The Shape of the Mixing Chamber of the Continuous Mixer

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Abstract--- Existing batch mixers for the preparation of wet feed mixtures are ineffective due to their low productivity and high energy intensity. The aim of the study is to substantiate the shape of the mixing chamber of a continuous mixer. The analysis of the influence of the shape of the mixing chamber on the technological process of mixing the feed mass. It was found that the presence of free space between the cover and the working body of the mixer provides a chaotic movement of feed particles after impact of the feed mass on the cover, thereby improving mixing conditions. The necessity of supplying the mixer with a cover in the form of a trihedral box, which excludes additional resistance to rotation of the screw due to the influence of forage masses reflected from the cover, is justified. Experimental studies were conducted on the selection of the rational shape of the mixing chamber of the mixer. It is established that the use of a cover in the form of a triangular box in the mixer provides a reduction in the required drive power by 25% and an improvement in mixing quality by 4-5% compared to a mixer equipped with a flat cover. The optimal angle of inclination of the reflecting plane of the cover in the form of a trihedral box of the mixer mixing chamber is 31-35 ° with a screw diameter of 400 mm, a reflecting plane height from the screw axis of 350 mm and a rotation frequency of 36.61 s^{-1}.

Keywords--- Feed, Mixer, Chamber Shape, Lid, Mixing Quality, Power Requirement.

I. Introduction

The world is conducting research work aimed at the development of new scientific and technical foundations of resource-saving technologies and technical means for tillage, sowing, harvesting and primary processing of crops [1-5]. In this direction, one of the central places is the production and preparation of feed.

The mechanization of the preparation of feed, in particular on large livestock farms and complexes, provides for the flow organization of production, when the feed received for processing undergoes a series of interrelated operations without transshipment, requiring large expenditures of live labor. The final operation of preparation of feed mixtures is the mixing of components, which is carried out in special devices - batch or continuous mixers.

Currently, for the preparation of wet feed mixtures using juicy and green feed in the feed workshops of livestock farms and complexes, batch mixers with heat treatment of feeds are used. However, these mixers have low productivity, high energy and metal consumption, and the periodic principle of their action complicates the implementation of complete automation of feed preparation. Of great importance for improving the efficiency of preparation of wet feed mixtures is the choice of a mixing method and a device for its implementation [6]. Some modernization of the equipment of the feed mill production lines and the use of continuous mixers makes it possible to increase the feed mill productivity by 3-4 times and reduce the specific reduced costs for preparing feed mixtures by 35-42% [7]. It is known that one of the factors affecting the mixing process is the shape of the mixing chamber. This is especially true for mixers with bourgeois working body [8-11]. The mixing chambers of the mixer with the blender working body can be divided into two main groups: without free space above the working body for low-speed mixers and with free space for high-speed mixers [9-13]. The obvious advantages of the continuous method of preparing wet feed mixtures on livestock farms and complexes are not realized due to the fact that the industry does not produce continuous mixers. To a large extent, this is due to the lack of complete scientifically based recommendations on the technology and means of mechanizing the process of continuous mixing of wet feed.

The aim of the study is to substantiate the shape of the mixing chamber of a continuous mixer.

DOI: 10.5373/JARDCS/V12SP7/20202318
ISSN 1943-023X
Received: 20 May 2020/Accepted: 20 June 2020

II. Materials and Methods

The basic principles and methods of classical mechanics, mathematical analysis and statistics were used in this study. An analysis of the influence of the shape of the mixing chamber on the technological process shows that the presence of free space between the cover and the working body of the mixer provides a chaotic movement of feed particles after impact of the feed mass on the cover, thereby improving mixing conditions. It is advisable to equip the mixing chamber with a lid of such a form that would ensure the dismemberment of the thrown fodder mass and direct the movement of the reflected particle along the rotation of the screw.

For analysis, we consider the mixing process in a continuous mixer with a single-shaft working body and a U-shaped cross section of the body (Fig. 1). When the mixer is working, the feed mixture entering the screw surface begins to rotate due to the presence of friction between the feed and the screw. When the feed mass approaches point A, the friction between the housing and the material disappears and the feed mixture is thrown upward by centrifugal force into the free space of the mixing chamber [9-13].

At a low rotational speed of the screw, the initial speed of the feed is small, it will fall on the screw before reaching the mixer cover. In this case, the thrown fodder masses are not divided into small particles, and the mixing quality indicator will be low. With increasing rotational speed of the propeller, the initial speed of the feed particle increases, and it will reach the mixer lid, hit from it and be reflected. At the same time, during the impact, the feed mass is divided into small particles, which provides favorable conditions for mixing. In addition, feed particles planted at high speeds accumulate kinetic energy. The kinetic energy of the thrown particle will be the greater, the greater the rotational speed of the screw, and the direction of movement of the reflected particles will depend on the shape of the lid and its location above the working body, and by changing them, the direction of movement of the reflected particles can be used to one extent or another. kinetic energy to reduce energy consumption during the mixing process.

In this regard, we consider the influence of the shape of the mixer lid on energy costs and mixing quality.

The mixer lid can have a wide variety of shapes. As an example, we consider three simplest and economically feasible types of covers: flat (Fig. 1a), semicircular with a convex outward (Fig. 1b) and in the form of a trihedral box (Fig. 1c) [15]. From Fig. 1a it is seen that the reflected particles with a flat cap ¬ return to the left side of the screw, that is, against its rotation. The mixer works on one side, that is, additional loads on the screw occur, the screw "brakes" due to the kinetic energy of the reflected particles, and as a result, the required power increases.

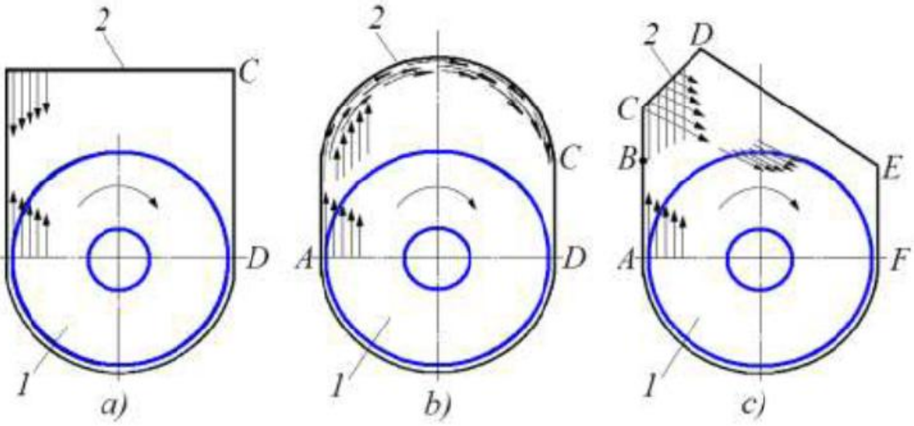

Fig. 1: The Scheme of the Trajectory of the Feed Particles in the Mixers:

a) With a Flat Cover; b) With a Semicircular lid; c) With a Cover in the form of a Trihedral Box: 1 - a Cover; 2 - Screw

In the second variant, when the mixer is equipped with a semicircular lid with a bulge outward (Fig. 1b), the particles will move along the rotor, however, due to the friction force arising between the thrown feed mass and the lid surface, the kinetic energy rotating mass is reduced. All thrown mass when moving along the convex surface of the lid moves without reflection in the form of a continuous layer, without the chaotic movement of particles. Under such conditions, energy consumption decreases, but uniform mixing conditions worsen.

In the third variant, when the mixer is equipped with a cover in the form of a trihedral box (Fig. 1c), the thrown particles are reflected from the working surface of the cover (CD side) and sent to the right side, i.e. in the direction of

DOI: 10.5373/JARDCS/V12SP7/20202318
ISSN 1943-023X
Received: 20 May 2020/Accepted: 20 June 2020

rotation of the screw. In this case, the reflected particles give their kinetic energy to the screw, thereby reducing the energy consumption for mixing. In addition, since the reflected particles are returned to the screw at different speeds, the conditions and quality of mixing are improved. Thus, we can conclude that the mixing chamber with a cover in the form of a trihedral box is most effective. Therefore, further studies to determine the optimal parameters of the mixer were carried out in a mixing chamber with a cover of this shape.

III. Results and Discussion

To select the rational shape of the mixing chamber, preliminary experimental studies were conducted. For this, the mixer was equipped with three types of covers: flat, semicircular with a convexity facing outward, and in the form of a trihedral box.

The data obtained showed that the type of caps changes the shape of the mixing chamber and significantly affects the quality of mixing and the required power of the mixer when performing the technological process.

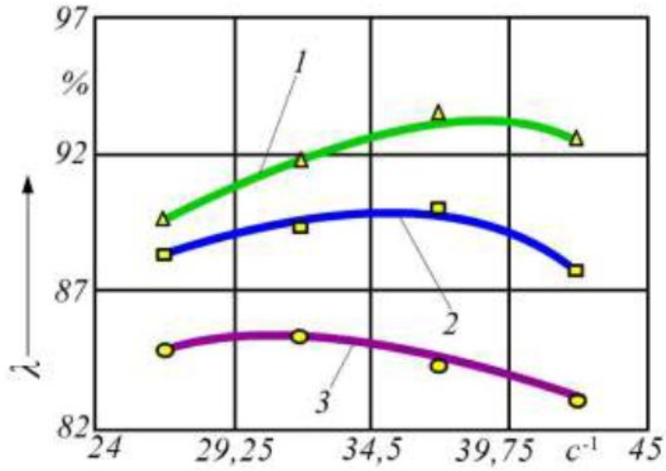

Fig. 2: Dependence of the Quality of Mixing the Components on the Shape of the Lid of the Mixing Chamber and the Rotational Speed of the Screw (For Performance *Q*=15 т/час, *L*=2 м): 1– With a Cover in the form of a Trihedral Box; 2 - With a Flat Cover; 3 - With a Semicircular Lid.

It can be seen from Fig. 3 that the best quality of mixing is ensured with a cover made in the form of a trihedral box with a screw rotation frequency of about 36.61 s-1. When the mixer is supplied with a flat lid with an increase in the rotational speed of the screw to 36.61 s-1, the mixing quality improves and then deteriorates, but remains less in value than with a box-shaped lid.

This shows that with a capacity of Q = 15 t / h and a screw speed of ω = 36.61 s-1, good conditions are created for mixing. If the mixer is equipped with a semicircular lid, then with an increase in the rotational speed of the screw to 31.38 s-1, the quality of mixing improves, and with a further increase in the frequency of rotation of the screw, the quality of mixing deteriorates. This suggests that as the rotor speed increases, the thrown mass of the feed moves along the inner surface of the cover in a continuous flow.

In mixers with different types of lids, the direction of movement of the feed mass in the mixing chamber after tossing upwards with a working body (screw) and interactions with the lid are different.

Based on the research results, we plotted the dependences of the required power on the mixer performance for different forms of the lid (Fig. 3). As can be seen from the graphs, the required power of the mixer with a flat cover increases with increasing mixer performance more intensively than the required power of mixers with semicircular and box-shaped covers.

With a capacity of 25 t / h, the required power of the mixer with a flat cover is 2.22 kW. When using a semicircular lid with a bulge facing outward and a lid in the form of a triangular box, the required drive power of the mixer is 1.84 kW and 1.66 kW, respectively.

From this we can conclude that the optimal shape of the mixing chamber is a mixer chamber with a lid in the form of a trihedral box.

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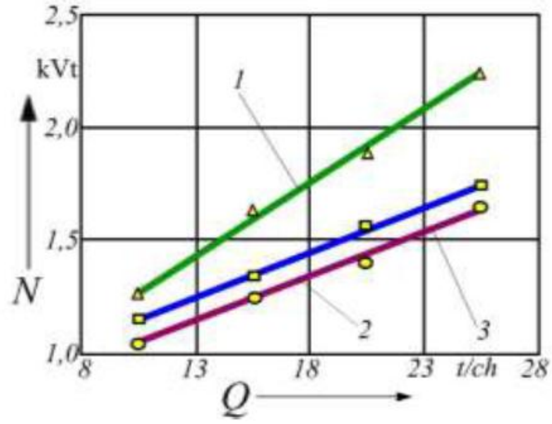

Fig. 3: Graphs of the Dependence of the Required Power on the Second Feed Mixture for different forms of Cover (at ω=31,38 c^{-1} and L=2 м): 1-Mixer with a Cover in the Form of a Trihedral Box; 2-Mixer with a Flat Cover; 3- Mixer with a Semicircular Lid.

To determine the optimal tilt angles of the reflecting plane of the mixer cover, we consider the kinematics of particle motion in the mixing chamber (Fig. 5).

It is known [6, 13, 15] that when the mixer is in the lower part of the casing, the screw captures the feed particle and raises it along the rotation. At point A, the friction between the particle and the casing disappears and the screw ejects the particle towards the mixer lid at a speed V_n, which we conventionally take equal to the peripheral speed of the screw V_o, i.e

$$V_n = V_o = \omega \cdot r, \quad (1)$$

Where ω – screw angular velocity c^{-1}; r – screw radius, m

The thrown particle, having reached the cover and reflected off it, returns to the screw [12]. In the case when the reflected plane of the lid is located horizontally relative to the axis of the screw, the angle of reflection of the particle is zero, that is, the particle practically returns to the ejection zone. In this case, the resulting particle velocity V_p at the moment of meeting with the screw it will be equal to the sum of speeds V_n and V_o, obtained after reflection, i.e.

$$\overline{V}_p = \overline{V}_n + \left(-\overline{V}_o\right) \quad (2)$$

A negative sign indicates that the movement of the reflected particles is directed against the rotation of the screw. In this case, additional forces of resistance to rotation of the screw arise.

With a change in the angle of inclination of the reflecting plane of the lid, the angle of reflection increases, while the value of the resulting speed increases V_p and its direction changes, coinciding with the direction of rotation of the screw. When the direction of movement of the reflected particle is tangent to the outer circle described by the screw, the speed of the reflected particle and the peripheral speed of the screw at the point of encounter with the particle coincide in direction, that is, the resulting speed reaches, to the maximum, and the reflected particles will not create additional resistance to rotation of the screw. With a further increase in the angle of inclination of the lid plane, the reflected particle reaches the opposite wall of the mixer casing and, reflected, is directed to the screw. In this case, the resulting particle velocity decreases, and the forces of resistance to rotation of the screw increase.

With a change in the angle of inclination of the reflecting plane of the lid, the reflection angle increases, at the same time, the value of the resulting velocity Vp increases and its direction changes, which coincides with the direction of rotation of the screw. When the direction of movement of the reflected particle is tangent to the outer circle described by the screw, the speed of the reflected particle and the peripheral speed of the screw at the point of encounter with the particle coincide in direction, that is, the resulting speed reaches, to the maximum, and the reflected particles will not create additional resistance to rotation of the screw. With a further increase in the angle of inclination of the plane of the lid, the reflected particle reaches the opposite wall of the mixer casing, and, being reflected, is directed to the screw. In this case, the resulting particle velocity decreases, and the forces of resistance to rotation of the screw increase.

From Fig. 4 it is seen that the optimal angle of inclination of the reflecting plane of the lid is the angle at which the resulting velocity Vp of the reflected particle is directed tangentially to the circumference of the screw.

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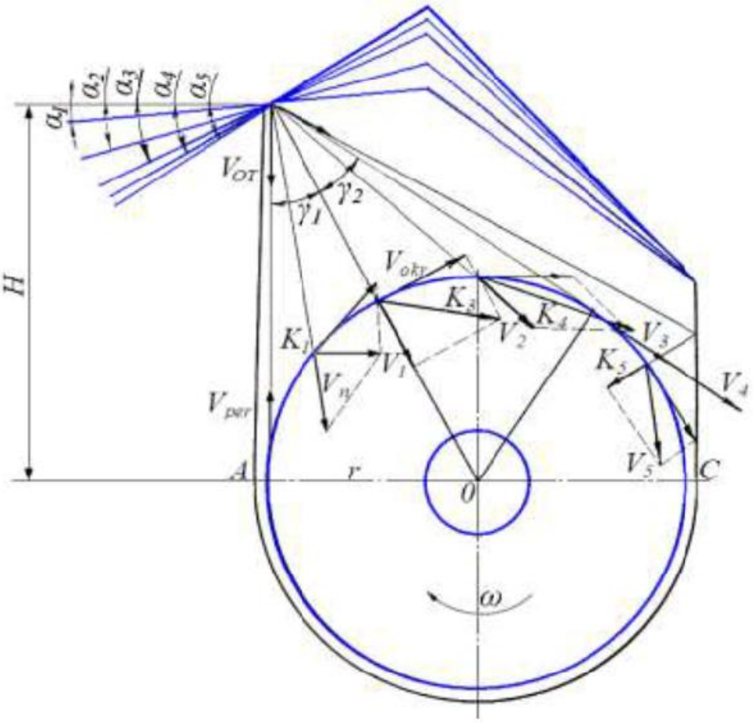

Fig. 4: Scheme for Determining the Angle of Inclination of the Reflecting Plane of the Mixer Lid

To simplify the calculation of the relative angle of inclination of the reflecting plane, we assume that the feed particle is very elastic. With this assumption, the angle of reflection of the particle is equal to the angle of encounter of the thrown particle with the plane of the lid.

It can be seen from the diagram (Fig. 4) that the segment of the BO line is the bisector of the angle ABK4 formed by the direction of the particle's trajectory, and at the same time normal to the reflecting plane of the lid. As a result, two equilateral triangles are obtained *OAB* and *OK₄B*. Here $OA=r$ and $AB=H$ a angle $\gamma_1=\gamma_2=\alpha_4$ где α_4 – the angle of inclination of the reflecting plane of the cover to the horizon; γ_1, γ_2 – the angle of encounter of the particle with the plane of the lid and the angle of reflection from it. To determine the value α_4, define γ_1 and γ_2 through the ratio

$$tg\gamma_1 = \frac{r}{H} = tg\gamma_2 \quad (3)$$

Hence, the angle of inclination of the reflecting plane of the lid is

$$\alpha_4 = \gamma_1 = \gamma_2 = arctg\frac{r}{H}. \quad (4)$$

Substituting the value of r and H in the formula (4), we obtain the value of the optimal angle α_4.

As mentioned above, in this cover the reflecting surface is the face located above the zone of ejection of feed particles. From the angle of inclination of this face relative to the horizon depends on the amount of feed reflected in the zone that does not coincide with the zone of release and, in turn, the quality of mixing. In this regard, to determine the optimal angle of inclination of the reflecting plane of this cover, we consider three characteristic directions of motion of the reflected feed particles in the free space above the screw.

First option. Feed particles are reflected on the screw (Fig. 5a), that is, the bulk of the cover of particles reflected from the reflecting plane (CD face) will be directed radially to the axis of the screw. In this case, the kinetic energy of the feed particles is not used, that is, they do not create additional torque for the rotation of the screw, less time is in free space above the screw. Such conditions do not provide good mixing of feeds and do not reduce the energy intensity of the process.

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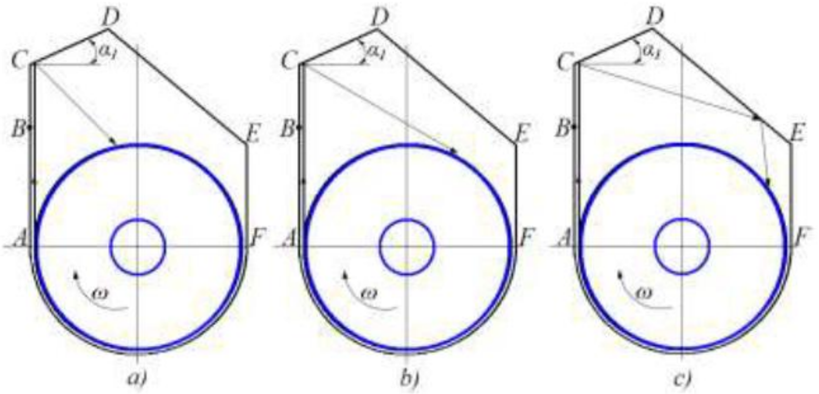

Fig. 5: Particle Trajectory Diagram for different Tilt Angles of the Reflecting Plane of the lid: *a)* α=24°; *b)* α=31°; *c)* α=38°

In the second version, when the particles reflected from the CD face are directed tangentially to the outer surface of the screw in the direction of its rotation (Fig. 6b), the majority of the reflected particles fall on the screw surface of the screw turns from the back side and, transmitting its kinetic energy, contributes to the rotation of the screw, that is, reducing the energy intensity of the process. In addition, the time spent by the particles in the free space above the screw will be longer than in the first case, that is, the feed particles more fully disperse and mix better.

In the third variant, particles reflected from the CD face are directed to the opposite side of the mixer (face DE) and after repeated reflection fall down along the rotation of the screw (fig. 6c). The main part of the reflected particles in this case falls, as in the second embodiment, on the back side of the surface of the screw, thereby transferring part of its kinetic energy to the shaft of the screw.

To confirm the above theoretical premises, we conducted experimental studies on three types of covers (Fig. 5) with different angles of inclination of the reflecting surface. In this case, the angle of inclination of the reflective surface of the cover relative to the horizon was 24 °, 31 °, and 38 °.

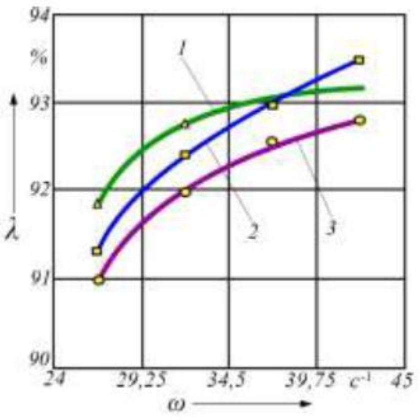

Fig. 6: Dependence of the Quality of Mixing the Components on the Angle of Inclination of the Reflective Cover and the Rotational Speed of the Screw

1 – α=31°; 2 – α=38°; 3 – α=24°

The results of the study are shown in graphical form in Fig. 6. The figure shows that with an increase in the rotational speed of the screw, the mixing quality improves. When the speed of the screw reaches 36.61 s^{-1} slows down improvement in blending quality. From this graph we can conclude that from the point of view of mixing, the most effective is a cover with an angle of inclination of the reflecting plane of 31-38 °, and the optimal rotational speed of the screw is 36.61-41.84 s^{-1}

To determine the effect of the shape of the chamber on the required power of the mixer during the technological process, preliminary experimental studies were conducted on the mixer made on three types of covers (Fig. 6) with different angles of inclination of the reflecting surface.

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The results of the study are shown in graph form (Fig. 7). It can be seen from the graph that the optimum angle of inclination of the reflecting plane of the lid is α = 31 °, since at this angle the required drive power is lower than at other angles. Therefore, further studies were carried out at the optimum value of the rotational speed of the screw n = 31.38 s^{-1} and the angle of inclination of the reflecting plane of the cover α=31°.

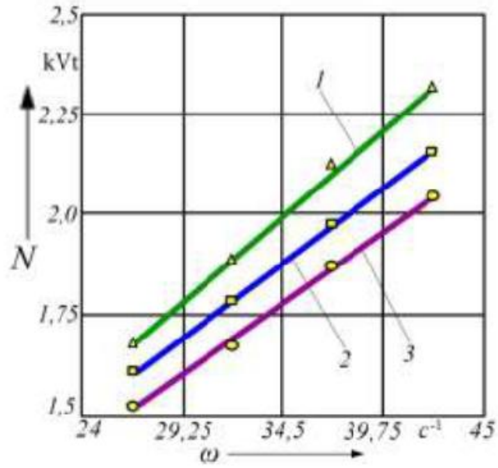

Fig. 7: The Dependence of the Required Power on the Rotational Speed of the Screw at Various Angles of Inclination of the Reflecting Plane of the Cover and Performance Q=15 t/ch: 1 – at α=24°; 2 – at α=38°; 3 – at α=31°

IV. Conclusions

1. Existing batch mixers for the preparation of wet feed mixtures are ineffective due to their low productivity and high energy intensity. Continuous mixers with a semicircular and flat lid do not provide the required quality of mixing the feed mass.
2. It was found that the use of a cover in the form of a triangular box in the mixer reduces the required drive power by 25% and improves the quality of mixing by 4-5% compared with a mixer equipped with a flat cover.
3. It was found that the optimal angle of inclination of the reflecting plane of the cover in the form of a trihedral box of the mixing chamber of the mixer is 31-35 ° with a screw diameter of 400 mm, a height of the reflecting plane from the axis of the screw 350 mm and a rotation frequency of 36.61 s^{-1}.

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