Z_0+Z_T}\right) \qquad (1)$$

Where:

V_0 power supply voltage:
Z_0 Impedance of metallic plate;
Z_T Impedance at threshold value;

Generally, the value of Z_T is about 2700Ω. Therefore, in normal management with worker wearing the conductive socks and footwear as well, and therefore the damage-prevention functionality, it will realize a bridge between ground and Z_A that not entail functionally variation. When the stem is being cut, the circuit is closed at point D thus to the ground, setting Z_D and Z_A in series. However, considering that Z_D is at least an order of magnitude greater than Z_T, the current flow will be insignificant but the resulting voltage being inversely proportional will consequently be higher than the threshold value V_T. Then, the protection circuit will not be activated and the scissor will perform the cutting. In this pruning scenario, the use of conductive socks and footwear is not mandatory since the protection circuit works anyway, nevertheless it not prevent to the accidental wire breaking.
In the case of absence of conductive element to the ground (no bridge with Z_A) no circuit closing is performed hence, there is no interference of the safety circuit on the normal functioning. When the injury occurs (contact between body and blades), in the line 4 there is a current passage therefore a voltage drop towards the threshold value V_T. Then the decision block (84) reads the value, stops the blade closing, and start the immediate reopening.
To accomplish the total protection (worker and trellis system) is necessary the use of conductive wear since there is a contact with blades and conductive installation element the circuit is closed at point C thus to the ground, setting Z_C and Z_A in series. The magnitude of this sum is lower than Z_T because the metallic structure with high conductivity, so the current flow will be remarkable and the related voltage will be lower than the threshold value V_T and enough to trigger the safety stop.
To analyse a real field condition, a pruning yard with two specialized workers equipped with pneumatic shear operating on Sangiovese vineyard cultivars raised to cordon, was surveyed. The training was set to cordon placed at 0.8 m from the ground with four spurs each of which was pruned, leaving 2/3 buds. The supporting structure was made of a curtain wire, for the cordon support, fixed in metallic support stakes placed every 5 m along the line of the row. Other two pairs of wires, at 0,4 m apart them, were placed to support the development of the canopy vineyard.
To monitor the overcoming of the safety area has been developed an RFID device based on Arduino platform comprising a transponder that generates an electromagnetic field of omnidirectional type with a maximum spread of 0.4 m placed on the right wrist of the worker (RX). The receiving element "reader" was instead placed on the left wrist (SX). Whenever that the hands entered in the buffer zone a counter recorded the data (number of times and duration) on a storage memory.
With the aim to define the impedance range values encountered laboratory and in field measurements, were performed. Some types of conductive under shoes were analysed for the trellis damage prevention function. Furthermore, in order to assess the extent of the occurrence of critical situations and the overcoming of safety area between the hands, an operational monitoring during the pruning steps, was carried out.

3. Results

Some field tests were carried out considering a total of ten row portion of 5 m each one. The analysis has been looking the overall cutting time, the time exposure i.e. the relative time in percentage and the amount of times during which the worker has the hands inside the respecting area (RA) (0,4m apart them). A descriptive statistical synthesis was reported in table 1. As regards the impedance measurements of the involved elements monitored by the system, it has been detected values between <200 Ω and >13.000 Ω. In particular, for body with gloves is <1.000 Ω while the values between the body to ground in which the first 0.03 m of soil profile were dry is about <4.000 Ω. In the connection between Iron wire to soil, the values are the lowest i.e. 200 Ω because the high conductivity of steel pole. Finally, the measurements on vine branch showed the highest insulation value with 13.000 Ω of impedance. About the trellis damage prevention function, as explained in the previous paragraph, is required the use of a conductive element to ensure a ground connection. In this specific case, the measurements have highlighted the necessity of a socks made of a conductive material, that allow a resistance of less than 10 Ω per cm^2, while for the shoe-ground connection to ensure a contact with hand-ground impedance through the body (ZA) of less than 1.000 Ohm.

With regard to the exceeding of respecting area (RA), results showed a mean residence time in such risk conditions of 31.300 seconds, equivalent to 17.428 % of mean cutting time. In terms of times that the system has detected an excess over the reference value it has been documented a frequency average value of 6.3 %.

Table 1: Descriptive statistical synthesis of field trials in a vineyard-pruning yard.

Trial	Cutting time (sec)	Time exposure (sec)	Incidence Inside RA (%)	Cuttings (n°)	Threshold excess (n°)	Frequency (%)
1	178,000	40,000	22,727	61	4	6,557
2	186,000	41,000	22,043	71	6	8,451
3	183,000	51,000	27,869	79	3	3,797
4	158,000	29,000	18,354	68	3	4,412
5	186,000	18,000	9,677	81	4	4,938
6	200,000	64,000	32,000	79	5	6,329
7	173,000	17,000	9,827	66	4	6,061
8	154,000	16,000	10,39	60	6	10
9	167,000	18,000	10,778	60	4	6,667
10	179,000	19,000	10,615	69	4	5,797
Mean	176,400	31,300	17,428	69,4	4,3	6,301
StdDev	13,882	16,918	8,364	8	1	1,841

4. Discussion

The evaluation of materials' conductivity that encounter the shear blades shown clear differences. In order to ensure adequate protection levels, a threshold value of 6000 Ω was set. Below this sill, the circuit is activated. Such value is slightly less than half of the detectable impedance measurements in vine shoots with 0,02 m diameter thus largely sufficient to guarantee a working continuity.

Regarding the active protection functionality for the operators, the performed tests in the laboratory have shown the complete protection with the safety stop, which is always activated when the blades touch the operator's skin. The system functionality, as previously described, is guaranteed by an electrical continuity between the metallic plate of the shear pruning and the operator's hand. Therefore, considering the compulsory use of gloves as PPE (Italian Law D.Lgs.9 April 2008, 81 of Title III, Chapter II, Art.76), to ensure the safety system operation it is necessary the use of conductive gloves with resistivity below 10 Ω per cm^2 in both hands. The advantage, compared to similar protection systems, consists in the decoupling from electric connections-cables and in the protection keeping even if the operator forgets to wear gloves.

With reference to the damage-prevention function, considering the extreme variability among the agricultural contexts, in terms of trellis system (wood or metallic structure) and operating conditions (soil moisture) it can be found limited impedance conditions. This, for instance, is the case of vineyards with metal wire that extends little in length between two wooden support stakes. In this context, the worker protection is in any case guaranteed, but the wire's damage-prevention is assured if the rows are longer than 40 m. Such length is the minimum to achieve a Z_T impedance value, which activates the safety stop. Below that sill, the trellis must be grounded. The architecture of safety stop system can be optimized in relation to the item that shall be protected setting the impedance sill values. This allows to manage specifically the blade behaviour differentiating between if it is necessary or not to take action. In any case, the activation time (contact-measure-activation) is about some milliseconds.

5. Conclusion

This paper proposes a new safety stop system that enriches the possible solutions to protect workers during repetitive cutting operations in agriculture field. The simple design architecture, that prevents possible malfunctioning risk, together the versatility which not cause any obstacle or awkwardness in normal use of the cutting tool, make it extremely useful to solve this issue. Moreover, these features makes the circuit implementable in different cutting systems not only in those with blades turning around a hinge point but also in model with reciprocating blades. The use of current or voltage signals (2 mA and 5 V) which crossing body part is already widely used in biomedical monitoring system therefore it does not constitute any physiological hazardous. The performed test have highlighted the system reliability, further investigation will be performed in order to analyse the criticality in different vineyard condition in terms of soil water content, trellis type and system timing respond.

Acknowledgments

The authors are grateful to the Inventor Dr. Stefano Gemignani that provided the system specification and to the Flash Elettronica company for their technical support in this work.

Reference

Ellis, K. (2000). Human Body Composition: In Vivo Methods. Physiological Reviews, 80(2), 649-680. Retrieved from http://physrev.physiology.org/content/80/2/649.short#sec-15

Infaco (2017) Protective system for user of powered cutting tools France Patent 2712837-A1 available at http://patent.ipexl.com/FR/2712837-a1.html accessed 2017 march 10

Lee, S. Y., & Gallagher, D. (2008). Assessment methods in human body composition. Current opinion in clinical nutrition and metabolic care, 11(5), 566.

Sarri, D., Lisci, R., Rimediotti, M., Vieri, M., & Storchi, P. (2015). Applications of the precision viticulture techniques in the chianti district. Paper presented at the 1st Conference on Proximal Sensing Supporting Precision Agriculture - Held at Near Surface Geoscience 2015, 121-125.

Vieri, M., Sarri, D., Rimediotti, M., Perria, R. and Storchi, P. (2013). The new architecture in the vineyard system management for variable rate technologies and traceability. Acta Hortic. 978, 47-53 DOI: 10.17660/ActaHortic.2013.978.3 https://doi.org/10.17660/ActaHortic.2013.978.3