ISSN 1068-3712, Russian Electrical Engineering, 2019, Vol. 90, No. 5, pp. 370–374. © Allerton Press, Inc., 2019.
Russian Text © The Author(s), 2019, published in Elektrotekhnika, 2019, No. 5, pp. 15–20.

The Pipe Rotation Electric Drive of a Cold Rolling Mill at JSC Chelyabinsk Pipe Plant

I. A. Belykh[a], * and M. A. Grigorev[b]

[a] *Research and Innovation Services, South Ural State University National Research University, Chelyabinsk, 454080 Russia*
[b] *Department of Automated Electric Drives, South Ural State University National Research University, Chelyabinsk, 454080 Russia*
**e-mail: journal-elektrotechnika@mail.ru*

Received March 26, 2019; revised March 29, 2019; accepted March 29, 2019

Abstract—This article proposes a technique for selecting power electric equipment and an algorithm for synthesizing the control system of critical works of metallurgical production by the example of the pipe rotation electric drive of the cold rolling mill at JSC Chelyabinsk Pipe Plant. The optimal parameters of the power parts of the electric drive were chosen against the maximum response speed criterion, which allowed improving the overall output of ultrafine-wall pipe production. It is shown that the amplitude of self-oscillations conditioned by the finite stiffness of the transmission between the engine and the actuating device can be restricted by selecting an appropriate gear ratio for the reducer. Simplification of the system's mechanical transmission made it possible to reduce mechanical losses and more easily to adjust the electric drive with a load described in the two-mass system, but required uprating the installed capacity by around 100%. The parameters of corrective devices of electromagnetic torque, speed, and position adjustment loops were determined by the classical techniques of frequency analysis and synthesis. As shown by analyzing transient process curves, the response speed of the rotation electric drive was increased by around 80% and the overall output rate of the mill by 15 to 20%. The expected annual economic effect of the adopted engineering solutions amounts to around 250 million rubles.

Keywords: positional electric drive, cold pipe rolling mill, pipe rotation electric drive

DOI: 10.3103/S106837121905002X

Pipes with ultrafine walls subject to tough requirements on the uneven gage level are used in the nuclear industry, helicopter engineering, and the automotive industry. Pipes produced on hot rolling piercing mills are around two times thicker than required by the process conditions, which is why the pipes of the considered range of sizes are made on cold rolling mills (CRMs) only. These mills include several critical parts, such as the main reciprocating electric drive, the pipe and the mandrel feed drives, the pipe rotation electric drive, and other ancillary devices. All of them are operated together as a multiple connected system with a rolled pipe as its connecting link. An earlier upgrade of the feed electric drive allowed increasing the response speed and improving the rolled stock quality by the uneven gage level by 30 and 15%, respectively. The next phase of revamping the KHPT-450 mill involves replacing the pipe rotation electric drive system by giving up a complex mechanical transmission and outdated electric equipment. With two spur-gear reducers and one angular reducer, the complex mechanical transmission between the electric engine and the pipe rotation electric drive makes the system less reliable, leads to significant mechanical losses, and requires higher operating costs. The refusal to use the complex mechanical transmission will allow reconsidering the reducer's general gear ratio that can be chosen by the criterion of the maximum response speed; however, this step will require refining the installed capacity of the electromechanical converter. In this context, the development of techniques of selecting power equipment by the example of the cold rolling mill rotation drive is a topical task waiting for solution.

In the 1970s, when the cold pipe rolling mill was developed, the rotation mechanism was actuated by a nonadjustable electric drive and the actuating device speed was mechanically changed by affecting the gear. In the 1980s, the mill was rebuilt and the nonadjustable electric drive replaced with an adjustable counterpart, but the mechanical transmission was left unchanged, which was why the general gear ratio between the electric machine and the rotation mechanism did not change. The response speed achieved during the system fettling process in the positional adjustment loop did not exceed 500 ms. The subsequent increase in the response speed was restricted by the oscillations caused by elastic links in the adjustment line. The intensity of oscillations can be reduced by selecting the reducer gear ratio; that said, however,

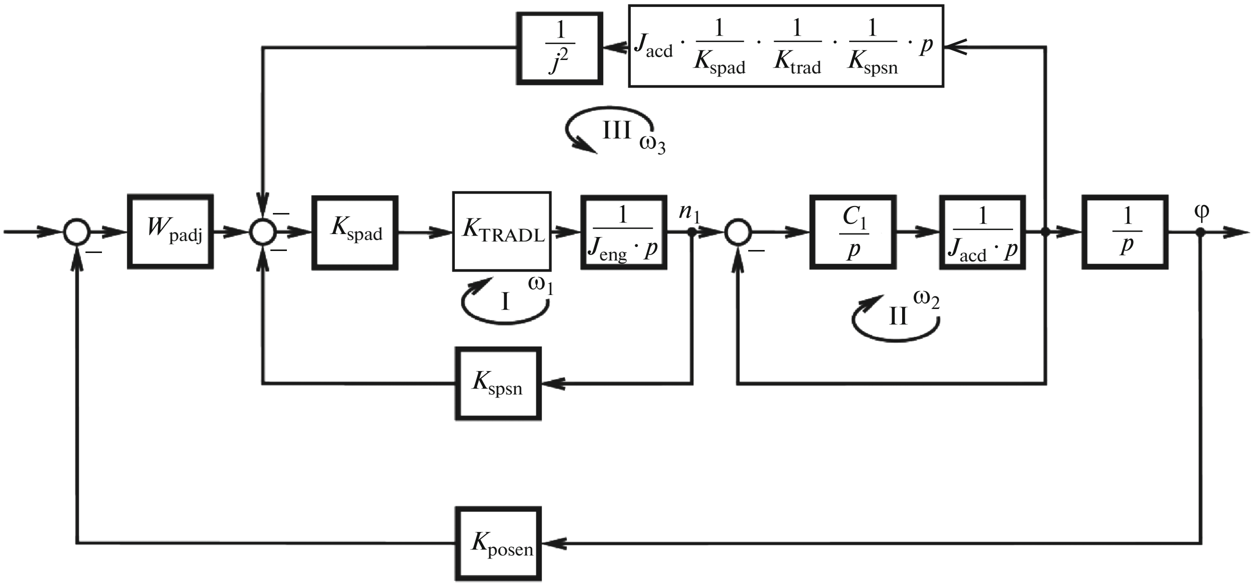

Fig. 1. Model electric drive of the rotation gear of the cold pipe rolling mill.

the mechanical loads imposed on the engine shaft usually increase [1]. An increased installed capacity of the actuating electric engine increases dynamic loads, which makes it far more difficult to determine the parameters of power electric equipment. The reducer's gear ratio also affects the parameters of the loop factors of the "unchangeable" part of the adjusted object, which requires synthesizing an adjustment algorithm and fixing the positional system.

As has been shown by analyzing the operation of the cyclic automation system responsible for controlling all the assemblies of the cold pipe rolling mill, the share of the rotation electric drive running time in the entire rolling cycle ranges from 25 to 30%, which allows assessing the engineering and economic performance of the newly suggested solutions.

In positional electric drives, the reducer's gear ratio is commonly chosen on the basis of the criterion of the minimum kinetic energy accumulated on the engine and actuating device shaft [1]. However, the transmission factor calculated against this criterion for polymass systems must be considerably refined, which is due to the influence of the reducer's gear ratio on the loop factors of the unchangeable part of the system (Fig. 1). The system taken for the model controlled object has three generic loops:

—speed loop I with adjuster K_{spad}, internal torque adjustment loop K_{trad}, engine link with inertia torque J_{eng}, and speed sensor K_{spsn};

—loop II, taking into account the elastic link with torsional rigidity $C1$ and actuating device with inertia torque J_{acd}; and

—loop III, which serves to provide the electromechanical connection between the engine and the actuating device and includes a reducer with factor j and reverse transmission functions of the speed adjustment loop and the actuating device loop.

The response speed of each of the loops is indirectly evaluated from the respective crossover frequencies ω_1, ω_2, and ω_3. The external loop of positional adjustment is tuned using positional adjuster W_{padj} and positional sensor K_{posen}. At $\omega_2 > \omega_1$, the resonance peak in the object's combined frequency characteristic, conditioned by the oscillatory kind of loop II, can be significantly reduced by affecting mechanical transmission j. The reducer's preupgrade resultant gear ratio was 8. As has been shown by recalculating the mechanical transmission factor against the minimal oscillability criterion, if we give up the angle reducer and, therefore, simplify the mechanical part, the transmission factor will be 4. The reconsidered principle of selecting the reducer's gear ratio means additional dynamic loads for the engine shaft and requires checking the engine in terms of heating conditions. The relations clarifying the choice of the reducer's gear ratio are shown in Fig. 2. Curve *BA* (Fig. 2a) shows the relation of the resonance peak amplitude as a function of the reducer's gear ratio. Line *2* (Fig. 2a) restricts the limit value of the reducer's gear ratio, whereas line *1* outlines the lower boundary of the resonance peak amplitude; that said, the maximum and the minimum value of this amplitude are found in the range *A*–*B*. The relation of mean square torque M_{mnsq}, in correspondence with the engine heating, to the reducer's gear ratio is shown in Fig. 2b. This is an extremum relation, whereas the critical heating point of the electric machine is observed at the gear ratio value corresponding to the minimum kinetic energy.

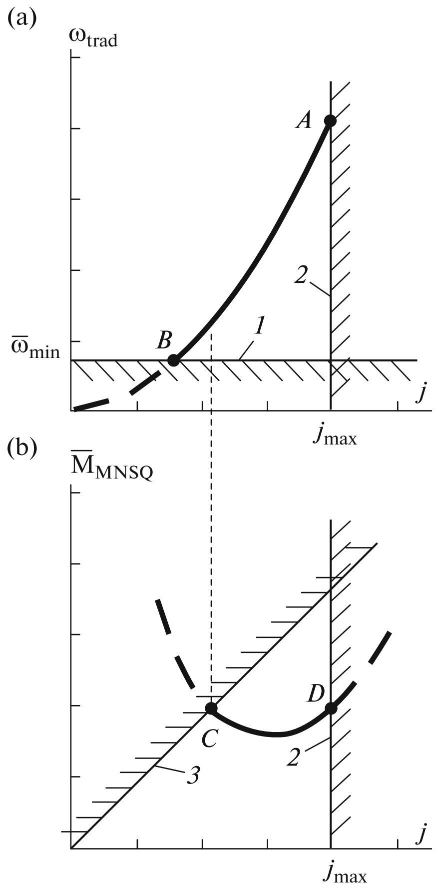

Fig. 2. Selecting the reducer's gear ratio.

Oblique line *3* (Fig. 2b) restricts the limit values of the engine torque by heating conditions. At point *C* permissible in heating conditions (Fig. 2b), the resonance peak compensation makes up 120–130% of the steady-state adjustable coordinate, whereas the full resonance peak compensation (point *B* in Fig. 2a) requires increasing the engine capacity by around 50–100%.

The rotation mechanism electric engine was redesigned following the results of selecting the optimal gear ratio for the reducer. It was necessary to increase the installed engine capacity by 100% as compared to the original electric machine: P_{rt} = 1000 kW, n_{rt} = 990 rpm, and f_{rt} = 50 Hz. As shown by the calculations, the inertia torques of the preupgrade and the newly designed engine are the same, which is due to configuring electric machine for different rated speeds and applying advanced electric insulation materials. Generally, a more powerful engine will have an increased inertia torque, which may require recalculating the installed capacity of the electric drive because of increased dynamic loads on the engine shaft.

The calculated data may be generalized for developing adjustable electric drives for metallurgical production facilities. The main phases of synthesizing adjustable positional electric drives are shown in Fig. 3.

As a rule, it is recommended to use modal control structures to reduce resonance peaks for polymass system objects. In some cases, however, high adjustment figures for two-mass systems can be achieved in conventional multiloop circuits with subordinate control of variables.

The general procedure of synthesizing the power part of the electric drive and its control system for objects running in tracking modes or positioning the actuating device may consists of the following phases:

—determining the best motion path (phase 1, Fig. 3);

—determining the parameters of power electric equipment (phase 2, Fig. 3); and

—selecting the structure and parameters of corrective ties (phase 3, Fig. 3).

The first phase problem is solved by classical variational calculus techniques. The overall displacement of the actuating device and the limit values of electromagnetic torque, current, and speed variables are taken as the original data. In this case, the best motion path ω(*t*) is implemented against the criterion of minimum electric losses [2]. This condition is formally recorded as

$$Q = \min_{\varphi \in \varphi} Q(i, r),$$

where *i* is the phase current and *r* is the active coil resistance.

That said, the actuating device motion path described using general equation $\varphi = f(M_C(t)$; $\omega(t)$ = const is restricted by the limit displacement of the controlled object (in this case, we mean the displacement angle of the rotation mechanism of the KHPT-450 mill). In variational calculus theory, the considered problem is considered an isoperimetric task and solved by numerical techniques. The pipe rotation mechanism is characterized by large dynamic loads, which is why the continuous plot of the target function is split into piecewise-continuous sections each of which is affected, first, by the maximum allowed torque restriction, then by the maximum speed restriction, and, in the final case, by the maximum allowed current restriction. As is shown by the calculation, the electric drive is best used in heating when the startup section is twice as large as the braking section. This can be due to a complex load pattern when it is necessary to overcome the large torque conditioned by the resistance of resistance force.

The second phase consists in selecting the parameters for the electric drive's power parts. This phase involves determining the best value of reducer gear ratio *j* and electromechanical converter's parameters l/D_p given that $(M/m) = \max f(l; (l/D_p))$, where *M* is the electromagnetic torque of the engine with active parts mass *m*, while *l* and D_p are the main dimensions of the electric machine (length and diameter of the active part of the magnet system). The main dimensions of electromechanical converters are chosen by

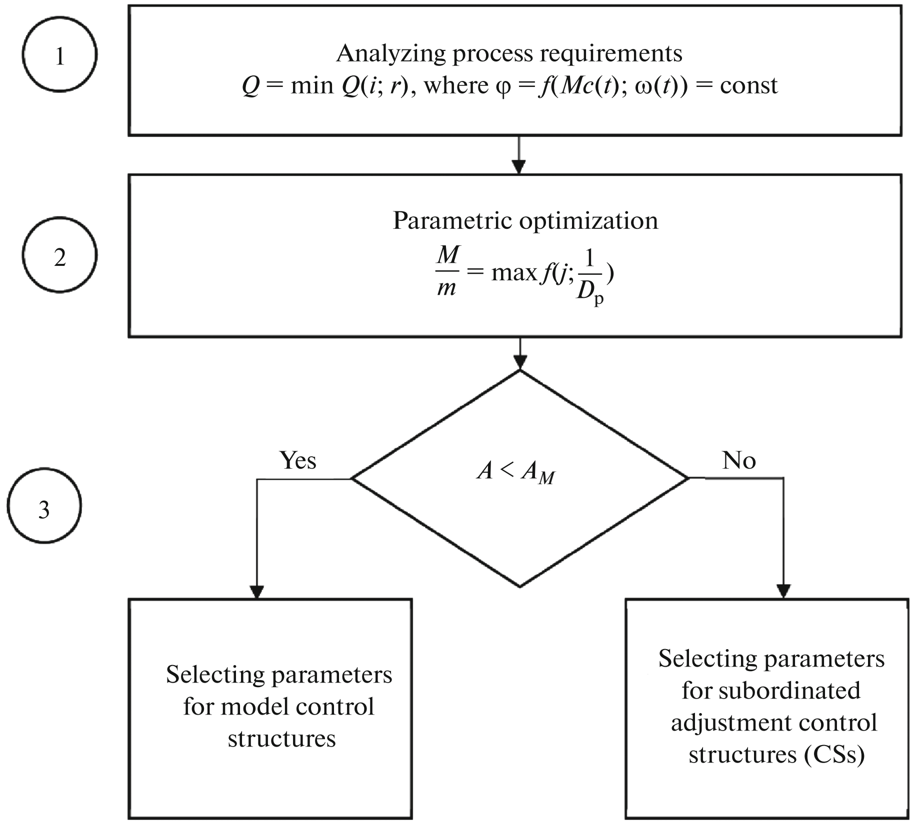

Fig. 3. General procedure of selecting power parts of electric equipment in positioning mechanisms.

standard electric machine design techniques; however, the optimal length/diameter ratio for positional electric drives can be significantly refined. Since these drives run in start-brake modes, the proper choice of the main dimensions ratio can minimize inertia torque J_{eng} of the engine shaft. This problem is solved most efficiently in electric drives with a synchronous reactive independent excitation machine, where a solid and, therefore, more axially rigid electric machine shaft can be installed. Whereas in conventional electric drives the l/D_p ratio rarely exceeds 1.5, in synchronous reactive machine it may exceed 4.

The most convenient way to synthesize the control system (phase 3, Fig. 3) is to use experimental frequency techniques, which allows solving two problems: the parameters of the controlled object are refined by frequency identification techniques, and the structure and parameters of corrective ties are chosen using the set of gain-frequency characteristics.

For example, the resonance peak value is refined during the object's frequency identification by synchronous signal detection techniques [3]. If the choice of the reducer's gear ratio in this phase allows significantly restricting the resonance peak amplitude and, therefore, reducing the phase shift angle at the system crossover frequency, the adjustment system can be synthesized in subordinate adjustment structures typical of electric drives. That said, the system's peak response speed is ensured by determining the parameters of sequential corrective device W_{padj} by the engineering optimum technique [4].

In the case in which this resonance peak cannot be significantly compensated (phase 3, Fig. 3), the problem must be solved in modal-controlled structures. Here, the topical task for solution while building the adjustment structure is to find the observer's parameters. Whereas the engine current, voltage, torque and speed coordinates are measured with certainty, the determination of elastic connection parameters presents several challenges. It is known that, in modal adjustment systems, the maximum even pass band can be implemented only when a reliable model supervisory device is available. For this reason, the set of chosen tools also includes experimental frequency techniques that allow refining both the elastic link parameters and the model supervisory device.

The experimental oscillograph records of (*1*) current and (*2*) speed in the system before the object's upgrade and the curves of (*1*') current and (*2*') speed after the replacement of the mechanical transmission and the adjustable electric drive system are shown in Fig. 4. It follows from Fig. 4 that the system's produc-

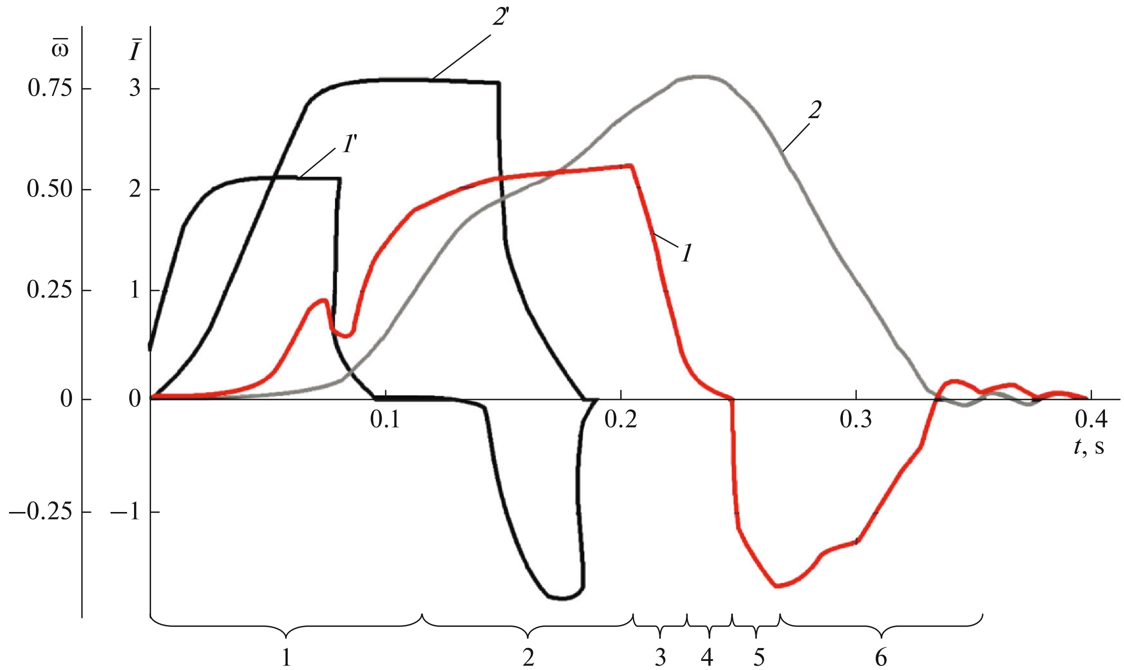

Fig. 4. Oscillograph patterns of (*1*) current and (*2*) speed before and after the object upgrade (*1*', *2*').

tivity has increased by around 100% not only because of the accelerated response speed of the electric drive, but also due to the adjusted rotation angle of the rotation drive according to the process conditions and for ensuring a better positioning precision.

The performance indicators of the potential economic effect of adopting the new electric drive on the KHPT-450 at shop 5 of JSC Chelyabinsk Pipe Plant were calculated by the count-up method. For this purpose, the system's variables were measured and the object's energy consumption was calculated after debugging the electric drive system for one operating shift. Those data were then extrapolated onto the operating year. As was shown by the calculation, if we consider overall costs (variable expenses on electricity and materials and constant expenses on maintaining the shop), the potential annual effect of adopting the adjustable ac electric drive amounts to around 250 million rubles.

FUNDING

This work was financially supported by the Ministry of Education and Science of the Russian Federation, project no. 13-9662-2017/BP.

REFERENCES

1. Usynin, Yu.S., *Sistemy upravleniya elektroprivodov* (The Control Systems of Electric Drives), Chelyabinsk: Yuzh.-Ural. Gos. Univ., 2004.
2. Belykh, I.A., Grigor'ev, M.A., and Belousov, E.V., An electrical feed drive-control system for a cold reducing mill, *Russ. Electr. Eng.*, 2018, vol. 88, no. 4.
3. Feofilov, S.V., Periodic movements in digital relay control systems, *Mekhatronika, Avtom., Upr.*, 2006, no. 11.
4. Faldin, N.V. and Morzhov, A.V., Self-oscillations in relay systems with piecewise linear control objects, *Mekhatronika, Avtom., Upr.*, 2007, no. 2.

Translated by S. Kuznetsov