Contemporary Engineering Sciences, Vol. 8, 2015, no. 27, 1245 - 1256
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2015.56181

Technical Analysis and Re-Design of a Screw Log Splitter: New Methods of Risk Management

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Abstract

In the recent years, the proper design of agricultural machines for both professional and non-professional use has assumed a relevant role in workers protection and accident avoidance. The activities related to cutting and sawing of firewood is the main cause of injuries or death of the operator. This is often due to the use of inadequately built or modified machines, improper use of equipment and use of tools intended for other purposes. This study aimed to design a conical screw log splitter that meets the criteria of the European Directive 2006/42/EC and the technical standards of EN 609-2:1999+A1:2009(E) guideline. For a proper design we determined the forces that influence the machine during its use, and sized the machine accordingly. The log splitter was scanned and digitalized in three dimensions. From the digital model we obtained a real model in 5:1 scale. Comparing the created log splitter with other solutions available on the market we confirmed its similar costs with the costs of tools currently marketed. The productivity of the machine was only slightly lower than that of machines not equipped with protections, but its safety was significantly improved.

Keywords: agricultural machine, log splitter, occupational safety

1 Introduction

Agriculture has always been considered as one of the sectors with the highest risk of accidents and injuries. In 2011 there were 47 054 accidents reported to INAIL (National Institute for Insurance against Accidents at Work), compared with 57252 accidents in 2007 showing a decline of 17.8%. The fatal accidents reported to INAIL, which exclude those that occurred due to non-professional use and/or not protected operations were 109 in 2011 with an increase compared to 2007, when overall fatal accidents were 104 (4.8%). In the case that are considered also fatal accidents occurred after non-professional and/or not protected operations, those related to the use of tractors and agricultural machinery were 167 in 2011 of which 141 related to the use of the tractor and 26 related to the use of agricultural machinery [12].

The so called Equipment Directive is the European Directive 2006/42/EC issued in 2006. This Directive aims to "reduce the social costs of numerous accidents caused directly by the use of the equipment. It is focused on the integration of safe equipment design and construction as well as proper installation and maintenance" (Directive 2006/42/EC, consideration 2). In order to ensure the safety and health protection, the equipment considered by the above-mentioned Directive must comply with the essential safety requirements which take into account the state of the art at the time of construction and all technical and economic requirements (Directive 2006/42/EC, consideration 14). The Directive was implemented by the Italian Republic with the Legislative Decree 17/2010 of 27 January 2010. The article 5 of this Decree (point 1, letter a) states that the manufacturer of the equipment or his authorized representative must ensure that all equipment complies with essential safety requirements and health protection set out in Annex I of the Directive, before placing it on the market and/or putting into use. Article 7 of this Directive says that "the equipment manufactured in accordance with harmonized standards (Official Journal of the European Union), shall be presumed to meet the essential safety and health protection covered by this harmonized rule (Directive 2006/42/EC, Article 7). An agricultural machine is considered “in accordance” when it is built based on all above-mentioned technical standards and, therefore based on the Equipment Directive. All equipment has to possess the technical standards concerning its specific type, documentation of origin as well as the certification that no modifications were performed on the equipment. In some more complex cases is also necessary to consider experts which perform adaptations on the equipment and must declare the successful modification in accordance with all available guidelines [2, 3, 4, 5]. At the moment, in the agro-mechanical sector are present and in use different types of equipment.

The aim of this work was to design and develop a conical screw log splitter which meets all the above-mentioned requirements and regulations.

2 Materials and methods

The project set-up was planned and performed in 2013. It was initiated following a serious injury and fatal accident which occurred during the use of a log splitter with a conical screw in Friuli Venezia Giulia (North-East Italy). From the methodological point of view the work was divided into three phases as follows:

Phase 1; data collection on injuries related to the use of cutting equipment. Numerous news articles regarding injuries related to cutting and wood sawing were found by internet search. Currently, no specific database for such accidents is available.
Phase 2; technical and regulatory analysis. For the analysis of the conical screw log splitter the technical standard EN 609-2: 1999 + A1: 2009 (E) was considered.
Phase 3, project design. The developed model was based on two types of analysis, one referring to the volumes processed by the equipment (maximum load) and the other related to the intrinsic forces, resistance of the single components (construction and safety). To determine the volumes and the forces that can be processed by the log splitter we have considered three types of wood: poplar, beech and fir. We have searched for specific maximum and minimum weights of green wood and humidity above 50%. It was calculated the volume of the wood logs which were similar to cylinders with heights from 0.4 to 1.6 m, all having the same diameter of 0.3 m (1), (2), (3):

$$A = \pi r^2 \tag{1}$$

where A is the area of the base of the log (m^2) and r is the radius of the log (m).

$$V = Ah \tag{2}$$

where V is the volume of the log, (m^3) and h is the height of the log (m).

$$P = \gamma V \tag{3}$$

where P is the weight of the log (kg), γ is the specific weight (kg/m^3) and V is the volume of the log (m^3). To calculate the working forces in the machine we determined the tangential force considering a screw log splitter moved by the PTO (Power Take Off) of a tractor with a power of 70 CV and a rotation from 200 to 700 revolutions/min both of the PTO and of the conical screw assuming the diameter of conical screws of 100, 150 and 200 mm. To calculate the different F under hypothesized different working modes and with different diameters of the screw, we converted the hypothesized schemes from revolutions per minute to revolutions per second (Hz), thus obtaining the frequency, (4):

$$\frac{\boldsymbol{revolution}}{\boldsymbol{s}} = \frac{\boldsymbol{revolution}/_{\boldsymbol{min}}}{\boldsymbol{60}} \text{ (Michetti, 1965)} \tag{4}$$

With the obtained frequency of the motion it was calculated the period (5)

$$T = \frac{1}{f} \text{ (5) (Michetti, 1965)} \tag{5}$$

where T is the period (seconds) and f the frequency (Hz). Consequently it was calculated the angular velocity of the screw (Michetti, 1965) (6):

$$\omega = 2\pi f \tag{6}$$

where ω is the angular velocity (rad/s). The unit of power measurement of the tractor was then transformed from CV to W, according to the relation (Michetti, 1965) (7):

$$1\ CV = 735\ W \tag{7}$$

Hence it was decided to calculate the machine torque; according to the equation (8):$M = \frac{P}{\omega}$ (8)

where M is the machine torque (Nm). With the calculated torque we can then calculate the F based on the used screws of different hypothesized diameters (9):

$$F_{tg} = \frac{M}{r_{mean}} \tag{9}$$

where F_{tg} is the tangential force (N) and r mean (m), is the radius of the screw in the middle point of the cone. Ftg units were converted from N to kg_{force} and t_{force} (Michetti, 1965) (10 and 11):

$$1\mathrm{kg}_{\mathrm{force}} = 9{,}81\ \mathrm{N} \tag{10}$$

$$1t_{force} = 1000\ kg_{force} \tag{11}$$

It was calculated the strength of the moment of the log, if it comes into rotation (Michetti, 1965) (12):

$$F = \frac{M}{r} \tag{12}$$

where F is the moment of the force of the of the trunk, M is the machine torque (Nm), and r is the length of the log (m). To the moment of the trunk force must be added the component related to the kinetic energy of a rigid body in a rotation with axial symmetry around the axis of symmetry that has an angular velocity ω and moves in the space with a velocity v. For this purpose, maintaining the hypotheses and the angular velocity as well as the frequency, it was calculated the period (i.e. the time necessary for the log in rotation to complete one revolution; Michetti, 1965) (13):

$$T = \frac{1}{f} \tag{13}$$

where T is the period (seconds). It was determined the diameter of the log (14):

$$C = 2r\pi \tag{14}$$

where C is the diameter (m). Consequently, it was obtained the tangential velocity of the log (15):

$$v = \omega r \tag{15}$$

where v is the tangential velocity (m/s). The unit of the tangential velocity was transformed from m/s to km/h (16):

$$^{km}/_{h} = 3{,}6\ ^{m}/_{s} \tag{16}$$

It was calculated the inertia possessed by the log in rotation (17):

$$I = \frac{mr^2}{6} \tag{17}$$

where I is the inertia and m the mass of the log (kg). Afterwards, it was calculated a second angular velocity ω, (18):

$$\boldsymbol{\omega} = \frac{\mathbf{2\pi}}{\mathbf{f}} \tag{18}$$

Then it was calculated the total kinetic energy possessed by the log in rotation, or the work that a force needs to perform so it can stop it (Michetti, 1965) (19):

$$K = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \tag{19}$$

where K is the total kinetic energy expressed in Joule and v expressed in m/s. Consequently, we calculated the force required to stop the log (20):

$$F = \frac{K}{C} \tag{20}$$

The guards and the rotation bar of the log splitter must resist the force calculated above (20). After the calculations of all involved forces we have continued with the design of the tool according to the requirements of the technical standard EN 609-2:1999+A1:2009. The log splitter was sized to work with logs of about 50 cm in diameter and 1 meter of height with a conical screw of 100 mm diameter. We performed the project set-up which was subjected to verification and technical regulations. Afterwards, we made a virtual 3D model. The model has been reproduced as a static model in 1: 5 scaling. After the implementation of the project, the booklet for its use and maintenance was prepared. In addition, we performed a comparison of the hypothesized log splitter and the commonly used hydraulic log splitters.

3 Results

With a detailed research we identified 52 accidents that occurred from 2003 to 2014 in Italy, during cutting and sawing of wood. The age of the injured has been divided into four classes: 0-20, 20-40, 60-80 and 80-100 years; the majority of accidents affected people between the ages of 60 and 80 years (36.7%). The injured men were 87% while only 13% were female. The 81% of accidents has resulted in an injury, while 19% had a fatal outcome. In 46.2% of injuries the sites of the lesion were hands, in 14.4% the thigh and in 11.5% the face. The type of equipment involved in the accident included the log splitter in 32.6%, followed by chain saws (26.1%), circular saw (21.7%) and ax (10.9%). The cause of the accident could be attributed to the age of the machine or non-standardized modifications. The region with highest number of accidents was the Trentino-Alto Adige (17.3%); followed by Lombardy and Tuscany (13.8%), and Friuli-Venezia Giulia (11.6%). The volume of the logs varied from 0.03 m3 to 0.11 m3, all examined logs had a diameter of 0.3 m. The weights of the logs ranged from 23.74 kg (poplar) up to 113.04 kg (fir). For the same power of the tractor, the engine torque and the Ftg decrease with increasing speed of the PTO; switching from a torque of 200 Nm at 2457.80 revolution/ min of the PTO to a torque of 702.23 Nm at 700 revolution/min of the PTO. At higher rpm of the PTO corresponds a lower Ftg transmitted to the log from the conical screw and a milder split action of the log. Ftg increases with the decreasing diameter of the screw; considering a rotation speed of the PTO of 540 revolution/min, going from a Ftg of 1.86 t applied to the log by the screw with a 200 mm diameter, to a Ftg of 2.47 t applied to the log by the screw of 150 mm diameter, up to Ftg of 3.71 t, applied to the log by the screw with 100 mm a diameter. Smaller diameter of the conical screw corresponds to a more effective log split action and with the increased Ftg applied to the log decreases the risk of jamming of the machine as well as the possibility that the log enters into a rotation because it is stuck with the conical screw. The moment of the trunk strength decreases as the speed of the PTO and the length of the log increase. In fact considering a log of 1 m length the moment of the trunk passes from 2457.80 N (200 revolution/ min) to 702.33 N (700 revolutions/ min). Considering a 220 revolutions per minute of the PTO, the moment of the trunk shifts from 6144.51 N possessed by 0.4 m long log to 1536.13 N possessed by a log long 1.6 m. The force related to the kinetic energy increases with the number of revolutions of the PTO, considering a fir log of 1 m, we pass from a force equal to 251.60 kgforce (200 rpm) up to a force equal to 3078.01 kgforce (700 rpm). Moreover, the force increases as the length of the log increases; considering a log of silver fir and a 200 rpm, the values go from 40.26 kgforce for a log of 0.4 m to 644.10 kgforce for a log 1.6 m long.

In Figure 1 is presented the designed log splitter. The main parts are three: the frame, on which is mounted the screw with the conical coupling shaft and the housing for the release of the transmission; the three-point hitch of the tractor; the guides for the power supply; the anti-rotation bar; side guards and the supply cart in which is placed the log; external, lateral and top protections. The conical screw is mounted 650 mm from the ground, on its front part is positioned the release box of the conical screw shaft and the inverting of the rotation, which serves as a disengagement mechanism of the logs. From this box a lever reaches the position of the operator with the function of release of the emergency transmission and the inverter. The front of the box works as the protection of the drive shaft connection. The rotation bar, mounted at 340 mm from the ground and 500 mm long prevents that the log jammed during splitting does not go into rotation. On the front part of the frame is mounted the three-point hitch of the tractor, while on the rear, in contact with the support surface are present as two bars of steel long 1000 mm each, on which are mounted the guides within which slides the power supply cart.

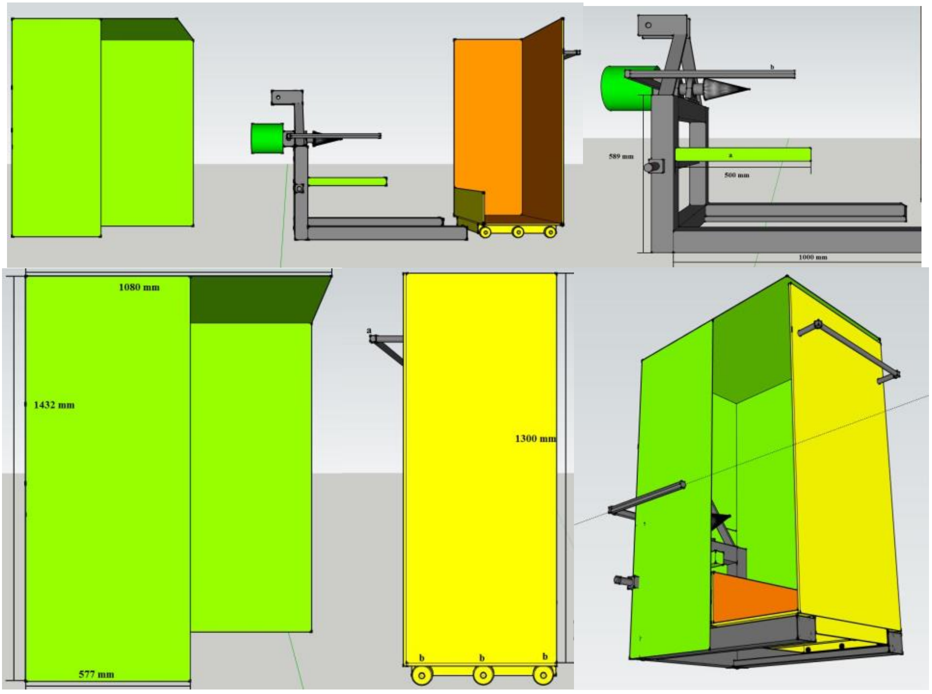

Figure 1 – Open log splitter with all components. Lateral view

The power supply cart moves bounded within the guides while the log splitter is working. The bottom surface of the cart is 500 mm long and 740 mm wide and has the profiles that allows the firm holding of the log. The cart has a useful height of 1300 mm and is closed on the two sides (rear and right one), while the left side is open to allow the loading and unloading of the log. The front side is closed to a height of 200 mm, in order to retain the logs on the cart. The complex of external protection has the aim to prevent operator contact with the conical screw. The protection on the right side of the machine has a length of 1080 mm for the entire length of the machine while the guard on the left side is 577 mm long in order to allow the operations of loading and unloading of the machine; the front guard covers the whole machine. On the upper side the protection covers entirely the machine. The brake lever clutch and the inverter are located outside of the above-mentioned protections. The log is loaded from the left side on the cart, and then, using the handle, the cart is pushed forward until the log comes into contact with the conical screw that splits it. At the moment that the log is splatted, the carriage is pulled outward allowing the discharge of the chopped wood, which has remained on the cart. The overall protections and the specific cart avoid the operator contact with the conical screw during its rotation. The lever that controls the release transmission mechanism and the inverter allow to promptly stop the machine in case of any danger and to free out any jammed logs. In addition, to prevent the rotation of the log which remains stuck is provided a rotation bar. The designed log splitter meets the essential safety requirements of EN 609-2:1999+A1:2009 and of the European Directive 2006/42/EC. The log splitter is designed with a conical screw diameter of 100 mm that can develop the necessary force to break logs as calculated. In the case that the designed machine is driven by a tractor with a power of 52 kW the range of useful forces to split the logs goes from 10.02 t_{force} (200 revolutions/min) to 2.80 t_{force} (700 revolution/min). These considerations make this designed log splitter comparable to a vertical or horizontal hydraulic log splitter that develops a power of 10 t. The model was produced in 1:5 scaling and was issued its user and maintenance manual. The comparison of the designed log splitter and a traditional hydraulic log splitter shows that the model developed is potentially competitive with those marketed at the moment. The introduction of security elements has only partially decreased the performance of the equipment by increasing the operation time about 10% However, these security elements increased the costs, the final price of the proposed model is from 1000 to 1200 € VAT included which is still in accordance with other technologies on the market. Added and improved elements of this tool are undoubtedly the safety parts that make this log splitter at low risk of accidents. It is also important to notice the greater ease of construction, ease of maintenance and increased operational duration compared to other conventional hydraulic models.

4 Conclusions

This work developed an innovative contribution in the agricultural mechanics, developing new equipment that is in accordance with the highest levels of security and performance. The research, based on an occurred accident, created the foundations for future projects which have to focus on safety planning in order to avoid numerous accidents and injuries. In addition, it should be emphasized that not only the design but also the cognitive aspect such as informing and training of the workers on the farm or working place must be the starting point for any operation. The adaptions of the machine to the mandatory regulations do not increase the costs and overall performances remain unchanged. The death of a person during the use of non-regulated equipment has moral consequences, but also economic and social ones. In this study also emerged the critical issues related to the use different tools or equipment which are maintained or modified without standard guidelines or self-implemented and altered avoiding any regulations or even rational logic.

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Received: March 30, 2015; Published: October 16, 2015