

THEORETICAL INVESTIGATION OF A DEVICE FOR FORMING A TUNNEL IN A SEED-COTTON BUNT

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Annotation. This article presents a theoretical investigation and design improvement of a device for forming an air-ventilation tunnel inside seed-cotton bunts to enable safe storage of high-moisture cotton. The proposed template-type former is installed during piling, allows uniform distribution and compaction, and is later extracted mechanically. The analysis considers plastic and elastic deformation of bulk cotton, including effects of bulk density, internal friction, cohesion, and shear resistance. Key parameters—especially tunnel cross-section—are optimized; the width is adjustable within 300–600 mm to minimize plastic deformation, enhance airflow, reduce self-heating risk, cut manual labor, and preserve fiber quality.

Keywords: seed cotton; storage; ventilation tunnel; cotton bunt (pile); bulk density; plastic deformation; elastic deformation; internal friction; shear resistance; cohesion; compaction; airflow; moisture content; self-heating mitigation; template former; tunnel geometry coefficient; mechanized extraction; process optimization; pre-cleaning/pretreatment; fiber quality preservation; ginning logistics.

In our republic, the broad rollout of cotton–textile clusters and the focus on producing high value-added finished goods impose stringent requirements on the quality of fiber produced by ginning enterprises. This, in turn, depends on proper storage of seed cotton. At procurement points and ginning facilities, seed cotton is received and stored separately by breeding and industrial grades, as well as by harvesting method. The stacking of cotton piles, their storage, and subsequent processing are carried out separately for each farm in accordance with the Instruction on the Harvesting and Procurement of Cotton, taking into account the fiber type and its quality indicators [1].

In the primary processing of cotton, one of the most important factors is the proper storage of high-moisture seed cotton. Since, in practice, neither sun-drying of raw material with high moisture, trash, and green plant matter is used at procurement points and ginning enterprises, nor are alternative pre-cleaners available for its preliminary cleaning, ginning mills are compelled to accept raw cotton with elevated levels of moisture and green impurities. Under the regulations, the reception of seed cotton with moisture content up to 22% is permitted [2].

However, for piling seed cotton into bunts (windrows), a moisture limit of 14% has been established; storing cotton with higher moisture is not recommended by the process regulations, which require its immediate drying and processing. At the same time, the share of such raw material in total procurement is 6–7%, and at some ginning enterprises it reaches 15–20%, indicating that immediate processing is not always possible.

Currently, at procurement points and ginning plants, seed cotton is received and stored separately by breeding and industrial grades, as well as by harvesting method. For better and longer-term storage—and for proper organization of long-term storage—cotton should be stacked differentially with regard to its moisture content. Cotton with moisture up to 14%

should be placed in the area of the cleaning department, while cotton with moisture of 14% and above should be placed in the area of the drying-cleaning shop. Cotton with moisture exceeding 20% must be stacked in locations closer to the drying-cleaning shop, since it needs to be dried and processed promptly [3].

When high-moisture, grade IV seed cotton is piled into bunts, self-heating begins after 2–3 days. When the height of bunts composed of high-moisture grade IV and V cotton reaches 3.5–4.0 m, ventilation must be provided as quickly as possible.

At present, due to insufficient availability of tunnel-forming equipment and the mismatch of existing mechanisms with production requirements, tunnels at most ginneries are excavated by heavy manual labor. Because of high energy and resource demands, as well as shortages of components, the operations of evenly distributing cotton across bunt pads, compacting it, and forming ventilation tunnels are performed predominantly by hand [4].

Therefore, the task is to reduce manual labor and improve the tunnel-formation process during cotton piling (bunt formation).

For this purpose, a device has been developed to form an air tunnel inside a cotton bunt. The device is made as a forming template: it is installed at a specified location on the bunt pad, then seed cotton is fed into the bunt by mechanized means, evenly distributed over the surface, and compacted. After the bunt is fully formed, the overall dimensions of the template are reduced using a drive mechanism, after which it is extracted from inside the bunt by a tractor.

The template's drive mechanisms are simple, the likelihood of failures during operation is low, and its practical use is convenient.

As part of solving this task, the tunnel-forming device was improved. This made it possible to pile cotton of various moisture contents. The proposed tunnel-forming device has been modernized [5].

A drawing of the new device for forming an air tunnel in a cotton bunt is shown in Figure 1.

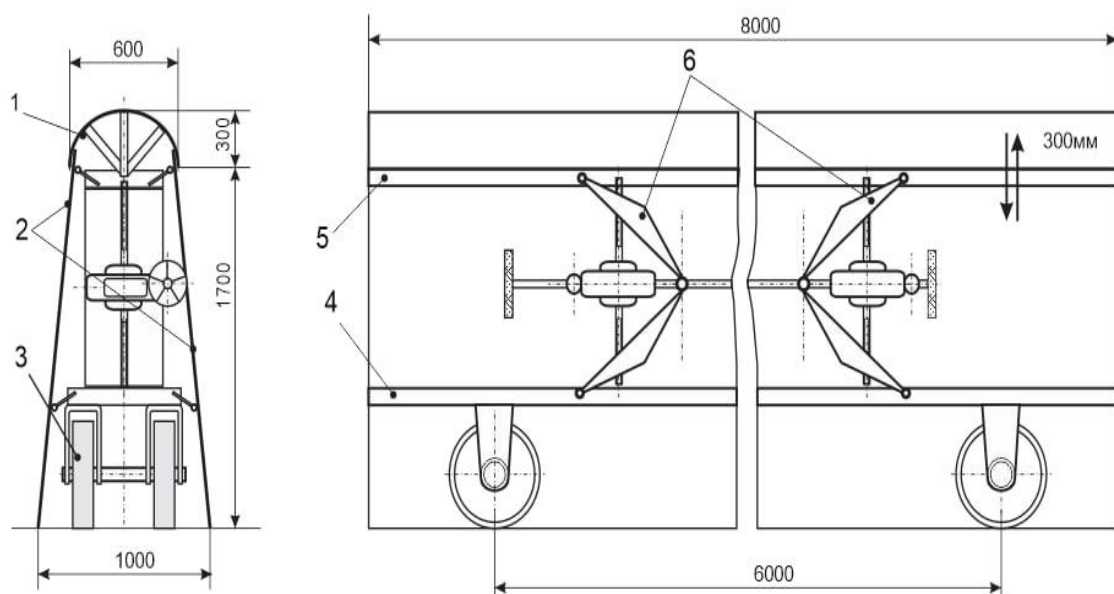


Figure 1. Mobile tunnel former.

1 - arched cover; 2 - side guards; 3 - wheels; 4, 5 - upper and lower base;

6 - lifting mechanism.

As is known, raw cotton undergoes plastic and elastic deformations. Plastic deformation arises primarily due to the alignment of particles in the loosened bulk. When, in the course of compression, the possibilities for alignment and plastic displacement are exhausted, the deformed cotton mass, owing to the elastic forces that emerge, develops the ability to resist external loads [6].

At the same time, the compacted cotton mass can retain its shape and therefore exhibits properties of a solid material. A deformable body can be considered sufficiently strong if, under external forces, it undergoes elastic deformations while plastic deformations are practically absent [7].

The key prerequisite for conducting experimental studies to select the optimal parameters of a device that forms a tunnel in a cotton bunt is that the cotton possess physico-mechanical properties whereby, being a weakly bending bulk material, it tends to freely take shape and, when compacted, can assume any stable form. According to the literature, the mobility of raw cotton depends on internal friction forces and cohesion between its clumps [8].

Functionally, this property is characterized by the following types of phenomena:

$$\tau = g * tg\varphi * c$$

τ - tension, N/cm²;

g - specific pressure, N/cm³;

$tg\varphi$ - coefficient of internal friction:

c - shear strength.

The formed cotton bunt together with the tunnel created inside it can be regarded as a deformable body. The transition of a deformable body from one volumetric state to another primarily depends on the mass (bulk) density of the raw cotton. According to the literature, to describe the state of this mass during deformation—both in loosened and compacted conditions—a set of special concepts is recommended [9].

For this purpose, the following terms are introduced:

Longitudinal relative deformation E ,

$$E = \frac{\Delta h}{h_n}$$

Δh - compressive stress, mm

h_n - initial pile height, mm

Modulus of deformation E equals

$$E = \frac{q}{\varepsilon}, \text{ N/sm}^2$$

q - Contact pressure on the surface under compression

transverse (lateral) strain, ε_0

$$\varepsilon_0 = \frac{\Delta b}{b_n}$$

Δb - expansion strain, mm.

b_n - initial width of the mass, mm

In the course of improving the tunnel-forming device, the elastic deformation of the seed-cotton mass within the bunt was examined. However, preliminary studies showed that the principal factor that precisely determines the overall dimensions of the tunnel former is the area of its cross-section, while its general parameters depend on the magnitude of plastic deformation of the laid cotton masses [10].

In this regard, it is first proposed to study the longitudinal component of plastic deformation and the relative share of its transverse components.

$$\varepsilon_p = \frac{\Delta H}{H_h}$$

$$\varepsilon_{pn} = \frac{\Delta B}{B}$$

here ε_p - is the relative longitudinal component of plastic deformation:

ε_{pn} - relative transverse component of plastic strain;

ΔH - longitudinal plastic shear deformation;

H_h - initial height of the laid cotton (at the initial moment equal to the height of the tunnel-forming device/tunnel former);

ΔB - transverse plastic shear deformation;

B - initial width of the laid cotton mass (at the initial moment equal to the width of the tunnel-forming device/tunnel former).

For our cases, the magnitude of plastic deformation is a function of several parameters.

$$\varepsilon_n = f(\gamma; W; B; t; Q; K)$$

here, γ - mass (bulk) density of cotton, kg/m³;

W - moisture content of cotton, %;

B - width of the cavity, initially equal to the width of the tunnel-forming device, mm;

t - residence time of the tunnel-forming device in the cotton stack (bunt)—from the start of cotton laying to the moment the tunnel template is removed, h;

Q - pressure of the cotton mass on the tunnel former, N;

K - coefficient accounting for the geometric shape of the tunnel in the stack.

In this case, the parameters are K and γ , B , t , with the latter taken into account only within certain limits. Thus, the bulk density γ depends on the magnitude and frequency of the applied load.

As a conclusion: the width of the tunnel former can be varied on both sides within 300–600 mm—either decreased or increased. This regulates the required geometric dimensions of the tunnel and ensures the most effective aeration of the cotton stack.

Given the multifactor dependence of plastic deformation, in experiments to determine the optimal parameters of the tunnel former, it is proposed to minimize its magnitude by varying the adjustable parameters within specified ranges. Ideally, the value of plastic deformation is to be brought as close to zero as possible.

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