Static analysis and strength calculation of drive shaft of large-scale cone crusher

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Abstract. The paper analyzes the causes of failures of coarse crushers "KKD 1500-180" at JSC "Almalyk MMC". It has been established that the most common cause of these failures is a drive shaft failure. Static analysis of the strength of the drive shaft was performed using Autodesk Inventor 2020 CAD software. A dangerous shaft section was found, and recommendations aimed at improving its operability were proposed.

1 Introduction

At the present stage of the development of innovative technologies [1-15], it is necessary to conduct research aimed at improving the reliability of technological equipment [16-29]. Improvement of settlement and analytical and design solutions. One of the urgent tasks of modern mechanical repair production is to assess the load and deformations of various parts that are subject to frequent restoration, repair or new manufacture.

Extensive experience in operating large-size cone crushers "KKD 1500-180" at JSC "Almalyk Mining and Metallurgical Combine" indicates frequent equipment downtime due to emergencies associated with the loss of operability of large-sized parts. One of the problematic parts of this equipment is the drive shaft.

2 Analytical calculations

To identify the most loaded sections of the crusher drive shaft, a static analysis and strength analysis were performed using Autodesk Inventor 2020 software. Strength criterion is one of the most significant operability criterion of machine parts [30-40].

The initial data used for conducting static analysis:

- drive shaft of a step-type crusher with diameters from 158 to 200 mm and a length of 3121 mm;
 - mass of the drive shaft, m = 710 kg;
 - electric motor power P = 355 kW;
 - rotation speed n = 1500 rpm.

Rotational motion is transmitted from the electric motor through the clutch to the shaft, then the crusher's drum operates through the bevel gear.

Torque is determined by the formula:

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$$M_r = \frac{P}{\omega} = \frac{30P}{\pi n} = \frac{30 \cdot 355}{3.1416 \cdot 1500} = 2.26 \text{ kNm}$$
(1)

where ω – is the angular velocity.

To carry out a static analysis, we determine the forces appearing on the shaft during rotation.

We calculate the forces acting from the clutch:

$$F'_{\tau} = \frac{M_r}{r_c} = \frac{2260}{0.25} = 9040 \text{ N}$$
 (2)

$$F'_{n} = 0.4F'_{\tau} = 3616 \text{ N}$$
 (3)

$$F' = \sqrt{\left(F'_{\tau}\right)^{2} + \left(F'_{n}\right)^{2}} = 9736 \text{ N}$$
(4)

We determine the forces on the shaft section under the gear:

$$F''_{\tau} = \frac{M_r}{r_g} = \frac{2260}{0.405} = 5580 \text{ N}$$
(5)

$$F''_{n} = 0.4F''_{\tau} = 2233 \text{ N}$$
(6)

$$F'' = \sqrt{\left(F''_{\tau}\right)^{2} + \left(F''_{n}\right)^{2}} = 6010 \text{ N}$$
(7)

We constitute the equations of forces equilibrium and determine the prop reactions R' and R'' (figure 1):

$$\sum M'_{y} = R' \cdot 1.805 - mg \cdot 0.9025 + F''_{n} \cdot 0.3325 - F'_{n} \cdot 2.536 = 0$$
(8)

$$R' = 1190 \text{ N}$$
 (9)

(11)

$$\sum M"_{y} = -R" \cdot 1.805 + mg \cdot 0.9025 + F"_{n} \cdot 2.1375 - F'_{n} \cdot 0.731 = 0$$
(10)



R'' = 7591 N

Fig. 1. Forces acting on the shaft.

We will verify the correct determination of forces:

$$mg + R'' + R' - F'' + F' = 0 \tag{12}$$

$$6965 + 7591 + 1190 - 6010 + 9736 = 0 \tag{13}$$

The equilibrium condition is satisfied, therefore, we can further use the calculated forces acting on the shaft for static analysis.

3 CAE calculations

The result of calculating the stresses according to Mises is presented in figure 2.





Figure 3 shows the maximum displacement of drive shaft.





Figure 4 shows the equivalent deformation.



Fig. 4. Equivalent strain.

The numerical results of the analysis performed in Autodesk Inventor 2020 are presented in the table 1.

Name	Minimum	Maximum
Volume	90494800 mm ³	
Mass	710,384 kg	
Von Mises Stress	0,00450251 MPa	32,9513 MPa
1st Principal Stress	-5,99087 MPa	32,5363 MPa
3rd Principal Stress	-39,0433 MPa	2,60024 MPa
Displacement	0 mm	0,257126 mm
Safety Factor	10,6217 ul	15 ul
Stress XX	-32,4949 MPa	32,3698 MPa
Stress XY	-6,23733 MPa	11,9029 MPa
Stress XZ	-5,47142 MPa	17,3469 MPa
Stress YY	-12,2677 MPa	6,76512 MPa
Stress YZ	-1,73897 MPa	2,00225 MPa
Stress ZZ	-12,3199 MPa	6,42019 MPa
X Displacement	-0,0415655 mm	0,0416311 mm
Y Displacement	-0,00227041 mm	0,0892219 mm
Z Displacement	-0,000196482 mm	0,23855 mm
Equivalent Strain	0,000000229683 ul	0,0001483 ul
1st Principal Strain	0,0000000102571 ul	0,000155541 ul
3rd Principal Strain	-0,00016906 ul	-0,0000000181391 ul
Strain XX	-0,000150454 ul	0,000154466 ul
Strain XY	-0,0000402308 ul	0,0000767734 ul
Strain XZ	-0,0000352906 ul	0,000111888 ul
Strain YY	-0,000035485 ul	0,0000374621 ul
Strain YZ	-0,0000112163 ul	0,0000129145 ul
Strain ZZ	-0,0000464921 ul	0,0000438258 ul

Table 1. Crusher drive shaft static analysis results

4 Summary

The paper presents the results of a study aimed at improving the operability of crushers using CAD. In accordance with the results obtained, it was found that the neck of the shaft, in the place where the liner is installed, is a dangerous section.

It is proposed to change the shaft design, increasing the diameter of the shaft in its dangerous section and thereby increasing its strength.

It is recommended to significantly reduce interruptions in the operation of crushers, since when starting and stopping the machine there are uneven peak loads that reduce its strength.

References

- Bratan S and Roshchupkin S 2018 Synthesis of lunberger stochastic observer for estimation of the grinding operation state *MATEC Web of Conferences* 224 01133. DOI: 10.1051/matecconf/201822401133
- 2. Roshchupkin S and Kharchenko A 2018 Method of building dynamic relations, estimating product and grinding circle shape deviations *MATEC Web of Conferences* **224** 01001. DOI: 10.1051/matecconf/201822401001
- Bratan S, Roshchupkin S and Revenko D 2017 Probabilistic Approach for Modeling Electroerosion Removal of Grinding Wheel Bond *Procedia Engineering* 206 pp 1426-31. DOI: 10.1016/j.proeng.2017.10.656
- Bardovsky A D, Gerasimova A A and Basyrov I I 2019 Study of oscillating process of harp screens *Lecture Notes in Mechanical Engineering* 0(9783319956299) pp 133-139. DOI: 10.1007/978-3-319-95630-5_14
- Gorbatyuk S, Kondratenko V and Sedykh L 2019 Influence of critical speed when working shafts with asymmetrically located monolithic weighting on the accuracy of work surfaces *Materials Today: Proceedings* 19 pp 2117-20. DOI: 10.1016/j.matpr.2019.07.222
- Bardovsky A D, Gerasimova A A and Basyrov I I 2020 Constructive solutions for upgrading of the drive of processing equipment *IOP Conference Series: Materials Science and Engineering* **709(2)** 022015. DOI: 10.1088/1757-899X/709/2/022015
- Gorbatyuk S, Kondratenko V and Sedykh L 2019 Influence of critical speed when working shafts with symmetrically located monolithic weighting on the accuracy of work surfaces *Materials Today: Proceedings* 19 pp 2361-64. DOI: 10.1016/j.matpr.2019.07.695
- Chichenev N A 2015 Import-replacing re-engineering of the drive of the rollers in the intermediate roller table of a continuous bloom caster *Metallurgist* 58(9-10) pp 892-895. DOI: 10.1007/s11015-015-0013-9
- Gerasimova A A, Radyuk A G and Glukhov L M 2014 Applying Coatings to the Narrow Walls of Continuous-Caster Molds to Improve the Quality of the Surface of Slabs *Metallurgist* 58(5-6) pp 397-400. DOI: 10.1007/s11015-014-9922-2
- 10. Gerasimova A A, Radyuk A G and Titlyanov A E 2016 Wear-resistant aluminum and chromonickel coatings at the narrow mold walls in continuous-casting machines *Steel in Translation* **46(7)** pp 458-462. DOI: 10.3103/S0967091216070068
- Gerasimova A, Mishedchenko O and Devyatiarova V 2020 Determination of temperature conditions for steel plate rolling at Vyksa Steel Works (AO VMZ) *IOP Conference Series: Materials Science and Engineering* **709(2)** 022016. DOI: 10.1088/1757-899X/709/2/022016
- Keropyan A, Gorbatyuk S and Gerasimova A 2017 Tribotechnical Aspects of Wheel-Rail System Interaction *Procedia Engineering* 206 pp 564-569. DOI: 10.1016/j.proeng.2017.10.517

- Kobelev O A, Albul S V and Kirillova N L 2020 Research and development of broaching methods on mandrel of large-sized pipe forgings *IOP Conference Series: Materials Science and Engineering* **709(4)** 044104. DOI: 10.1088/1757-899X/709/4/044104
- 14. Gorbatyuk S M, Morozova I G and Naumova M G 2017 Reindustrialization principles in the heat treatment of die steels *Steel in Translation* 47(5) pp 308-312. DOI: 10.3103/S0967091217050047
- 15. Gorbatyuk S, Kondratenko V (2) and Sedykh L 2019 Investigation of the Deep Hole Drill Stability When Using a Steady Rest *Materials Today: Proceedings* 11 pp 258-264. DOI: 10.1016/j.matpr.2018.12.140
- 16. Gorbatyuk S, Pashkov A and Chichenev N 2019 Improved Copper-Molybdenum Composite Material Production Technology *Materials Today: Proceedings* 11(1) pp 31-35. DOI: 10.1016/j.matpr.2018.12.102
- 17. Gerasimova A A, Keropyan A M and Girya A M 2018 Study of the Wheel–Rail System of Open-Pit Locomotives in Traction Mode *Journal of Machinery Manufacture and Reliability* **47**(1) pp 35-38. DOI: 10.3103/S1052618818010065
- 18. Keropyan A M 2016 Features of interaction of traction wheels of an electric locomotive and a diesel locomotive with rails in the conditions of open mountain works *Journal of Friction and Wear* 37(1) pp 78-82. DOI: 10.3103/S1068366616010074
- Gorbatyuk S M, Pashkov A N, Zarapin A Y and Bardovskii A D 2019 Development of Hot-Pressing Technology for Production of Aluminum-Based Metal-Matrix Composite Materials *Metallurgist* 62(11-12) pp 1261-66. DOI: 10.1007/s11015-019-00784-0
- 20. Keropyan A M, Gorbatyuk S M, Bibikov P Y and Bardovski A D 2019 Influence of Roughness of Working Surfaces of the Wheel–Rail System of Open-Pit Locomotives with an Implementable Adhesion Coefficient *Journal of Friction and Wear* 40(1) pp 73-79. DOI: 10.3103/S1068366619010082
- 21. Bibikov P Y, Bardovskiy A D and Keropyan A M 2019 Investigation of press classification process of weak rocks *Materials Today: Proceedings* 19 pp 2552-54. DOI: 10.1016/j.matpr.2019.08.207
- 22. Gerasimova A, Gorbatyuk S and Devyatiarova V 2018 Application of gas-thermal coatings on low-alloyed steel surfaces *Solid State Phenomena* **284 SSP** pp 1284-90. DOI: 10.4028/www.scientific.net/SSP.284.1284
- 23. Gorbatyuk S, Kondratenko V and Sedykh L 2018 Tool stability analysis for deep hole drilling MATEC Web of Conferences 224 01035. DOI: 10.1051/matecconf/201822401035
- 24. Gorbatyuk S M and Sedykh L V 2010 Improving the durability of rolling-mill rolls *Metallurgist* **54(5-6)** pp 299-301. DOI: 10.1007/s11015-010-9297-y
- 25. Bast J, Gorbatyuk S M, Kryukov I Yu 2011 Horizontal hcc-12000 unit for the continuous casting of semifinished products *Metallurgist* **55(1-2)** pp 116-118. DOI: 10.1007/s11015-011-9399-1
- 26. Gorbatyuk S M, Pavlov V M, Shapoval A N and Gorbatyuk M S 1998 Experimental use of rotary rolling mills to deform compacts of refractory metals *Metallurgist* 42(5-6) pp 178-183. DOI: 10.1007/BF02766359
- 27. Naumova M G, Morozova I G, Zarapin A Y and Borisov P V 2018 Copper alloy marking by altering its surface topology using laser heat treatment *Metallurgist* 62(5-6) pp 464-469. DOI: 10.1007/s11015-018-0682-2
- 28. Glukhov L M, Gorbatyuk S M, Morozova I G and Naumova M G 2016 Effective Laser Technology for Making Metal Products and Tools *Metallurgist* 60(3-4) pp 306-312. DOI: 10.1007/s11015-016-0291-x
- 29. Bardovskii A D, Gerasimova A A, Keropyan A M and Bibikow P Y 2018 Influence of the mechanical characteristics of harp screen material on screening process *Izvestiya Ferrous Metallurgy* **61(9)** pp 678-682. DOI: 10.17073/0368-0797-2018-9-678-682

- 30. Busygin A M 2018 The force analysis of the caterpillar excavator stick arrangement mechanism with three degrees of freedom *Mining Informational and Analytical Bulletin* 2018(1) pp 133-142. DOI: 10.25018/0236-1493-2018-1-0-133-142
- 31. Efremov D B, Gerasimova A A, Gorbatyuk S M and Chichenev N A 2019 Study of kinematics of elastic-plastic deformation for hollow steel shapes used in energy absorption devices CIS Iron and Steel Review 18 pp 30-34. DOI: 10.17580/cisisr.2019.02.06
- 32. Zakharov A N, Gorbatyuk S M and Borisevich V G 2008 Modernizing a press for making refractories *Metallurgist* **52(7-8)** pp 420-423. DOI: 10.1007/s11015-008-9072-5
- 33. Gorbatyuk S M and Kochanov A V 2012 Method and equipment for mechanically strengthening the surface of rolling-mill rolls *Metallurgist* **56(3-4)** pp 279-283. DOI: 10.1007/s11015-012-9571-2
- 34. Gorbatyuk S M, Morozova I G and Naumova M G 2017 Development of the working model of production reindustrialization of die steel heat treatment *Izvestiya Ferrous Metallurgy* 60(5) pp 410-415. DOI: 10.17073/0368-0797-2017-5-410-415
- 35. Gorbatyuk S M, Osadchii V A and Tuktarov E Z 2011 Calculation of the geometric parameters of rotary rolling by using the utomated design system autodesk inventor *Metallurgist* **55(7-8)** pp 543-546. DOI: 10.1007/s11015-011-9465-8
- 36. Keropyan A and Gorbatyuk S 2016 Impact of Roughness of Interacting Surfaces of the Wheel-Rail Pair on the Coefficient of Friction in their Contact Area *Procedia Engineering* 150 pp 406-410. DOI: 10.1016/j.proeng.2016.06.753
- 37. Radyuk A G, Gorbatyuk S M and Gerasimova A A 2011 Use of electric-arc metallization to recondition the working surfaces of the narrow walls of thick-walled slab molds *Metallurgist* **55(5-6)** pp 419-423. DOI: 10.1007/s11015-011-9446-y
- 38. Kartsov S K, Kupriyanov D Y, Polyakov Y A and Zykov A N 2020 Non-local Means Denoising Algorithm Based on Local Binary Patterns Intelligent Systems Reference Library 182 pp. 153-164. DOI: 10.1007/978-3-030-39177-5_12
- 39. Jordan D W and Smith P 2007 Nonlinear Ordinary Differential Equations: An Introduction for Scientists and Engineers (Oxford: Oxford University Press)
- 40. Naumova M G, Basyrov I I and Aliev Kh B 2018 Reengineering of the ore preparation production process in the context of «almalyk MMC» JSC MATEC Web of Conferences 224 01030. DOI: 10.1051/matecconf/201822401030