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## Improving the Reliability of a Guide Vane Actuating Mechanism for Bulb –Type Units

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**Abstract.** The analysis has as purpose to notice the elements that can produce incidents during the running of the regulating apparatus of bulb turbines. The analyzed regulating device has a robust construction. Although, a critical element is the connecting rod which can produce two types of incidents: a) the detachment from the joining bolt of the regulating ring and b) the uncontrolled modification of the length during the running. The kinematical analysis of the guide vane regulating apparatus shows that the connecting rod fulfills a three-dimensional movement of great amplitude. There were made recommendations regarding the reliability increase of the system.  
**Keywords:**bulb-type units, conical guide vane regulating apparatus, reliability, kinematical analysis.

### 1. INTRODUCTION

In comparison with the ordinary axial machines the bulb-type units creates some difficulties of design and running. As a result of some operation observations it was made a demand to analyze the guide vane regulating apparatus with the purpose to notice the elements that can produce exploitation problems.

During this analysis it resulted that a critical element is the connecting rod, which can produce the following incidents: a) the detachment from the joining bolt of the regulating ring and b) the uncontrolled modification of the length during the running.

There have been made recommendations regarding the necessary interventions upon the connecting rod in order to increase the running safety.

### 2. THE ANALYZED GUIDE VANE REGULATING APPARATUS

For bulb-type units the guide vane-regulating device has a conical shape. This apparatus consists from the following important elements: the guide vane servomotors with the afferent rods, the

regulating ring with the joining bolts, the connecting rods, the cranks and the guide vanes.

In Figure 1 is presented a longitudinal cross section through the guide vane apparatus in which it can be seen: the guide vane, the crank, the joint crank-connecting rod, a small part of the regulating ring with the inclined vane in which is fastened the connecting rod joint bolt.

In Figure 2 it is presented the view of a regulating apparatus segment, seen from inside the bulb. One guide vane is presented in both the extreme positions: completely closed and completely open. The regulating device is actuated with two servomotors placed inside and at the lower part of the bulb. On the regulating ring are welded 16 vanes inclined at 60° (Figure1). The joining bolts are mounted on these vanes.

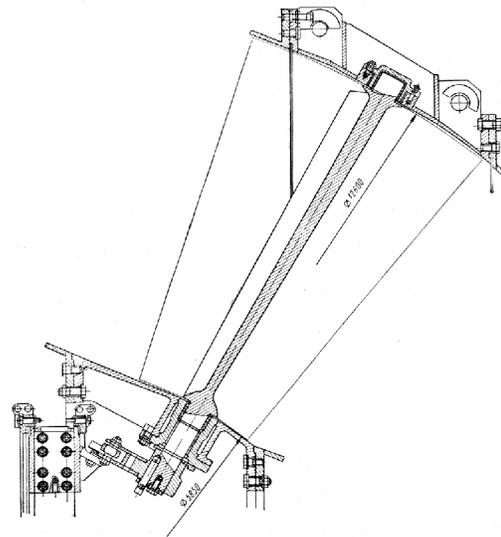


Fig. 1. Longitudinal cross section through the guide vane apparatus

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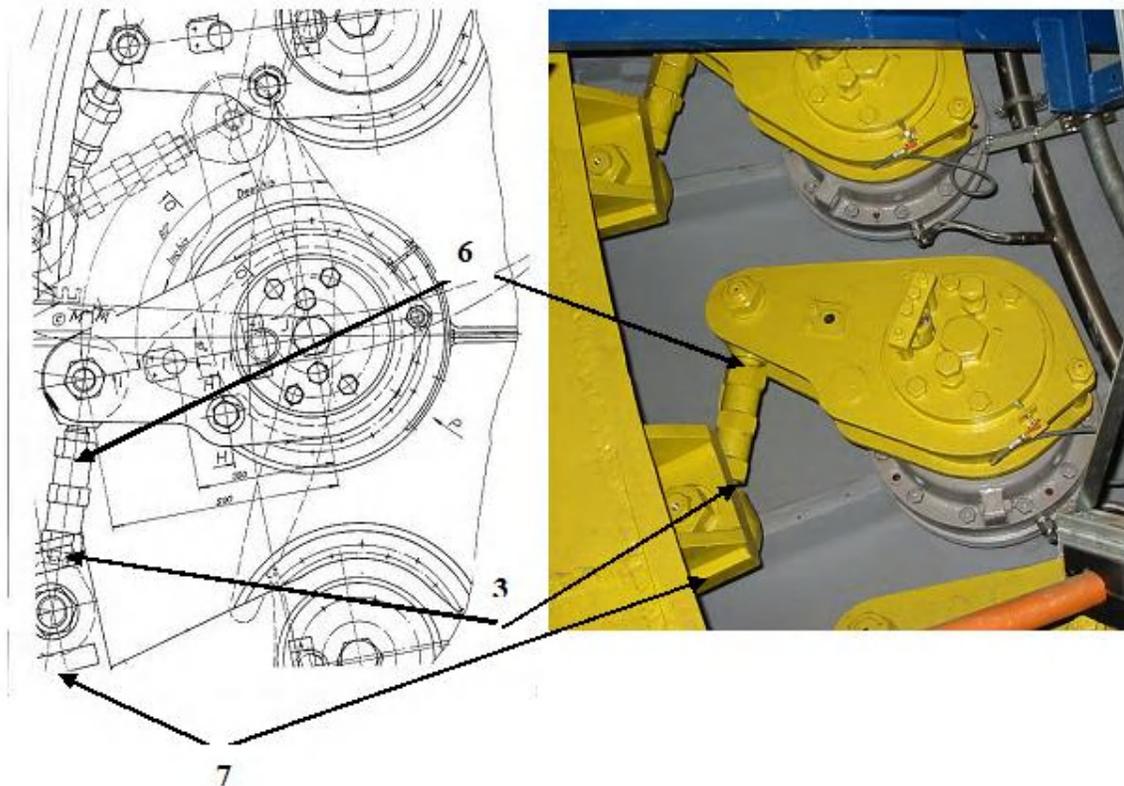


Fig. 2. Inner view of the regulating apparatus

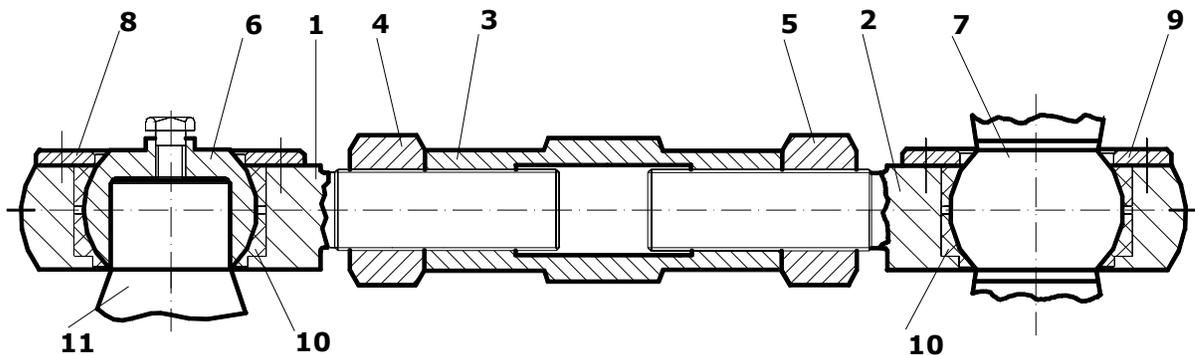


Fig. 3. The guide vane connecting – rod

The connecting-rod presented in Figure 3, is a complex detail having the following main parts: the left thread link ring (1), the right thread link ring (2), the lids (8, 9), the antifriction spherical bushings (10) and the joint bolt (11). Besides the transmission of the maneuvering force, the connecting rod fulfills two other important functions.

The first is represented by the spatial movement of the connecting rod, realized through the sliding of the bushings (10) over the metallic spheres (6, 7). These sliding allow the necessary spatial movement of the connecting rod in order to maintain the center of the sphere (6) in the movement plan of the regulating ring, concomitantly with the rotation of the link ring eyes (1, 2) in such a manner that the center of

sphere (7) has the possibility to remain in the rotation plane of the crank.

The second function of the connecting rod is to close the dimension chain. This function is fulfilled only in the assembling periods and is carried out as follows: after assembling all the involved details in the closed position the connecting rod is put in its normal position. The lengths of the connecting rod being adjustable through the rotation of the sleeve (3), provided with left/right thread, the dimensional chain is closed in an easy way.

The crank is also a complex element, composed from 26 individual pieces. The most important are: the proper crank, the inner cover plate, the outer cover plate, the shearing bolt and the joint with the connecting rod (the spherical arm 7 in the Figure 3).

The leading part played by the crank is to move the guide vane at the right angle demanded by the turbine. This movement is obtained as a result of the force delivered by the connecting rod. Supplementary the crank has also two secondary functions: a) the protection against the deterioration of the guide vane in the eventuality when a great solid object gets between two consecutive guide vanes and b) the possibility to rotate the guide vane in the opening direction even if the shearing bolt is fractured by the external forces. These two supplementary functions will be analyzed separately.

*Guide vane protection.* In order to fulfill this function the crank is realized from three distinct parts: the proper crank, the inner cover plate and the outer cover plate (Figure 1). These three parts are bounded together by three types of bolts: the shearing one, the massive support and two slender supports. The shearing bolt is a cylindrical piece manufactured from steel (OLC 45), heat treated, with a diameter of 50 mm and provided with two shearing cross sections. These shearing sections are realized by cutting two notches at 60° (stress raisers) that reduces the diameter till 40 mm. If a massive solid object is caught between two consecutive guide vanes and the regulating apparatus is moved towards closing, these guide vanes cannot effectuate the movement. As a result, the oil pressure increases in the hydraulic actuating system together with the acting force delivered to the crank. If this force exceeds with 40...50% the normal value of the tension, the notched sections resistance is exceeded and the shearing bolt will be fractured. In this way the bounds between the proper crank and the cover plates are interrupted. The cover plates can follow the movement imposed by the regulating ring but in the same time the proper crank and the guide vane are not obliged to follow this movement.

*Possibility to actuate the guide vanes even if the shearing bolt is fractured.* The designer offered the possibility to move the guide vane toward opening even when the shear bolt is fractured. When the regulating ring is moved toward opening the body of the massive support enter in the 120° clearance provided in the crank arm (Figure 2) and allow the actuation of the system crank/guide vane. The movement towards closing is not possible and the guide vane can occupy casual positions dictated by hydrodynamic forces with the restriction given by the position of the massive support.

### 3. POSSIBILITIES FOR CASUAL EVENTS

The shaft of the joining bolt (11) and the metallic sphere (6) are united by three threaded screws „M 16x35 group 5” (12) secured with Grower washers (13). For two till four guide vanes, namely for those placed at the lower part of the bulb, when the Grower washers are out of use the monolith (11)-(6) is compromised. As a result of the vibrations and without the Grower washers, all the M16x35 bolts get unscrewed and finally fall at the bottom of the bulb. Under the influence of gravity the assembly formed

by the left thread link ring (1), the antifriction bushing (10), the lid (8) and the metallic sphere (6) can slide over the cylindrical journal of the bolt (11). For an easy assembling the fitting between the metallic sphere (6) and the cylindrical journal of the bolt (11) is H7/g6. Consequently the minimum clearance of the sphere is zero and the maximum clearance is 0.03 mm. The joining bolt journal minimum clearance is 0.013 and the maximum is 0.062. This means that the minimum clearance of the assembly is 0.013 mm and the maximum is 0.065 mm. The length of the journal being 54 mm, the maximum inclination in the first moment can reach a hexadecimal minute.

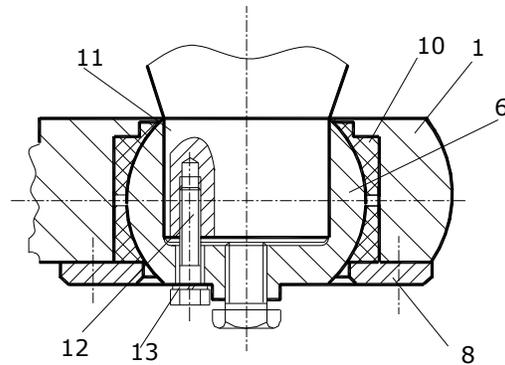


Fig. 4 Detail of the left thread link

The total mass of the parts subjected to gravitations is about 19.914 kg. Taking into account the inclination of the thread link ring, the force in the direction of the journal axis is approximately 9,75 N, and can gradually rotate the metallic sphere in the antifriction bushing and finally the connecting rod fall from the joint. Evidently, this process is a slowly one, especially the unscrewing of the tree M16x35 bolts. An extremely critical circumstance is the fact that, during the periodic inspections, the intermediate phases of the detachment are very difficult to be observed.

Even the lost of the Grower washers cannot be observed at the periodical inspections. From discussions with the inspection personnel resulted that they found fragments of Grower washers in the bulb interior but they cant say if these fragments result from the assembling period or from the running period.

In the literature [1], [5], the Grower washers are recommended till the group 8.5. Because the used screws are in the group 5 they enter in the recommended interval. In [2], [6], it is specified: “The Grower washer is a spitted one, manufactured from spring steels and in disassembled state the branches are in a far off position. This elastic washer is put between the part and the nut and is compressed by screwing the nut so that the sharp end penetrates both in the part and the nut. In this way the unscrewing of the nut is prevented. Although, this method does not offer an absolute assurance, so the assembly must be verified periodically.” In [3] is mentioned: “ The unscrewing of the hexagonal head bolt can be

prevented by passing a wire through their heads.” In the literature there are presented also other safety solutions as for example split plates applied to the screw head. This solution is difficult to be applied in our condition because the lack of space (the free end of the plate must be fastened by a distinct screw).

Upon our opinion, ensuring this very important bond only with Grower washers does not offer the necessary confidence and the detachment of the bond regulating ring-connecting rod, in peculiar conditions, can generate important injuries followed by expensive repair works. The fact that in this area were found washer fragments leads to the conclusion that after the heat treatment they are in some cases to fragile so, they can crack and fall from the joint. Consequently, the bond can be detached by unscrewing of the three threaded screws.

A rough analysis of the probability for the connecting rod to go out from the regulating mechanism can be realized simply, by examining the possibility of inclining the right link ring in the distance between the crank plates. It resulted that the inclination of the connecting rod overcame  $6^\circ$ , which allow the metallic sphere (6) to go over the superior end of the joint bolt journal (11). Taking into account the gravity of such a situation it was decided to analyze carefully the connecting rod kinematics, which will be presented as a distinct chapter.

Another possible malfunction is generated by the rotation of the whole assembly sleeve (3) - securing nuts (4, 5) as a result of the vibrations. If the distance between the axes of the sphere (6) and the bolt (7) increases, the respective guide vane will be heavily pressed on the adjacent vanes, which leads to the deterioration of the tightness rubber cords. When the rotation is in the contrary direction (the length of connecting rod is reduced), in the closed position of the regulating mechanism, it remains a clearance between the vanes and important leakages can occur. In the other positions of the regulating apparatus, the hydrodynamic field is perturbed and the hydraulic efficiency of the turbine is reduced.

#### 4. KINEMATICS ANALYSES

Analyzing the constructive solution in Figures 1, 2, and 3 it can be observed that during the movement from the position complete closed to complete open the guide vanes imposes a three-dimensional movement of the connecting rod. In order to determine the correlation between the servomotor piston position „ $\delta$ ” and the guide vanes position „ $\gamma$ ” the kinematical analyzes of the guide vane regulating apparatus is necessary. The kinematical scheme can be seen in Figure 5. The apparatus presents itself as a three-dimensional articulated quadrilateral ABCD with the cylindrical articulations A and D and spherical ones B and C. The articulations A and D allow the rotation around the guide vane axis respectively around the servomotor axis. The unchangeable rotational axis passes through the points A and D. The extremities B and D are mobile and perform evolutions on arcs of circle. These arcs of

circles are placed on different space planes and form the  $\alpha$  dihedral angles. The case analysis, in conformity with Figure 4, leads to the data presented in Table 1.

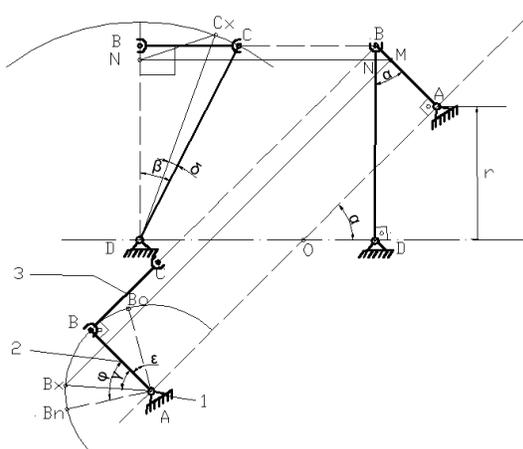


Fig. 5. The kinematical scheme of the guide vane regulating apparatus

Table 1

AB [mm]	BC [mm]	BD [mm]	r [mm]	$\alpha$ [°]	$\epsilon$ [°]	$\phi$ [°]	$\widehat{OAB}$ [°]
500	500	2130	1880	60	-10	70	90

$\gamma$  – is the current angle for a random intermediate position

With the hypothesis of normal angles:

$$\widehat{ABC} = \widehat{CBD} = 90^\circ \quad (1)$$

it is successively determined

$$AM = AB_x \cos(\gamma) \quad (2)$$

but

$$AB_x = AB \quad (3)$$

and

$$MB = AB - AM = AB(1 - \cos \gamma) \quad (4)$$

$$MN = MB \sin \alpha = AB(1 - \cos \gamma) \sin \alpha$$

From  $\Delta B_x C_x N$ , rectangular with

$$B_x \widehat{NC}_x = 90^\circ \text{ result}$$

$$\sin \omega = \frac{MN}{B_x C_x} \text{ where } \widehat{\omega} = B_x \widehat{C}_x N$$

$$\text{and with } B_x C_x = BC$$

result

$$\sin \omega = \frac{AB(1 - \cos \gamma) \sin \alpha}{BC} \quad (5)$$

In this way it can be determined  $\widehat{\omega}$ , angle made by the connecting rod with the crank plane of rotation in a position marked by the index x. From (6) result that at the extremities of the servomotor piston stroke there are obtained the extreme values of the angle  $\omega$  for the positions  $\gamma = 0$  and not  $\gamma = \epsilon$  and respectively  $\gamma = \phi$ . By replacing the numerical values for the analyzed case it was obtained  $\omega_{\gamma=\phi} = 17,23^\circ$ . For the detachment of the cylindrical journal (11) from the

metallic sphere (6) (see Figure 3) is necessary a rotation angle  $\psi = 5,906^\circ$  measured in figure 3.

Because,  $\omega_{\gamma=\varphi} > \psi$  such a detachment becomes possible if there are not taken special measures to maintain the journal (11) bounded to the metallic sphere (6).

For the movement of the guide vanes from the position complete close  $\gamma = \varepsilon$  to the position complete open it correspond both an angular movement and a stroke of the piston, which can be computed as follows.

The radius of the regulating ring is:

$$CD = \sqrt{BD^2 + BC^2} = 2187,898 \quad (6)$$

$$\text{tg}\beta = \frac{BC}{BD} = 0,234741784 \dots \beta = 0,23056724 \text{ rad} = 13,21^\circ \quad (7)$$

$$NC_x = B_x C_x \sqrt{1 - \sin^2 \omega} = \sqrt{BC^2 - AB^2 \sin^2 \alpha (1 - \cos^2 \gamma)^2}$$

$$= \sqrt{250000 \left[ 1 - \frac{3}{4} (1 - \cos \gamma)^2 \right]} \quad (8)$$

$$BN = MN \text{ ctg } \alpha = AB (1 - \cos \gamma) \cos \alpha \quad (9)$$

$$ND = BD - BN = 2130 - 500 \cdot (1 - \cos \gamma) \frac{1}{2}$$

(10)

The point  $C_x$  fall at the intersection of two circles, one with the radius  $CD$  and the center in  $D$  and the other with the radius  $NC_x$  and the center in  $N$ . In an orthogonal system having  $D$  as origin, the coordinates of the point  $C_x$  ( $x$ ,  $z$ ) are noted  $DO$  after  $Dx$  and  $DN$  after  $Dz$  (Figure 4), it results:

$$\begin{cases} z = \frac{DN^2 + DC^2 - r^2}{2DN} \\ x = \sqrt{DC^2 - z^2} \end{cases} \quad (11)$$

the angle  $\hat{\delta}$  can be computed from:

$$\hat{\delta} = \hat{\beta} - \text{arctg} \frac{x}{z} \quad (12)$$

the arc length is:

$$CC_x = DC \cdot \hat{\delta} \quad (13)$$

with the substitution  $\gamma = \varphi$  it results:

$$DN = 1965,5 \text{ mm}$$

$$NC_n = 376,518 \text{ mm}$$

$$z = 2164,417 \text{ mm}$$

$$x = 319,685 \text{ mm}$$

$$\hat{\delta} = 4,808^\circ$$

$$\widehat{CC}_n = 183,625 \text{ mm}$$

The regulating ring circumferential stroke is  $\widehat{C}_0 C_n$ , can be approximately computed from:

$$\widehat{C}_0 C_n \cong \widehat{CC}_n \cdot \frac{\varphi + \varepsilon}{\varphi} = 182,624 \cdot \frac{80}{70} = 208,713 \text{ mm} \quad (14)$$

An accurate value can be obtained in a way similar with that used for the point “n” and the point “O” and finally the stroke can be computed from:

$$\widehat{C}_0 C_n = \widehat{CC}_n + \widehat{C}_0 C \quad (15)$$

In this way, we reach to the conclusion that the spatial movement of the connecting rod allows the detachment from the joining bolt if the Grower washers do not play their role.

## 5. SOLUTIONS FOR AN INCREASED RELIABILITY

From the analysis carried out on the conical guide vane regulating apparatus results that for the solution adopted by the designer the deterioration of a low cost piece (the Grower washer) can lead, in favorable situations, to the detachment of the connecting rod from the regulating ring. In such a situation the respective guide vane has a free movement under the action of the hydrodynamic forces. The connecting rod, which remains bounded to the crank, follows a chaotic movement generated by the guide vane, perhaps amplified as the result of the articulation.

If by misfortune, the free end of the connecting rod is blocked by an other part there are possible great damages as for example: the fracture of the shearing bolt or the push of the crank into that of the guide vane situated in the proximity with the possibility to blocking up both guide vanes. As a consequence, occur important deterioration of some parts of the regulating apparatus.

Even if the detachment of the connecting rod is a slowly process it has the great disadvantage of not being easy to be seen, at the regular inspections. The deterioration becomes evident only when the injury is so great that the running of regulating apparatus is impossible.

Consequently there were proposed, for the connections of the regulating apparatus parts, two supplementary safety measures. The first, extremely economical and efficient, is that found in [3]: “passing a wire through the heads of the joining screws”. As an experiment it was proposed also the more elegant solution to use Nord-Lock washers [4], [7]. Those washers have the following advantages: assures maximum security for the bounding subjected to vibrations, they are not influenced by temperature and technical lubricants do not influence the blocking function. To avoid corrosion effects there were proposed the stainless steel washers (A4, AISI 316).

For preventing the uncontrolled modifications of the connecting rod lengths it was proposed to maintain the extremely simple but efficient solution proposed by the exploitation team, namely the welding of a metallic strip to bound the important fifth parts of the connecting rod (see the figure 3): the left link ring (1), the sleeve (3), the nuts (5 and 6) and the right link ring (2).

It was also recommended for the future a careful examination of the guide vane apparatus also from

other points of view, especially the reliability of the tightness, the behavior of the journal bearings, the behavior of the crank details.

## CONCLUSIONS

1. The analyzed guide vane apparatus has a robust construction.
2. The assurance of the bound between the connecting rod and the joining bolt only by Grower washers does not offer complete confidence although this solution is in general accepted in most references.
3. The kinematical analysis of the guide vane regulating apparatus shows that the connecting rod fulfills three-dimensional movements of great amplitudes. If the Grower washers suffer cracks the three screws, which connects the metallic sphere with the bolt of the regulating ring, are unscrewed. This fault can lead, in certain cases, to important damages of the regulating apparatus parts.
4. There were proposed two alternative solutions: the assurance by passing a wire through the heads of the joining screws or the assurance with Nord-Lock washers.
5. The solution adopted by the beneficiary to prevent the uncontrolled modifications of the rod length, by welding a strip along it, is considered adequate.

6. The careful examination of the guide vane apparatus also from other points of view, especially the reliability of the tightness, the behavior of the journal bearings, the behavior of the crank details is recommended in the future.

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