Development and research of the tower for hanging supports on hop-gardens

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Abstract. In recent years, in the conditions of economic sanctions and food embargo in Russia, the issue of import substitution has become acute. These phenomena are directly related to agricultural products and, in particular, to the production of hops. Currently, about 90% of commercial hops are imported to the Russian market from abroad. Current trends in the improvement of modern hop-growing technology require the introduction of high-tech innovations into the cultivation process. Its productivity and product quality depend on timely and proper technological operations in the production of hops. Accordingly, it is necessary to introduce improved low-cost technologies in the production of hops. The most important aspect at the present stage is the mechanization of such a process as hanging supports using mobile towers. The use of these towers can increase productivity in this operation in 5-6 times compared to manual labor. The tower must contain a horizontal frame with a trailed device, a working platform, hydraulic cylinders for its lifting, a system of guide rings for support beams. A small ladder should be provided for lifting workers to the site. As a result of the design, the optimal parameters of the scissor-type perspective tower were determined, providing the required stability, both static and dynamic.

1. Introduction
Hops belong to agricultural crops with a small volume of production – the world area of its plantations is more than 51 thousand hectares [1, 2]. Hop farming in Russia was, and in a number of European countries, a large and important branch of agricultural production. In the second half of the last century, in our country and abroad, there was a tendency of specialization in hop growing, enlarging the area under the main crops. In recent years, in the conditions of economic sanctions and food embargo in Russia, the issue of import substitution has become acute. These processes are directly related to agricultural products, and, in particular, to hops. Currently, about 90% of commercial hops are imported to the Russian market from abroad.

hop growing as a traditional branch of the Chuvash Republic [3 - 4].

Its productivity and product quality depend on timely and proper technological operations in the production of hops. Given the increasing prices of energy, it is necessary to introduce improved low-cost technologies in the production of hops.
The purpose of the research is to expand the areas of increasing the efficiency of the hop industry, the use of resource-saving low-cost technology of cultivation of hops, which involves the use of a set of technological measures. Among them, the most important at the present stage is the mechanization of such a process as hanging the supports with the help of mobile towers. The development of resource-saving technologies of cultivation, processing, and use of hops can reduce the cost of cultivation of hops by 30-35% [11 - 15].

2. Materials and methods
BH-4 towers and PPH-1 platforms are used for partially mechanized mounting of hops supports. But the towers for the garter of twine for trellis, designed and produced earlier, do not correspond to the dimensions established by the requirements of the Traffic Regulations of the Russian Federation in width. In practice, they do not correspond to the width and height of the entrance gates and bridges. This aspect severely limits its operation not only in a limited area of the farm but also during transportation.

The use of towers for hanging supports of hops allows increasing productivity in this operation in 2-3 times. The technological process of the tower is as follows. At the edge of the hop garden, workers fill tufts of supports into the guide rings of the tower. After that, a tractor with a tower enters the hop garden and, using a hydraulic cylinder, raises the site with the workers to the desired height. The workers pull out the ends of the supports from the beam and tie them to the upper longitudinal wire through 0.8 - 1 m. When the support unit moves, it is pulled out of the beam and sags on the trellis. Workers behind the tower, tie the lower ends of the supports to the string, stretched along the row.

Productivity per shift of a nine-person crew is 2-3 hectares, the number of longitudinal wires to which support is tied up for one pass of the unit is 4, and working cassettes for supports are 4. Height of raising of the working platform to 3.5 m. The tower is aggregated with tractors of 0.9-1.4 classes.

In this regard, the projected tower for hanging hops supports is assumed to be with adjustable gauge width: in the working position - up to 3.3 m, in the transport position - 2.5 m. The offset point of the trailer also has a significant impact on the stability of the movement of the tower [5].

Thus, when designing, it is necessary to fulfill the established regulatory requirements for carrying out calculations of the stability of mobile towers for hanging hop supports, for which correct consideration of dynamic loads is of great importance [6, 7].

The data to justify the parameters of the tower for hanging hops supports are determined by the size of the hop landing (Figure 1).

![Figure 1. The layout of the elements of the tower in the rows of hops](image-url)
The choice of the tower scheme is carried out according to four main criteria.
1. Ensuring the lateral stability of the tower for the comfortable and safe operation of personnel [8, 9].
2. The absence of hitting the support wheels of the tractor and the tower on the rows of hops.
3. Modernization, implementation of automated binding of the twine knot at a given step.
4. Calculation of the displacement of the trailer point of the tower to ensure maximum longitudinal stability [10].

In most cases, the tractor moves strictly in the center of the aisle, therefore, the technological gap is defined as

\[ b_u = b_m + 2\Delta b, \]  \hspace{1cm} (1)

where, \( b_u \) – row width of hops, m;
\( b_m \) – tractor track gauge, m;
\( \Delta b \) – the distance from the hop row to the nearest track of the tractor wheel, m.

Hence,

\[ \Delta b = \frac{b_u - b_m}{2} \]  \hspace{1cm} (2)

The technological gauge of the tower for hanging hops should be as close as possible to the width of the aisle, i.e. \( b_u = b_m \).

Calculation of the trailer point displacement relative to the center of the row spacing or the axis of symmetry of the tractor.

When designing a tower for hanging hops supports, we consider that the simplest and at the same time the ergonomic design is of scissor type.

Preliminary baseline data for design:
1) a 2-lever scheme has been adopted for reliability and stability, taking into account the specifics of work in the field;
2) the required maximum height of the scissor lift - \( H_n = 3.8 \) m;
3) the height of the platform (chassis) of the lift is selected taking into account the size of the support wheels, on which the dynamic stability of the structure \( h_n = 1.0 \) m depends;
4) the required angle of elevation of the levers \( \alpha = 45 \ldots 55^\circ \) from the analysis of the required factors and features of the work of the tower.

Calculation of the inertial forces arising during acceleration of the lift and during braking Acceleration (deceleration) is determined by the general formula

\[ a = \frac{v_p - v_0}{t_p}, \]  \hspace{1cm} (3)

where, \( v_0 \) - the initial speed of movement, m / s;
\( v_p \) - working speed, m / s;
\( t_p \) - acceleration time, s.

In the general case, the force acting on one person (average weight 75 kg) is determined according to 2nd laws of dynamics:

\[ F_l = m \cdot a \]  \hspace{1cm} (4)

Calculation of the length of the scissor lift arms.

For the initial data for the calculation of the geometrical parameters of the lift, we take the angle of the solution of the levers \( \alpha = 45 \ldots 55^\circ \), as well as the required height of the tower lift \( H_n = 3.5 \) m.

The geometric parameters of the levers are related to each other by the following relations (Figure 2):

\[ \sin \alpha = \frac{H_n/2}{L} = \frac{H_n}{2L} \]  \hspace{1cm} (5)
\[
\cos \alpha = \frac{L_H}{L} \\
\tan \alpha = \frac{H_{H/2}}{L_H} = \frac{H_H}{2L_H}
\]

(6) \hspace{2cm} (7)

Calculation of forces on the supports and levers of the scissor mechanism. Source data: personnel mass \( m_p = 225 \) kg; the mass of the cradle (basket) \( m_l = 100 \) kg; weight of the scissor mechanism \( m_n = 100 \) kg. The total mass of the lifting mechanism, platform (basket) and personnel \( m_\Sigma = m_p + m_l + m_n \)

The gravity falling on one lower support:

\[
F^H_Z = \frac{G_Z}{4} = \frac{m_\Sigma g}{4}.
\]

(8)

The gravity of the upper supports:

\[
F^B_Z = \frac{G_B}{4} = \frac{(m_n + m_l) g}{4}.
\]

(9)
Since during acceleration and deceleration, inertial forces arise that act on the lower and upper fixed supports, as well as creating an overturning moment, it is important to obtain their value at the design stage of the tower geometry.

3. Results and discussion
In the final calculations, according to (1) and (2), when the initial data is substituted, the distance from the hop row to the nearest tractor wheel track is \( \Delta b = 0.65 \) m.

The total width of \( b_{\text{total}} = 4.0 \) m, therefore, the center of displacement of the tower is located relative to the middle of the aisle. The center of the tractor is located at a distance of 1.61 m from the pole row. Consequently, the asymmetry of the tower relative to the axis of the tractor should be \( C = 0.6 \) m when using inter-row spacings on hop gardens 3.3 m.

To use the tower on the hop gardens with a row spacing of 2.5 m, no trailer point offset is required.

To take the initial data when determining the inertial forces when starting off, a series of measurements of the starting time of the tractor MTZ-82 was carried out, with which it was planned to aggregate the designed tower for hanging hop supports. For this, the total mass of the lifting mechanism, platform (basket) and personnel, which amounted to \( m_x = 425 \) kg, was approximately calculated by computer simulation.

Since it is planned to work on the 3rd gear with a reduction gear, the tractor speed is 7.4 m / s. In order to maximally approach the working conditions on the hop gardens with a tower, a trailer with a total weight of 450 kg was installed on the tractor.

The results of measuring the starting time of a tractor with a trailer are shown in Table 1.

| No of repetition | Starting time, s |
|------------------|-----------------|
| 1                | 3.0             |
| 2                | 2.7             |
| 3                | 2.1             |
| 4                | 2.9             |
| 5                | 1.0             |
| 6                | 2.6             |
| 7                | 3.2             |
| 8                | 2.5             |
| 9                | 3.2             |
| 10               | 1.5             |
| Average          | 2.47            |

At the same time, during the tests, no correlation was observed between the starting time and the field gradient.

Taking into account the starting from the state of rest when \( v_0 = 0 \) m / s and with the acceleration time value: \( t_p = 2.47 \) s. We obtain, using (3), the acceleration at the start of \( a = 0.4 \) m / s².

However, as it was revealed, with a sharp starting or braking time can reach \( t_p = 1.0 \) s. In this case, we obtain the acceleration value up to \( a = 0.4 \) m / s².

In the average statistical case, the inertia force acting on one person (average weight 75 kg) according to (4) is approximately equal to \( F_u = 30 \) N, and with a sudden start, its values increase to \( F_u = 75 \) N.

As a result of calculations of the geometry of the designed tower for hanging hops, the optimal combination of the solution angle \( \alpha \) and the lever length \( L \) was found according to (5), (6) and (7). The result is shown in figure 3.
Figure 3. Diagram of changes in the angle of solution α depending on the length of the lever L.

It can be seen from the diagram that the optimal geometry starts from the intersection of the solution angle curve and the lever length, which corresponds to $\alpha = 52^\circ$ and $L = 2.25$ m.

Thus, the longitudinal length of the grip in the raised (working) state with the maximum raised position is $L_n = 1.47$ m.

Choose a length of 2.25 m along the axis of the roller lever. Then, taking into account the substitution, we obtain the horizontal shortening value $\Delta L = 0.81$ m (Figure 2).

Taking into account the location of the axles of the roller axle, as well as the mode of operation of hydraulic cylinders, the length of the guide length cannot exceed 1 m, which is provided with a small margin.

With further substitution, using (8) and (9), we obtain the force of gravity per one lower support $F_z^H = 1042.3$ N, as well as the force of gravity per upper support $F_z^B = 797$ N.

These values should be considered when designing the height of the handrails and the width of the basket for staff.

4. Conclusion

The value of the overturning momentum rapidly increases with a multiple of the angle of inclination. In order to give the tower the best stability in the designed tower, wheels are provided with the ability to move them along the axis of rotation. In the transport position, the distance between them is determined by the maximum permissible dimensions of vehicles for movement on public roads, and in the working position, this distance increases. Taking into account the fact that the required maximum height of the scissor lift must reach $H_n = 3.8$ m with the length of the horizontal arm $L = 2.25$ m. The height of the platform (chassis) of the lift $H_n = 1.0$ m was chosen taking into account the size of the supporting wheels, on which the dynamic stability of the structure depends. The gauge size in the transport position on the middle line is 2.50 m, and in the working position - 3.30 m. Such chassis parameters provide the required stability, both static and dynamic.
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