ANALYSIS OF CALCULATION METHODS APPLIED TO THE RINGS OF PORTAL CRANE

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Abstract: *The paper deals with calculation methods which have been applied to circular rings of portal cranes having revolving columns. The first part of the paper includes theoretical analysis of the loads of circular rings and calculation methods, too. In the second part of the paper the theoretical results of the calculation have been checked by finite element method (FEM) and by calculation software. It has been proved that calculation results have a high level of conformity, which provides the possibility for theoretical analysis of influence of different parameters on the intensity of ring stress and ring deformation.*

Key words: *circular ring, portal, loads, calculation methods*

1. INTRODUCTION

The supports of revolving column of portal cranes transmit the external loads to carrying structure of the crane. Lower support, as a rule, takes the horizontal force from the moment and it also takes the vertical force from the resulting vertical loads (fig.1a). Circular ring connecting portal tops takes the second horizontal force from the moment. The ring carries not only the big gear which is a constituent part of the mechanism used for column revolution but also the circular track which supports column wheels used for transmission of horizontal force.

Depending on the geometric characteristics of the ring and portal, the following combinations are possible:

a) circular ring, and upper and lower part of the portal are elastic,
b) circular ring, and upper and lower part of the portal are rigid,
c) circular ring, and upper part of the portal are elastic, whereas the lower part of the portal is rigid, and
d) circular ring is rigid, whereas upper and lower parts of the portal are elastic.

The forces at connections between the circular ring and upper part of the portal are variables. They depend on the position which loaded boom takes with respect to direction of portal moving, on optional solution of the connection of the circular ring and portal as well as on the number of portal legs.

Four-legged portal supports can not be in contact with the track without additional elastic deformation of the portal or with the ring. In order to eliminate the influence, the analysis of calculation methods of circular ring is applied to three-legged portal.

2. CALCULATION MODEL OF CIRCULAR RING

Research results [1] show that three-legged portal having a rigid ring and elastic upper and lower part is an optimal solution in view of the intensity of forces at connections. Besides, that kind of solution provides forming the model of connection between circular ring and the portal by means of joints without bigger deviations.

If calculation theory of circular rings with constant cross sections [2] is applied, it is possible to analyse the loads of the rings. These loads are:

- horizontal force of revolving column,
- radial force of driving gear,
- peripheric force of driving gear,
- weights of the ring, circular track, and big gear.

Horizontal force of revolving column, radial force of driving gear and peripheric force of driving gear act in the plane of circular ring (fig. 1b).

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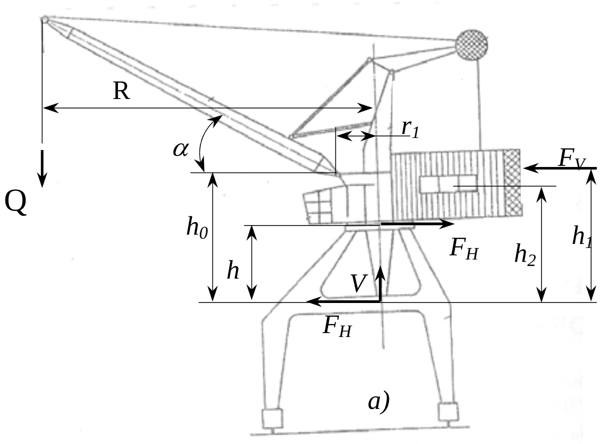


Fig. 1.

Weights of circular ring, circular track, and big gear act perpendicular to the plane of circular ring.
External loads of circular rings cause the following:

- bending moment X_1
- axial force X_2
- radial force X_3 (fig. 2)

Their values are defined by equation system (1) and expressions (2) [2]:

$$X_1 = \sum_{i=1}^{n} P_i \cdot r \cdot \chi_{1P}(\varphi_i) + \sum_{j=1}^{m} T_j \cdot r \cdot \chi_{1T}(\varphi_j) + \sum_{k=1}^{i} M_k \cdot \chi_{1M}(\varphi_k)$$

$$X_2 = \sum_{i=1}^{n} P_i \cdot r \cdot \chi_{2P}(\varphi_i) + \sum_{j=1}^{m} T_j \cdot r \cdot \chi_{2T}(\varphi_j) + \sum_{k=1}^{i} M_k \cdot \chi_{2M}(\varphi_k)$$

$$X_3 = \sum_{i=1}^{n} P_i \cdot r \cdot \chi_{3P}(\varphi_i) + \sum_{j=1}^{m} T_j \cdot r \cdot \chi_{3T}(\varphi_j) + \sum_{k=1}^{i} M_k \cdot \chi_{3M}(\varphi_k) \quad (1)$$

where:

$$\chi_{1P}(\varphi_i) = \frac{1}{2\cdot\pi}\cdot(1+\varphi\cdot\sin\varphi)$$

$$\chi_{1T}(\varphi_i) = \frac{1}{2\cdot\pi}\cdot(\varphi\cdot\cos\varphi - \sin\varphi - \varphi)$$

$$\chi_{1M}(\varphi_i) = \frac{1}{2\cdot\pi}\cdot(-\varphi - 2\cdot\sin\varphi)$$

$$\chi_{2P}(\varphi_i) = \frac{-\varphi\cdot\sin\varphi}{2\cdot\pi}$$

$$\chi_{2T}(\varphi_i) = \frac{1}{2\cdot\pi}\cdot(-\varphi\cdot\cos\varphi + \sin\varphi)$$

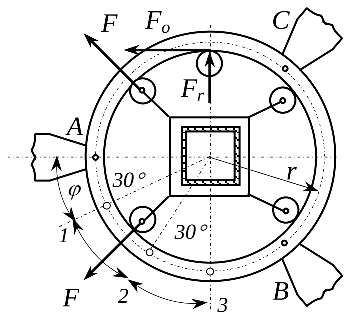
$$\chi_{2M}(\varphi_i) = \frac{\sin\varphi}{\pi}$$

$$\chi_{3P}(\varphi_i) = \frac{-\varphi\cdot\cos\varphi}{2\cdot\pi}$$

$$\chi_{3T}(\varphi_i) = \frac{1}{2\cdot\pi}\cdot(\varphi\cdot\sin\varphi + \cos\varphi)$$

$$\chi_{3M}(\varphi_i) = \frac{\cos\varphi}{\pi} \quad (2)$$

P_i - radial force in the ring plane,
T_j - tangent force in the ring plane,
M_k - moment in the ring plane.



b)

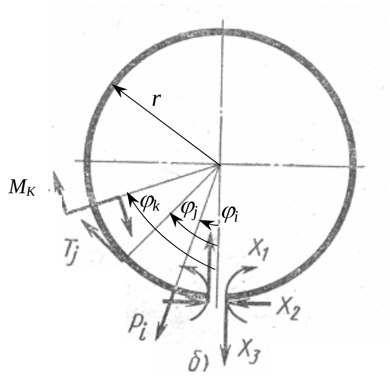


Fig. 2.

The loads caused by weights of circular ring, circular track, and big gear act in the plane perpendicular to the plane containing the ring. The moments X_1 and X_2 and forces X_3 (fig. 3) are defined by equation system (3) and expressions (4):

$$X_1 = \sum_{i=1}^{n} P_i \cdot r \cdot \mathfrak{M}_{1P}(\varphi_i) + \sum_{j=1}^{m} M_j \cdot \mathfrak{M}_{1M}(\varphi_j) + \sum_{k=1}^{i} M_k \cdot \mathfrak{M}_{1K}(\varphi_k)$$

$$X_2 = \sum_{i=1}^{n} P_i \cdot r \cdot \mathfrak{M}_{2P}(\varphi_i) + \sum_{j=1}^{m} M_j \cdot \mathfrak{M}_{2M}(\varphi_j) + \sum_{k=1}^{i} M_k \cdot \mathfrak{M}_{2K}(\varphi_k)$$

$$X_3 = \sum_{i=1}^{n} (-P_i)\cdot\varphi_i\cdot\frac{1}{2\cdot\pi} + \sum_{k=1}^{i}\frac{M_j}{2\cdot\pi\cdot r} \quad (3)$$

where:

$$\mathfrak{M}_{1P}(\varphi_i) = \frac{\varphi\cdot\sin\varphi}{2\cdot\pi}$$

$$\mathfrak{M}_{1M}(\varphi_i) = \frac{\varphi\cdot\cos\varphi + \sin\varphi}{2\cdot\pi}$$

$$\mathfrak{M}_{1K}(\varphi_i) = \frac{-\varphi - \sin\varphi}{2\cdot\pi} + \frac{\cos\varphi}{\pi\cdot\left(1+\frac{G\cdot I_0}{E\cdot I_x}\right)}$$

$$\mathfrak{M}_{2P}(\varphi_i) = \frac{-\varphi + \varphi\cdot\cos\varphi}{2\cdot\pi}$$

$$\mathfrak{M}_{2M}(\varphi_i) = \frac{-1 - \varphi\cdot\sin\varphi + \cos\varphi}{2\cdot\pi}$$

$$\mathfrak{M}_{2K}\left(\varphi_i\right) = \frac{-\varphi\cos\varphi}{2\cdot\pi} - + \frac{\sin\varphi}{\pi\cdot\left(1+\dfrac{G\cdot I_0}{E\cdot I_x}\right)} \qquad (4)$$

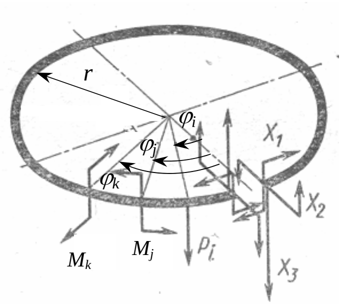


Fig. 3.

According to the expressions (4) relating to $\mathfrak{M}_{1K}\left(\varphi_i\right)$ and $\mathfrak{M}_{2K}\left(\varphi_i\right)$, there are relations GI_0/EI_x, too (5).

$$\frac{G\cdot I_0}{E\cdot I_x} \qquad (5)$$

where
E - modulus of elasticity,
G - modulus of sliding,
I_x - rectangular moment of inertia,
I_0 - torsional moment of inertia.

If the ring has the shape of a box-like carrier made of steel sheets having constant thickness, the dependence (5) can be transformed into less complicated form by means of relation [3].

$$\frac{I_x}{I_0} = \frac{2\cdot k}{3} \qquad (6)$$

where
$k = \dfrac{h}{b}$ - relation between the height and width of the cross section of box-like carrier (fig.4).

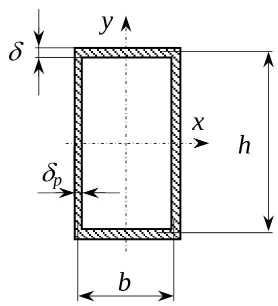


Fig. 4

A new relation is obtained by transformations (5):

$$\frac{G\cdot I_0}{E\cdot I_x} = \frac{\sqrt{3}}{3\cdot k} \qquad (5.1)$$

Radial and tangent forces act in the plane of circular ring, while forces act in the plane perpendicular to the ring plane, so the addends containing the moments M_k can be taken out from equation system (1). Only the first addends (perpendicular forces P_i, fig.3) remain in equation system (3).

Equations (1) and (3) as well as above mentioned conclusion have been applied in order to calculate the circular ring of a three-legged portal crane (fig. 1a) having the following characteristics:

Q = 3,2t - load weight
R = 22m - maximum boom reach
n = 1,6°/min - number of column revolutions
α = 25° - minimal angle of boom
h = 3,75m - distance between upper and lower support
r_1 = 1,2m - distance between boom joint and axis of revolving column
h_0 = 8,5m - distance between boom joint and lower support
h_1 = 8,5m - distance between wind force acting on the column and counterweight
h_2 = 6,5m - distance between counterweight centre and lower support
r = 1,5m - radius of circular ring

Pressure forces of supporting wheels acting on the ring, and peripheric and radial force of gear are presented although the calculation has not been shown here:

F= 270kN - force acting on a supporting wheel,
F_o = 96kN - peripheric force acting on the gear,
F_r = 35 kN - radial force acting on the gear.

The analysis of the ring loads is done at the part of the ring between two joints (A and B).

The values of moment X_1 at any cross section of the ring are determined if the first equation from equation system (1) is used. Diagram (fig.5) shows the calculation results of moment X_1 at ring cross sections A, 1, 2, 3 and B. Maximum value is at point 2:

$$X_{1,max} = \left(\frac{X_1}{r}\right)\cdot r = 110.51\cdot 150 = 16576.5\ kNcm$$

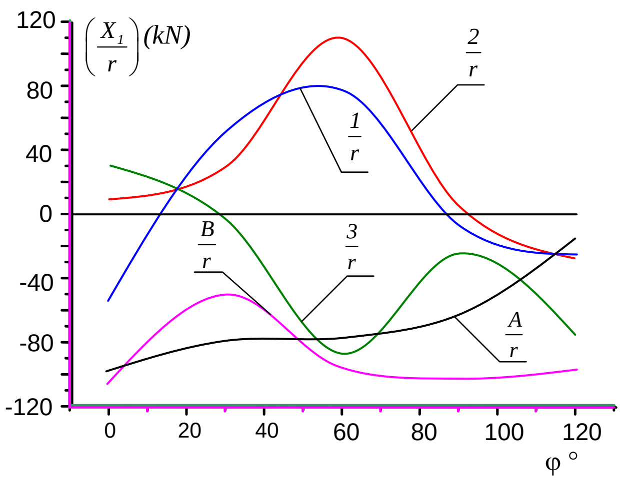


Fig. 5

The values of axial forces X_2 at any cross section of the ring are determined if the second equation from equation system (1) is used. Diagram (fig.6) shows the values for ring cross sections A, 1, 2, 3 and B.

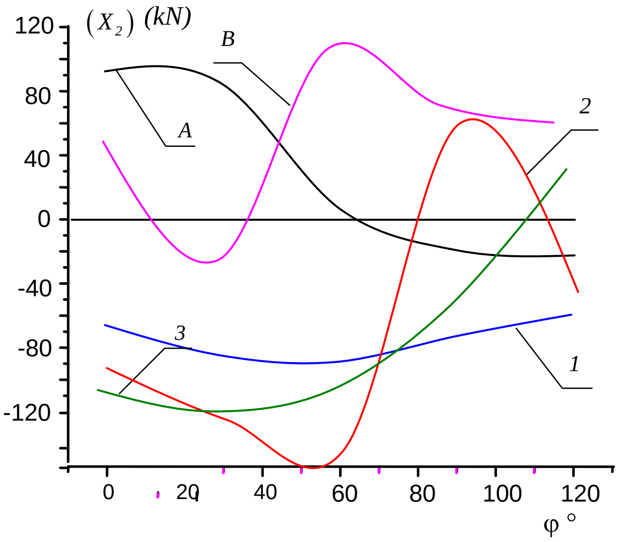


Fig. 6

The values of transversal forces X_3 at any cross section of the ring are determined if the third equation from equation system (1) is used. Fig.7 shows the calculation results of points A, 1, 2, 3 and B.

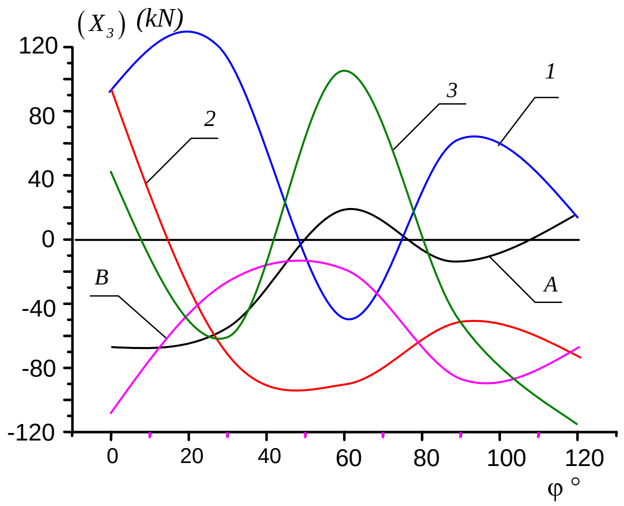


Fig. 7

The loads of ring, circular track and big gear are small in comparison to the loads at horizontal plane, so these influences are neglected, i.e. the moments X_1 and X_2 and force X_3 are not presented in the paper.

If loads are presented for that position of supporting wheel by means of FME, we get the following results (Table 1). These results are also maximum values of X_1, X_2 and X_3.

	Point	Axial force, kN	Transversal force, kN	Moment, kNm
FME	2	- 148,623	- 91,088	16634,260
Theoretical calculation	2	- 148,10	- 91,28	16576,50

Table 1

It should be mentioned that the values of X_1, X_2 and X_3 for points (A, 1, 3 and 4) are approximately equal to the values obtained by FME (deviations less than 10%).

4. CONCLUSION

If the calculation results of circular ring at portal cranes having a column are analysed by theoretical expressions for ring calculation, they fully correspond with the calculation results obtained by FME. This conclusion is very important because theoretical analysis of ring loads can be done with the influence of various parameters being significant for decreasing the ring stress.

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