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Investigation and Calculation of Power Parameters of Hinged Gate System for Slag Cut-Off when Steel Tapping from Basic-Oxygen Converter

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The design features are described and results of theoretical and experimental investigation of parameters of mechanical hinged gate system intended for technological slag cut-off when steel tapping from basic-oxygen converter into steel teeming ladle are presented.

Keywords: POWER PARAMETERS, SLAG CUT-OFF, CONVERTER, HINGED GATE SYSTEM

Introduction

Creation of equipment that allows preventing entry of considerable amount of aggressive converter slag into teeming ladle during hot metal tapping is one of priorities in steelmaking [1]. In this conjunction, various systems of slag melt cut-off have been developed and patented for the last decade. They differ by design and operating principle, however, only three of them were applied in current oxygen-converter plants. Thus there are considered either installation of sliding shutter on the melting unit body or lock tilting mechanism for closing outlet or addition of cutting-off element into converter bath which is floating on the interface slag-metal and clogs the hole [2].

Expediency of using sliding gate for converter slag cut-off was proved by foreign companies Salzgitter AG, Stopinc AG and RHI Refractories. They have developed a sliding shutter which is successfully operating on 210-ton basic-oxygen converter for a long time.

Application of sliding gate as final technological slag cut-off system assumes high-sensitivity control and measuring equipment instrumentation for early detection of slag inclusions in metal as well as a powerful drive. This drive should be placed below a mantle ring of basic-oxygen converter. Otherwise, drive power-unit will be subjected to intensive thermal loading that has a negative effect on its working capacity.

Operation of such system requires performance of the corresponding scope of work related to replacement of worn-out refractory products and drive repair. A self-moving transport facility supplied with manipulator is necessary for service of the gate with considerable weight. One of substantial problems is time shortage when replacing the gate [2].

In order to reduce the duration of preparation for work and installation of slag cut-off device on a basic-oxygen converter, it is suggested to install a hinged gate, useful area of which refractory plate increases in 3 times which will increase the frequency rate of application of gate ceramic elements.

Theoretical and experimental investigation was necessary as there was no operating experience of hinged gate as a production unit of basic-oxygen converter as well as procedure of its power parameters calculation.

Results and Discussion

In theory, the primary task is to obtain interrelations for accurate computation of technological loading acting on the elements of hinged gate during its operation and to determine the drive power. Laboratory and industrial experiments are necessary in order to check accepted engineering solutions.

According to kinematic scheme of the gate introduced in **Figure 1**, the static moment of resistance to moving bearing body 3 placed in body 2 on the rolling-contact bearing 4 is caused by resistance forces acting between bearing surfaces of refractory plates 1, 6 during their relative motion and breaking of metal sinterskin 5 appeared on the outlet walls.

$$M_s = M_p + M_{fr1} + M_{fr2} \quad \text{(Eq. 1)}$$

where M_p - resisting moment caused by force necessary for cutting of metal sinterskin appeared on the outlet walls; M_{fr1} - resisting moment caused by friction force between the contact surfaces of refractory plates at their relative motion; M_{fr2} - resisting moment in the bearing assembly of gate moving bearing body.

The moment related to breaking of metal sinterskin on the walls of steel-tapping hole is caused by action of shear force (**Figure 2a**) and can be computed as:

$$M_b = F_b \cdot r \quad \text{(Eq. 2)}$$

where F_p - force necessary for breaking of metal sinterskin; r - turn radius of hole centre of refractory plate in relation to axis of rotation.

We can use interrelation presented in [3] for definition of F_b force value:

$$F_b = \alpha \cdot \sigma_B \cdot S_b \quad \text{(Eq. 3)}$$

where α - factor equal to ratio between the maximum shearing strength of sinterskin material to its ultimate stress limit; $\sigma_в$ - ultimate strength of steel crystallized on the walls of steel-tapping hole; S_b - cross-sectional area of cut sinterskin.

Cross-sectional area of cut metal sinterskin in the gate channel is as follows:

$$S_b = \pi (D_c \delta - \delta)^2 \quad \text{(Eq. 4)}$$

where D_c - diameter of gate channel on the contact area of working surfaces of refractory plates, δ - thickness of metal sinterskin. We accept α = 0.6; $\sigma_в$ = 60-90 MPa. When determining refractory plate turn resisting moment caused by friction, we assume that pressure p on its round working surface with radius R induced by action of compression force Q is distributed uniformly, i.e. :

$$p = Q/(\pi R^2) = const. \quad \text{(Eq. 5)}$$

We will define a circle $d\rho$ wide and with internal radius ρ as shown in **Figure 2b** on the plate surface. The elementary moment of friction forces:

$$dM_{fr1} = dF_{fr1} \cdot \rho \quad \text{(Eq. 6)}$$

where dF_{fr1} – elementary friction force that appears in the circle area at plate rotation.

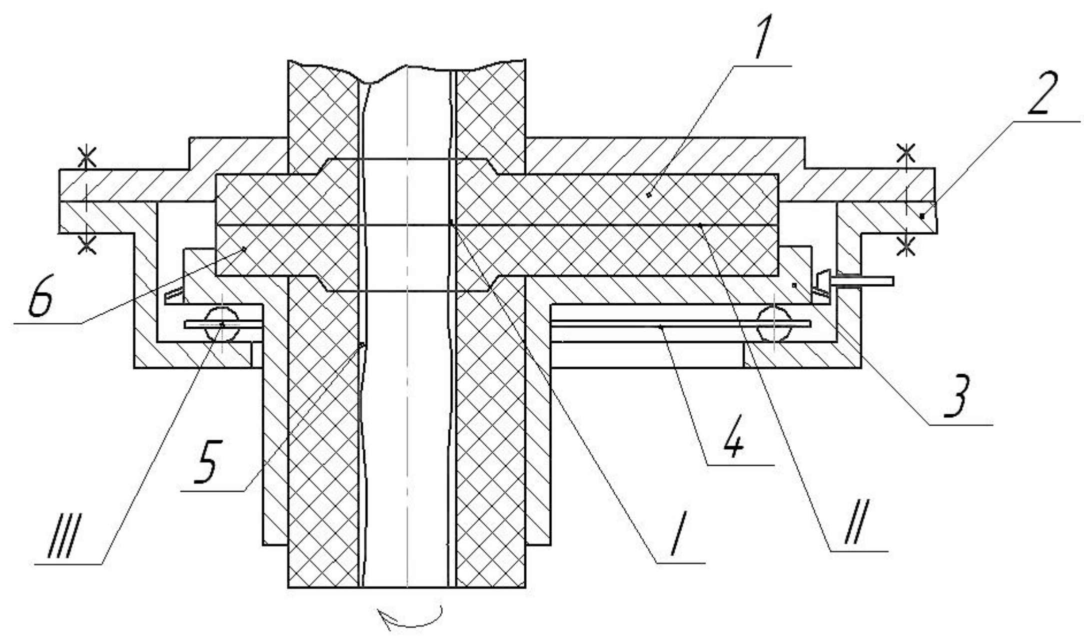

Figure 1. Kinematic scheme of hinged gate with identification of zones, in which the components of static moment of resistance to moving bearing body act: 1 - refractory plate, 2 - gate body, 3 - moving bearing body, 4 - rolling-contact bearing, 5 - metal sinterskin, 6 - refractory plate

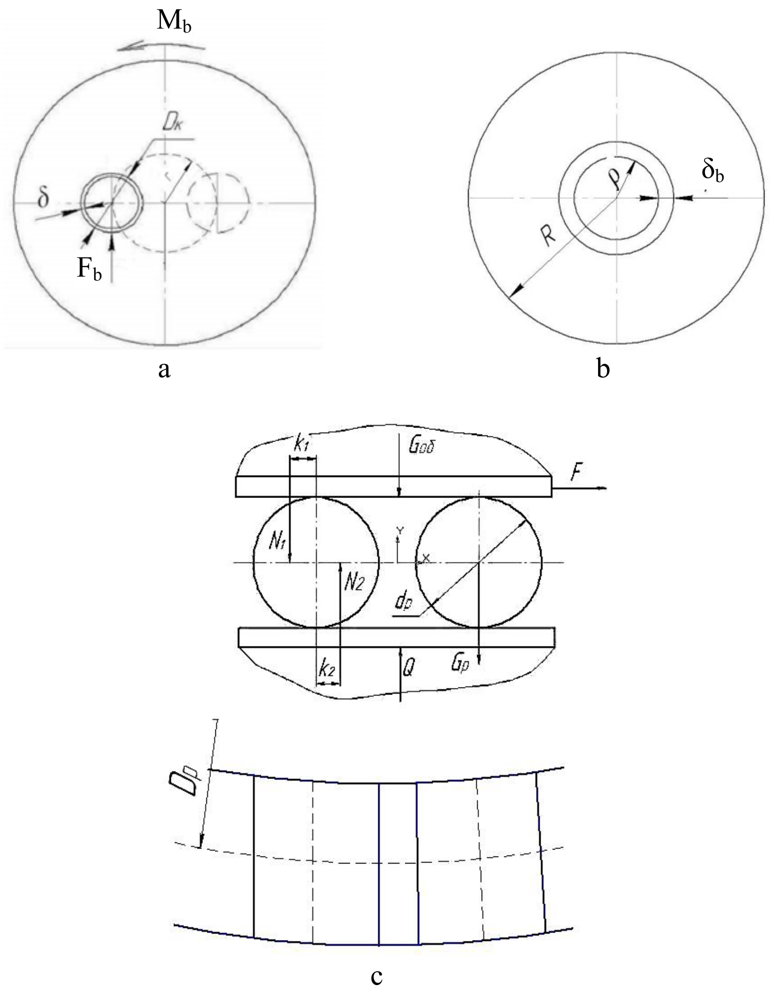

Figure 2. Computational models for definition of components of static moment of resistance to moving bearing body caused by force action: *a* - metal sinterskin cutting; *b* - force of sliding friction between contact surfaces of refractory plates during their relative motion; *c* - rolling friction in bearing assembly

According to classic friction theory:

$$dF_{fr1} = f_o \cdot dN \quad \text{(Eq. 7)}$$

where f_o – coefficient of sliding friction between working surfaces of refractory plates; dN – axial elementary force acting on the circle.

$$dN = p \cdot dS \quad \text{(Eq. 8)}$$

where dS – area of selected circle.

$$dS = 2\pi \rho \, d\rho \quad \text{(Eq. 9)}$$

$$dM_{fr1} = 2\pi f_o p\rho^2 \, d\rho \quad \text{(Eq. 10)}$$

To determine the total friction moment in the beginning of refractory plate motion we will take the integral of expression 10:

$$M_{fr1} = \int_0^R dM_{fr1} = 2\pi f_0 p \int_0^R \rho^2 d\rho = \frac{2}{3}\pi f_0 p R^3 = \frac{2}{3} Q f_0 R \quad \text{(Eq. 11)}$$

Resistance in the roller bearing at motion of moving bearing body is caused by rolling friction in pairs: roller – supporting surface of bearing body, roller - supporting surface of body (**Figure 2c**).

We will define the moving force F which should be applied to moving bearing body for its uniform rotation in a horizontal plane. There are following symbols on presented scheme: Q - required pressing force of refractory plates; G_{gr} - gravity force of moving member of the gate, G_r - total gravity force of rollers, N_1 and N_2 -

reactions of upper and lower supporting surfaces in points of contact with roller, respectively; d_r - roller diameter; κ_1 - coefficient of rolling friction between roller and supporting surface of moving bearing body, κ_2 - coefficient of rolling friction between roller and supporting surface of gate body.

We conditionally apply all the forces to one roller and set up a balance equation:

$$M_F = M_{k1} + M_{k2} \quad \text{(Eq. 12)}$$

where $M_F = Fd_r$ – drive moment; $M_{k1} = N_1\,\kappa_1 = (Q - G_{gr})\,\kappa_1$ - moment of rolling friction between roller and supporting surface of moving bearing body; $M_{k2} = N_2\,\kappa_2 = (Q - G_{gr} - G_r)\,\kappa_2$ - moment of rolling friction between roller and supporting surface of gate body.

Required pressing force of refractory plates according to recommendations [4] should not exceed permissible load Q_{perm} at which maximum allowed stresses occur. Therefore we can accept $Q = (0.7\text{-}0.8)\ Q_{perm}$. Value Q_{perm} should be set with account of strength characteristics of refractory material and its basic geometric parameters (length, width and thickness). For round ceramic plates with longitudinal size to 500 mm and thickness within 40-60 mm Q_{perm} = 60-100 kH.

Having substituted the values of moments in equation 12 and accepting that the total gravity force of rollers is substantially small as compared to other forces, we will obtain:

$$F = (k_1 + k_2)\,(Q - G_{gr})/\,d_r \quad \text{(Eq. 13)}$$

Then, resisting moment in bearing assembly of moving bearing body will be:

$$M_{fr2} = F\,D_r/2 \quad \text{(Eq. 14)}$$

where D_r – roller cage diameter.

According to recommendations in [4], we can accept the values of coefficients in the equations (10) and (13) as follows: f_o = 0.3-0.7; $k_1 = k_2$ = 0.10-0.15 mm.

The static moment from technological loading applied to motor shaft is:

$$M_{st} = M_s/(u_o\,\eta_o) \quad \text{(Eq. 15)}$$

where u_o - total gear ratio of mechanism; η_o – overall efficiency of mechanical system.

Total gear ratio of mechanism is:

$$u_o = \omega/\omega_m \quad \text{(Eq. 16)}$$

where ω - angular speed of motor shaft; ω_m - angular speed of moving bearing body of the gate defined as a ratio of rotation angle φ to time period t_3.

Inertia moment acts on the gate drive in transition periods along with static moment:

$$M_{dyn} = I_{red}\,d\omega/dt \quad \text{(Eq. 17)}$$

where I_{red} - joint inertia of gyrating masses of mechanical system reduced to motor shaft; $d\omega/dt$ - angular acceleration of motor shaft.

With constant acceleration, the inertia moment is defined by formula:

$$M_{dyn} = I_{red}\,(\pm\,\omega/t_{trans}) \quad \text{(Eq. 18)}$$

where t_{trans} - duration of transition period.

We reduce the inertia moments of gyrating masses proceeding from condition of equality of equivalent system kinetic energy and valid mechanism.

To estimate the correctness of obtained interrelations for calculation of parameters of hinged gate, we computed and created its physical analogue, on which carried out the test measurements of characteristics under investigation. After that we compared their theoretical and experimental values. The basic geometric parameters of elements of gate analogue were as follows: R = 135 mm, D_c = 40 mm, r = 30 mm, D_r = 200 mm, d_r = 20 mm.

Behavior of rotational moment necessary for rotation of moving bearing body with bottom refractory plate was studied in laboratory experiments, and also relationship between static and dynamic loads acting on the drive under various conditions of contact of sliding system elements was estimated. Static resistance acting on the elements of gate analogue and caused by friction forces were provided by creation of compressive load developed by three coiled springs of supporting node.

For modeling of loading related to breaking of metal sinterskin appeared on the walls of steel-tapping hole, leaded stopper was installed in it during laboratory experiment. Flow characteristics of lead in solid condition allow simulating steel at its chilling temperature. Stopper wall thickness was 4 mm. Type of signal registered at control of resisting moment in case of pressing force Q = 10 кH is presented in **Figure 3**.

Comparison of results of measuring the rotational moment surpassed by drive of hinged gate analogue at different pressing force to computed data accomplished with the use of obtained theoretical interrelations confirmed satisfactory correlation of theoretical $M_{shaft\ red.}$ and experimental $M'_{shaft\ red.}$ values of sliding system (**Table 1**).

Results of theoretical and laboratory research were used when working out and designing of production equipment prototype of hinged gate intended for 60-ton basic-oxygen converter.

Technical characteristic of developed hinged gate system

Electromechanical drive	
Type of motor	asynchronous
Power of motor, kW	3
Rotation frequency, min^{-1}	750
Weight, kg	50
Type of reduction unit	double-reduction right-angle
Gear ratio of reduction unit	8.5
Maximum rotational moment on output shaft, N·m	350
Weight, kg	190
Hinged gate	
Turn radius of moving bearing body , mm	100
Diameter of refractory plates, mm	450
Gear ratio of beveled gear	9
Action time, c	1.5
Weight, kg	440

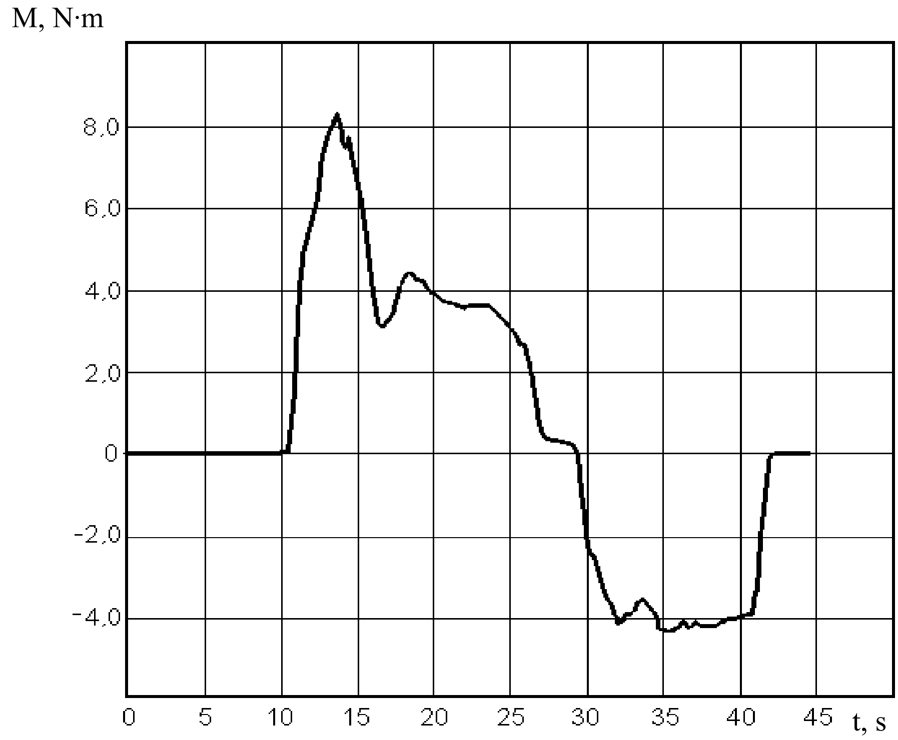

Figure 3. Signal type registered at control of rotational moment caused by drive of hinged gate physical analogue

Table 1. Calculated and experimental values of resisting moments surpassed by drive of hinged gate analogue at different pressing force of its refractory plates

Experiment No.	Q, kN	Calculated values of moments, N·m							Measured values of moments reduced to motor shaft *, N·m		
		M_r	M_{fr1}	M_{fr2}	M_s	M_{st}	M_{shaft}	$M_{shaft\ red.}$	$M'_{shaft\ red.}$	M'_p	$M'_{fr1}+M'_{fr2}$
1	2	475	90	15	580	0.81	0.03	0.84	0.82	0.76	0.06
2	4	475	180	30	685	0.95	0.03	0.98	1.02	0.87	0.15
3	6	475	270	45	790	1.10	0.03	1.13	1.11	0.83	0.28
4	8	475	361	60	896	1.24	0.03	1.27	1.24	0.87	0.37
5	10	475	452	75	1002	1.36	0.03	1.39	1.54	0.87	0.67

* Data obtained as result of division of rotational moment values recorded with the use of piezoresistive transducer by gear ratio u = 6 and efficiency η = 0.9 of high frequency gearhead of gate physical analogue

The distinctive features of recommended gate are: possible self-adjusting of bottom refractory plate with the use of spherical surface of moving bearing body; protection of bevel gearing teeth from dust and spatters of molten steel owing to its installation inside the gate case; elimination of fast deterioration of friction surfaces and decrease of drive loading at the expense of installation of rotating bearing body on the combined antifriction bearing. During hot metal tapping, electromechanical drive of gate connected with beveled gear and fixed in the bottom part of converter body is taken out from zone of direct radiant heat exchange with metal mirror in the ladle [5].

Conclusions

The results of theoretical and experimental investigations carried out in present work can be used by scientific-research and design companies when working out mechanical equipment for steelmaking plants regarding creation of highly effective systems of final converter slag cut-off.

References

1. S. P. Yeronko, A. N. Smirnov, D. P. Kukuy. *Metallurgicheskaya i Gornorudnaya Promyshlennost*, 2003, No. 8, pp. 33-37.*

2. U. Gref, A. Berghofer, G. Ameler, M. Vinkelmann. *Stal*, 2005, No. 7, pp. 51-54.*

3. S. P. Yeronko *Metallurgicheskaya i Gornorudnaya Promyshlennost*, 2007, No. 3, pp. 104-108.*

4. S. P. Yeronko, S. V. Bykovskih, E. V. Oshovskaya. *Calculation and Design of Steel Out-Of-Furnace Treatment and Teeming Equipment*, Kyiv, Tekhnika, 2007, 344 p. *

5. S. P. Yeronko, A. Yu. Tsuprun, S. A. Bedarev, et al. *Bulleten Nauchno-Tekhnicheskoy Informatsii. Chernaya Metallurgiya*, 2007, pp. 81-87.*

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Исследование и расчет энергосиловых параметров системы поворотного затвора для отсечки шлака при выпуске стали из кислородного конвертера

Еронько С.П., Ошовская Е.В., Бедарев С.А., Романова Г.С., Федяев Д.И.

Описаны конструктивные особенности и приведены результаты теоретических и экспериментальных исследований параметров механической системы поворотного затвора, предназначенного для отсечки технологического шлака при выпуске стали из кислородного конвертера в разливочный ковш.