Adaptive and energy-efficient solutions in modern bulldozer blade designs

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ABSTRACT

The current trends in the development of bulldozer blades with an emphasis on their adaptability and energy efficiency are analyzed in the paper. The transition from traditional straight and spherical to transformed and specialized blades with expanders, two-blade and disk sections is considered. An overview of blade designs (PAT/VPAT, Σ-type, SU-blades) is presented with the comparative assessment of performance, capacity and energy consumption. The calculated assessment of the blade geometry influence on the volume of the soil drag prism and the technical performance of the bulldozer is performed. It is shown that the use of adaptive and energy-efficient blades allows to increase bulldozer performance by 20–40%, reduce specific fuel consumption by up to 15% and expand the versatility of use in various conditions.

Keywords: bulldozer, blade, design, energy efficiency, adaptability, performance, earthworks, soil.

1. INTRODUCTION

Modern trends in transport construction and the mining industry determine increased requirements for the efficiency of earthworks. Bulldozers, as universal earth-moving machines, remain the basic equipment in the development, movement and planning of soils. At the same time, their performance and efficiency largely depend on the design characteristics of the working element – the blade. Traditional straight and spherical bulldozer blades, which have been widely used for decades, today no longer fully meet modern requirements for energy efficiency, versatility and adaptation to various engineering and geological conditions.

The development of adaptive and energy-efficient solutions for bulldozer blades is becoming the priority area of mechanical engineering in the context of rising energy costs, global challenges of sustainable development and the need to reduce harmful emissions. Of particular importance is the increase in technical performance while simultaneously to reduce specific fuel consumption, to ensure the ability to work in limited conditions of construction sites, as well as the integration of modern automated control systems [1–3].

Therefore, the study of trends in the development of blade designs, the analysis of innovative foreign solutions, and the assessment of their energy efficiency are urgent tasks.

2. DEVELOPMENT TRENDS OF BULLDOZER BLADES

Several key directions of development of bulldozer blade designs can be traced in modern mechanical engineering. Foremost, this is an increase in versatility – the transition from highly specialized blades (straight, hemispherical, spherical) to multifunctional designs with the possibility of changing the geometry (PAT, VPAT). Such solutions allow for both rough movement of large soil volumes and precise surface planning without the need to replace working equipment.

An important trend is energy efficiency, which is achieved by to optimize the profile of the blade front surface, to reduce soil resistance forces, to use high-quality wear-resistant steels and new composite materials. This allows you to reduce specific fuel consumption by up to 10–15%.

The third direction of development is digitalization and automation. Leading foreign equipment uses integrated GPS navigation systems and automatic control of the blade inclination angle. This allows to minimize soil loss, to ensure high profiling accuracy (up to ±2 cm) and to reduce the impact of the human factor [2, 4].

It is worth noting the trend towards environmental friendliness and sustainability: manufacturers are striving to reduce the environmental footprint of machine operation by to introduce adaptive traction control systems, to reduce vibration loads and use highly efficient hydraulic drives [5]. As a result, modern blades are becoming not only the performance working element, but also the part of the overall construction process management system.

The analysis of information provided in open sources shows that leading manufacturing companies (Caterpillar, Komatsu, John Deere, Liebherr) are actively to introduce new types of bulldozer blades with increased functionality (Table 1).

Among the most common options are next.

PAT (Power Angle Tilt) and VPAT (Variable Power Angle Tilt) blades – versatile multi-position blades that allow you to change the angle of tilt and rotation directly during operation. This ensures high performance both when to move soil over long distances and when to perform grading work.

U-blade (Universal blade) – the large-sized bulldozer blade with curved sidewalls that allows you to move large volumes of soil over long distances. It is used mainly in mining and large-scale earthworks.

SU-blade (Semi-Universal blade) – the intermediate option between the straight and spherical blade, combining high performance with relative versatility. This type is used in road construction for to form embankments and planning slopes.

Sigma-blade (Σ-blade) – the innovative design from Komatsu with the special profile in the form of the letter Σ. This blade provides the 10–15% reduction in soil resistance and uniform load distribution, which contributes to fuel economy.

DSAB (Disc Spherical Adaptive Blade) – the adaptive and energy-efficient type of blade to new generation, which is currently being actively researched by global manufacturers of bulldozer equipment. Structurally, it consists of the central blade part and side disk sections that rotate, to provide the effect of the soil «oblique cutting». This scheme allows reducing the resistance to soil move and increase the machine performance.

Table 1: Main technical characteristics of modern bulldozer blade designs

Blade type	Main purpose	Planning accuracy, cm	Performance, m^3/h	Specific fuel consumption, l/m^3	Design features
Straight (S-blade)	Planning, development of dense soils	±3.0	300–450	0.055–0.060	Simple profile, high reliability
U-blade	Moving large volumes of soil over the distance	±4.5	500–700	0.060–0.065	Large side wings, high capacity
SU-blade	Embankments, slope formation, universal works	±3.5	400–600	0.050–0.058	Compromise between S and U blade types
PAT blade	Precise profiling, universal application	±2.0	350–550	0.048–0.055	Tilt and swivel angle are hydraulically adjustable
VPAT blade	Planning complex surfaces, work in limited conditions	±1.5	320–520	0.045–0.052	Variable blade geometry, GPS integration
Σ-blade	Quarry work, reducing energy consumption	±2.5	480–650	0.042–0.050	Special Σ profile, reducing soil resistance
DSAB	Adaptive cutting, increased energy efficiency	±2.0	450–650	0.040–0.048	«Rolling prism» effect, reducing soil resistance
Special	Snow, coal, forest areas	±5.0	250–400	0.050–0.060	Increased height or profile for the material

Laboratory studies have shown an increase in bulldozer performance by 30–50% compared to the straight blade and up to 34% compared to the spherical blade [1].

Special bulldozer blades – to clean forest areas, move coal or loose materials, as well as snow blades with increased height.

The use of modern bulldozer blade designs in combination with electronic control systems allows to significantly increase efficiency of machines in various operating conditions (Fig. 1). For example, the introduction of VPAT blades in the USA road construction ensured the reduction in the duration of earthworks by 12–18%. The use of blades in quarrying works in Japan allowed to reduce fuel consumption by an average of 8%.

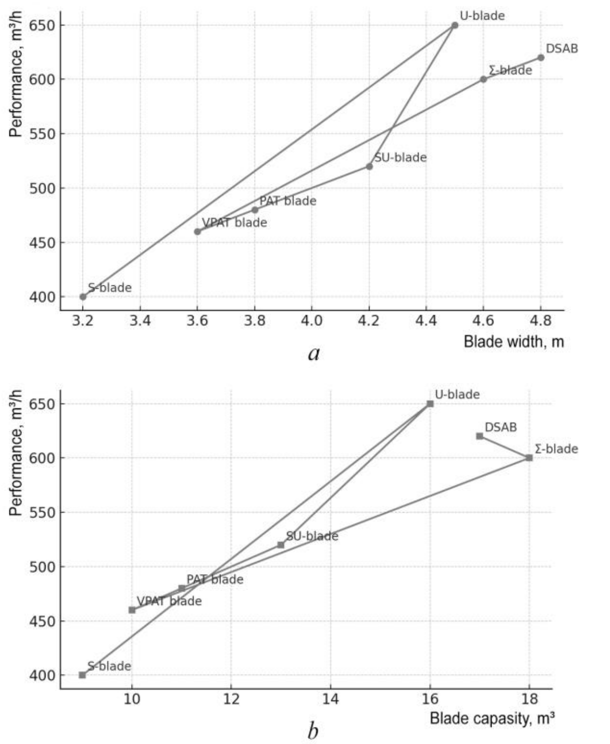

Figure 1. Dependences of bulldozer performance on the blade width (*a*) and capacity (*b*)

Modern bulldozer blade designs are the integration example of mechanical introduction, materials science innovations, and digital technologies, which together form the new paradigm of energy efficiency in transport construction.

3. CONCLUSIONS

The promising direction is the widespread introduction of adaptive and energy-efficient blades into construction practice to reduce fuel consumption, increase bulldozer performance and versatility. Thus, the use of modern bulldozer blade designs confirms the effectiveness of variable blade geometry in different soil conditions.

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