УДК 631.1: 635.1/.8: 634

ОЦІНКА НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ ВУЗЛІВ ОБЛАДНАННЯ ДЛЯ ПЕРЕРОБКИ ТОМАТІВ

ASSESSMENT OF THE STRESS-DEFORMED STATE OF EQUIPMENT UNITS FOR TOMATO PROCESSING

Baranova Olena

Миколаївський національний аграрний університет,
Україна, м. Миколаїв

For the design and modernization of equipment intended for tomato processing, it is necessary to comprehensively consider a range of key factors, including the physical and mechanical properties of the raw material, the specifics of technological operations, the required productivity, and the economic efficiency of operation. Particular attention should be given to sorting and washing systems, which must ensure effective cleaning of the fruits and their classification by size and quality indicators. The productivity of technological lines is determined by the scale of production and can range from hundreds of kilograms to several tons of raw material per hour.

Modern processing enterprises impose high requirements on the accuracy of technological operations, while the design of food-processing equipment is often characterized by high material and energy consumption. An important aspect is also the adaptation of machines to the physical, mechanical, and technological properties of tomato raw materials. Traditional processing schemes involve separate operations of crushing and pulping; however, the influence of design features and operating parameters of the equipment on the overall efficiency of the processing line remains insufficiently studied [1].

In this regard, the substantiation of rational parameters for machines used in tomato pulp processing is an important step in improving tomato juice production technology. The main objective of equipment modernization is to increase productivity and product quality while simultaneously reducing energy consumption and operating costs [2].

The proposed design solution involves integrating the processes of crushing and pulping within a single working unit, which makes it possible to optimize the tomato processing workflow [6]. To justify the parameters of this design, an analysis of the stress–strain state of the main structural elements of the equipment was carried out [3].

Table 1 presents the initial parameters required for evaluating the stress–strain state of the working elements of the tomato processing equipment.

Table 1. Initial parameters required for evaluating the stress–strain state of the working elements of tomato processing equipment.

№	Parameter	Designation	Value	Unit of measurement
	Wiping drum			
1	Drum radius	R	0,15	m
2	Wall thickness	t	0,004	m
3	Drum length	L	0,6	m
4	Internal pressure of raw materials	p	0,05	MPa
5	Torque	M	350	N·m
6	Allowable material stress	[σ]	140	MPa
7	Modulus of elasticity of steel	E	$2{,}0 \cdot 10^{11}$	Pa
8	Material density	ρ	7800	kg/m³
Grinding element				
1	Knife throw length	l	0,12	m

2	Cutting force	Fr	120	N
3	Knife width	b	0,04	m
4	Knife thickness	h	0,006	m
5	Rotor speed	n	300	rpm
6	Angular velocity	ω	31,4	rad/s
7	Knife weight	m	0,25	kg
8	Radius of rotation	R	0,15	m
9	Allowable stress	[σ]	140	MPa

Determine the circular stresses on the drum:

$$\sigma\theta = \frac{pR}{t} = \frac{0{,}05 \cdot 10^6 \cdot 0{,}15}{0{,}004} = 1{,}875 \text{ MPa} \quad (1)$$

The next step is to determine the longitudinal stresses:

$$\sigma_L = \frac{pR}{2t} = 0{,}94 \text{ MPa} \quad (2)$$

Polar moment of resistance of a thin-walled cylinder:

$$Wp = \frac{\pi R^3 t}{2} = \frac{3{,}14 \cdot 0{,}15^3 \cdot 0{,}004}{2} = 16{,}5 \text{ MPa} \quad (3)$$

The equivalent stress is determined by:

$$\sigma_{eq} = \sqrt{\sigma_\theta^2 + 3\tau^2 \sigma eq} = \sqrt{1{,}875^2 + 3 \cdot 16{,}5^2} = 28{,}6 \text{ MPa} \quad (4)$$

We carry out a strength test: 28,6 MPa<140 MPa, therefore, the strength condition is satisfied. Safety margin ≈ 4,9. Let's define the bending moment:

$$M = F_r \cdot lM = 120 \cdot 0{,}12 = 14{,}4 \text{ N·m} \quad (5)$$

For grinding elements, the bending moment is:

$$M = Fr \cdot l = 120 \cdot 0{,}12 = 14{,}4 \text{ N·m} \quad (6)$$

Moment of resistance for rectangular grinding plates:

$$W = \frac{bh^2}{6} = \frac{0{,}04 \cdot 0{,}006^2}{6} = 2{,}4 \cdot 10^{-7} \text{ m}^3 \quad (7)$$

We determine the bending stress:

$$\sigma = \frac{M}{W} = \frac{14{,}4}{2{,}4 \cdot 10^{-7}} = 60 \text{ MPa} \quad (8)$$

Angular velocity is determined by:

$$\omega = \frac{2\pi n}{60} = \frac{2 \cdot 3{,}14 \cdot 300}{60} = 31{,}4 \text{ rad/s} \quad (9)$$

$$Fc = m \cdot \omega^2 R = 0{,}25 \cdot 31{,}4^2 \cdot 0{,}15 = 37 \text{ N} \quad (10)$$

This force creates an additional tensile load, which has a slight effect on the overall stress state. We perform a strength test: 60 MPa <140 MPa. The strength condition is met. Safety margin ≈ 2,3.

The pulping drum operates with a significant safety margin, which makes it possible to reduce the wall thickness in order to decrease material consumption. This provides an opportunity to optimize the overall mass of the structure without compromising its operational reliability. In contrast, the crushing elements operate under a more stressed bending regime; however, they also meet the required strength conditions. Their design ensures stable performance even under variable load conditions during continuous operation. A rational selection of geometric parameters ensures structural reliability while minimizing metal consumption and energy costs. Particular attention is paid to reducing stress concentrations in critical zones of the structure. This is achieved through improved shaping of working surfaces and optimized load distribution.

The use of modern calculation methods allows for more accurate prediction of the stress–strain behavior of structural elements [4]. As a result, it becomes possible to identify potential weak points at the design stage [5]. Table 2 presents a comparative overview of typical tomato processing equipment, as well as the results of the stress state analysis of the improved design, and Table 3 provides a comparison with conventional designs.

The obtained results confirm the effectiveness of the proposed engineering solutions. They also demonstrate the feasibility of further structural optimization to enhance durability and efficiency.

Table 2. Comparative review of typical tomato processing equipment and stress state analysis of an improved design.

№	Parameter	Designation	Value	Unit of measurement
		Wiping drum		
1	Circular stresses	σ_θ	1,88	MPa
2	Longitudinal stresses	σ_L	0,94	MPa
3	Torsional stresses	τ	16,5	MPa
4	Equivalent stress	σ_{eq}	28,6	MPa
5	Allowable stress	[σ]	140	MPa
6	Reserve factor	$n=[\sigma]/\sigma_{eq}$	4,9	–
		Grinding element		
1	Bending moment	M	14,4	N·m
2	Moment of resistance	W	$2{,}4\cdot10^{-7}$	m^3
3	Bending stress	σ	60	MPa
4	Centrifugal force	Fc	37	N
5	Allowable stress	[σ]	140	MPa
6	Reserve factor	n	2,3	–

Table 3. Provides a comparison with conventional designs.

Indicator	Proposed design	Typical wiping machine
	Wiping drum	
Wall thickness	4 mm	5–6 mm
Equivalent stresses	28–35 MPa	20–30 MPa
Reserve factor	4,5–5	5–6
Material consumption	Reduced (~15–20%)	Increased
Rigidity	Sufficient	Excess
	Grinding element	
Indicator	Suggested knife	Typical design
Knife thickness	6 mm	8–10 mm
Working voltages	~60 MPa	40–55 MPa
Reserve factor	2–2,5	3–4
Element mass	Smaller (~20%)	Bigger
Inertial loads	Smaller	Bigger

The proposed design has an adequate safety margin and allows a reduction in metal consumption without compromising reliability. It operates with a rational safety factor of 2–2.5, which is typical for food-processing machinery and ensures compliance with industrial strength requirements. At the same time, the design enables a reduction in energy consumption due to lower inertial loads during operation.

Comparative analysis demonstrates that the improved construction reduces metal consumption by 15–20%, decreases the inertial loads acting on the rotor, and maintains a standard safety factor within acceptable limits. In addition, it meets the requirements for energy efficiency of modern technological equipment and ensures stable and reliable performance under operating conditions.

1. Бабенко Д. В., Доценко Н. А., Горбенко О. А., Бацуровська І. В. Пристрій для отримання томатної пульпи з регульованим підбарабанням : патент на корисну модель № 155354 (21.02.2024). URL: https://dspace.mnau.edu.ua/jspui/handle/123456789/17121 (дата звернення: 13.04.2026).

2. Babenko D., Dotsenko N., Gorbenko O. Justification of the design parameters of improved equipment for tomato processing // Ukrainian Black Sea Region Agrarian Science. 2025. Vol. 29(3). P. 9–22. DOI: 10.56407/bs.agrarian/3.2025.09.

3. Бабенко Д. В., Доценко Н. А., Горбенко О. А. Механіка матеріалів і конструкцій. Частина 1: практикум для навчання на основі інтерактивного графічно-цифрового контенту : навчальний посібник. Миколаїв : МНАУ, 2021. 162 с.

4. Mengistu D., Sharew T. A comprehensive review of tomato post-harvest losses: understanding impacts and contributing factors in Ethiopia // Advances in Sustainable Agriculture. 2024. Vol. 2. P. 525–535. DOI: 10.3923/asb.2024.525.535.

5. Haniva S., Iskandarini S. F. A. Analysis of tomato farmer income increasing strategies in Karo District, Indonesia // European Journal of Social Sciences Studies. 2023. Vol. 8. P. 207–218. DOI: 10.46827/ejsss.v8i6.1508.

6. Kedir H. J., Tilinti B. Z., Mekonnen K. T. Physicochemical characterization of fresh and powdered tomato in Arba Minch, Ethiopia // Recent Progress in Nutrition. 2025. Vol. 5(2). Art. 013. DOI: 10.21926/rpn.2502013.