Application of fiber-optic measuring current transformer in control and relay protection systems of belt conveyor drives

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Abstract: Until recently, control and protection systems used electromagnetic current transformers as information sensors. Due to the nonlinearity of the magnetization curve of the magnetic circuit, such current transformers cannot fundamentally provide satisfactory metrological characteristics in transient conditions, as well as after passing short-circuit currents when the magnetic circuit of the current transformer is deeply saturated with the aperiodic component of the short-circuit current. This is the main disadvantage of electromagnetic current transformers, which complicates and makes unreliable operation of control systems and protection of asynchronous conveyor motors. The article suggests the use of optoelectronic current transformers as information sensors for control and protection systems of Induction Motor.

1. Introduction

The article suggests using a fiber optic current transformer as a signal sensor for protection and control systems of a belt conveyor. This transformer, by virtue of its design, does not have the above drawbacks and can be used, along with the electric power industry and high voltage measuring equipment, also in the field of automation of electric drive control and relay protection systems as a source of operational information [1-12]. The technical result consists in increasing the reliability and stability of measurements in long-term operation for all types of changes in the acting electric voltage, mechanical loads and various environmental factors [13-22]. The relevance of this task is determined by several factors: accuracy of cargo positioning (especially important on automated production assembly lines and automated warehouses); performance safety requirements. To solve this problem, it is necessary to use a system for controlling the speed of the conveyor electric drive. Due to the depreciation of technological equipment and a number of other reasons, the real Electromechanical System (EMC) of the conveyor belt is a substantially unsteady object, the properties of which change significantly over time.

2. Methodology

There is a need to develop the structure and effective functioning algorithms of an optimal adaptive system for automatic control of an electric conveyor belt drive, the use of which will most effectively limit load fluctuations in combination with high performance regardless of the nature of the non-stationary EMC conveyor and the influence of external disturbing factors on it. Of course, for the
effective functioning of the adaptive control system for the operation of the electric conveyor belt, reliable information on the parameters of the supply network is required. Typically, measuring current transformers are used for these purposes. Until recently, measurements of electrical quantities in switchgears of industrial enterprises, are carried out using electromagnetic current transformers.

The purpose of current transformers is to convert current in the supply network to a low voltage signal, i.e. current transformers are signal sensors for control and relay protection systems. The disadvantages of these construction designs are [1, 2]:

- The high probability of electrical breakdown of the insulating gap between the power and secondary (measuring) windings of the transformer;
- Due to the nonlinearity of the magnetization curve of the magnetic circuit, such current transformers cannot provide satisfactory metrological characteristics in transient conditions;
- After the occurrence of short-circuit currents, when the magnetic circuit of the current transformer is deeply saturated with the aperiodic component of the short-circuit current, and of course the measurement error increases. (residual saturation after the occurrence of short-circuit currents can remain for several months);
- It is expensive; the cost of electromagnetic current transformers is a significant part of the cost of all complex of measuring equipment.

Thus, the possibilities of using electromagnetic current transformers as sensors are almost completely exhausted. Considering the task of creating an adaptive control system for a belt conveyor, sensors based on electromagnetic current transformers do not suit us. A fundamentally different approach, based on the use of the magneto-optical Faraday effect, is implemented in optoelectronic current transformers used in combination with modern digital signal processing and transmission technologies data [3].

![Figure 1. Schematic diagram of a fiber optic current transformer](image)

The fiber-optic current transformer includes a current-carrying circuit covered by a magneto-optical sensor in the form of a coil of optical fiber, means for inputting a polarized light signal into the fiber, means for dividing the polarized light signal into mutually orthogonal linearly polarized components, and also a conversion unit components into normalized in intensity electric signals and a unit for generating a measuring signal and determine on it measured value [4].
**Figure 2.** Schematic diagram of current measurement using a fiber–optic current transformer

The principle of their operation [2] is based on the induction of voltage in a coil, which is affected by a magnetic field arising around a conductor due to the current flowing through it. This solution allows to simplify the design of the transformer, because the insulation provides a sufficient distance between the coil and the current conductor. Optoelectronic transformers do not have these limitations. Optical measuring probes can be placed close enough to current conductors without disturbing the distribution of magnetic fields. It consists of completely insulating material, optical transformers guarantee the safety of operation. There is another advantage arising from the application of optoelectronic transformers, namely. possibility of non-invasive measurement. The magnetic field around conductor 1 creates a magnetic field around conductor 1. With the passage of linearly polarized light from the radiation source of the means 3 through the magneto-optical material located in this field of length l (sensitive element 2, its polarization plane rotates by an angle α

\[ \alpha = V \int_{I}^{\infty} H_{1} dl \]

where \( V \) is the Verde material constant;

\( H_{1} \) – component of the magnetic field along the direction of propagation of light.

When choosing as the sensitive element 2 optical fiber, forming n turns around the conductor 1 with the measured electric current \( i \), the angle \( \alpha \) of rotation of the plane of polarization of light at the fiber output will be \( \alpha = Vni \).

When using one polarization divider, as a rule, installed at an angle of 45° to the direction of polarization of the incident light, the light signal is divided into a pair of mutually orthogonal linearly polarized components. In the ideal case (in the absence of double refractions caused, for example, by
thermal and mechanical stresses), these components are converted at node 5 into intensity-normalized electrical signals

\[ I_1 = I_0 \cos(\alpha + 45^\circ) \text{ and } I_2 = I_0 \sin(\alpha + 45^\circ) \] (2)

As a result, it is possible to form a measuring signal that depends only on the angle of rotation of the plane of polarization, and hence on the magnitude of the measured current:

\[ M = \frac{(I_1 - I_2)}{(I_1 + I_2)} = \sin(2 \alpha) = \sin(2Vn) \] (3)

\( M \) - measuring signal magnitude

Using (3), we determine the value of the controlled current we need

\[ i = \arcsin(M/2Vn) \] (4)

The analysis of expressions (1–4) makes it possible to determine the value of the measured current and the fiber-optic current transformer can be used as a current sensor or a sensor of external random influences.

3. Results and Discussion

Thus, in all respects, the fiber-optic current transformer can be used as a random signal sensor in the adaptive control model of the belt conveyor. This was tested on an adaptive controller that controls the speed of the induction motor drive (A.D) with inaccurate models.

![Figure 3. Block diagram of a model for adaptive control of a conveyor belt drive](image)

The proposed controller consists of an adaptive control link with direct coupling, which compensates for non-linear and uncertain factors, and a control loop with feedback, which guarantees the stability of the system. As a sensor of signals of random factors, we used an optoelectronic current transformer. Figure 3 shows a diagram of the adaptive control model of a conveyor belt drive based on the RS-485/Modbus (RTU) frequency controller.
The proposed scheme is not only simple and easy to operate, but also guarantees accurate and quick tracking of speed [6, 7]. The experiments conducted on an induction motor electric drive with a rated motor power of P = 4 kW confirmed good control characteristics (better stability, lower mean square and maximum absolute error), especially in case of serious discrepancy between the parameters of the real drive and the model used to develop the control system.

![Figure 4. Starting characteristics of the AD drive of the conveyor belt](image)

Figure 4. Starting characteristics of the AD drive of the conveyor belt

Figure 4 shows the starting characteristics of the Induction Motor drive of the conveyor using an adaptive control system: a, b – start-up without taking into account current fluctuations in the supply network; c – taking into account the network factor and using an optoelectronic current transformer as a sensor [8-11].

![Figure 5. Adaptive conveyor control system RS-485/Modbus (RTU)](image)

Figure 5. Adaptive conveyor control system RS-485/Modbus (RTU)

4. Conclusion

To date, experiments have been carried out to replace electromagnetic measuring current transformers with optoelectronic measuring transformers. The measurement accuracy increased by (10 – 18) % due to a decrease in the influence of transients associated with Short Circuits and blackouts of individual capacities in the supply network.

The experiment was carried out at the assembly plant for air conditioners and refrigerators of the company ARTEL.
References

[1] Rian IU 2018 Experimental comparison of Conventional and non-conventional optical current transformers, Norwegian University of Science and Technology, Stockholm.

[2] Starostin NI, Ryabko MV, Chamorovskii YK, Gubin VP, Sazonov AI, Morshnev SK, Korotkov NM 2020 Key Engineering Materials 437 314-318.

[3] Fidanbolu K, Efendiogly H 2017 Fiber optic sensors and their applications, Fatih University, Istanbul.

[4] Alexander AG 1989 Optimal and adaptive systems, Higher School, Moscow.

[5] Meakin L, Saxby P 2018 IEEE Transactions on Industrial Electronics 65(11) 8532 – 8542.

[6] Manjunath KS, Roberts AW 1986 Bulk Solids Handling 6(5) 903-911.

[7] Kumpati NS, Zhou H 2011 International Federation of Automatic Control 18(1) 362–367.

[8] Gang T 2014 Automatica 50(11) 2737–2764.

[9] Girish G, Eric J 2011 Journal of Guidance, Control and Dynamics 34(2) 592–607.

[10] ISO 5048 1988 Continuous mechanical handling equipment, Belt conveyors with carrying idlers, Calculation of operating power and tensile forces.

[11] Manjunath KS, Roberts AW 1986 Bulk Solids Handling 6(4) 769-775.

[12] Blake J, Williams W, Glasov C, Bergh R, Fetting K, Hadley E, Sanders G 2000 Optical Current Transducers for High Voltage Applications, 2nd EPRI Optical Sensors Systems Workshop, Atlanta.

[13] Barczak K, Pustelny T, Szpakowski A, Blahut M 2005 Journal de Physique IV(129) 85–90.

[14] Pustelny T, Grabka M 2009 Acta Physica Polonica A 116(3) 385–388.

[15] Barczak K, Pustelny T, Dorosz D, Dorosz J 2009 Acta Physica Polonica A 116(3) 247–249.

[16] Barczak K, Pustelny T, Zycki Z, Blazejczyk T 2009 Acta Physica Polonica A 116(3) 250–253.

[17] Yurevich EI 2007 Theory of automatic control, BHB-Petersburg, Saint Petersburg.

[18] Efimov DV 2014 Robust and adaptive control of nonlinear oscillations, Science, Saint Petersburg.

[19] Teryushov IN 2007 Fafurin-Systems of automation and control, Workshop for laboratory work, Publishing House of Kazan State Technological University, Kazan.

[20] Domanov VI, Shiryaev AR 2014 Electric Control System, Collection of laboratory works Part 2, Ulyanovsk State Technical University, Ulyanovsk.

[21] Karl A 2008 Adaptive control, Dover, pp 25–26.

[22] Eugene L, Kevin W 2013 Robust and adaptive control, Springer, London, pp 317–353.