Research for reduction material-capacity of load-lift cranes with multi-engine electric drives on the base electromagnetic work shaft systems

K. Abidov[1*], *K.* Dadajanov[2], *U.* Absoatov[3], and *S.* Sabitov[4]

[1]Tashkent State Technical University, Street University, 2A, 100095 Tashkent, Uzbekistan
[2]Uzneftgazaloka LLC, st. Istikbol, house 21, 100115 Tashkent, Uzbekistan
[3]Tashkent State Pedagogical University, Bunyodkor avenue, 27, 100070 Tashkent Uzbekistan
[4]ABSOLUTE TECH LLC, st. A. Khodzhaev, 2, 1507082 Tashkent, Uzbekistan

Abstract. This work is devoted to the study of multi-machine systems of coordinated rotation of the engines of handling equipment. The purpose of the work is to identify, by theoretical calculation, the reduction in the metal consumption of cranes equipped with multi-motor electric drives and operating on the principle of an electromagnetic working shaft, in comparison with the current ones. The analysis of the shifting moments of these systems in dynamics was made and conclusions were drawn about the reduction in the weight of the metal structures of cranes and the saving of metal in their production.

1 Introduction

The efficiency of many technological processes at a number of industrial enterprises largely depends on the accurate, reliable and uninterrupted operation of lifting and transport mechanisms.

One such mechanism is a bridge type crane. The use in such cranes of mechanisms for a separate drive of supports without electrical synchronization of the speeds of rotation of the engines led to the emergence of a new type of load, the so-called skew forces or skew loads [1-5].

As a result of the action of skew forces, metal structures and running gears of the crane, as well as crane runways are loaded. Some influence of the skew force is also exerted on the elements of the support drives.

A characteristic feature for the mechanisms of movement are large moments of inertia, as well as the possibility of distortion of the crane structure due to unequal moments of static or different characteristics of the drive motors.

During normal operation of the crane, relatively large skew forces occur when the trolley with the load is located near the trolleys or above the cab. The skew forces reach a maximum and are oscillatory during periods of unsteady movement [6-16] (starting, braking and reverse of the crane). They load the crane simultaneously with technological loads, both during movement and after stopping. The relative stress in the elements of the crane from the skew

* Corresponding author: abidoff@rambler.ru

forces reaches 30%. One of the ways to eliminate the appearance of misalignment forces is to replace a separate electric drive with a multi-stage start with an electric drive with a synchronized speed of rotation of the drive motors.

The coordinated rotation of two or more axes, arbitrarily located in space, the mechanical connection between which is undesirable or impossible at all, is implemented in practice by synchronous rotation systems, depending on the requirement for the accuracy of the coincidence of speeds or conditional turns to control in the consistency mode and other indicators, various schemes are used synchronous communication systems.

2 Methods

One of the important task than reducing the energy consumption of electric crane drives is to reduce the consumption of materials, that is, the weight of cranes. The following conditions are imposed on the solution of this problem using the electromagnetic working shaft system:

1. The system must be oriented to the maximum load at which the crane remains stable for overturning (for gantry cranes), or the ability to lift a load (for overhead cranes).
2. Increasing the skew forces in the crane trusses with lightening of its weight and the use of an electromagnetic working shaft should not exceed in amplitude the corresponding amplitude values of the skew in a non-lightweight and non-synchronized crane system,
3. A decrease in metal consumption is possible in that part of the crane where this decrease does not lead to loss of stability, or a decrease in the lifting capacity of the crane at the design load.

To do this, we use the calculation models of cranes shown in Fig. 1. and 2. In these schemes, the calculation model is represented by two mass models, that is, the mass of the crane consists of two mass supports concentrated on the end beams. The mass of the cart is included in the reduced mass of the opera. To this mass is added the mass of the load. In the extreme position, it can be suspended either at the end beam (bridge crane) or to the free end of the elastic element, the stiffness of which is equal to the reduced stiffness of the cantilever in the horizontal plane (gantry crane).

When compiling design schemes and differential equations that describe the operation of the crane during the period of starting-braking modes, when transient loads act to the greatest extent, the following assumptions are made:

1. Elastic connection is weightless and has constant rigidity,
2. Drive elements are absolutely rigid.
3. Coupling of wheels with rails is not broken.
4. Bridge deformations are not limited.
5. Engines turn on at the same time exactly.
6. The brakes are also applied at the same time.
7. The damping properties of the motors are not taken into account, and their characteristics are assumed to be static.
8. Crane tracks are absolutely rigid.
9. Do not take into account the attenuation of vibrations, metal structures of the crane in the horizontal plane.

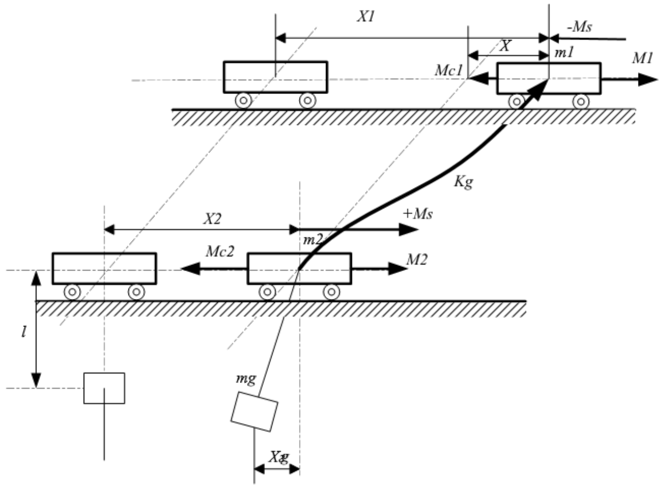

Fig. 1. Calculation model of an overhead crane.

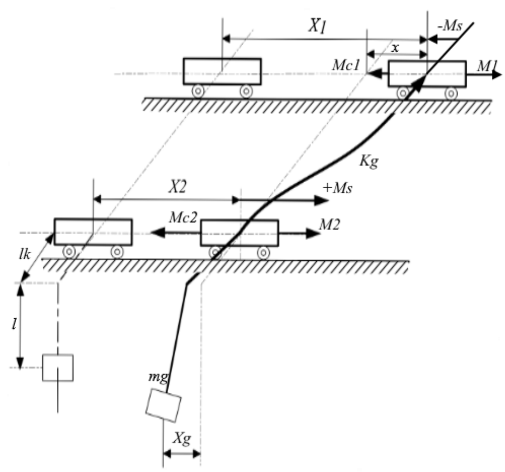

Fig. 2. Calculation model of a gantry crane.

Now it seems possible to make a description of the crane system with an electromagnetic working shaft and starting resistors for comparison with the first one. In this case, the parameters of the engines were selected from [17-26], the parameters of electromagnetic rheostats from [27-30], the equations of the two-mass system were built according to the method described in [31-36].

3 Results

Developers set the following parameters of cranes: $m_{\text{пм}}$– weight of half-bridge or half-span; m_{kb} - the mass of the crane beam or support; $m_{\text{кр}}$- total weight of the crane; m_g- mass of cargo passport. According to the method [4], the weight of the load, at which stability is still maintained, $m_{\text{кр}} = 1{,}4m_г$. Then the reduced masses will be:

$$m_1 = \frac{m_{\text{кр}}+m_{\text{gr}}}{2} \cdot (1 - sin\,\beta) + (m_{\text{пм}} + m_{\text{kb}}) \cdot sin\,\beta \tag{1}$$

$$m_2 = \frac{m_{кр}+m_{gr}}{2} \cdot (1 + sin\,\beta) - (m_{пм} + m_{kb}) \cdot sin\,\beta \tag{2}$$

where β is the angle of load distribution along the span of the crane. We further consider the limiting case when the load is located at the right support. Then $\beta = 90°$; $sin\,\beta = 1$; $m_1 = m_{ПМ} + m_{kb}$; $m_2 = \left(m_{кр} + m_{gr} + m_{ПМ} + m_{kb}\right)$.

We determine the moments of inertia and the moments of resistance for the reduced masses.

$$J_1 = m_1 \cdot \rho^2 \tag{3}$$
$$J_2 = m_2 \cdot \rho^2 \tag{4}$$

where ρ is the reduced radius of gyration. If R is the radius of the wheels of the crane movement mechanism, and K_p is the gear ratio of its gearbox, then

$$\rho = \frac{R}{K_p} \tag{5}$$
$$\mathrm{M}_{c1} = \frac{m_1 \cdot g \cdot \rho}{\eta \cdot w_o} \tag{6}$$
$$\mathrm{M}_{c2} = \frac{m_2 \cdot g \cdot \rho}{\eta \cdot w_o} \tag{7}$$

where g=9,8m/c2 ; $\mathrm{w_o} = 314\ \ 1/\mathrm{c}$; η- is the efficiency of the reducer.

These values remain unchanged during the entire calculation. The calculation of dynamics begins with the determination of motor slip.

$$S_1 = 1 - \frac{w_1}{w_o} \tag{8}$$
$$S_2 = 1 - \frac{w_2}{w_o} \tag{9}$$

Initial values at start: $S_{1o} = S_{2o} = 1$; $\omega_{1o} = \omega_{2o} = 0$. When braking, starting from synchronous speed: $S_{1o} = S_{2o} = 2$; $\omega_{1o} = -\omega_c$.

The moments of the engines of the system with the electromagnetic working shaft of the electromagnetic working shaft are calculated by the formula

Briefly, one can write

$$\mathrm{M}_1 = f(z_1, w_1, \alpha) = M_{a1} - M_{ур1} \tag{10}$$
$$\mathrm{M}_2 = f(z_2, w_2, \alpha) = M_{a2} - M_{ур2} \tag{11}$$

$M_{a1} = M_{a2}$ and $M_{ур1} = M_{ур2}$ only if$\alpha = \beta = 0$. In other cases, the drive and equalizing moments will be different for the 1st and 2nd engines, because $w_1 \neq w_2$.

We substitute the values of the moments of the engines into the equations:

$$\frac{dw_1}{dt} = \frac{M_1 - M_{c1} - M_3}{J_1} \tag{12}$$
$$\frac{dw_2}{dt} = \frac{M_z - M_{c2} + M}{J_2} \tag{13}$$

The values w_1 and w_2 are determined by one of the numerical integration methods, for example, the Euler method.

For an unsynchronized system with starting resistors:

$$M_{1,2} = \frac{U^2 p}{w_o} \sum_{i=1}^{3} \frac{\frac{r_2 + R_{nij}}{S_{1,2}}}{\left(r_1 + \frac{r_2' + R_{nij}}{S_{1,2}}\right)^2 + \left(x_1 + x_2'\right)^2} \tag{14}$$

where is the resistance of the starting resistor of the i-th phase, j-th stage. The change in resistance steps occurs on average through.

The found values of the angular velocities are substituted into the formulas for the paths traveled by the wheels of the crane movement mechanism

$$\mathrm{x}_1 = \rho \int_0^t w_1 \, dt \tag{15}$$

$$\mathrm{x}_2 = \rho \int_0^t w_2 \, dt \tag{16}$$

Then the value of the skew moment will be:

where K is the rigidity of the bridge (span) structure. Considering the rigidity of the structure as average with a coefficient of 6, we determine its value.

$$K = \frac{6E \cdot J_{\text{м}}}{l_{\text{пр}}^3} = \frac{12E \cdot m_{\text{п ш}} \cdot \rho^2}{l_{\text{пр}}^3} \tag{17}$$

$J_{\text{м}}$ where is the moment of inertia of the bridge; $l_{\text{пр}}$– span length; E is the modulus of elasticity, (span), different on average for structural steel 20000 kg/mm2.

Initial conditions at start-up: $x_1 = x_2 = M_S = 0$ according to the Simpson trapezoid method.

On Fig. 3 and 4 illustrate the calculation of dynamic modes for crane engines. The calculation was carried out for the starting mode with a duration of 12.0 s and with a calculation step of 0.2 s. In connection with the purpose of this work, the moments of the engines and their speeds are not included in the graph, but only the moments of distortion, which have the form of damped harmonic oscillations. On Fig. 3. Shows the values for a resistor unsynchronized system. Characteristic 1 belongs to the system with really existing parameters. Characteristic 2 refers to the same type of crane that has the mass of the bridge (span) is lightened by 20%. Characteristic 3 is calculated with the value of the mass of the trolley 40% lighter than the actual one. The M values for the electromagnetic working shaft system in Fig. 4. marked with the same numbers. The angle of mismatch of the rotors of the engines (the most severe mode).

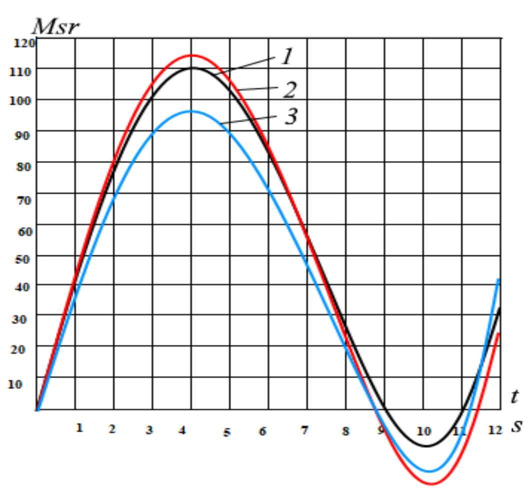

Fig. 3. Moments of distortion of the resistor system.

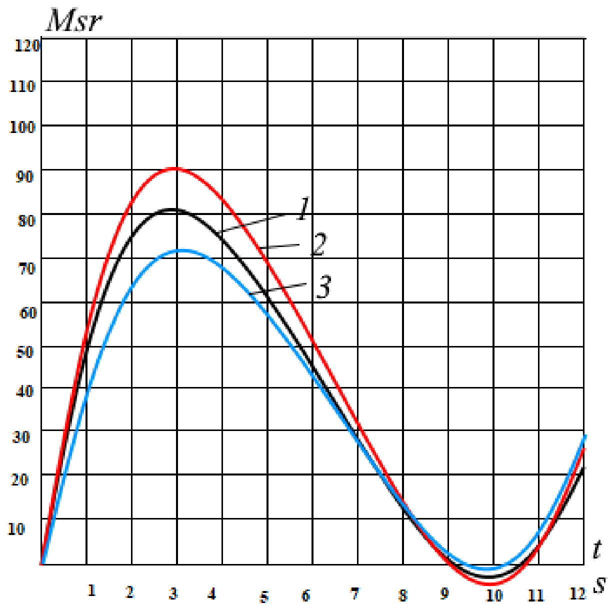

Fig. 4. Misalignment moments with Electromagnetic working shaft system.

4 Analysis

An analysis of the characteristics of M shows [10] that approximately at $t = 5$ s, they reach the 1st maximum, which can be significant. M_{SR} № 1-110 n.m. ; M_{SR} № 2-113 n.m. , which is approximately equal to the starting torque of the motors. Somewhat lower M_{SR} № 3-92 n.m. , the 1st minimum occurs at about 10 s; it is for M_{SR} № 1-(-15 n.m.), for M_{SR} № 2-(-27 n.m.), for M_{SR} № 3-(-25 n.m.). The 2nd maximum can be approximated at 15 s at the level of 40 nm.

On another graph, it can be seen that the values M_{SS}, changing according to a similar law, have a lower order. So the level of the 1st maximum is: M_{SS} № 1-80 n.m. , M_{SS} № 2-90 n.m. ; M_{SS} № 3-70 n.m. For the 1st minimum, respectively: M_{SS} № 1-(-3 n.m.); M_{SS} № 2-(-5 n.m.); M_{SS} № 3-(-1 n.m.).

5 Discussion

From here, returning to the initial conditions, it can be seen that a 20% decrease in the metal consumption of the span worsens the process (M_{SS} № 2), but does not bring it out of the amplitude values of the original process (M_{SR} № 1). It is also possible some reduction in the metal consumption of the trolley. However, it should be remembered that a significant part of the weight of the trolley is the lifting motor with a gearbox, and lightening this weight can also affect the lifting capacity of the crane.

Bridge engines with gearboxes occupy a small part in relation to the weight of the entire structure, and therefore reducing its metal consumption will only facilitate their work [37-42]. However, in this case, it is necessary to prevent the skew moment from exceeding the established limits, as well as strong vertical deformations of the bridge.

Similar calculations were also carried out for heavy-duty gantry 4-motor cranes (graphs are not shown here). It was found that the transverse loads in this case are smaller both in magnitude and in the difference between and. Therefore, although the relative reduction in metal consumption should be smaller here, the absolute savings in metal increase, since. the weight of the cranes is 100 tons, and the span is 40 tons.

In general, you can install the following dependencies:

1. Lightweight cranes - 30% reduction in span weight - 1 t metal savings.
2. Medium cranes - respectively, 20% - 2 tons.
3. Heavy cranes - respectively, 10% - 4 tons.

For large factories of hoisting and transport equipment, such metal savings could be 2000 tons per year, which is equivalent to an additional production of 100 cranes [43-57].

6 Conclusion

As already mentioned, the purpose of this work was to develop a methodology for calculating and study energy indicators for hoisting and transport equipment from an electromagnetic working shaft, as well as to study distortion phenomena in such systems. This task was performed theoretically - by calculation methods, as well as during measurements and tests of the electromagnetic working shaft system on real cranes. Based on the results of the work, the following conclusions can be drawn.

1. The transverse forces in the synchronized and non-synchronized crane movement system were studied in dynamics. It is concluded that the electromagnetic working shaft significantly reduces distortions in metal structures and, within certain limits, it is possible to reduce the weight of crane trusses or a bridge.

2. In general, it was concluded that the system of an electromagnetic working shaft for handling equipment not only ensures the synchronization of the speed of engines, the smoothness of their transients, a significant reduction in repairs, but also a reduction in energy consumption, as well as a further reduction in the metal consumption included in the project.

References

1. Decree of the President of the Republic of Uzbekistan dated August 23, 2017 No. PP-3238 “On measures for the further introduction of modern energy-efficient and energy-saving technologies”
2. K.R. Allaev, Modern energy and prospects for its development. Under the general editorship of Academician A.U.-T. Salimov: “Fan va texnologiyalar nashriyot-matbaa uyi” (2021)
3. K.R. Allaev, Energy of the world and Uzbekistan. Analytical review (2006)
4. I.M. Sadovsky, Coordinated rotation of asynchronous motors (Electricity. M.-L.: Gosenergoizdat, 1948)
5. A.G. Yaure, E.M. Pevzner, Crane electric drive: Handbook (M.: Energoatomizdat, 1988)
6. N.M. Usmankhodzhaev, R.I. Belokovsky, B.S. Usmanov, Elektromekhanika (News of higher educational institutions) **1,** 29-36 (1988)
7. V.N. Meshcheryakov, Improvement of an asynchronous electric drive based on induction resistors for the movement mechanism of overhead cranes. Diss... cand. tech. Sciences. Year of birth No. 04870011357. Lipetsk (1987)
8. M.M. Gokhberg (ed), Handbook of cranes. t.1 (L.: Mechanical engineering. Leningrad. department, 1988)
9. V. Ungru, G. Jordan, Systems for matching the rotation of asynchronous electric motors (L., Energia, 1971)

10. L.Ya. Budikov, Multivariable Analysis Crane Dynamics bridge type: Monograph (Lugansk, 2003)
11. K.S. Demirchyan, L.R. Neiman, N.V. Korovkin, V.L. Chechurin, Theoretical foundations of electrical engineering. vol. 1. (St. Petersburg: publishing house Peter, 2003)
12. M.G. Chilikin, V.I. Klyuchev, A.S. Sandler, Theory of automated electric drive (M., Energia, 1979)
13. N.G. Pavlov, Examples of crane calculations (M.: Mashinostroenie, 1976)
14. V.P. Balashov, Tr. VNIIPTMash **1(96),** 96-103 (1970)
15. I.A. Lobov, Dynamics of movement of cranes along the rail track (M.: Publishing house of MSTU im. N.E. Bauman, 2003)
16. V.P. Balashov, Tr. VNIIPTMash **7/91,** 91-127 (1969)
17. V.I. Dvornikov, V.A. GemmerlingProceedings of DonNTU **83,** 71-81 (2004)
18. I.M. Orin, Engineering tasks for calculating crane metal structures (M.: Mashinostroenie, 1972)
19. K.P. Mandrovskiy, Dynamics and mathematical modeling of machine movements in the assessment of stability (M.: MADI, 2012)
20. V.P. Balashov, Tr. VNIIPTMash **7(94)** (1969)
21. L.R. Neiman, Surface effect in ferromagnetic bodies (M.-L.: Gosenergoizdat, 1949)
22. N.S. Ushakov, Overhead electric cranes (L.: Mashinostr.: 1980)
23. A.G. Bykov, A.L. Luvishins, Electrotechnical prom.ser. Traction and lifting-transp. electrical equipment **6/96,** 1-3 (1984)
24. S.N. Veneshevsky, Characteristics of motors in an electric drive. 6th edition corrected (M.: Energy, 1977)
25. M.G. Chilikin, V.I. Klyuchev, A.S. Sandler, Theory of automated electric drive (M., Energia, 1979)
26. V.I. Klyuchev, Limitation of dynamic loads of the electric drive (M., Energia 1971)
27. R. Dargad, G. Dubey, IE (1) J.-EL **56(10),** 51-56 (1975)
28. V.F. Gaidamaka, New starting and braking devices for hoisting machines (Kharkov Vysh. School, 1975)
29. Ja. Toshov, E. Saitov, E3S Web of Conf. RSES **139**, 01087, 1-4 (2019)
30. N.F. Zikrillaev, S.A. Tachilin, E.B. Saitov, *Efficient inverters for alternative energy sources.* International scientific-practical conference "Problems of modern engineering" Andijan May 16-17 (2013)
31. N. Zikrillayev, E. Saitov, B. Botirov, B. Nasirdinov, Yu. Kurbanov, F. Turayev, N. Shodiyeva, Austr. J. of Tech. and Nat. Sci. «East West» Association for Advanced Studies and Higher Education GmbH. **1-2,** 56-61 (2019)
32. M.K. Bahadyrkhanov, Kh.M. Iliev, et. al., X Conf. on topical problems of physics, materials science and diagnostics of silicon, nanometer structures and devices based on it "Kremniy-2014", Irkutsk, RF (2014)
33. E.B. Saitov, Asian J. of Multidimensional Res. (AJMR) **8(3),** 494-499 (2019)
34. Yu.M. Kurbonov, E.B. Saitov, B.M. Botirov, IOP Conf. Ser.: Earth and Env. Sci. **614,** 012034 (2020). DOI: 10.1088/1755-1315/614/1/012034
35. E.B. Saitov, E3S Web of Conf. **220** (2020). DOI: 10.1051/e3sconf/202022001080

36. E.B. Saitov, Y.B. Sobirov, I.A. Yuldoshev, I.R. Jurayev, S. Kodirov, E3S Web of Conf. **220** (2020). DOI: 10.1051/e3sconf/202022001061
37. E.B. Saitov, E3S Web of Conf. **216,** 01134 (2020). DOI: 10.1051/e3sconf/202021601134
38. S. Shoguchkarov, I. Yuldoshev, E. Saitov, A. Boliev, E3S Web of Conf. **216** (2020). DOI: 10.1051/e3sconf/202021601149
39. E.B. Saitov, J.B. Toshov, A.O. Pulatov, B.M. Botirov, Yu.M. Kurbanov, E3S Web of Conf. **216,** 01133 (2020). DOI: 10.1051/e3sconf/202021601133
40. I. Sapaev, E. Saitov, N. Zoxidov, B. Kamanov, IOP Conf. Ser.: Mat. Sci. and Eng. **883,** 1, 012116 (2020)
41. Ja. Toshov, E. Saitov, E3S Web of Conf. **139,** 01087 (2019). DOI: 10.1088/1757-899X/883/1/012116
42. M.K. Bakhadyrkhanov, S.A. Valiev, N.F. Zikrillaev, E.B. Saitov, S.A. Tachilin, Appl. Solar Energy (English translation of Geliotekhnika) **52(4),** 278–281 (2016). DOI: 10.3103/S0003701X1604006X
43. N. Zikrillayev, E. Saitov, Silicon materials -the future of photovoltaics (Monograph - LAP LAMBERT Academic Publishing, 2019)
44. N.F. Zikrillaev, E.B. Saitov, O.B. Tursunov, A.J. Khusanov, K.K. Kurbonaliev, Eur. J. of Molecular & Clinical Medicine **08(01),** 935-939 (2021)
45. E.B. Saitov, N.F. Zikrillayev, Eur. J. of Molecular & Clinical Medicine **08(01),** 982-992 (2021)
46. S.P. Kundas, S.S. Poznyak, L.V. Shenets, Renewable energy sources (Minsk: MGEU im. HELL. Sakharova, 2009)
47. Y.S. Ergashov, B.E. Umirzakov, Technical Physics **63(12),** 1820-1823 (2018)
48. Y.S. Ergashov, Technical Physics **62(5),** 777-780 (2017)
49. Y.S. Ergashov, D.A. Tashmukhamedova, F.G. Djurabekova, B.E. Umirzakov, Bull. of the Rus. Academy of Sci.: Phys. **80(2),** 138-140 (2016)
50. B.E. Umirzakov, D.A. Tasmukhamedova, M.A. Tursunov, et. al., Tech. Physics **64(7),** 1051-1054 (2019)
51. E.S. Ergashov, Z.A. Isakhanov, B.E. Umirzakov, Tech. Physics **61(6),** 953-955 (2016)
52. Y. Ergashov, B. Donaev, S. Khudainazarov, J. Normuminov, E3S Web of Conf. **264,** 05036 (2021)
53. E. Yokub, U. Boltakhodja, E3S Web of Conf. **178,** 01079 (2020)
54. Z.E. Mukhtarov, Z.A. Isakhanov, B.E. Umirzakov, T. Kodirov, E.S. Ergashev, Tech. Phys. **60(12),** 1880-1883 (2015)
55. Y.S. Ergashov, D.A. Tashmukhamedova, B.E. Umirzakov, J. of Surface Investigation **11(2),** 480-484 (2017)
56. Y.S. Ergashov, D.A. Tashmukhamedova, E. Rabbimov, J. of Surface Investigation **9(2),** 350-354 (2015)
57. Y.S. Ergashov, B.E. Umirzakov, J. of Surface Investigation **12(4),** 816-818 (2018)
58. Y.S. Ergashov, B.E. Umirzakov, J. of Comm. Techn. and Electr. **62(6),** 612-615 (2017)