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Modelling of the hardwood harvesting process: feeding model

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Résumé :

Les travaux relatés concernent la modélisation de procédés de bûcheronnage au sein du projet ECOMEF (Éco-concevoir un outil de mécanisation pour le bûcheronnage dans les peuplements feuillus), en vue d'évaluer et d'optimiser leurs performances (gain de productivité et efficacité énergétique). Cette publication présente une démarche de décomposition fonctionnelle basée sur la méthode SADT, afin de déterminer des «briques élémentaires» de modélisation. Ainsi, quatre fonctions permettent de modéliser le fonctionnement d'une tête de bûcheronnage, à savoir modéliser le contact et le serrage du tronc par les différents organes, modéliser l'entraînement, modéliser l'ébranchage par choc, et modéliser le billonnage, les trois premiers modèles énoncés ayant été identifiés comme indispensables. Ensuite, le modèle d'entraînement est détaillé. Le développement d'une approche analytique et la réalisation de campagnes d'expérimentations en vue du recalage du modèle sont menés simultanément. L'approche théorique est développée, ainsi que les premiers résultats expérimentaux et les essais à venir.

Abstract :

This work deals with modelling and simulation of harvesting processes within the framework of the ECOMEF project (Eco-design of a mechanized equipment for hardwood harvesting), the purpose being the assessment and optimization of processes' performance (productivity and energy efficiency). This paper presents a function modelling methodology, based on the SADT method, used to determine "fundamental components" of an existing harvesting system model. Thus, four functions are proposed to model the actual cut-to-length logging process, namely modelling the contact and gripping of the trunk, modelling stem feeding, modelling delimiting, and modelling bucking, the three first models being identified as essential to develop. The feeding model is then detailed. The development of an analytical approach and the establishment of experimental tests for the calibration of the model are conducted simultaneously. The theoretical approach of the feeding model is developed, and the first experimental results and tests planned are discussed.

Mots clefs : Harvesting head ; feeding model ; experimental characterization

1 Introduction

This work is a part of the ECOMEF project which aims to develop a tool more specifically designed to harvest hardwoods. Within the framework of this project, the work presented focuses on modelling current harvesting processes and new developed concepts to evaluate and optimize their energy performance and productivity.

The process that should be modelled is the one mainly used in Europe, that is to say cut-to-length logging (CTL) [1]. CTL is usually performed with two machines, a forestry harvester and a forwarder. As presented in [1], a typical CTL operation is composed of felling, and processing trees, processing being itself composed of delimiting and bucking. More precisely, this paper concentrates on the single-grip feller-processors which are attachments mounted on the harvester boom, able to process each step detailed above.

2 Function modelling

2.1 Processes to model

To identify the processes that should be modelled in order to simulate CTL as widely as possible in a mechanical perspective, a top-down approach based on the SADT method has been used. Starting from an "A-0" top level which only contains the main goal of this work, namely *Modelling the CTL process : felling and processing (delimiting + bucking)*, the lower "A0" level is naturally composed of four functions that almost represents the different phases of the CTL process (figure 1).

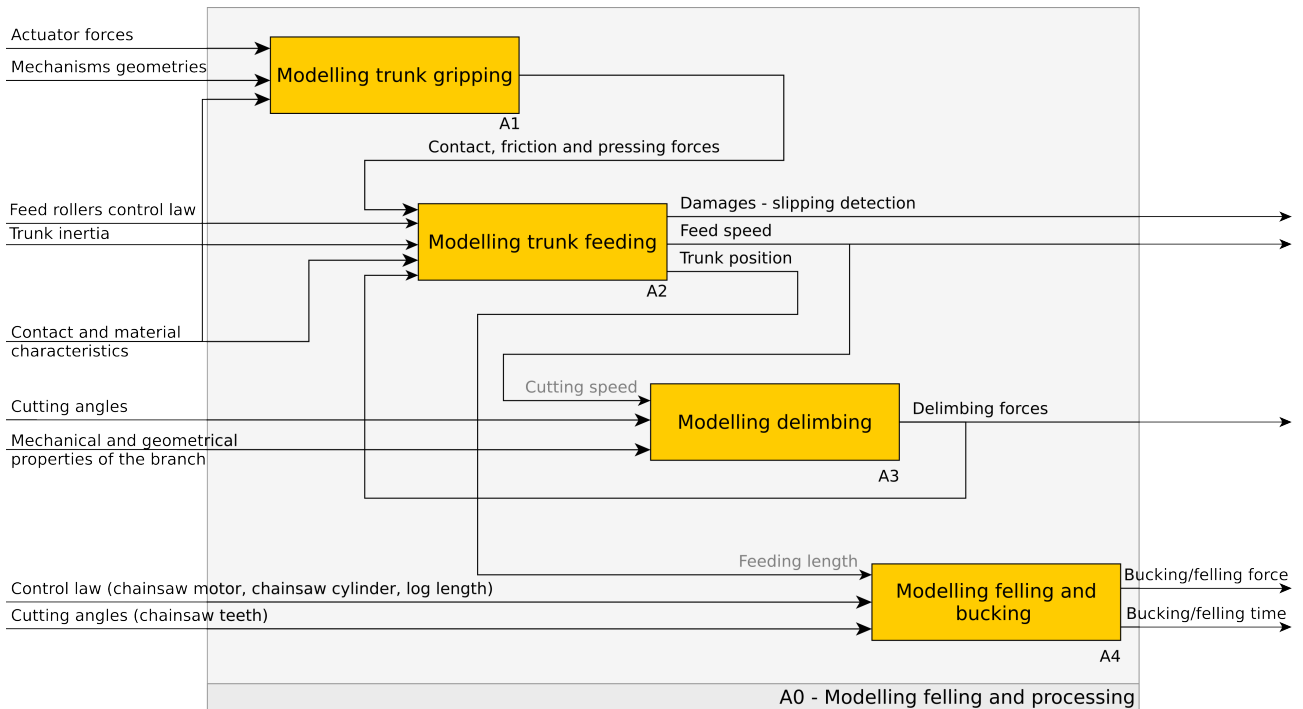


FIGURE 1 – A0 level of the SADT diagram

We can see that felling and bucking have been gathered together in one single function because from a mechanical point of view, these two steps boil down to driving the chain saw, even if the conditions are not exactly similar [2]. The tree is indeed vertical while felling and almost horizontal while bucking which leads to different stresses in the trunk.

Lower levels are created using the same methodology and the same mechanical point of view. This leads to the definition of indivisible base components, such as the A21 function *Calculating transmitted and transmissible forces* described in this paper and referred later as the feeding model.

2.2 Fundamental components

Using this top-down function analysis, an exhaustive inventory of modelling components has been obtained. Before trying to adapt existing models and/or trying to develop new ones, fundamental components should be highlighted. Considering the ECOMEF project as the framework of this study, it has been decided to focus on the components dealing directly with hardwood specificity. Compared to softwood, broad-leaved trees have indeed more crooked trunk and bigger branches with more varied implantation angles, which makes them more difficult to delimit and mechanically more stressful for the harvesting head.

The components showing feedbacks between each other are also preferred, because closed loops denote a great source of optimization. Based on this analysis, three components are defined as fundamental to model CTL : A1 function *Modelling trunk gripping*, A2 function *Modelling trunk feeding* and A3

function *Modelling delimiting*. The second part of this paper will focus on the feeding model, more specifically using feed rollers.

3 Feeding model

To feed the trunk through the harvesting head, two technologies can be used on single-grip feller-processors : feed rollers and stroke cylinder.

Stroke feeding is based on a linear hydraulic actuator. Trunk is fed by an alternate movement of the stroke cylinder, coupled with the gripping/releasing of the trunk alternatively with the upper and the lower knives. Delimiting forces are often higher, but this solution remains slower than the feed rollers.

When using a harvesting head equipped with feed rollers, the rollers are pressed against the trunk using a gripping mechanism that can have concentric, lateral or hybrid motion. As explained in [2], concentric gripping mechanisms are not very suitable for small stems, whereas lateral gripping mechanisms facilitates passing of crooked parts of the trunk but could lack pressing force when processing large trunks. Of course, the hybrid solutions try to adapt the kinematics of the gripping motion to the diameter of the trunk, in order to be efficient on the whole range of considered diameters.

3.1 Context

Feeding has been studied using different points of view. In [4], the authors carried out an experimental study of stud damages to logs, in order to determine which type of roller causes the most.

In [3], the damage of different feed rollers are compared too, but the authors also consider the operational efficiency of each roller and establish models of the effective feeding time and the fuel consumption for three different tree species (pine, birch and spruce).

Even closer to mechanical considerations, [5] and [6] present two experimental studies about penetration depth and admissible traction force depending on the type of feed roller.

Unfortunately, there is actually neither analytical study of the feeding process, nor model of the mechanical behaviour of gripping / feeding trunk with rollers. In order to optimize the efficiency of this process, a model should thus be developed. The purpose is to be able to calculate and then to optimize, for a given configuration (geometrical, mechanical and dynamical known parameters), the actual and maximum admissible forces.

3.2 Theoretical approach

The approach presented above is mainly based on the model of non-elastic deformation of the chip by an asperity of the tool proposed by Klamecki [7]. This model has been initially developed to calculate the friction coefficient due to the creation of a furrow by a conical asperity travelling through the chip. Klamecki expresses the transverse and frontal forces on the asperity using the simple relation $F = \sigma S$, F being the force and S the projected area in the considered direction.

For the transverse force T , the considered surface A_t is half a disk of diameter d (maximum penetration of the cone into the chip, figure 2), and the stress linking force and area is the yield strength of the chip material. For the frontal force N , the A_f area represents the projection of the cone in a radial plane, perpendicular to the force (triangle of the height of x and of the base of d). The considered stress is the strength of the chip material.

The feeding model follows a similar approach. First, the maximum stress admissible by a given wood species in the gripping direction (perpendicular to grain) needs to be experimentally determined, in order to link the measured gripping force with the projected area normal to this direction. Then, an analytical model allows the calculation of the penetration depth and the projected area normal to the feeding direction (parallel to grain). Finally, the maximum stress admissible in this direction (to be determined experimentally too) will permit to calculate the maximum transmissible feeding force.

Still being one of the most used type of stud on feed rollers, the elliptical stud or steel spike could be geometrically obtained by two successive oblique cuts in a rod (figure 3).

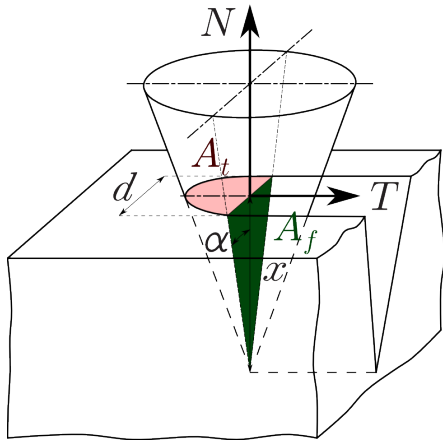


FIGURE 2 – Klamecki definition of the frontal and transverse surfaces

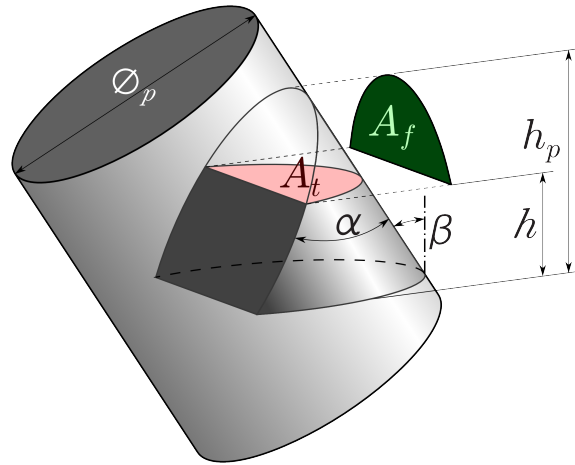


FIGURE 3 – Geometrical definition of an elliptical stud

The parameters used to define the geometry of the elliptical stud are the following :

- \varnothing_p the diameter of the rod
- h_p the stud height
- α the top angle
- β the inclination angle of the stud with respect to the vertical
- h the "free height" of the stud (height of the stud that has not penetrated into the trunk)

Looking at figure 3, the frontal surface A_f and transverse surface A_t can be modelled as portions of ellipse. Considering a centred ellipse with semi-major axis a and semi-minor axis b , the portions are delimited by a vertical line with abscissa $x = a'$ (figure 4), with A_f being approximated by a surface like S_1 (when $x \in [-a; a']$) and A_t by a surface like S_2 (when $x \in [a'; a]$). The areas can be calculated :

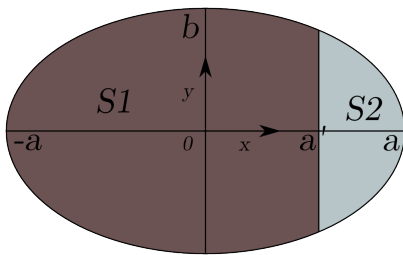


FIGURE 4 – Portions of ellipse

$$A_{[-a;a']} = \frac{ab}{2} \left[\pi + \sin \left(2a \sin \left(\frac{a'}{a} \right) \right) + 2a \sin \left(\frac{a'}{a} \right) \right] \quad (1)$$

$$A_{[a';a]} = \frac{ab}{2} \left[\pi - \sin \left(2a \sin \left(\frac{a'}{a} \right) \right) - 2a \sin \left(\frac{a'}{a} \right) \right] \quad (2)$$

Starting from (1), the parameters a , a' and b can be expressed using the geometrical definition parameters of the stud to analytically express the area of A_t . The same can be done for A_f using (2).

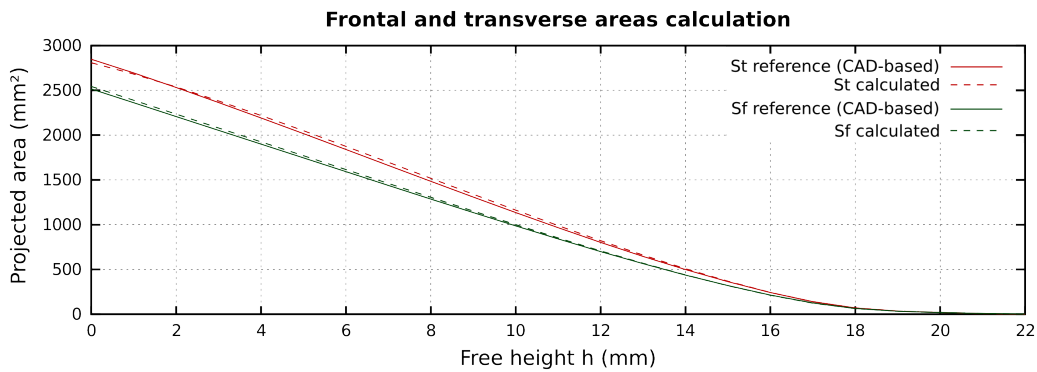


FIGURE 5 – "Real" and calculated areas of the frontal and transverse global surfaces

Using these formulae for every stud penetrating the trunk, the global frontal and transverse areas S_f and S_t can be obtained. To confirm the calculated values, a CAD model of the configuration were created to obtain reference surfaces and global areas (figure 5). For each area, the relative error never exceeds 5%.

3.3 Experimental approach

Specific stress in both gripping and feeding directions (perpendicular and parallel to grain) is experimentally determined by measuring forces and penetration depth (used to calculate areas). To determine these values, two experiments are carried out, one for each direction. The experimental device and the first results of force as a function of penetration depth obtained for the gripping operation are presented.

Figure 6 presents the gripping test bench. A portion of a feed roller and a frame supporting the trunk are inserted into the chuck jaws of a tension/compression testing machine. The machine is then moved to the contact point between the roller and the stem. Starting from this point, the displacement and the applied force are measured until the cylindrical surface of the roller touches the trunk.

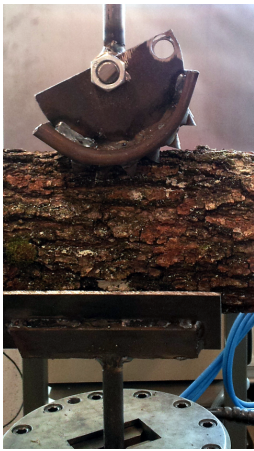


FIGURE 6 – Gripping test bench

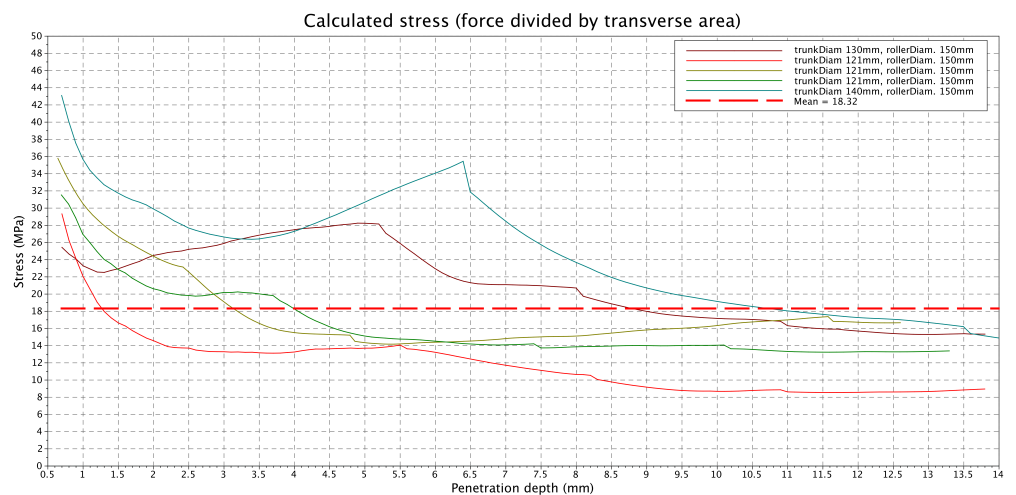


FIGURE 7 – Stress curves obtained for each test and average value

Curves of force as a function of penetration depth are then obtained. Knowing the penetration depth, the global transverse area is computed for each time step using equations (1) and (2). This allows to plot stress (force divided by transverse area) as a function of penetration depth (figure 7).

Preliminary tests were made with different log diameters. Every tests have been made on logs coming from the same trunk of green sessile oak. It is then possible to consider that the moisture content and the specific gravity are not relevant parameters in this case.

The stress curves can then be approximated as horizontal lines. This assumption is based on the simple formula $\sigma = F \div S$ with F the applied force and S the projected surface normal to the application direction, σ being equivalent to the maximum admissible stress when pressing the feed roller against the trunk. Considering that wood has the same mechanical properties for each test, the maximum admissible stress should be unique. As presented on figure 7, the calculated average stress value is approximately 18 MPa. This value is positioned between the compressive stress perpendicular to grain and the hardness values usually found in the literature [10].

This value allows the calculation of the projected area and the penetration depth. Experimental study of the feeding operation is the next step to be able to compute the maximum transmissible feeding force. Of course, more tests are needed to determine values for each hardwood species of interest and to investigate the influence of specific density and moisture content on this maximum admissible stress.

4 Conclusions

An analytical model to determine the global projected surfaces of the feed roller was developed. This model allows to calculate the areas when using elliptical studs. To extend the study to other shapes of studs, derived analytical formulations or a CAD-based calculation method will be proposed, in order to help engineers to optimize the feeding process (maximizing the maximum transmissible feeding force by adapting the roller geometry but also the shape and the pattern of the studs).

Concerning the gripping of the trunk, first tests seem to confirm the trend of a constant relationship between calculated stress and penetration depth. More experimentations are needed to verify this hypothesis and to study the influence of several parameters on the admissible stress.

To study the feeding operation, a specific workbench has been designed. The bench allows the application of both an adjustable gripping force of the roller against the clamped trunk and a feeding force, applied to the roller using a hydraulic actuator and causing its rotation. These two forces and the stroke of the actuator are measured until the total bulk failure to determine the maximum stress in the feeding direction.

Acknowledgements

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