

# Elaboration of the Methodology for Calculating the Brush Cutter with Passive Operating Element

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**Abstract** – The physical process of interaction of the working member of the brush cutter with trees located on the path of the machine movement is considered. In the development of existing ideas set out in the textbooks, the method for calculating brush cutters with a passive working body is refined, based on a detailed analysis of the acting forces. Recommendations for the calculation and selection of the parameters of the working member of the brush cutter are presented. Dedicated to the memory of our mentors and outstanding scholars, Nikolai Iakovlevich Kharkhuta (Leningrad Polytechnic Institute named after M.I. Kalinin) and Konstantin Aleksandrovich Artemiev (Siberian State Automobile and Highway University), who made significant contributions to development of a theory of interaction between working attachments of construction and road machinery and treated environment.

**Keywords** – brush cutter, working body, calculation technique, recommendations.

## I. INTRODUCTION

Every year the structure and fleet of machinery used in construction are made more complex by means of introduction of more and more efficient machinery, which is usually provided with new types of working attachments. Machinery for preparatory works, such as brushcutters, is involved in the process to the full extent. Active equipment with moving elements of working attachments in the form of milling cutters, circular saw blades, inertial saws, etc. find ever wider application in brushcutters.

Nevertheless, brushcutters with a passive working attachment (Fig. 1), are still being manufactured and developed, as their simple design provides high efficiency in clearing construction sites of shrub and brushwood [1].



Fig. 1. General view of a brushcutter on the base of a T-10M tractor

Older models of this type are still operated and form a part of fleet of many industrial enterprises.

Brushcutting equipment consists of a tapered bull blade and a link-motion system of its attachment to a towing vehicle (Fig. 2).

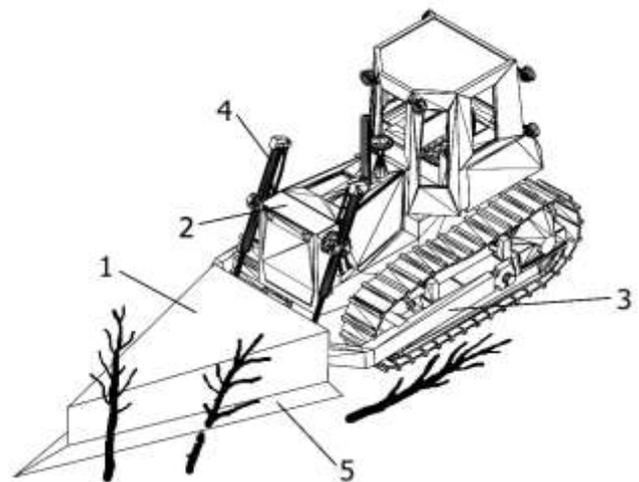


Fig. 2. Structure diagram and operation of a brushcutter

The working attachment (1) usually consists of two bull blade surfaces manufactured in a form of a symmetrical wedge. It is hanged up onto a base vehicle (2) by means of a pushing frame (3), which is positioned with hydraulic cylinders (4). The lower parts of the tapered bull blade surface are provided with a straight or saw-toothed cutting edge (5) on both sides.

The physical process of interaction between the working attachment and trees standing on the machine's route was analyzed and presented in textbooks [2, 3], which are widely known in Russian universities and which serve as a source of borrowing for more recent literature.

## II. STATE-OF-THE-ART AND ANALYSIS

In the textbooks, the loads acting upon a tree trunk on a contact with a cutting working attachment are determined by decomposing the propulsive force ( $T$ ) of the tractor (Fig. 3a) into two components – a force ( $N$ ) normal to the cutting edge and a force ( $P_p$ ), directed along the cutting edge. The first ( $N$ ) provides cutter's embedding into the tree and a possible spalling, while the second ( $P_p$ ) overcomes the friction force between the cutter and the trunk ( $F$ ).

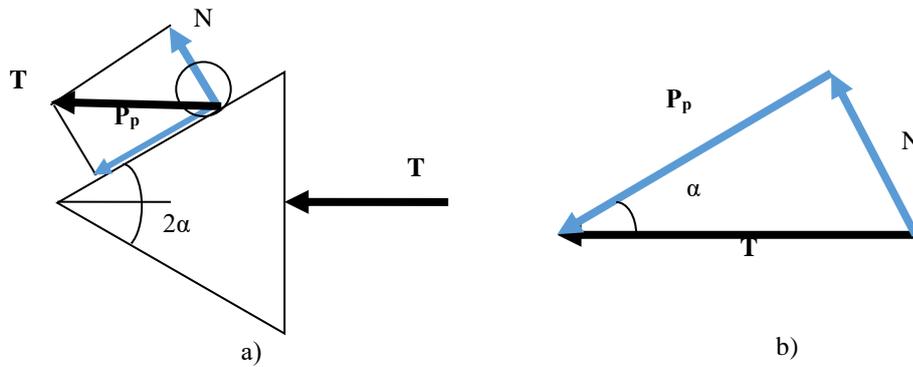


Fig. 3. A diagram of forces acting upon the working attachment, as proposed in textbooks

Under such approach (Fig. 3b), the value of the force (N) is equal to

$$N = T \cdot \sin \alpha, \tag{1}$$

where  $\alpha$  is a half-angle of the knife installation in plan view.

In its own turn, the friction force is

$$F = Pp = T \cdot \sin \alpha \cdot \mu, \tag{2}$$

where  $\mu$  is a friction coefficient between the cutter and timber, which is held as being equal to 0.25.

While it seems geometrically correct, such a decomposition, however, does not reflect the physical nature of the process.

In particular, from the obtained function (1) it follows that the force (N) increases with increased angle ( $\alpha$ ) and achieves the maximum value equal to the propulsive force (T) at  $\alpha=90^\circ$ , that is, when cutting with the bull blade.

However, such a result of the decomposition is in contradiction with the principle of operation of a triangle in plan view (tapered cutter), for which the force (N) is increasing then the angle ( $\alpha$ ) is decreasing and not when it is increasing.

Besides, a seemingly logical conclusion is made that the force acting along the blade ( $P_p$ ) shall be larger than the

friction force (F). Consequently,  $T \cdot \cos \alpha \cdot \mu \geq T \cdot \sin \alpha \cdot \mu$ , resulting in a function  $\text{ctg } \alpha \geq \mu$ .

However, substituting  $\mu=0.25$  we get the angle ( $\alpha$ ) of over  $76^\circ$ , and, thus, the total angle of the brushcutter knife ( $2\alpha$ ) shall be over  $152^\circ$  in plan view, which does not reflect the geometric parameters of real-life brushcutters.

In order to understand the actual nature of the physical process and remove the above mentioned contradictions, we shall consider an equilibrium state of the working attachments for various loading cases analyzing all the forces acting upon it.

For that purpose, as well as to simplify understanding, initially it was proposed that the working attachment contacts with identical tree trunks located symmetrically on both sides. At that, it was assumed that the trees have a provisional possibility of rotation around the vertical axis in the contact location between the cutter and the trunk, and thus, friction forces may be disregarded (Fig.4a).

Then, if the working attachment is in equilibrium, the sum of projections of all the forces applied to it and forces acting on the axis of the propulsive force (T) is equal to zero (Fig. 4b).

Thus,

$$T = N_1 \cdot \sin \alpha + N_2 \cdot \sin \alpha.$$

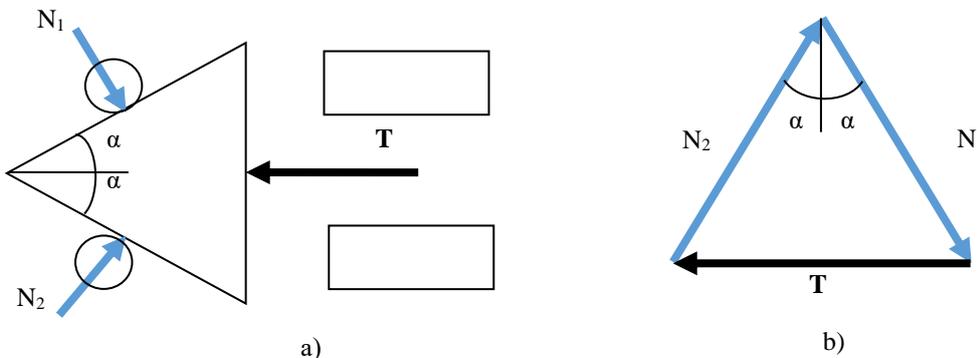


Fig. 4. Force diagram for two-sided cutting

And as from the initial conditions the normal reactions are equal, their values are

$$N_1 = N_2 = \frac{T}{2 \cdot \sin \alpha} \quad (3)$$

It is becoming evident that the value of normal forces ( $N_1$ ) and ( $N_2$ ) decreases with an increase in the angle ( $\alpha$ ). When it increases to  $\alpha = \frac{\pi}{2}$ , (that is, to cutting with the bull blade) their sum reaches the minimal value equal to the propulsive force ( $T$ ).

With such an approach, it is evident that the working attachment of the brushcutter acts as a normal wedge and decreasing the angle ( $\alpha$ ) leads to an increase in the normal forces ( $N_1$  and  $N_2$ ).

If, using the same assumption, the cutting with the tapered knife will be single-sided, then, to provide static equilibrium, it is necessary to supplement the diagram with a restraining force ( $P_r$ ) that reflects the connection between the propulsor and the ground and prevents dislocation of the working attachment together with the propulsor around the vertical axis that passes through the center of gravity (Fig. 5a).

The value of this force is limited by the value of

$$P_{y\alpha} \leq \frac{M_{y\alpha}}{R}$$

where  $R$  is the force's arm with respect to the tractor's C.O.G.

The moment of the traction force between the tractor's tracks and the ground ( $M_{y\alpha}$ ) is determined with a function

$$M_{y\alpha} = \frac{1}{2} G \cdot f_c \cdot L$$

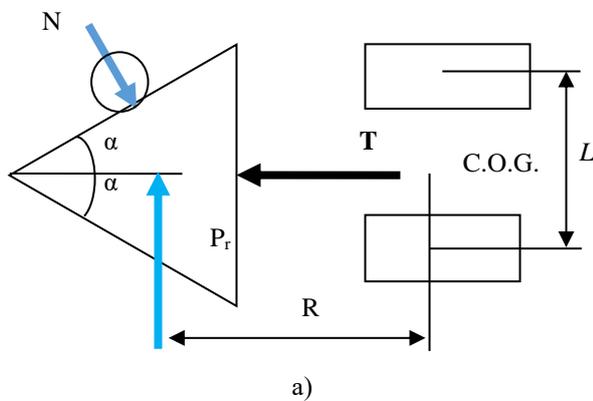
where  $G$  is a weight of the tractor;

$f_c$  is the traction coefficient between the tracks and the ground;

$L$  is the track gauge.

From the equilibrium of forces (Fig. 5A) acting upon the working attachment

$$N = \frac{T}{\sin \alpha}$$



Thus, in the case of single-sided cutting as well we may see that the normal force ( $N$ ) increases when the angle ( $\alpha$ ) decreases.

In actual practice, the equilibrium state shall naturally take into account the friction forces appearing from the moment of embedding the knife into a tree trunk.

For the two-sided cutting case (Fig. 6a) after projecting all the forces that act upon the working attachment onto the propulsive force axis (Fig. 6b) and taking friction into account, the equilibrium state becomes expressed with the function

$$T = N_1 \cdot \sin \alpha + N_1 \cdot \mu \cdot \cos \alpha + N_2 \cdot \sin \alpha + N_2 \cdot \mu \cdot \cos \alpha.$$

Taking the symmetric nature of the load into account, one may get

$$N_1 = N_2 = \frac{T}{2 \cdot (\sin \alpha + \mu \cdot \cos \alpha)} \quad (4)$$

In the case of single-sided cutting (Fig. 7a), in order to provide static equilibrium, the diagram shall be supplemented with the force ( $P_r$ ) that reflects connection between the propulsor and the ground.

Equilibrium of the forces acting upon the cutter is geometrically expressed as a polygon (Fig. 7b).

The cutting force is determined from the polygon as

$$N = \frac{T}{\sin \alpha + \mu \cdot \cos \alpha} \quad (5)$$

Thus, when cutting with the bull blade ( $\alpha=90^\circ$ ), the cutting force ( $N$ ) is equal to the propulsive force ( $T$ ). When the angle is decreased, this force starts increasing. The calculations show that, for example, when  $\alpha=30^\circ$  ( $\mu=0.25$ ) the cutting force attains the value 30 % higher than the propulsive force of the base machinery. It is evident, that increase in the force ( $N$ ) is limited by traction between the tractor's propulsion device and the ground.

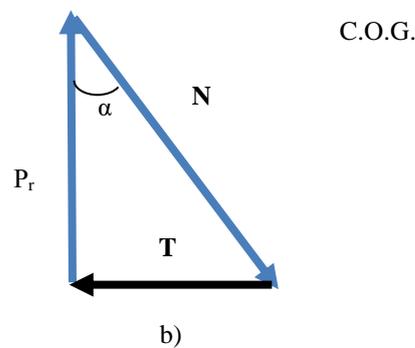


Fig. 5. Force diagram for one-sided cutting disregarding friction

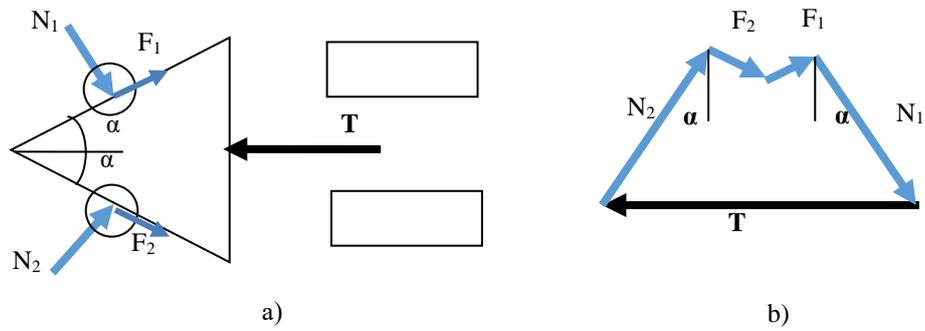


Fig. 6. Force diagram for two-sided symmetric cutting accounting for friction

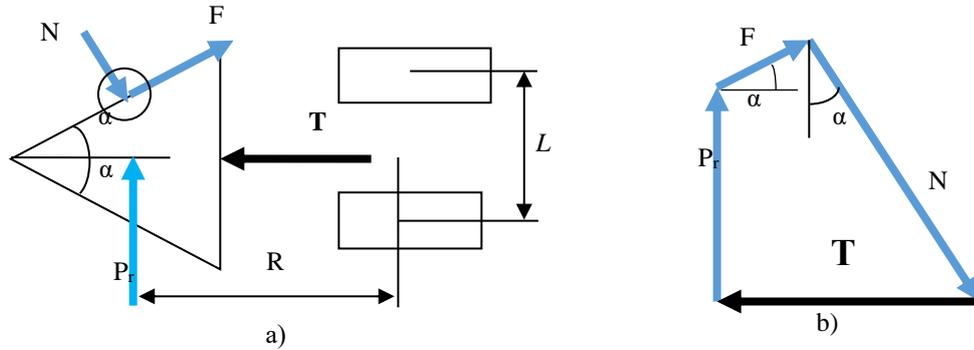


Fig. 7. Force diagram for one-sided cutting accounting for friction

### III. CONCLUSIONS AND RECOMMENDATIONS

From the analysis of the physical interactions of a brushcutter provided with a passive working attachment (a triangular in plan breast), it may be stated that the force ( $N$ ), normal to the cutting edge of the knife and providing the cutting of a trunk is not limited to the propulsive force ( $T$ ), but rather increases with reduction in the angle of knife installation in plan view ( $2\alpha$ ).

Design of the working attachment shall take into account that increase in the cutting force is limited by possible traction of the tractor's propulsion device and the ground during the one-sided cutting.

It is not practical to aim at a significantly increased cutting force during the design of the working attachment, as it may lead to impractical increase in its dimensions (resulting in increased metal consumption and impeded maneuverability). Recommended value of the total angle ( $2\alpha$ ) for knife installation is  $60^{\circ}$ - $65^{\circ}$  in plan view.

The results of analyzing the physical process of interaction between the working attachment and the treated environment are intended to be used by scientific and engineering personnel involved in studying and designing construction machinery.

The refinement of the calculation method for the brushcutter is practical and it is of principal nature in teaching specialists to correctly understand the physical meaning of the working process.

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