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STUDY OF THE PENDULAR MOTIONS OF THE FORESTRY GRAPPLE

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ABSTRACT

In this paper, an analysis of the dynamics of the technological work processes of forestry grapples was carried out. The purpose of the paper is to highlight the dynamic effects of shock-type actions on the movement of the loaded grapple. Several constructive grapples variants were proposed and the influence of the position of the center of mass on the oscillations of the working tool in perpendicular planes was analyzed. The simulation of the movements was performed in the Matlab environment and the rotation velocities diagrams for both slewing and swaying motions of the grapple were obtained, for sudden commands performed by a less experienced operator. The results will form the basis for developing a solution for reducing the amplitudes of these movements, to improve the stability of the grapple in the working process.

KEYWORDS: grapple, pendular motion, transfer function, swaying, slewing

1. INTRODUCTION

The operation of forestry machinery requires a lot of training as the working conditions are often unfavorable. The stabilization of sway motion in suspended payloads is essential in applications like the operation of cranes, the management of payloads by rotors and the manipulation of hanging loads by robotic arms. The components of a grapple mounted on a crane arm are detailed in figure 1.

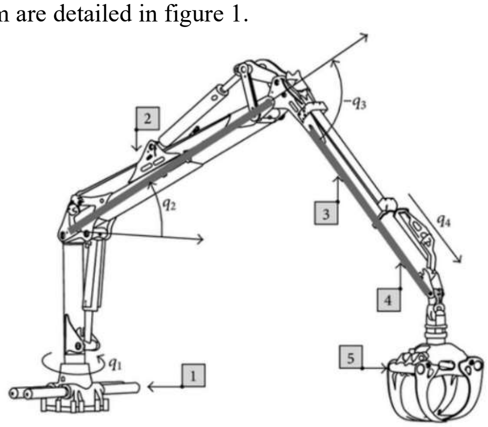
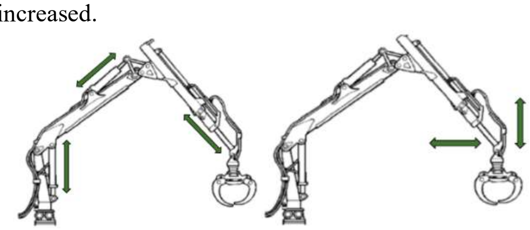


Fig. 1 Crane architecture [1]:
1. slewing; 2. inner boom; 3. outer boom; 4. telescope; 5. grapple.

Most forestry machines today are under manual control, i.e. controlled directly by an operator, but in other industries manual control has been superseded by remote control, teleoperation and automation (see fig. 2). Therefore, new technologies are increasingly being integrated into everyday tasks to assist users and could radically change the manner of how industries operate [2,3]. Therefore, the automation of some movements (partially or completely) is currently a topic of great interest. Thus, the tasks of the operators can be reduced, and the productivity and operational efficiency can be increased.



a) b)

Fig. 2 John Deere intelligent boom control [3]:
a) common control; b) IBC - Intelligent control.

On the other hand, sudden movements of the equipment (specific to inexperienced operators) generate oscillations that have a negative impact on productivity. Also, unloading activity of the materials [4] is another factor that affects the dynamics of the grapple by introducing additional oscillations in flexible elements, such as cables. The modeling of the excitation effect on the grapple movement is done in an open loop system, thus preventing unwanted oscillations by modifying the control signal before transmitting it to the system [5]. By simulating different excitations (considered as input data for the system) and considering the parameters of the model attached to the grab (e.g. natural frequency values and the damping ratio), it is possible to identify the way to reduce the oscillations of the working equipment.

2. THEORETICAL CONSIDERATIONS

In the study carried out in this paper, the author considered only the grapple-type working equipment, isolated from the base machine, and analyzed its behavior during the log loading operations. Among all the operations, the case will be analyzed where the grapple has two pendulum movements, but in perpendicular planes, each motion being described by an angular variation, noted with θ_1 and θ_2, as schematized in figure 3.

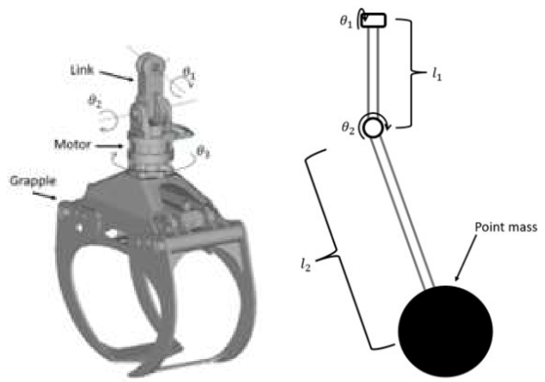


Fig. 3 Pendulum model assimilated to the grapple [6]

These two motions can be studied based on the transfer functions (typically represented in the Laplace domain) of the mechanical system associated.

The general form of a transfer function for a stable system must be a ratio of polynomials, like Eq. (1), where all coefficients in the denominator are positive, and consequently, all roots of the denominator are negative. Only in this case, the system's response to excitations will not grow unboundedly over time, indicating motion stability.

$$G(s) = \frac{K\omega_n^2 s^2}{s^2 + 2\xi\omega_n s + \omega_n^2}. \quad (1)$$

Thus, the angular velocities of the two movements of the gripping device can be expressed as transfer functions (G_1 and G_2) of the system subjected to excitations of the form [1]:

$$\dot{\theta}_1 = G_1(s)\dot{\theta}, \quad (2)$$

$$\dot{\theta}_2 = G_2(s)\dot{x}, \quad (3)$$

where: θ represents crane arm rotation; x is translation motion of the grapple; G_1 and G_2 are the next forms [6]:

$$G_1(s) = \frac{\frac{1}{l_1 + l_2} s^2}{s^2 + \frac{c_1}{m\,(l_1 + l_2)^2} s + \frac{g}{l_1 + l_2}}, \quad (4)$$

$$G_2(s) = \frac{-\frac{3}{l_2} s^2}{s^2 + \frac{c_2}{m l_2^{\,2}} s + \frac{g}{l_2}}, \quad (5)$$

where: l_1, l_2 - the lengths indicated in the pendulum model in figure 3; m - the mass of the grapple when it is loaded with material; c_1, c_2 – damping coefficients; g – gravitational acceleration.

The distribution of mass within the grapple and the load (with direct linkage on the position of the center of mass) influences the stability of the system during lifting and movement in the technological work process [7]. The grabbing forces of the grapples are also dependent on their structural parameters and the mass of the grapple loaded [8]. Thus, in figure 4 are schematized the log grapples for loading, unloading, and sorting in the various shapes, each designed for specific tasks.

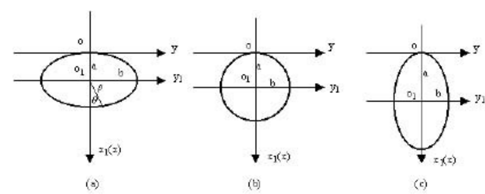
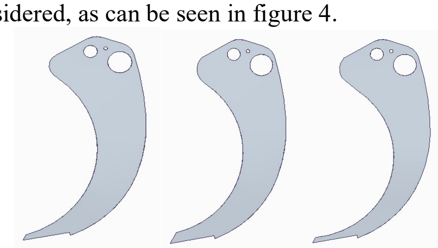


Fig. 4. Basic tong shapes of log grapple [9]

For study from this paper, three grapples with different construction types of tongs will be considered, as can be seen in figure 4.



a) b) c)

Fig. 4 Usual tong shapes of the grapples:
a) horizontal ellipse; b) circle; c) vertical ellipse.

The common identification data of the analyzed grapples are: l_1 =0,23 m; c_1 = 46 kgm/s; c_2 = 54 kgm/s; m = 500 kg. Since the distance to the center of mass (l_2) of these tong shapes is variable, three study cases are distinguished with the parameters specified in Table 1, each case having the transfer functions with the parameters centralized in Table 2.

Table 1 Description of case scenarios

Study case	Tong shapes	l_2 [m]
1	Horizontal ellipse	0,55
2	Circle	0,60
3	Vertical ellipse	0,65

Table 2 Coefficients identification for all study cases

Study case	Transfer functions	ξ	ω_n	K
1	G_1	0,021	3,54	0,102
	G_2	0,042	4,22	-0,306
2	G_1	0,019	3,43	0,102
	G_2	0,031	4,04	-0,306
3	G_1	0,017	3,33	0,102
	G_2	0,033	3,88	-0,306

After replacing the values of the constructive parameters of the grapples, we obtain data centralized in Table 3.

Table 3 Transfer functions for studies cases

Tong shapes	Symbol	Expression
Horizontal ellipse	G_1	$\frac{1.278\,s^2}{s^2+0.148\,s+12.53}$
	G_2	$\frac{-5.449\,s^2}{s^2+0.354\,s+17.8}$
Circle	G_1	$\frac{1.053\,s^2}{s^2+0.13\,s+11.764}$
	G_2	$\frac{-4.994s^2}{s^2+0.25\,s+16.321}$
Vertical ellipse	G_1	$\frac{1.131\,s^2}{s^2+0.113\,s+11.088}$
	G_2	$\frac{-4.606\,s^2}{s^2+0.256\,s+15.054}$

These expressions of the transfer functions will be the basis for simulating the motions of the grapple under the action of imposed perturbations.

3. SIMULATION RESULTS

The dynamic model of grapple enables prediction of changes in dynamic behavior reflecting the type and severity of excitations.

Firstly, the graphical representation of the ω_n values (see table 2) of the two pendulum motions of the grapple is given in figures 5 and 6 for all the cases analyzed.

It is observed that natural pulsation is dependent on the constructive characteristics of the grapple, and the damping is influenced by the modification of its mass, by adding a larger number of logs (for example).

The shape of the grapple's gripping elements has a greater influence in the case of swaying motion because increasing the distance to the center of mass (l_2) by 18% led to a 20% decrease in the natural pulsation value, while in the rotational motion only by 5.6%.

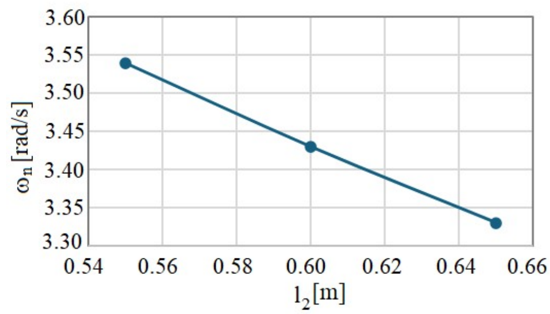


Fig. 5 Representation of $\omega_n - l_2$ variation for pendulum motion in the perpendicular direction

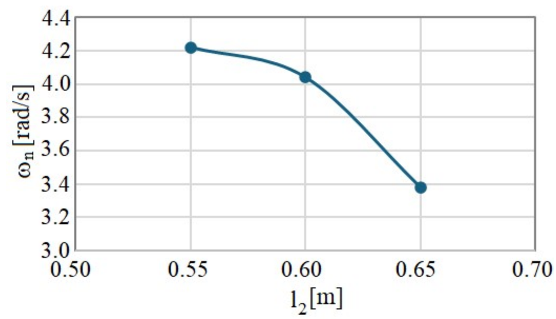


Fig. 6 Representation of $\omega_n - l_2$ variation for pendulum motion in the parallel direction

To understand the effect of the excitation on the dynamic behavior of grapples, simulation will be conducted to investigate the influence of two actions that were done by a less experienced operator which commands the rotation arm of the grapple (fig. 7) and, respectively, the displacement of the crane (fig. 8).

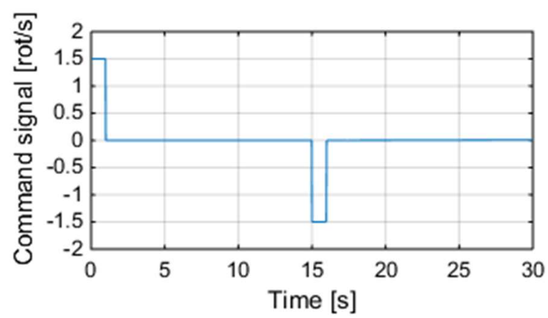


Fig. 7 Command signal for slewing of grapple

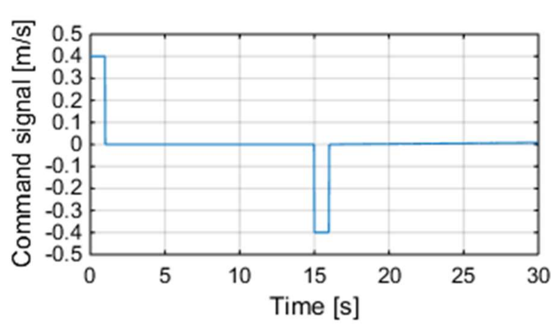


Fig. 8 Command signal for swaying of grapple

Using the transfer functions from Table 3, we can predict the system's behavior and know rise time, settling time, and other transient characteristics. Thus, the simulation results in the MATLAB/Simulink environment are given in the figures 9 and 10.

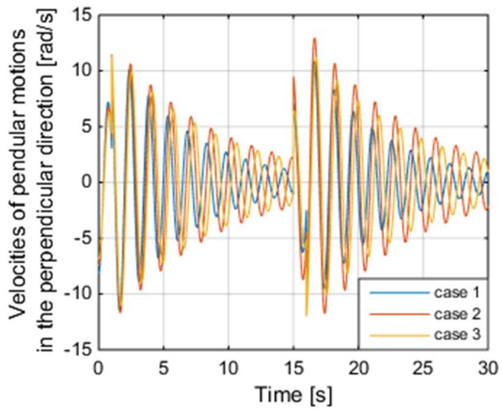


Fig. 9 Effect of grapple motion to slewing

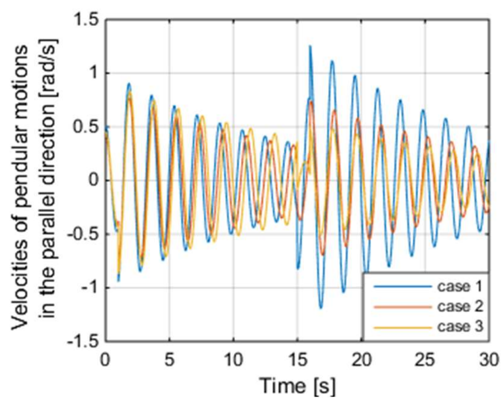


Fig. 10 Effect of grapple motion to swaying

The diagrams in figure 10 show the major influence of the excitation in the perpendicular plane, the slewing motion having an amplitude 10 times greater than that of the swaying of the grapple.

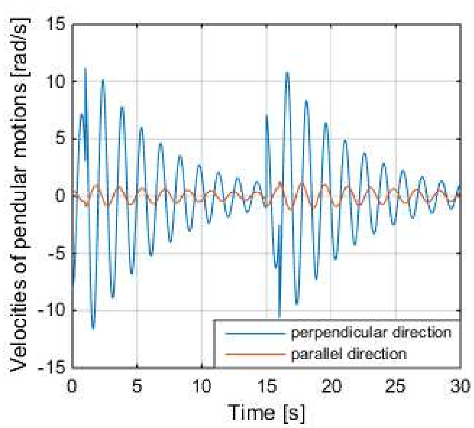


Fig. 11 Comparative diagrams for perpendicular motions of grapple (for case 1)

Among the three cases analyzed, it is observed that the amplitude of the oscillations is smaller for the horizontal ellipse shape in the slewing motion which significantly influences the dynamics of the grapple (in respect with the swaying motion).

4. CONCLUSIONS

This paper addresses a current topic regarding the dynamics of widely used forestry grapples. The results highlighted the dynamic effects introduced by operator commands on the grapple motion. The pendulum motions in perpendicular directions of the grapple were studied when the shape of the gripping elements have specific shapes. The transfer functions of the mechanical system were implemented in Matlab/Simulink, and the results consisted in the representation in the time domain of the velocities of the pendulum motions of the grapple with highlighting the influence of the claw shape. Transfer functions are fundamental for designing the control of mechanical systems. By introducing a variety of types of excitations (input data), control of movements can be achieved to prevent oscillations of the forestry equipment grapple, an aspect that leads to a decrease in productivity and operational efficiency and makes it difficult to safely grapple loads.

The future direction of research will consist in the development of a method for parameters control of the highlighted movements, to fast amortization the oscillations to maintain the stability of the technological equipment. This control of movements is necessary for the grapple to work without the appearance of significant swings introduced most often by the untrained operator of the equipment, because of a lack of professional experience.

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