

DESIGN OF CLAMPING DEVICE STRUCTURE AS PART OF SEMI-AUTOMATIC PROCESSES OF MOBILE WORKING MACHINE

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Abstract. Preparing wood logs is still current in many households, mainly in rural areas. Wood serves as a source of energy for heating houses. Easy, efficient and reliable preparation of sufficient amount of wood requires to employ robust machines, which can help with these activities. Mobile working machines are suitable for these purposes. The presented work is focused on the issue of applied research of a structural design, i.e. a modification of a mobile working machine. It is a semi-automatic machine for processing wooden logs. The solved mobile working machine combines several processes, such as movement of long wood logs to a chain saw by means of chain conveyors, hydraulically operated wedges for splitting wood logs as well as a folding device to manipulate with smaller pieces of wood. The manually controlled log clamping process by the machine manufacturer often showed zero efficiency, especially when processing logs of larger diameters. For this reason, there was a space for a modification, which consists in replacing the manually operating clamping process by a semi-automatic system. After its implementation, the design will be deployed in production and implemented in the process of processing the output product (sawn and split firewood). The individual structural units of the system under consideration are designed in the work by analytical calculations, while further research will be oriented towards numerical simulations of the designed mechanism. Based on the results obtained in this presented way, it will be possible to manufacture individual parts and safely install them in the working machine.

Keywords: mobile working machine, analysis, simulation, clamping device.

Introduction

Professional semi-automatic and automatic log-splitting machines are designed to transport the log into the machine (to the processing position), where it is typically cut into selected billet lengths using a chain saw [1; 2]. These billets are subsequently split into several firewood pieces – depending on the log diameter – by a splitting wedge actuated by a hydraulic cylinder, and the processed material is finally conveyed to the desired location via a transport conveyor [3-5]. Therefore, such machines perform multiple operations simultaneously, which makes them more efficient and economical compared to manual processing [6-8].

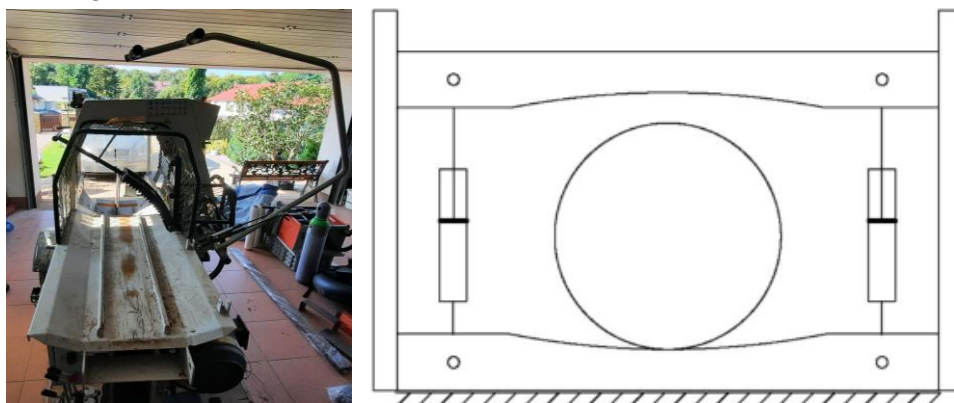


Fig. 1. Original lever- type log holder concept of the commercially produced Lumag SSA 500E mobile working machine (on the left) and schematic representation of Variant A of the clamping design (on the right)

The authors in the study [3] highlighted, among other aspects, issues related to the clamping mechanism of the Lumag SSA 500E mobile working machine [9]. Based on the analysis of these and other studies, it can be stated that the selection of an appropriate clamping device can significantly influence the overall outcomes of the working process. The primary requirements for a clamping system include sufficient clamping force, even at high cutting speeds, and ease of operation. Secondary requirements may include clamping accuracy (which, in the case of log-splitting machines, is generally negligible) and protective functions, such as damping vibrations generated during the processing

operation. A schematic representation of the mechanical clamping device of the investigated machine is shown in Fig. 1. For this type of clamping, the clamping force is generated solely by the individual mechanical components without any additional internal clamping systems. This clamping method is widely used due to its simplicity, as it operates based on the creation of sufficient frictional force to prevent movement of the processed log [10]. As can be seen, both theory and practice of log clamping are critical for the proper design and selection of an appropriate mechanism, which directly affects the quality and efficiency of the entire process. The mechanical method of log clamping, being physical and time-demanding, must be replaced by a hydraulic pressure system to generate sufficient clamping force to hold the log in position and to overcome forces occurring during the operation (e.g. cutting forces, moments, and vibrations). Since the hydraulic circuit is integrated into the machine from the manufacturer, its utilization represents a logical design solution. While design of the clamping device for the log was created, the construction of the original manually operated holder was used as a basis, specifically its arcuate toothed section (Fig. 1, left), and three alternative design variants were developed, designated as A, B, and C**. The current technical solution does not include a clamping device, which would serve to hold a wood log. This will ensure, that the wood log will be safely placed in a location, where it will be further processed. All necessary actions are described in the following sections of this contribution.

Materials and methods

Variant A (Fig. 1, right) was designed so that the log-gripping mechanism consists of two horizontally oriented toothed profiles, with a fixed lower section and an upper section that would move vertically via two linear hydraulic actuators positioned at the ends of the structure. The anticipated advantage of this variant is its ability to securely grasp the log in any horizontal position as it is delivered to the designated location by the chain conveyor [11-13]. A potential drawback is that this concept would only resist vertical forces exerted by the log. Based on the experience with the original holder, it can be concluded that the original clamping system was ineffective because it was unable to counteract horizontal forces from the log. Consequently, under the influence of forces from the chain saw, the log was often pulled out of the holder.

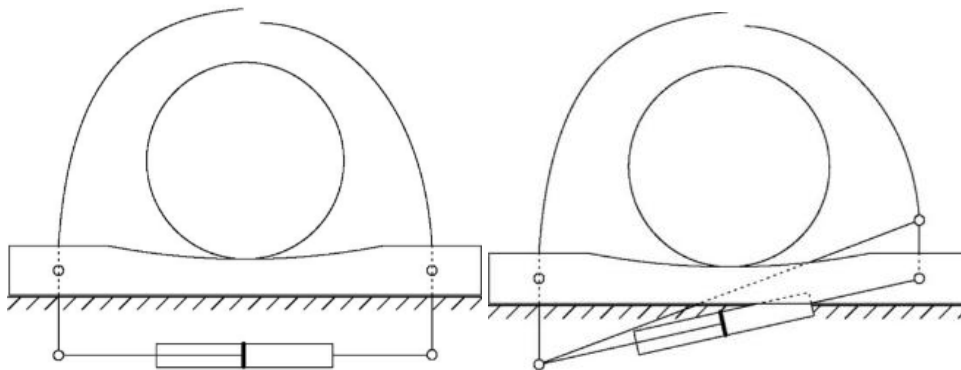


Fig. 2. Schematic representation of Variant B of the clamping device design (on the left) and schematic representation of Variant C of the clamping device design (on the right)

The design of Variant B was inspired by the gripping mechanism commonly used in hydraulic arms for log handling. This variant consists of two curved toothed arms, which are connected at their ends to a linear hydraulic actuator, thereby enabling controlled movement of the arms. A schematic of Variant B is shown in Fig. 2, left. The advantage of this arrangement, as with Variant A, is its capability to grasp the log in any horizontal position while simultaneously being able to transmit horizontally acting forces from the log, including circumferential forces. A potential drawback, however, is that the arms may not close synchronously, which, during chainsaw cutting and the resulting circumferential force of the saw, could lead to log slippage and, consequently, blocking the chain. Variant C (Fig. 2, right) was conceptually derived, as in the case of Variant B, from grapple mechanisms commonly used on hydraulic arms mounted on vehicles or forwarding trailers for log handling. The gripping mechanism in this design consists of two curved toothed arms. The arms would move dependently by means of a linkage, forming a single-degree-of-freedom mechanism [14]. The advantages are identical to those of

Variante B – specifically, the proposed geometry enables the mechanism to counteract most of the circumferential forces acting on the log and because the arms move synchronously log slippage during chain-saw cutting is eliminated.

Following a detailed analysis of the benefits and limitations of each design concept, Variant C was selected for further development of the log clamping device. A significant improvement in log stabilization efficiency compared to the original holder is expected. The gripping mechanism therefore consists of two curved toothed arms. The right arm is mounted to the frame at its base via a rotational joint, together with a linear hydraulic motor. The left arm is mounted to the frame at an offset position from its base, while its base is pivotally connected to the motor. To ensure synchronized (dependent on each other) motion of both arms, the mechanism includes a linkage connecting the left arm to the structure of the right arm and to the end of the opposite arm (together with the linear hydraulic motor).

The geometry of the clamping mechanism and the linkage also enables self-centring of the log when the arms close. The structural design of the clamping device is shown in Fig. 3.

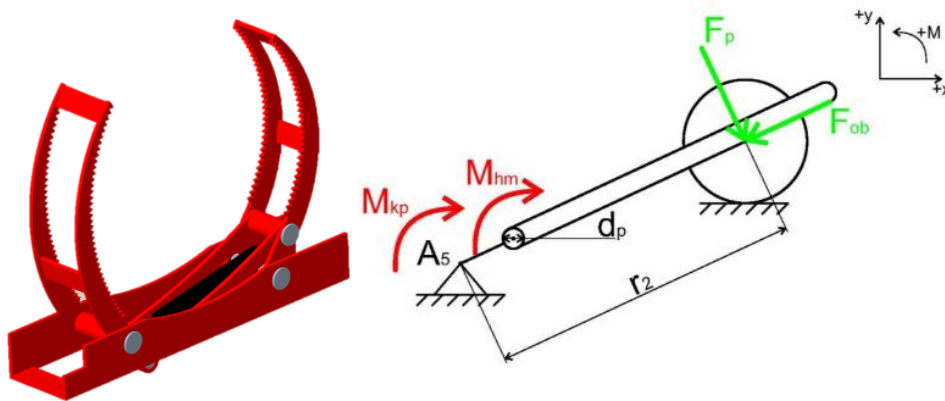


Fig. 3. 3D CAD model of the structural design of the clamping device (on the left) and schematic representation of the force conditions of the saw actuation and the chain drive during log cutting (on the right)

While calculating the required power of the linear hydraulic motor, the forces acting on the clamping device from the log are considered (Fig. 3, right), with the constant circumferential chain force, further referred to as F_{ob} , and the variable pressing force from the guide bar, further referred to as F_p , which changes with the feed motion of the chain saw. Therefore, the calculation assumes the most unfavorable case, namely the maximum attainable value of F_p . The required power of the hydraulic motor, further referred to as P_{hm} , is determined using equation (1), where the electric motor power integrated into the Lumag SSA 500E log-splitting machine is $P_e = 9.5$ kW with an efficiency of $\eta_e = 0.95$, and the assumed overall efficiency of the hydromechanical system is $\eta_{hm} = 0.75$:

$$P_{hm} = P_e \cdot \eta_e \cdot \eta_{hm}. \quad (1)$$

By substituting the corresponding values into equation (1), we obtain $P_{hm} = 6.77$ kW. The power of the rotary hydraulic motor is likewise expressed by (2):

$$P_{hm} = M_{hm} \cdot \omega_{hm}, \quad (2)$$

where the angular velocity, further referred to as ω_{hm} , of the hydraulic motor shaft can be determined as (3):

$$\omega_{hm} = \frac{2 \cdot \pi}{60}. \quad (3)$$

From equations (2) and (3), equivalent transformations yield the expression for calculating the driving torque of the chain saw rotary hydraulic motor (4):

$$M_{hm} = \frac{60 \cdot P_{hm}}{2 \cdot \pi \cdot n_{hm}}, \quad (4)$$

where the rotational speed of the hydraulic motor is $n_{hm} = 3,000 \text{ min}^{-1}$. Substituting these values into equation (4) yields $M_{hm} = 21.55 \text{ N}\cdot\text{m}$. The circumferential (tangential) force of the saw chain driven by a rotary hydraulic motor with a sprocket diameter of $d_p = 46 \text{ mm}$ can be obtained using equation (5):

$$F_{ob} = \frac{2 \cdot M_{hm}}{d_p}, \quad (5)$$

from which, after substitution, we obtain $F_{ob} = 936.96 \text{ N}$. Furthermore, as follows from Fig. 3 (on the right), the value of the guide-bar clamping force F_p acting at the lever arm $r_2 = 540 \text{ mm}$ can be determined using equation (6). The guide bar is actuated by the saw lever, on which a torque of $M_{kp} = 154.5 \text{ N}\cdot\text{m}$ is applied [3].

$$F_p = \frac{M_{kp}}{r_2}. \quad (6)$$

After substituting into equation (6), we obtain $F_p = 286.13 \text{ N}$. The remaining parameters required to perform the functional calculation of the clamping mechanism are the volume of the processed log, further referred to as V_k (7) and its mass m_k (8):

$$V_k = \frac{\pi \cdot d_k^2}{4} \cdot l_k, \quad (7)$$

$$m_k = V_k \cdot \rho_{buk}. \quad (8)$$

By multiplying the obtained log mass m_k by the gravitational acceleration $g = 9.81 \text{ m}\cdot\text{s}^{-2}$, it is possible to express the force that will be applied for various log diameters, referred to as d_k , and for the minimum utilized log length, referred to as l_k . The force interactions acting on the log during cutting are schematically illustrated in Fig. 4.

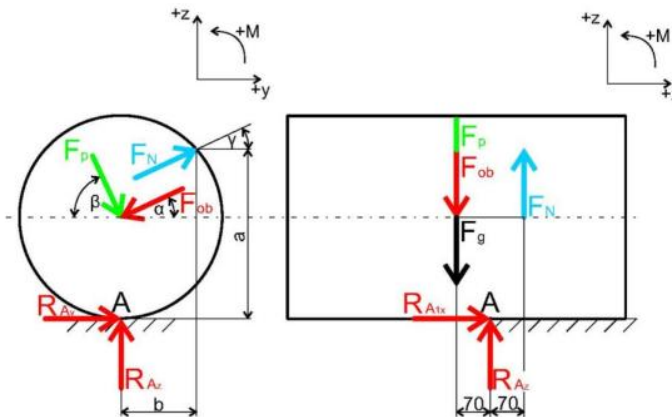


Fig. 4. Force distribution of the log and the geometric configuration of the task during cutting with the mobile working machine Lumag SSA 500E

Results and discussion

From Fig. 4, the moment arm (9) to point A can be determined:

$$\sum M_{iA} = 0, \rightarrow F_g \cdot 0,07 - F_p \cdot \cos \beta \cdot r_k + F_p \cdot 0,07 \cdot \sin \beta + F_{ob} \cdot \cos \alpha \cdot r_k + F_{ob} \cdot 0,07 \cdot \sin \alpha - F_N \cdot a \cdot \cos \gamma + F_N \cdot b \cdot \sin \gamma + F_N \cdot 0,07 \cdot \sin \gamma, \quad (9)$$

from which the required normal force F_N (10) can be determined:

$$F_N = \frac{F_g \cdot 0,07 - F_p \cdot \cos \beta \cdot r_k + F_p \cdot 0,07 \cdot \sin \beta + F_{ob} \cdot \cos \alpha \cdot r_k + F_{ob} \cdot 0,07 \cdot \sin \alpha}{a \cdot \cos \gamma - b \cdot \sin \gamma - 0,07 \cdot \sin \gamma}. \quad (10)$$

Fig. 5 (on the left) illustrates the force conditions of the right arm, and Fig. 5 (on the right) shows the force condition of the left arm. From there, the moment exceptions at point B and C can be expressed as equations (11) and (12):

$$\sum M_{iB} = 0, \rightarrow -F_N \cdot f \cdot \cos \gamma + F_N \cdot d \cdot \sin \gamma + F_{tiahlo} \cdot e \cdot \cos \delta - F_{tiahlo} \cdot c \cdot \sin \delta = 0 \quad (11)$$

$$\sum M_{iC} = 0, \rightarrow F_N \cdot f \cdot \cos \gamma - F_N \cdot h \cdot \sin \gamma + F_{tiahlo} \cdot g \cdot \cos \delta + F_{tiahlo} \cdot i \cdot \sin \delta - F_{HM1} \cdot g \cdot \cos \omega - F_{HM1} \cdot i \cdot \sin \omega = 0 \quad (12)$$

From equation (11), the axial force in the rod can be determined (13), and from equation (12), the force of the linear hydraulic motor can be calculated, referred to as F_{tiahlo} (14):

$$F_{tiahlo} = \frac{-F_N \cdot f \cdot \cos \gamma + F_N \cdot d \cdot \sin \gamma}{c \cdot \sin \delta - e \cdot \cos \delta} \quad (13)$$

$$F_{HM1} = \frac{F_N \cdot f \cdot \cos \gamma - F_N \cdot h \cdot \sin \gamma + F_{tiahlo} \cdot g \cdot \cos \delta + F_{tiahlo} \cdot i \cdot \sin \delta}{g \cdot \cos \omega + i \cdot \sin \omega} \quad (14)$$

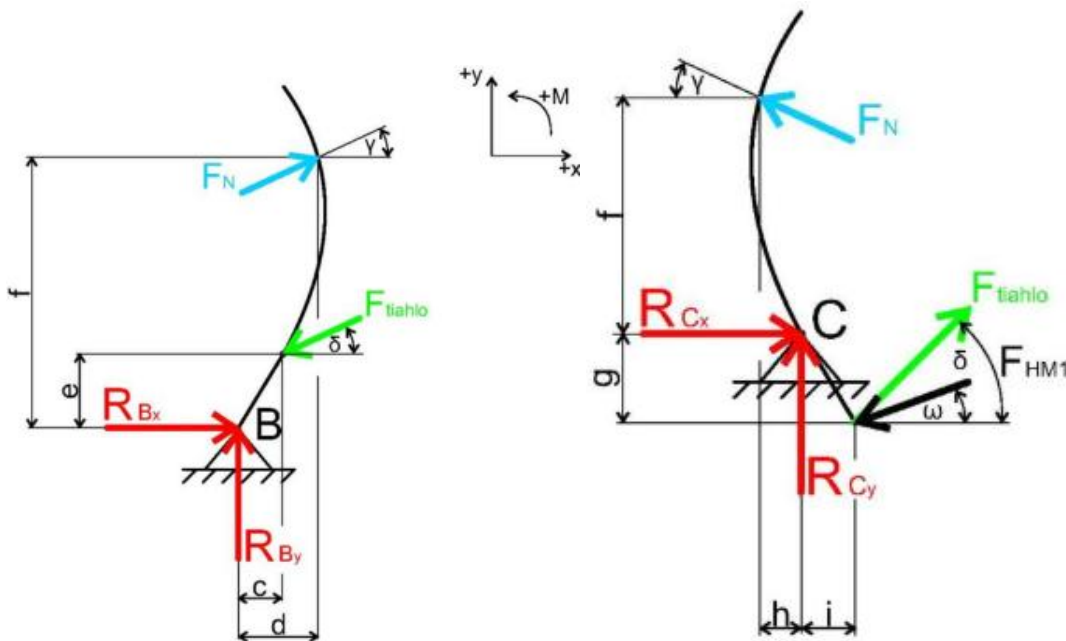


Fig. 5. Schematic representation of the force conditions of the right arm (on the left) and the left arm (on the right) of the proposed clamping mechanism

The clamping device changes its geometry when clamping logs of different diameters, which also results in variations in the force effects. Therefore, the exact geometry of the mechanism was determined in the CAD model for logs with variable diameters of $d_k = 500, 450, 400, 350, 300, 250$ and 200 mm. The Inventor CAD software was used for modelling. For the selected diameters, all forces acting on the clamping device were quantified using the developed mathematical model. In this way, the precise value of the force F_{HM1} , that must be exerted by the linear hydraulic motor for different log diameters, was determined. The results are summarized in Table 1. The results indicated that the maximum required force of the linear hydraulic motor acting when clamping a log with diameter of $d_k = 500$ mm is $F_{HM1} = 16,444$ N. For operational safety, an increased value of $F_{HM1} = 18,000$ N was selected as the actual acting force of the linear hydraulic motor in the clamping device. The mechanism designed in this way will be capable of safely and effectively securing the position of the sawn log for any task geometry. The future research will be focused on strength analysis of the selected parts of the machine. The finite element method will be applied for these purposes. It is a standard method, which is often used not only for working machines [15-17], but also for transport means [18-22]. The achieved results of the presented research will be verified by means of experimental tests on a real machine. It is necessary to manufacture it based on the performed calculations.

Table 1

**Results of the determined force and geometric parameters
of the proposed clamping device for variable log diameters**

| Param. | Log diameter d_k , m | | | | | | |
|------------------|------------------------|-----------|----------|----------|----------|-----------|----------|
| | 0.5 | 0.45 | 0.4 | 0.35 | 0.3 | 0.25 | 0.2 |
| F_g , N | 953.46 | 772.31 | 610.22 | 467.20 | 343.25 | 238.37 | 152.55 |
| α , ° | 33.7 | 31.5 | 29 | 26.5 | 24 | 21 | 18 |
| β , ° | 56.3 | 58.5 | 61 | 63.5 | 66 | 69 | 72 |
| γ , ° | 23 | 10 | 10 | 13 | 19.7 | 25 | 40 |
| δ , ° | 19 | 20.3 | 21.5 | 22.6 | 23.6 | 24 | 23.7 |
| ω , ° | 11 | 11.2 | 11.7 | 12 | 12.3 | 12.3 | 11.8 |
| a , m | 0.351 | 0.264 | 0.236 | 0.216 | 0.203 | 0.175 | 0.165 |
| b , m | 0.229 | 0.222 | 0.197 | 0.17 | 0.14 | 0.114 | 0.068 |
| c , m | 0.043 | 0.036 | 0.028 | 0.0185 | 0.007 | -0.005 | -0.022 |
| d , m | 0.0545 | 0.047 | 0.022 | -0.005 | -0.035 | -0.06 | -0.107 |
| e , m | 0.061 | 0.066 | 0.0695 | 0.0727 | 0.0746 | 0.0748 | 0.072 |
| f , m | 0.361 | 0.274 | 0.246 | 0.227 | 0.213 | 0.185 | 0.175 |
| g , m | 0.0576 | 0.061 | 0.064 | 0.068 | 0.071 | 0.074 | 0.0747 |
| h , m | 0.0537 | 0.0465 | 0.0216 | -0.005 | -0.035 | -0.06 | -0.099 |
| F_N , N | 1,333.14 | 1,201.81 | 1,226.46 | 1,305.58 | 1,495.39 | 1,922.42 | 3,455.94 |
| F_{tiahlo} , N | 9,492.71 | 6,364.69 | 5,375.54 | 4,836.69 | 4,843.30 | 5,273.40 | 9,375.20 |
| F_{HM1} , N | 16,443.81 | 11,345.83 | 9,768.73 | 8,929.64 | 9,118.48 | 10,063.15 | 9,689.55 |

Conclusions

The aim of the contribution was the structural design of a mechanism for securing the position of a log located on the mobile working machine Lumag SSA 500E during cutting with a chain saw. Through analytical functional calculations, the individual components were designed, and these will be further examined in subsequent research by means of numerical analysis using the FEA software Ansys. Based on the results obtained and verified in this work, the individual components of the gripping mechanism can be manufactured and safely installed on the working machine (Fig. 1, left). At this point, it can be stated that all expected objectives have been successfully achieved. After defining the dimensions of the mechanism, it will be possible to develop the semi-automation process of the log-clamping mechanism by designing a hydraulic system in FluidSIM Hydraulic.

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Author contributions

Conceptualization, M.B.; methodology, M.B. and J.D.; software, P.S.; validation, M.B. and I.D.; formal analysis, M.B. and I.D.; investigation, M.B., J.D., I.D. and P.S.; data curation, M.B., and I.D.; writing – original draft preparation, M.B. and I.D.; writing – review and editing, M.B. and J.D.; visualization, P.S.; project administration, J.D.; funding acquisition, P.S. All authors have read and agreed to the published version of the manuscript.

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