# CHECKING THE STABILITY OF A TRUCK MOUNTED CRANE AND DETERMINING THE REACTION FORCES IN THE SUPPORTS

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**ABSTRACT**. A methodology for the calculation of the mechanism for side movement and stretching of the supports of truck mounted cranes is developed. Checks are made for the stability of a truck mounted crane with load (at maximum range) and without load (at minimum range). The paper determines the turnover and establishes moments of the gravity and wind forces upon the boom, the platform, the load, the counterweight, and the truck, as well as the inertial and centrifugal forces upon the load. Two cases are considered - at maximum and at minimum length of the boom. The reaction forces in the left and the right hydraulic supports of the crane in the four end positions of the load are determined, which are obtained at minimum and maximum angle of inclination of the boom and at maximum and minimum length of the boom.
A concrete example for the KC-45717 crane mounted on the chassis of a KamAZ truck is solved.

**Keywords:** hydraulic support, load stability, own stability, reaction force

**ПРОВЕРКА НА УСТОЙЧИВОСТТА НА АВТОМОБИЛЕН КРАН И ОПРЕДЕЛЯНЕ НА РЕАКЦИИТЕ В ОПОРИТЕ**

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**РЕЗЮМЕ**. Разработена е методика за изчисляване на механизма за изнасяне и разпъване на страничните опори на автокранове. В настоящата статия са направени проверки на товарната (при максимален обсег) и собствената (при минимален обсег) устойчивост на автомобилен кран. Определени са обръщащите и установяващите моменти от силите на тежестта и вятъра върху стрелата, платформата, товара, противотежестта и ходовата част на крана и от инерционната и центробежната сила върху товара. Разгледани са два случая - при максимална и при минимална дължина на стрелата. Определени са опорните реакции в левите и десните изнесени хидравлични опори при четирите крайни положения на товара, които се получават при минимален и максимален ъгъл на наклон на стрелата и при максимална и минимална дължина на стрелата.
Решен конкретен пример за кран КС-45717, монтиран на автомобилно шаси КамАЗ.

**Ключови думи:** хидравлична опора, товарна устойчивост, собствена устойчивост, опорна реакция

## Introduction

The mobile cranes are automotive boom slewing cranes which move on railless tracks. They are used for assembly and load handling operations in the construction, industrial, and mining enterprises. The mobile cranes are mounted on standard trucks or on special truck or crawler chassis. They have great maneuverability and travelling speed and quickly change over from working- to transport position. In order to assure enough stability during operation, additional side supports are let down.

The aim of the present work is to determine the coefficients of load stability and the reaction forces in the supports at various lengths and angles of inclination of the boom. A concrete example for a truck mounted crane is solved.

As a result of the accomplished study, a methodology for the calculation of the mechanism for side shifting and stretching of the supports of mobile cranes is developed (choice of hydraulic supports and hydraulic cylinders for their side movement, time for the stretching and shifting of the supports, work liquid consumption).

In order to choose hydraulic supports, it is necessary to determine the reaction forces in the supports when the crane is in work position. On the other hand, in order to determine the reaction forces, it is necessary to determine in advance the mass of the counterweight and the distance between the left and right supports.

Therefore, when the mass of the counterweight and the distance between the supports are given, checks for the crane load and own stability are performed; after that the reaction forces in the supports are determined.

## Input data

The input data for the check of the crane stability and for determining the support reaction forces are (http://www.uks76.ru/upload/docs/Rukovodstvo_po_ekspluatatsii_KS-45717K-2.pdf):
- length of the boom $L$=9÷21 m;
- angle of inclination of the boom $\beta$=5÷75°;
- maximum lifting capacity of the crane at $L$=9 m and $\beta$=75° $Q_1$=25 t;
- lifting capacity of the crane at $L$=9 m and $\beta$=5° $Q_2$=6.35 t;
- lifting capacity of the crane at $L$=21 m and $\beta$=75° $Q_3$=6.35 t;

- lifting capacity of the crane at $L$=21 m and $\beta$=5° $Q_4$=0.9 t;
- mass of the boom $m_c$=1990 kg;
- mass of the slewing platfom $m_o$=5100 kg;
- mass of the hook block $m_{рб}$=306 kg;
- mass of the counterweight $m_n$=357 kg;
- mass of the unslewing part of the crane $m_н$=14.27 t;
- slope angle of the ground when the supports are not shifted aside $\theta$=0÷3° (Fig.1 and 2);
- slope angle of the ground when the supports are shifted aside $\theta$=0÷1.5°;
- distance between the axis of the side shifted hydraulic support and the slewing axis of the crane $a$=2.8 m (Fig.1);
- distance between the axis of symmetry of the front wheel and the slewing axis of the platform $a'$=1.013 m (Fig.2);
- speed of load hoisting $v$=6.1 m/min;
- slewing speed of the platform $n$=0÷2.4 min$^{-1}$.

## Check of the crane load stability

The crane load stability (Fig.1) is checked at maximum working radius of the crane (minimum angle of inclination of the boom $\beta$=5°) in a working position with stretched side supports and maximum permissible slope angle of the ground $\theta$=1.5°. The turnover and stabilise moments of all forces are determined toward point $B$ in which the right hydraulic supports contact with the ground.

Two cases are considered: at maximum boom length $L$=21m and lifting capacity $Q$=$Q_4$=0.9t; and at boom length $L$=9m and lifting capacity $Q$=$Q_2$=6.35t.

**Turnover moment from the normal components of the gravity forces of the load, the hook block, and the boom (perpendicular to the ground plane)**

$$M_{обр1} = \left(G_m + G_{рб}\right).\left(l_m - a\right).\cos\theta + G_c.\left(l_c - a\right).\cos\theta \quad (1)$$

$$M_{обр1} = \left(8,8+3\right).\left(20-2,8\right).\cos1,5^\circ + $$
$$+19,5.\left(9,31-2,8\right).\cos1,5^\circ = 329 \text{ kN.m}$$

where:
$G_m$, $G_{рб}$, and $G_c$ [kN] are the gravity forces of the load, the hook block, and the boom (Fig.1) (they are determined by formulae 2÷4);
$l_m$ and $l_c$ [m] are the distances between the applied points of the gravity forces of the load and the boom and slewing axis of the crane (Fig.1) (they are determined by formulae 5 and 6);

$$G_m = Q_4.g = 0,9.9,81 = 8,8 \text{ kN} \quad (2)$$

$$G_{рб} = 0,001.m_{рб}g = 0,001.306.9,81 = 3 \text{ kN} \quad (3)$$

$$G_c = 0,001.m_c g = 0,001.1990.9,81 = 19,5 \text{ kN} \quad (4)$$

$$l_m = L\cos\beta - e + 0,3 = 21.\cos5^\circ - 1,15 + 0,3 = 20 \text{ m} \quad (5)$$

$$l_c = 0,5.L\cos\beta - e = 0,5.21.\cos5^\circ - 1,15 = 9,31 \text{ m} \quad (6)$$

where $e$ [m] is the distance between the crane slewing axis and the boom suspension axis (Fig.1) (it is checked from the drawing of the slewing platform, $e$=1.15m).

**Turnover moment from the tangential components of the gravity forces of the boom, the slewing platform, the unslewing part of the crane, and the counterweight (parallel to the ground plane)**

$$M_{обр2} = \left(G_c.h_c + G_o.h_o + G_н.h_н + G_n.h_n\right).\sin\theta \quad (7)$$

$$M_{обр2} = \left(19,5.3,9 + 50.2,7 + 140.1,5 + 3,5.2,1\right).\sin1,5^\circ = 11 \text{ kN.m},$$

where:
$G_o$, $G_н$, and $G_n$ [kN] are the gravity forces of the slewing platform, the unslewing part of the crane, and the counterweight;
$h_c$, $h_o$, $h_н$, and $h_n$ [m] are the distances between the applied points of the gravity forces of the boom, the slewing platform, the unslewing part of the crane, and the counterweight and the ground plane (Fig.1) ($h_c$ is determined by formula (11), $h_o$, $h_н$ and $h_n$ are checked from the scheme given in Fig.1, proportionally to the boom length $L$=21m: $h_o$=2.7m; $h_н$=1.5m; and $h_n$=2.1m);

$$G_o = 0,001.m_o.g = 0,001.5100.9,81 = 50 \text{ kN} \quad (8)$$

$$G_н = m_н.g = 14,27.9,81 = 140 \text{ kN} \quad (9)$$

$$G_n = 0,001m_n.g = 0,001.357.9,81 = 3,5 \text{ kN} \quad (10)$$

$$h_c = 0,5.L.\sin\beta + h_{oc} = 0,5.21.\sin5^\circ + 3,05 = 3.9 \text{m}, \quad (11)$$

where: $h_{oc}$ [m] - distance between the axle of suspension of the boom and the ground plane (it is checked by the scheme given on Fig.1, $h_{oc}$=3,05 m).

**Turnover moment from the wind forces on the load, the boom and the slewing platform**

$$M_{обр3} = P_m.h_m + P_c.h_c + P_o.h_o \quad (12)$$

$$M_{обр3} = 0,3.3,3 + 0,1.3,9 + 0,2.2,7 = 1 \text{ kN.m}$$

where:
$P_m$, $P_c$, and $P_o$ [kN] are the wind forces on the load, the boom, and the slewing platform (Fig.1) (they are determined by formulae 13÷15);
$h_m$ [m] is the distance between the applied point of the gravity force and the ground plane (Fig.1) (it is determined by formula 16);

$$P_m = A_m.q.k_з.c = 2,5.0,09.1.1,2 = 0,3 \text{kN} \quad (13)$$

$$P_c = A_c.q.k_з.c = 0,78.0,09.1.1,4 = 0,1 \text{kN} \quad (14)$$

$$P_o = A_o.q.k_з.c = 2,1.0,09.1.1,4 = 0,2 \text{ kN} \quad (15)$$

$$h_m = L\sin\beta + h_{oc} - 1,5 = 21.\sin5^\circ + 3,05 - 1,5 = 3,3 \text{ m} \quad (16)$$

where:
$A_m$ [m$^2$] is the wind-beaten area of the load (it is taken from Table1 according to the lifting capacity of the crane). At $Q$=0.9t $A_m$=2,5 m$^2$;
$q$ [kPa] is the wind pressure at normal loading in work position ($q$=0.09 kPa);
$k_з$ is the filling coefficient of the crane construction (for loads and whole wall constructions $k_з$=1; for rod constructions $k_з$=0.2÷0.6). For the calculated crane $k_з$=1;
$c$ is an aerodynamic coefficient ($c$=1.4 for the boom and the platform; $c$=1.2 for the load);

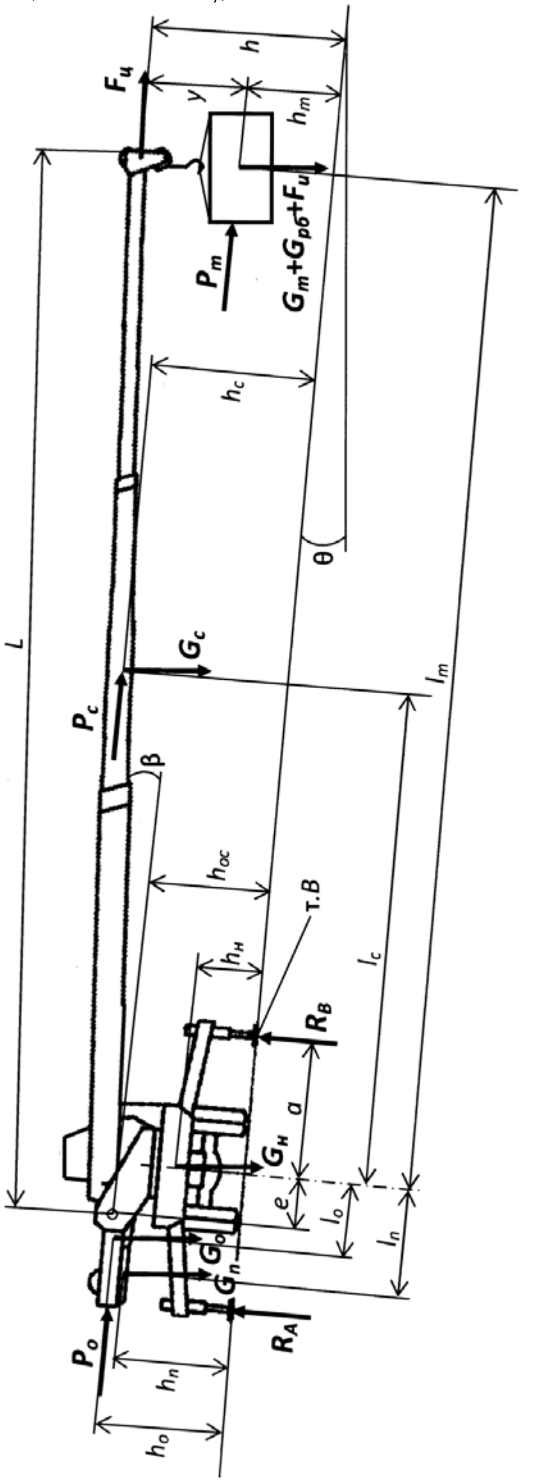


Fig.1. Scheme for determining the load stability and the reaction forces in the side supports of the crane

$l_n$, $l_o$, $l_c$, and $l_m$ are the distances between the applied points of the gravity forces of the counterweight, the platform, the boom, and the load and the slewing axis;
$e$ is the distance between the axis of boom suspension and the slewing axis;
$a$ is the distance between the slewing axis and the side shifted support;
$h_n$, $h_o$, $h_н$, $h_c$, and $h_m$ are the distances between the applies points of the gravity forces of the counterweight, the platform, the unslewing part of the crane, and the boom and the load and the ground plane;
$h_{oc}$ is the distance between the axis of boom suspension and the ground plane;
$h$ is the distance between the top of the boom and the ground plane;
$y$ is the distance between the gravity center of the load and the top of the boom;
$L$, $\beta$ are the length and the angle of inclination of the boom;
$\theta$ is the ground slope angle;
$G_n$, $G_o$, $G_н$, $G_c$, $G_m$, and $G_{рб}$ are the gravity forces of the counterweight, the platform, the unslewing part of the crane, the boom, the load, and the hook block;
$P_o$, $P_c$, and $P_m$ are the wind forces on the platform, the boom, and the load;
$F_ц$, $F_u$ - centrifugal force and force of inertia on the load;
$R_A$, $R_B$ - reaction forces in the side shifted supports.

$A_c$ [m$^2$] is the wind-beaten area of the boom (it is determined by formula 17);

Table 1.
*Wind-beaten area of the load $A_m$ according to the lifting capacity of the crane Q*

| Q [t] | 0.8 | 1 | 1.25 | 1.6 | 2 | 2.5 | 3.2 | 4 |
|---|---|---|---|---|---|---|---|---|
| $A_m$ [m$^2$] | 2.5 | 2.8 | 3.2 | 3.6 | 4 | 5 | 5.6 | 6.3 |

| Q [t] | 5 | 6.3 | 8 | 10 | 12.5 | 16 | 20 | 25 |
|---|---|---|---|---|---|---|---|---|
| $A_m$ [m$^2$] | 7.1 | 8 | 9 | 10 | 12 | 14 | 16 | 18 |

$$A_c = L.b_c.\sin\beta = 21.0,43.\sin 5^\circ = 0,78\ \text{m}^2, \qquad (17)$$

where $b_c$ [m] is the width of the boom ($b_c$=430mm=0.43m - it is checked from the drawing of the boom).

**Turnover moment from the force of inertia and the centrifugal force on the load**

$$M_{обр4} = F_u(l_m - a) + F_ц.h = 0{,}09.(20-2{,}8) + 11{,}1.4{,}8 = 54\ \textbf{kN.m}, \qquad (18)$$

where:
$F_u$ [kN] is the force of inertia from the load hoisting (Fig.1), (it is determined by formula 19);
$F_ц$ [kN] is the centrifugal force from the crane slewing (Fig.1), (it is determined by formula 20);
$h$ [m] is the distance between the applied point of the centrifugal force and the ground plane (Fig.1) (it is determined by formula 21);

$$F_u = Q_4 \frac{V}{60.t_n} = 0{,}9.\frac{6{,}1}{60.1} = 0{,}09\ \text{kN} \qquad (19)$$

$$F_{ц} = \frac{Q_4.g.\omega^2.l_m}{g-\omega^2.y} = \frac{0,9.9,81.0,25^2.20}{9,81-0,25^2.2,5} = 11,1\,\text{kN} \quad (20)$$

$$h = L.\sin\beta + h_{oc} = 21.\sin 5^\circ + 3,05 = 4,8\text{ m}, \quad (21)$$

where:
$t_n$ [s] is the starting time of the hoisting mechanism (it is assumed as the minimum permissible time, i.e. $t_n$=1s);
$\omega$ [rad/s] is the angular speed of the platform (it is determined by formula 22);
$y$ [m] is the distance between the gravity center of the load and the top of the boom (Fig.1) (it is assumed $y$=2.5m according to the scheme in Fig.1).

$$\omega = \frac{\pi.n}{30} = \frac{3,14.2,4}{30} = 0,25\text{ rad/s} \quad (22)$$

**Total turnover moment**

$$M_{обр} = M_{обр1} + M_{обр2} + M_{обр3} + M_{обр4} = 329+11+1+54 = 395\,\text{kN.m} \quad (23)$$

**Stabilise moment from the gravity forces of the counterweight, the slewing platform, and the unslewing part of the crane**

$$M_{уст} = G_n\,(l_n + a).\cos\theta + G_o.(l_o + a).\cos\theta + G_H.a.\cos\theta$$

$$M_{уст} = 3,5(2,2+2,8).\cos 1,5^\circ + 50.(1,3+2,8).\cos 1,5^\circ + $$
$$+140.2,8.\cos 1,5^\circ = 614\text{ kN.m}, \quad (24)$$

where:
$l_n$ [m] is the distance between the gravity center of the counterweight and the slewing axis of the crane (Fig.1) (it is assumed from the drawing of the platform, $l_n$=2.2m);
$l_o$ [m] is the distance between the gravity center of the platform and the slewing axis (Fig.1) (it is assumed from the drawing of the crane, $l_o$=1.3m).

**Check of the coefficient of load stability**

$$k_{my} = \frac{M_{уст}}{M_{обр}} = \frac{614}{395} = 1,55 \geq 1,15 \quad (25)$$

For the second case of loading at $L$=9m, $\beta$=5°, $Q$=$Q_2$=6.35t and $A_m$=8m$^2$, it is received: $M_{обр1}$=356kN.m; $M_{обр2}$=10kN.m; $M_{обр3}$=2kN.m; $M_{обр4}$=124kN.m; $M_{обр}$=492kN.m; $M_{уст}$=606kN.m; $k_{my}$=1.23. Consequently, the condition (25) is also satisfied.

## Check of the crane own stability

The crane own stability (Fig.2) is checked at minimum working radius of the crane (minimum boom length $L$=9m and maximum angle of inclination of the boom $\beta$=75°), load free position with unstretched side support, maximum permissible slope angle of the ground $\theta$=3°, and wind pressure $q$=0.7kN/m$^2$ (the wind pressure is assumed for maximum loading in load free position). The turnover and stabilise moments of all forces are determined toward point $A$ in which the left front wheel of the truck contacts with the ground.

**Turnover moment from the normal components of the gravity forces of the slewing platform and the counterweight (perpendicular to the ground plane)**

$$M'_{обр1} = G_o.(l_o - a').\cos\theta + G_n.(l_n - a').\cos\theta \quad (26)$$

$$M'_{обр1} = 50.(1,3-1,013).\cos 3^\circ + 3,5(2,2-1,013).\cos 3^\circ = 18\,\text{KN.m}$$

**Turnover moment from the tangential components of the gravity forces of the boom, the slewing platform, the unslewing part of the crane and the counterweight (parallel to the ground plane)**

$$M'_{обр2} = (G_c.h_c + G_o.h_o + G_H.h_H + G_n.h_n).\sin\theta \quad (27)$$

$$M'_{обр2} = (19,5.7,3+50.2,7+140.1,5+3.2,1).\sin 3^\circ = 25\,\text{KN.m},$$

where:

$$h_c = 0,5.L.\sin\beta + h_{oc} = 0,5.9.\sin 75^\circ + 3,05 = 7,3\text{ m}, \quad (28)$$

**Turnover moment from the wind forces on the boom 28and the slewing platform**

$$M'_{обр3} = P_c.h_c + P_o.h_o = 3,7.7,3 + 2.2,7 = 32\text{ kN.m} \quad (29)$$

where:

$$P_c = A_c.q.k_3.c = 3,73.0,7.1.1.4 = 3,7\text{ kN} \quad (30)$$

$$P_o = A_o.q.k_3.c = 2,1.0,7.1.1.4 = 2\text{ kN} \quad (31)$$

$$A_c = L.b_c.\sin\beta = 9.0,43.\sin 75^\circ = 3,73\text{ m}^2 \quad (32)$$

**Total turnover moment**

$$M'_{обр} = M'_{обр1} + M'_{обр2} + M'_{обр3} = 18+25+32 = 75\text{ kN.m} \quad (33)$$

**Stabilise moment from the gravity forces of the boom and the unslewing part of the crane**

$$M'_{уст} = G_c.(l_c + a').\cos\theta + G_H.a'.\cos\theta \quad (34)$$

$$M'_{уст} = 19,5.(0,01+1,013).\cos 3^\circ + 140.1,0.13.\cos 3^\circ = 161\,\text{kN.m}$$

where:

$$l_c = 0,5.L.\cos\beta - e = 0,5.9.\cos 75^\circ - 1,15 = 0,015\text{ m} \quad (35)$$

**Check of the coefficient of own stability**

$$k_{cy} = \frac{M'_{уст}}{M'_{обр} =} = \frac{161}{67} = 2,14 \geq 1,15 \quad (36)$$

## Reaction forces in the side shifted hydraulic supports

### Reaction forces in the left hydraulic supports

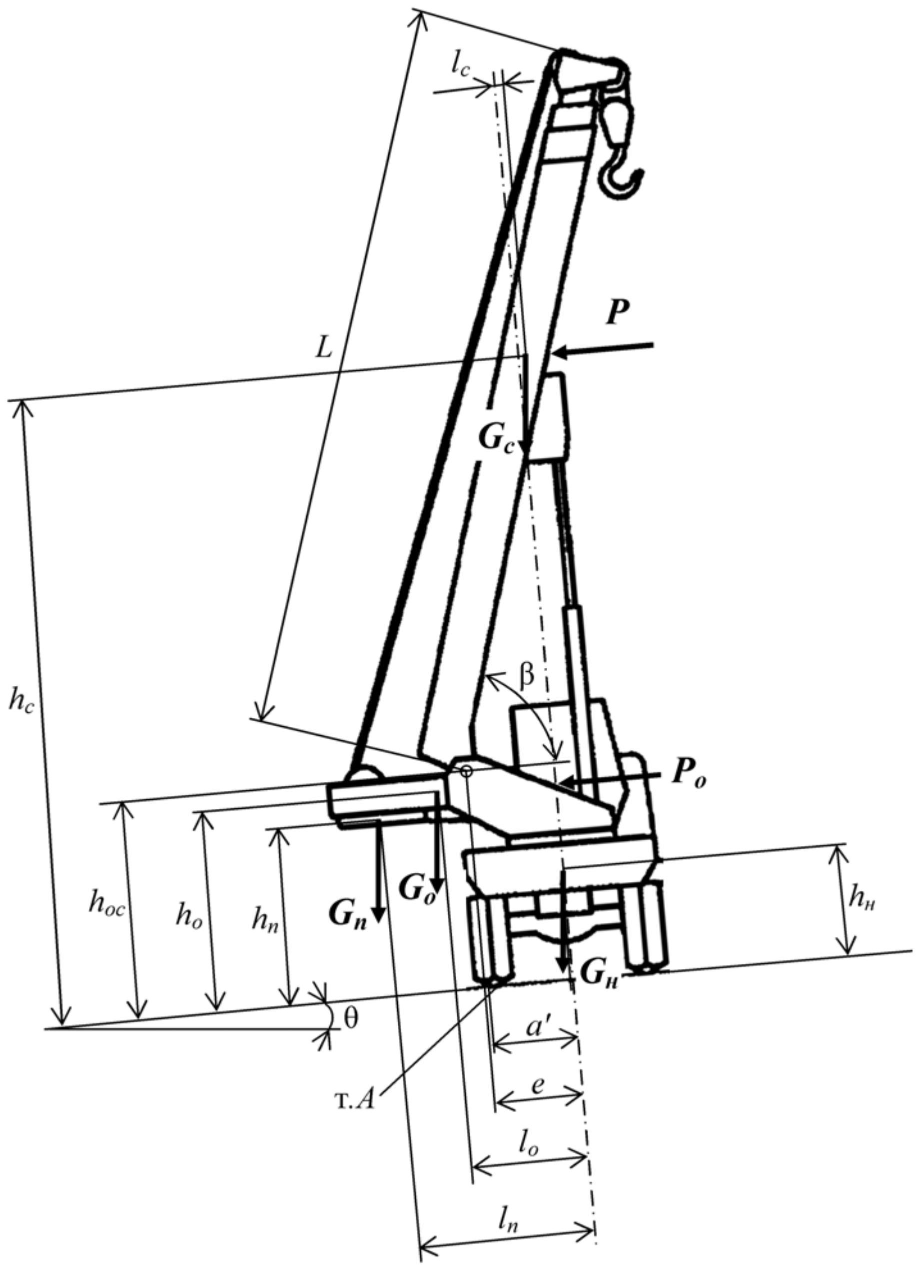


**Fig. 2. Scheme for determining the own stability of the crane**

$h_n$, $h_o$, $h_н$, and $h_c$ are the distances between the applies points of the gravity forces of the counterweight, the platform, the unslewing part of the crane, and the boom and the ground plane;
$h_{oc}$ is the distance between the axis of boom suspension and the ground plane;
$l_n$, $l_o$,, and $l_c$ are the distances between the applied points of the gravity forces of the counterweight, the platform, and the boom and the slewing axis;
$e$ is the distance between the axis of boom suspension and the slewing axis;
$a'$ is the distance between the axis of symmetry of the front wheel and the axis of rotation of the platform;
$L$ and $\beta$ are the length and the angle of inclination of the boom;
$G_n$, $G_o$, $G_н$, and $G_c$ are the gravity forces of the counterweight, the platform, the unslewing part of the crane, and the boom;
$P_o$ and $P_c$ are the wind forces on the platform and the boom;
$\theta$ is the ground slope angle.

$$R_A = \frac{M_{уст} - M_{обр}}{4.a} = \frac{614-395}{4.2,8} = 19 \text{ kN} \qquad (37)$$

**Reaction forces in the right hydraulic supports**

$$R_B = \frac{G_{кран} - 2.R_A}{2} = \frac{224-2.18}{2} = 93 \text{ kN}, \qquad (38)$$

where $G_{кран}$ [kN] is the gravity force of the crane with the load (it is determined by formula 39);

$$G_{кран} = G_н + G_o + G_c + G_n + G_{рб} + G_m \qquad (39)$$

$$G_{кран} = 140 + 50 + 19,5 + 3,5 + 3 + 8,8 = 224 \text{ kN}$$

The results from the calculation of the reaction forces $R_A$ and $R_B$ (Fig.1) for the forth end positions of the load are given in Table 2.

Table 2a.
*Reaction forces in the side supports for the forth end positions of the load*

| Load position | *L* [m] | *β* [°] | *Q* [t] | $M_{уст}$ [kN.m] |
|---|---|---|---|---|
| 1 | 9 | 75 | 25 | 614 |
| 2 | 9 | 5 | 6.35 | 614 |
| 3 | 21 | 75 | 6.35 | 614 |
| 4 | 21 | 5 | 0.9 | 614 |

Table2b.

| Load position | $M_{обр}$ [kN.m] | $G_{кран}$ [kN] | $R_A$ [kN] | $R_B$ [kN] |
|---|---|---|---|---|
| 1 | -114 | 461 | 65 | 165 |
| 2 | 492 | 278 | 10 | 129 |
| 3 | 552 | 278 | 4 | 135 |
| 4 | 395 | 222 | 19 | 93 |

From Tables 2a and 2b, it is clear that the maximum reaction force is received in the right support *B* at load condition 1 which is $R_B$=165kN. The value of this reaction must be used for determining the piston diameter of the hydraulic supports.

## Conclusions

1. In the calculations made for determining the coefficient of load stability of the crane for the two considered cases (maximum working radius of the crane with maximum boom length and maximum working radius with minimum boom length), it is received that, in the second case, the coefficient of load stability is smaller. But in both cases, the coefficient of load stability is greater than the minimum permissible coefficient.

2. In the calculations made for the forth end positions of the load, the maximum reaction forces are received in the right hydraulic supports (situated on the side of load lifting) at minimum boom length, maximum angle of inclination of the boom, and maximum lifting capacity.

3. For the calculated truck mounted crane, the permissible lifting capacities and the counterweight mass are chosen correctly, since as the checks of the load and own stability are satisfied.

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