Modernization of Harvesting and Processing Head

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ABSTRACT

Background and Purpose: The article is devoted to the reduction of energy consumption necessary for delimbing.

Materials and Methods: Branch delimbing method includes feeding the tree trunk through the ring formed by the delimbing knives and simultaneous reciprocator movement of the delimbing knives along the axis of the processed trunk. The distinctive feature of the construction is the presence of the beater unit comprising a pusher and a piston mounted inside a sealed housing.

Results: As a result of the suggested construction the force of the beater impact of the delimbing knife is increased. Using this method, the branches are removed not only due to the force generated when the knives come in contact with branches pushed by feed rolls moving the trunk, but also due to extra beater stress affecting the delimbing knife. The use of the aforesaid method and the construction of the mechanism allows to reduce energy consumption necessary for the delimbing process.

Conclusions: The design of harvesting and processing head proposed in this article can be used in the design and manufacture of logging machines and mechanisms. The technical solution may be an interesting advance of the delimbing process when processing trees, especially when cutting big branches or when cutting forces are temporarily higher than average force values.

Keywords: forestry machinery, harvester head, delimbing mechanism, tree, harvester, processor

INTRODUCTION

A shift of harvesting enterprises to progressive logging technologies ensures enhancing the productivity, improving the quality of the logging site processing and minimizing negative environmental impact. Over the past decade forestry machinery pool has significantly expanded and become diverse all over the world. Ever increasing requirements for such equipment force manufacturers to constantly improve forestry machinery. One of the most promising and intensively developing technological processes of timber harvesting are technological processes which use state-of-the-art harvesting machinery capable to remove branches from tree trunks on the logging site (harvesters and processors) [1].

Summing up the aforesaid, it is worthwhile to note that modernization of harvester and processor technological equipment is vitally important and has a valuable scientific and practical value.

LITERATURE REVIEW

Many researchers are involved in searching for solutions to improve the structure of the working elements of harvesting machines [2-6] and modern machines working in close connection with them [7-11]. Based on the functional and technological analysis of harvester head, Budnik [12] and Demchuk [13] devise a development matrix, which contains all possible ways for its improvement. Among other ways of efficiency enhancement of the harvester head operation we consider it to be necessary to reduce the impact of dissipative forces emerging during trunk feeding process.

At present, delimbing methods and the construction of mechanisms patented in [14-17] using the feeding wheels mounted on the movable gripping device and the delimbing device ensure the removal of branches on the side adjacent to the mechanism case. The feed rollers embrace the tree trunk from both sides and force the tree trunk with the effort...
necessary to remove branches by the delimbing knives. The
dependence on the feed roller drive with sufficient delimbing
capacity is a significant drawback of aforesaid method and the
construction of the mechanism.

Another delimbing method presented in the patent publica-
tions [18-20] comprises the use of three feeding rolls, one
of which is mounted on the frame structure, while the
other two are mounted on the movable gripping elements.
The device ensures increased feeding force. The branches are
removed through the impact force emerging when the feeding
rolls move in the absence of additional mechanical impact on
the branches. It means that the feed roller drive should have
the increased capacity, which again represents a significant
drawback of the aforesaid method and the construction of the
mechanism.

Attempts to create vibrations of the cutting tool to
influence the processes of mechanical processing of wood
have been known since the 1940s. They are among the options
for reducing the energy consumption necessary for delimbing.

Auto-resonant ultrasound technologies alongside with
vibration technologies in general are characterized by high
performance, efficiency and productivity, as they allow the
obtaining of the maximum possible amplitudes of the working
body (or other defining characteristics) with minimum power
expenditures [21]. Ultrasonic-assisted cutting experiments
have been performed on different wood species in dry and
wet state. Compared to conventional cutting, the reduction of
cutting forces by 50% is achieved at relatively small vibration
amplitudes of 8 μm. [22].

However, ultrasonic cutting of wood has not yet found
wide practical application for several reasons: the complexity
of the development of ultrasonic oscillatory systems for the
implementation of the processes of machine cutting; high
cost and low reliability of ultrasonic equipment (ultrasonic
generators and emitters) [23].

At the same time, high-performance perforators, original
designs of vibration-damping devices and new designs of
percussion mechanisms were developed and introduced
into mass production. In the system of pneumatic impact
mechanism, an increase in the working pressure is achieved
through the use of compressed air. The increase in shock
power by 2.8 times theoretically corresponds to an increase in
air pressure from 0.5 to 1 MPa, and with a further increase to
2 MPa - by 8 times, etc. [24].

A positive decision on obtaining a patent for the invention
of the Russian Federation on the design of this harvesting
and processing head was received by the authors of the
publication [25].

MATERIALS AND METHODS

Our invention aims to reduce the energy consumption
necessary for delimbing. When designing the mechanism,
the task was to develop a design that would increase the
power of the harvester head during the operation of cleaning
the branches from trees. The methods used in solving the
problem are most common in the design of percussion
mechanisms of jackhammers and perforators.

The proposed principle of impact is provided by the
reciprocating movement of the pusher in the cylinder. This
creates a compression of air between the pusher and the
piston. The energy of compressed air drives the piston, which
strikes the rod. The return of the piston occurs due to the
dilution of air during the return stroke of the pusher.

The suggested method is illustrated as follows.

Figure 1a represents a general view of the delimbing
mechanism. Branch delimbing method includes feeding
the tree trunk through the ring formed by the delimbing
knives and simultaneous reciprocator movement of the
delimbing knives along the axis of the processed trunk. The
delimbing mechanism is attached to the manipulator of
the harvesting vehicle and contains the following parts: (1)
the structural frame with the mounted feeding wheels (4,
5) driven by hydraulic motors (2, 3). Some feeding wheels
are mounted on the gripping elements (6), and some on the
frame structure to ensure the trunk grip from three sides
and feeding the processed tree trunks in the longitudinal
direction. The mechanism requires several delimbing knives
(7) with tilting axes (8) to grasp the tree trunk parallel the
aforesaid longitudinal direction. The device comprises one
fixed delimbing knife (9), ensuring branch removal on the
side of the tree trunk adjacent to the delimbing head, and a
chainsaw (10).

Figure 1b presents a general sectional view of the
delimbing mechanism against the plane of the beating
mechanism. The fixed delimbing knife is mounted on the rear
part of the rod (11). For the purpose of cross cutting of full-
length logs, the device comprises a chainsaw and a measuring
wheel (12) to measure the assortment lengths. The distinctive
feature of the construction is the presence of the beater unit
comprising a pusher (13) and a piston (14) mounted inside a
sealed housing (15). Only one delimbing knife is equipped
with the vibrating/bitting mechanism.

Figure 1c presents the type of interaction among the gear
wheels of the beating mechanism drive. The feed roller (5)
mounted on the mechanism frame features a fixed tooth gear
(16), which meshes with a set of consequently interacting
gears (17). These gears are mounted so that they carry out
torque transmission (16) and proportionally accelerate the
rotation speed of the final drive gear (18) which is a balance
wheel for the slider-crank mechanism. The crank-and-rod
mechanism (19) is used for the beater unit drive.

All the above described mechanisms driving the crank-
and-rod mechanism and comprising a feed roller (5), tooth
gear (16), a gear kit (17), and a balancing wheel (18) are
mounted in one housing (20) attached to the axis (21) in axial
alignment of the balancing wheel with a pressing element
(22) in order to provide its pivoting, and pressing the feed
roller against the tree trunk.

The exposed gears are very much subjected to
mechanical damage and blocking by branch residuals and
other contaminations, so gear wheels should be closed by a
casing (this is not shown in the figures).

The developed delimbing and cutting device operates as
follows.

The tree trunk is grasped by the feed rolls and is embraced
by the delimbing knives. The feed roll mounted on the frame
of the device is pressed against the frame due to stress
from the trunk embraced by the grapples. Thus, the frame
on which the feed roll is mounted rotates on its rotary axis
causing the pressing unit to come into the pressed position.
The knives form a ring. The wheels are driven in rotation to force the cut tree stem through the delimbing knives in the longitudinal direction.

Figure 2 presents the position of the striking elements after the forward moving of the pusher and beating on the piston rod. Figure 3 presents the position of the elements of the beating mechanism when the pusher returns to the initial position. The rotation of the feed rolls is accompanied by the rotation of the tooth gear, which, in its turn, transmits rotation via the gear kit onto the balance wheel of the slider-crank mechanism. The latter converts the rotary motion of the balance wheel into a reciprocal motion of the pusher inside the sealed housing. Sliding of the pusher inside a sealed housing under higher air pressure between a pusher and a piston when it moves forward and under lower air pressure when a pusher moves in the reversed direction causes a reciprocal motion of the piston. Sharp movement of the piston along the axis of the sealed housing towards the rod triggers a beater impact on the rod.

As soon as the desired length of a tree trunk is measured, it is crosscut by a chainsaw. After the crosscutting, the feeding of the tree trunk proceeds, until the entire tree trunk has been processed.

RESULTS AND DISCUSSIONS

When designing a device, it is possible to set a design optimization problem. The impact force required to cut the branches of a tree can be obtained at various values of the parameters of the mass of the piston (m) and its speed \( \vartheta \). Changing the speed of movement of the piston is possible when changing the gear ratio between the feed rollers and the pusher.

Cutting force \( F_p \) (N) without chip formation depends on a number of factors [26] and can be determined by the formula:

\[
F_p = \alpha_n \cdot \alpha_\vartheta \cdot \alpha_\delta \cdot \alpha_w \cdot \alpha_\rho \cdot n \cdot d_c^2 \cdot k
\]

\( k \) - the specific resistance to the cutting of branches, H/m² (\( k = 3.15 \times 10^6 \)); \( \alpha_n \) - correction factor for tree species (for pine, one can take \( \alpha_n = 1.0 \)); \( \alpha_\vartheta \) - correction factor for the angle of inclination of the branches (for pine, one can take \( \alpha_\vartheta = 1.0 \)); \( \alpha_\rho \) - correction factor for cutting angle (at a cutting
angle of 45° one can take \( \alpha_\delta = 1.0 \); \( \alpha_\omega \) - correction factor for wood moisture content (for freshly felled pine one can take \( \alpha_\omega = 0.95 \)); \( \alpha_\upsilon \) - correction factor for the feed rate (at cutting speeds not exceeding 50 m/s one can take \( \alpha_\upsilon = 1.0 \)); \( \alpha_\rho \) - correction factor for the blunting of the knife (depends on the time work of the knife after sharpening, one can take the average \( \alpha_\rho = 0.83 \)); \( n \) - the number of simultaneously cutting branches (\( n=1 \), because only the work of one knife of the harvester head is considered); \( d_c \) - average diameter of the cutting branches (m).

Consider an example of processing pine branches with \( 0.06 \) m. Substituting data into a formula, we get the result:

\[
F_\rho = 8.9 \text{ kN}.
\]

The power spent on cutting the branches at a speed of pulling a tree of \( \vartheta_\rho = 1 \text{ m} \cdot \text{s}^{-1} \) can be calculated by the formula:

\[
E_\rho = F_\rho \cdot \vartheta_\rho = 8.9 \text{ kW}
\]

We will model one blow of a knife with a tree pulling speed equal to \( \vartheta = 1 \text{ m} \cdot \text{s}^{-1} \).

Suppose that the gear ratio from the pulling roller to the pusher is 1/20. The pusher delivers 20 blows when moving a tree at a distance equal to one meter. The piston speed is 20 times faster than the tree pulling speed and is \( \vartheta = 20 \text{ m} \cdot \text{s}^{-1} \). One hit is \( t = 0.05 \) seconds.

We calculate the additional energy of the mechanism developed by a piston strike with a mass of three kilograms (\( m=3 \) kg).

\[
A = \frac{1}{2} m \cdot \vartheta^2 = \frac{1}{2} \cdot 3 \cdot 20^2 = 600 \text{ J}
\]

The additional power of the mechanism developed on impact will be:

\[
E = \frac{A}{t} = 12 \text{ kW}
\]

Thus, the obtained power value is sufficient for cutting branches of 0.06 meters in diameter and allows the reduction of the total power of the harvester head consumed during branch pruning. Cutting off the branches of a large diameter is carried out at the expense of several blows accompanying the cutting process.

The speed and mass of the piston can be adjusted, selecting a rational design of the device. Any efficiency of the harvester head achieved in its design can always be increased by increasing the mass of the piston, or by optimizing the gear ratio between the rollers and the pusher, without changing the mass of the piston.

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Thus, as a result of the suggested construction the force of the beater impact of the delimbing knife is increased. Using this method, the branches are removed not only due to the force generated when the knives come in contact with branches pushed by the feed rolls moving the trunk, but also due to extra beater stress affecting the delimbing knife.

The use of the aforesaid method and the construction of the mechanism allows to reduce energy consumption necessary for the delimbing process. To ensure the reliability of the presented developments and field tests, further theoretical and practical research is needed.

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