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S. P. Mokhov, PhD (Engineering), assistant professor, head of department (BSTU);
V. A. Simanovich, PhD (Engineering), assistant professor (BSTU);
S. E. Ariko, assistant lecturer (BSTU)

EXTERNAL FORCE FACTORS AFFECTING A TREE FALLING PROCESS: EFFECT ASSESSMENT

The tree falling processes are analyzed for various average stem volumes and elastic damping properties of crowns. The response in a tilting ball-and-socket hinge of the shear-and-grapple unit is investigated as a function of tree preloading force, interaction between the branches of crowns, wind load and air environment. The effects of external force factors affecting the tree falling process are assessed.

Introduction. Mechanization of intermediate and principal fellings includes design and implementation of the state-of-the-art high-performance fellers, feller bunchers, feller skidders and other multiple-function machines. The parameters of these machines must be selected with due consideration of dynamic loads arising in the structural elements when a machine carries out process techniques and operations [1]. To model the process of interaction between trees and harvesters, the primary task is to investigate the properties of the objects to be processed and the external force factors affecting this process.

1. Tree crown elastic damping parameters. The dynamic characteristics of the interaction between a tree and the ground are strongly affected by the crown stiffness and the damping coefficient. These parameters, however, vary greatly. According to V. F. Poletaikin [2], for forest stand diameters 0.36 m … 0.80 m, and depending on the height class, stiffness varies within 1185…4890 N/m, and the damping coefficient is 0.26…0.57 of the stiffness. In investigations carried out by P. S. Burmak [3], crown stiffness was assumed 4365 N/m, and the damping coefficient, 260 N·s/m. M. K. Asmolovsky [4], for the purposes of modeling a narrow-cut feller operation at an intermediate felling, has given the data demonstrating the stiffness variation from 1700 N/m to 6,000 N/m, with the damping coefficient assumed to be 0.1…0.2 of the stiffness.

For theoretical investigations, to choose the crown hardness *c* and damping coefficient *k*, the forces (F_Z) arising in the tilting hinge of the harvester head during interaction between the tree crown, with the stem volume 0.27 m^3, and the ground were analyzed; *c* and *k* values were varied. For the plots describing these processes, see Fig. 1 and 2.

These plots demonstrate that the growth of dynamic load in the tilting hinge of the shear-and-grapple unit results from reduction of the crown stiffness and damping coefficient. With the stiffness 5,000 N/m, the response becomes as high as 8467.5 N. Stiffness reduction to 1,000 N/m, with the similar stiffness / dampening coefficient ratio, results in 7.6% growth of the force arising in the hinge (see Fig. 1).

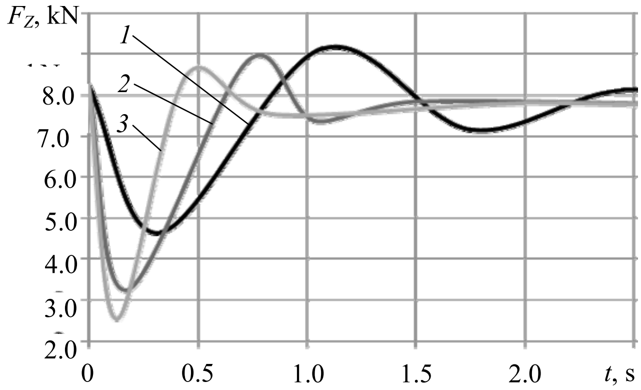

Fig. 1. Interaction between the tree crown and the ground (the crown damping coefficient equivalent to 0.1 of its stiffness):
1 – 1,000 N/m; *2* – 3,000 N/m; *3* – 5,000 N/m

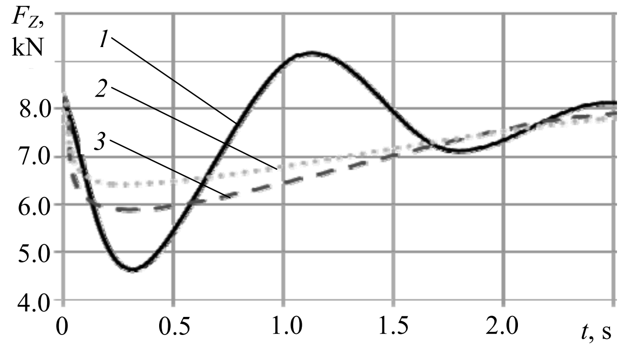

Fig. 2. Interaction between the tree crown and the ground (stiffness: 1,000 N/m):
1 – *k* = 100 N·s/m; *2* – *k* = 300 N·s/m; *3* – *k* = 500 N·s/m

Considering the process of interaction between the crown and the ground (see Fig. 2), it should be noted that the dynamic characteristics of this process strongly depend on the dampening coefficient. Growth of this parameter from 100 N·s/m to 500 N·s/m results in reduction of the vertical component in the hinge response by 14.6%. Because reduction of *c* and *k* results in longer times and higher amplitudes of the oscillation process, *c* and *k* were assumed to be 1,000 kN/m and 100 kN·s/m respectively for the purposes of subsequent research.

2. Average stem volume and stand density affecting the tree falling process dynamics. Fig. 3 and 4 demonstrate variations of forces arising in the harvester head's tilting hinge when the forest stand is processed, for various average stand volumes and stand densities. Wind loads are not considered.

When a harvester fells trees, the preload must be set while the shear-and-grapple unit grasps a tree. On the plots (see Fig. 3 and 4), the preloading operation is described by linear function; its duration is about 1 second. It should be noted that, with the tree volume growing, the preload also grows. For 0.1 m^3 average stem volume, the preload force is 7.43 kN; for 0.21 m^3 and 0.27 m^3, the preload force is 8.81 kN and 9.56 kN respectively. For these stem volumes, the time necessary for a single-shot tree felling is different: 0.79 s, 2.15 s and 1.38 s respectively. The later stages of tree falling are similar, in terms of variation of dynamic characteristics, for various tree volumes.

The dynamics of growth of the vertical component in the harvester head's tilting hinge force (F_Z) is strongly affected by the stand density. For the stem volume 0.1 m^3 and the stand density 0.70 and 0.85, the force becomes as high as 7014.1 N and 7022.7 N respectively. The maximum hinge response, 7430.0 N, appears at the time when the preload is set.

Stand density growth, up to 1.0, results in tree hanging; in such a case, the maximum vertical component in the tilting hinge of the shear-and-grapple unit grows up to 7303.9 N. This is 98.3% of the force appearing at the time when the preload is set. If the tree stands horizontally, F_Z = 6689 N.

The comparative analysis of the tree falling processes (for the stem volume 0.21 m^3) has demonstrated that, as a result of this operation, the tree falling time becomes 0.94…0.98 s longer, and the maximum force in the tilting hinge at preloading becomes 1.19 times higher. For the horizontal static position of the tree, the response grows up to 7371.0 N.

The tree falling process (for the stem volume 0.21 m^3 and 0.27 m^3, see Fig. 5), with the tree hanging, demonstrates typically decaying mode, suggesting that the impact of the harvester head weight on this process becomes less significant.

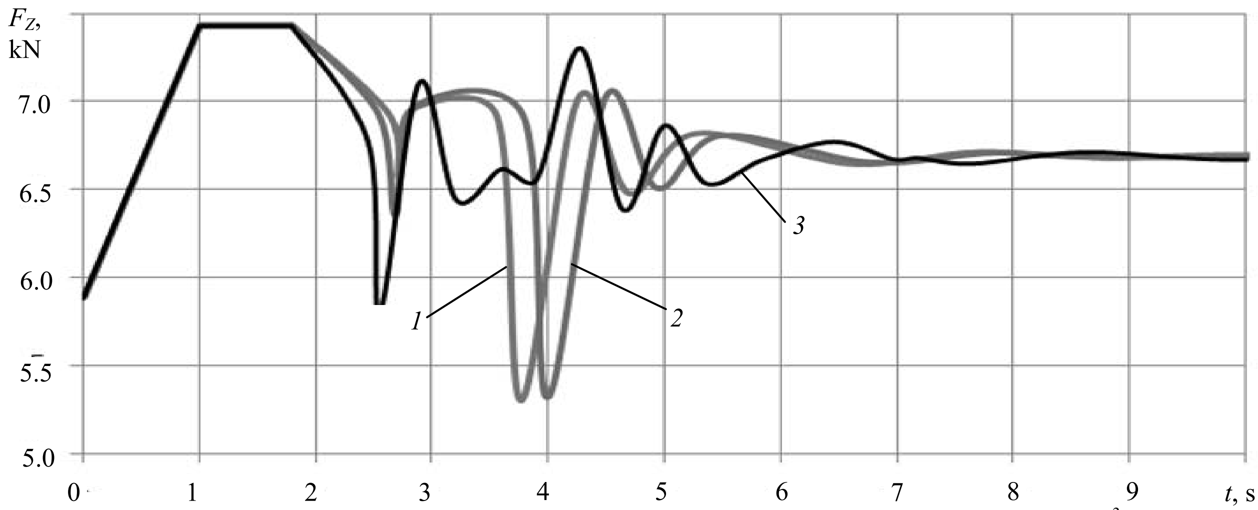

Fig. 3. Force (F_Z) in the harvester head's tilting hinge for the average stem volume 0.1 m^3:
1 – density 0.70; *2* – density 0.85; *3* – density 1.00 (tree hanging)

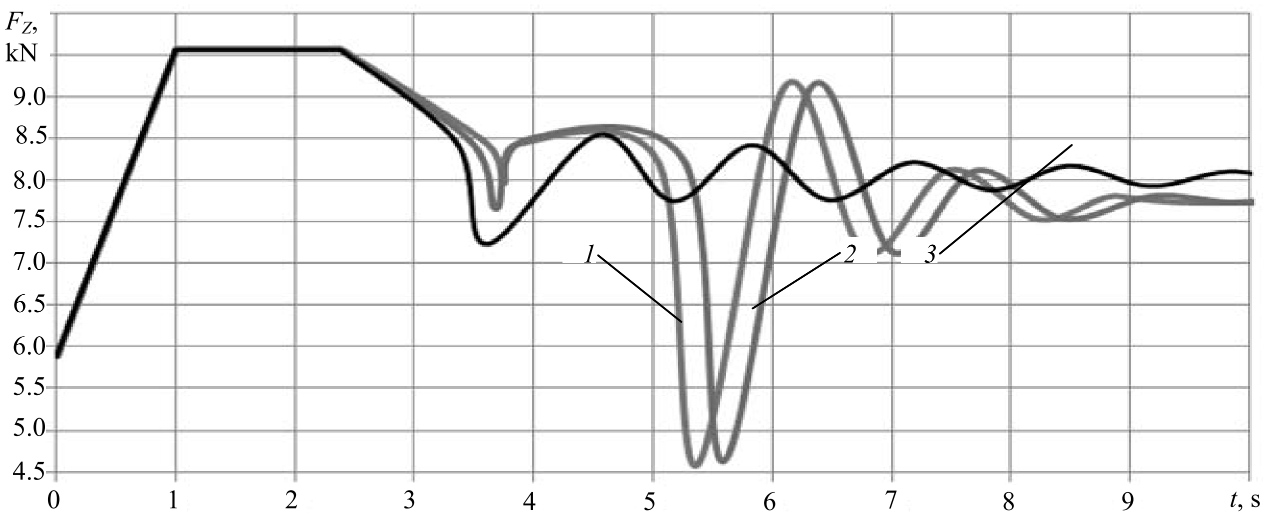

Fig. 4. Force (F_Z) in the harvester head's tilting hinge for the average stem volume 0.27 m^3:
1 – density 0.70; *2* – density 0.85; *3* – density 1.00 (tree hanging)

In such a case, the dynamic component of the force that arose in the shear-and-grapple unit's tilting hinge does not exceed the forces (F_Z) transferred to the feller during the preload setting process. The static component of the response, for the stem volume 0.21 m^3, exceeds the response arising for the tree standing horizontally by 157.5 N; for the stem volume 0.27 m^3, by 305.3 N.

For the stem volume 0.27 m^3, as compared with 0.1 m^3 and 0.21 m^3, the falling time becomes longer by 0.50…0.53 s and 1.47…1.48 s respectively (see Fig. 4), and the oscillation damping time becomes longer by 1.5…3.0 s. Also, F_Z grows up to 9564.0 N for the preload, 9119.6 N in case of tree falling, and 7737.0 N in case of static horizontal position.

The analysis of plots (see Fig. 3 and 4) demonstrates that, when the stand density is 1.0, irrespective of the average stem volume, the tree hangs when falling, resulting in additional operator's work time necessary to push it.

The research results confirm that the preload force does not affect significantly the tree falling process. When the preload force is varied within 1.2…1.4 of the tree weight, the resulting response variations not exceed 5.82% during the preloading operation and 2.52% while the tree falls and while its crown subsequently interacts with the ground. If this parameter is increased, the power necessary to cut the tree can be reduced; also, this results in a crosscut end quality improvement because the risk of cracking or splitting is reduced [5].

3. External force factors affecting the tree falling. The horizontal component of the response (F_Y) in the shear-and-grapple unit's tilting hinge is up to 44.8 N for the stem volume 0.1 m^3, up to 49.6 N, for 0.21 m^3, and up to 60.8 N, for 0.27 m^3.

In case of tree felling upwind, with the wind speed 9.5 m/s, the horizontal component in the hinge force becomes 3.5…4.1 times higher. If a tree is felled downwind, with the wind speed 10 m/s, F_Y grows up to 7.2% of the total response in the shear-and-grapple unit's tilting hinge. Therefore, this factor must be taken into consideration for the harvester stability analysis in critical loading modes.

The wind load significantly affects the tree falling time. If the wind load direction is the same as the tree felling direction, the falling time becomes 0.8 s shorter; however, the loading oscillation amplitude grows. The maximum response in the tilting hinge does not exceed the force arising as a result of preloading. If the tree is felled upwind, with the wind speed higher than 9.5 m/s, the tree falls downwind; if the wind speed is 8.5 m/s … 9.5 m/s, and the stand density is 0.85, the tree hangs.

See Fig. 5 for the plots describing how the external force parameters affect the tree falling process and the resulting forces in the harvester head's tilting hinge. The tree falling process, with all external forces taken into consideration, demonstrates easily observable interval in which the tree crowns interact, resulting in reduction of inertial forces and dynamic responses. The maximum force (F_Z) arising when the crown interacts with the ground is 9542.3 N; this is the case if the downwind tree falling process is considered, neglecting the interactions with the crowns of standing trees and air environment.

The felling process time becomes 0.1 s longer as a result of the air environment effect, and 0.2 s longer as a result of interactions with tree crowns. The wind load results in the process time reduction by 0.6 s if its direction is the same as that of felling.

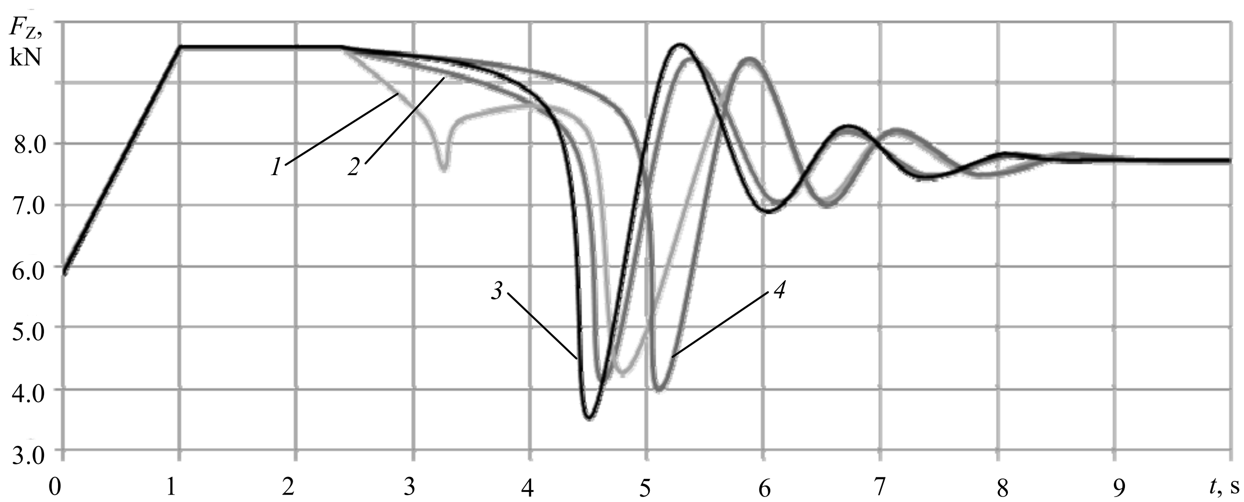

Fig. 5. Force (F_Z) in the shear-and-grapple unit's tilting hinge for the average stem volume 0.27 m^3 and the wind speed 10.0 m/s, downwind felling:
1 – all available forces considered; *2* – interaction with crowns of trees not considered;
3 – interaction with crowns of trees and air environment resistance forces not considered;
4 – all forces resisting the tree falling not considered

The analysis of plots (see Fig. 3–5) demonstrates that, with regard to the tree falling process dynamics, the crown interaction is the least significant factor affecting the vertical component of the response in the hinge (F_Z); this factor, if considered, reduces the process dynamics down to 3.1%. As a result of air environment effects, the oscillation amplitude is reduced by 2.6…17.7%. Among all external force factors considered, the wind load is the most significant factor affecting the horizontal component of the response in the harvester head's tilting hinge (F_Y). For the stem volume 0.27 m^3, this force is as high as 289.4 N.

When the critical loading mode is analyzed for the manipulator-type harvester's process equipment and carrier vehicle, the wind load magnitude and direction shall be taken into consideration; this load varies parabolically as a function of the wind speed. For the purposes of assessment of harvester's service properties, the wind speed is assumed to be 10 m/s [5]; in such a case, the wind load is 128 N for a forest stand with the stem volume 0.1 m^3; 215 N, for 0.21 m^3; and 290 N, for 0.27 m^3. Because the height at which this force is applied is 0.80…0.87 of the tree height, the resulting moment of force contributes to overcoming the resistances resulting from interaction between crowns and reduces the risk of tree hanging when the stand density is 1.00 and the wind direction is the same as that of felling. If these directions are opposite, the risk of tree falling downwind exists.

Conclusion. The tree felling process consists of several operations and techniques, and their interaction must be considered within the set of factors inherent to the process. When the feller-type machines are operated at the intermediate fellings, necessity appears to consider the forces resulting from interaction between crowns, wind loads and air environment. Consideration of these forces results in variation of responses arising in the tilting hinge of the shear-and-grapple unit within 17.7%. These forces reach their maximum when the preloads are set; for trees with the average stem volume 0.10 m^3, 0.21 m^3 and 0.27 m^3, these forces are 7.43 kN, 8.81 kN and 9.56 kN respectively.

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