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COMPUTER-AIDED DESIGN SYSTEM FOR TECHNICAL AND ECONOMICAL COMPARISON OF CRANE ELECTRICAL DRIVES

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Abstract: Computer-aided design system for technical and economic comparison of crane electrical drives, considering the ratio of static and dynamic modes, load and moment inertia, relative running time with reduced speed, is designed. The computer-aided design system provides an opportunity to make a better informed decision about the choice or upgrading of electrical drives.

Keywords: CAD, induction motor electrodrive, technical and economical comparison.

1. Introduction

Induction motors with different control systems are used in mechanisms of many cranes.

Electrical drives with resistance (Rvar) and voltage (Uvar) regulation are the most common for induction motors with phase-wound rotor and frequency converters (FC) with recuperation unit and without it – for a squirrel cage motor. For choosing electric drives a feasibility analysis of the expediency of its use must be performed, taking into account the costs and possible recuperation, the cost of electric motors and components [1, 2].

The aim of this investigation is to develop CAD-system for technical and economical comparison of crane electrical drives.

2. Theoretical and programming basis

The most difficult task in the development of the program is to unify approaches to the analysis of operation modes of crane mechanisms and electric drive systems.

Fig. 1 illustrates static mechanical properties and operating conditions (working points) of the majority of crane mechanisms:

1, 2 - lifting / lowering a nominal load with a nominal speed in hoist mechanisms;

3, 4 - horizontal movement (rotation) or lifting / lowering of an empty hook with a nominal speed;

1', 2', 3', 4' - the same modes with reduced speed.

A typical cycle of the mechanism includes all or part of the listed modes. And work with low speed usually is $t'_{cycle} / t_{cycle} = 5$ ... 20% of the running time at nominal speed.

The power consumption in each mode is determined by the type of electric drive and can be distributed according to the technical data of engines as follows [3].

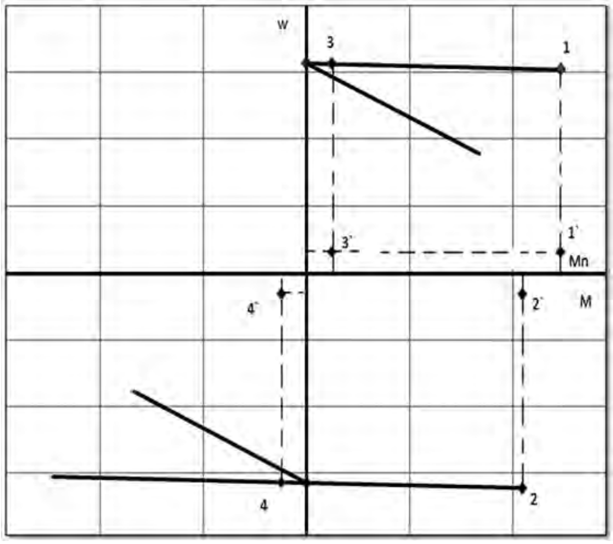

Fig. 1. Mechanical characteristics and operating modes of crane mechanisms.

Nominal losses when using induction motor with a rated speed can be determined as:

$$\Delta P_n = 3U_{1n}I_{1n}\cos\varphi_n - P_n, \quad (1)$$

where $P_n, U_{1n}, I_{1n}, \cos\varphi_n, \Delta P_n$ – nominal power, phase voltage and current, the cosine of the angle delay current, nominal power losses.

Mechanical losses are

$$\Delta P_{mech\ n} = 0,05\Delta P_n, \quad (2)$$

losses from idle current I_0

$$\Delta P_{0n} = 3I_0^2 R_1, \quad (3)$$

variable losses of operating current

$$\Delta P_{Mn} = M_n \omega_0 s_n \left(1 + \frac{R_1}{R_2'}\right), \quad (4)$$

iron losses

$$\Delta P_{Sn} = \Delta P_n - \Delta P_{Mn} - \Delta P_{0n} - \Delta P_{mech\ n}, \quad (5)$$

where $I_0, M_n, s_n, \omega_0, R_1, R_2'$ – idle current, nominal moment and slip, base speed, stator and rotor active resistance restricted to the stator.

Mechanical losses and losses in the steel are amended with speed control, voltage and speed fields in various electric drives as follows:

$$\Delta P_{mech} = \Delta P_{mech\,n}\left(\frac{\omega_1}{\omega_{1n}}\right)^2,$$
$$\Delta P_S = \Delta P_{Sn}\left(\frac{U_1}{U_{1n}}\right)^2\left(\frac{f_1}{f_{1n}}\right)^{1,3}\left(1+s^{1,3}\right). \qquad (6)$$

The duration of mechanical dynamic processes in crane mechanisms greatly exceeds the duration of electromagnetic processes. Therefore, the calculation of energy losses in the dynamic modes can be performed by means of the same equation, taking into consideration changes of slip, extra degrees of rheostats in the rotor, the working quadrant of an electric drive, the possibility of recuperation, the load and total moment inertia of the mechanism with a nominal load or without it. The total power losses during a cycle are defined as the integral of the required power in static and dynamic modes.

The necessary data having been considered, the interface has been created (fig. 2). It is divided into several working windows consisting technical data of engines with the phase-wound and squirrel cage rotors of the same dimension-type. If the motors are presented in referral database, you should specify only types of engines (fields with bold red type). Also the duration of the steady movement cycle, the number of cycles per year, relative load and relative total inertia moments of the mechanism for each operating point should be determined. The bottom row – “Calculate” – determines which of the points 1, 2, 3, 4 are present in the cycle and for which of them the speed can be reduced (1 ', 2', 3 ', 4').

In additional window the number of additional degrees of rheostats for motors with a phase-wound rotor can be determined.

A key START starts the calculation.

Technical data of the induction motor							
With the phase-wound rotor				With the short-circuited rotor			
Description	Variable	Value		Description	Variable	Value	
Type	Type	4MTH225M8		Type	Type	4MTKH225M8	
U1n, V	U1n	220		U1n, V	U1n	220	
Pn, W	Pn	30000		Pn, W	Pn	30000	
n_nom,rpm	n_nom	720		n_nom,rpm	n_nom	700	
cos(φn)	cos_fin	0,72		cos(φn)	cos_fin	0,77	
I1n, A	I1n	74,6		I1n, A	I1n	68,0	
I0, A	I0	46,7		I0, A	I0	38,8	
R1 / X1, Ohm	R1 / X1	0,140	0,230	R1, Ohm	R1	0,140	
R2 / X2', Ohm	R2_/ X2	0,051	0,420	R2', Ohm	R2	0,310	
R2', Ohm	R2	0,084		Rsc' / Xsc', Ohm	Rsc / Xsc	0,450	0,570
Mmax, Nm	Mmax	1030		Mmax, Nm	Mmax	1128	
pole pairs	p	4		pole pairs	p	4	
Jd, kgm^2	Jd	1,070		Jd, kgm^2	Jd	1,070	
Cycle duration in statical mode	tc, s	50					
Number of cycles per year	nc	60000					

Work point	1	1'	2	2'	3	3'	4	4'
|Mc*|	1	1	0,85	0,85	0,15	0,15	0,1	0,1
JmΣ*	0,1	0,1	0,1	0,1	0,05	0,05	0,05	0,05
Calculate	1	1	1	1	1	1	1	1

START

Fig. 2. Program interface of input data.

A window with calculation results also consists of several sections (fig. 3). At the first one the total electricity losses during static and dynamic modes per cycle, as well as the total losses of each of the drives for three values of the relative work duration with low speed are shown.

The results are summarized in the table, which presents total losses with respect to the basic drive (Rvar)

$$(\Sigma\Delta A)_i - (\Sigma\Delta A)_{R\,var}.$$

Rel. dur. with 0,1n_nom	Duration of stat. mode tc= 50 s	Rvar	Uvar	FC w/o recuperation	FC with recuperation
5%	ΔA / cycle (stat. mode), kWh	0,2362	0,2504	0,2851	0,2271
	ΣΔA / year, kWh	**15 330**	**16 238**	**17 196**	**13 684**
10%	ΔA / cycle (stat. mode), kWh	0,2392	0,2532	0,2727	0,2177
	ΣΔA / year, kWh	**15 509**	**16 405**	**16 452**	**13 123**
20%	ΔA / cycle (stat. mode), kWh	0,2452	0,2588	0,2479	0,1990
	ΣΔA / year, kWh	**15 866**	**16 738**	**14 964**	**12 002**
ΔA / cycle (dyn. mode), kWh		0,0193	0,0202	0,0015	0,0010
Duration of dyn. modes td, s		1,50	1,39	1,37	1,37

Relative duration with 0,1n_nom	$(\Sigma\Delta A)_i - (\Sigma\Delta A)_{R\mathrm{var}}$ / year, kWh			
5%	0	908	1 866	-1 646
10%	0	896	943	-2 386
20%	0	873	-902	-3 864

Fig. 3. Program interface for data calculated.

The results from this table in the shape of graphs (fig. 4) with linear trends t'_{cycle} / t_{cycle} up to 30 % provide an opportunity to identify the dependence of losses on the time of work at the reduced speed for any ratio t'_{cycle} / t_{cycle}.

It is obvious that in the crane hoist mechanisms with $t'_{cycle} / t_{cycle} < 10$ % the possibility of recuperation during lowering the load with nominal speed in the simplest electric drive (Rvar) makes it more economical than drives with adjustable voltage and frequency without using a recuperator.

In the swinging mechanism (horizontal movement) dynamic modes are the most important. Therefore the drives with frequency converters are more economical. Fig. 5 illustrates typical relations for these mechanisms.

However, the final decision is made on the basis of comparison of the cost of annual energy savings, capital and depreciation costs for each type of an electric drive.

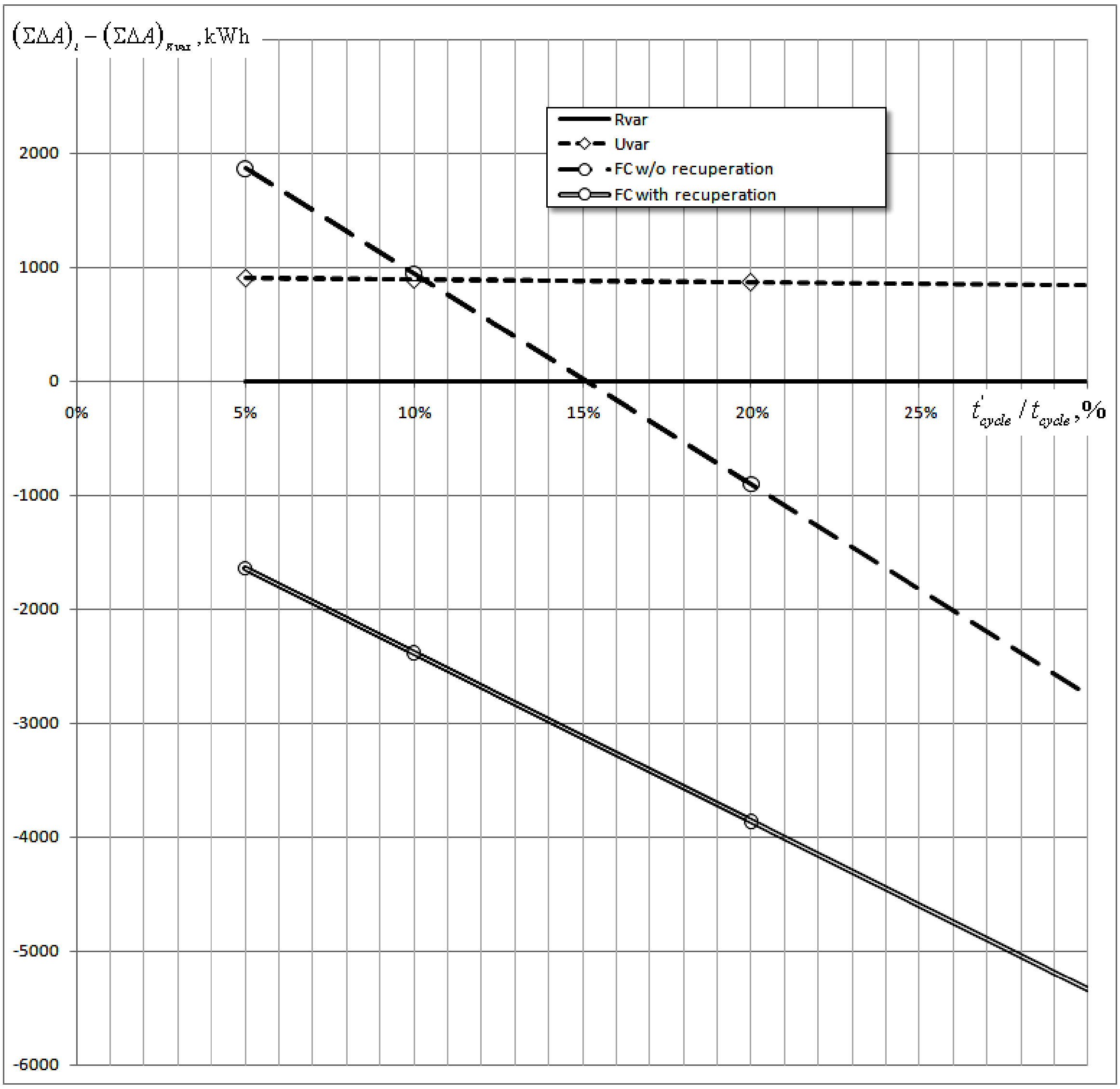

Fig. 4. Graphic dependence of losses on the duration t'_{cycle} / t_{cycle} in the lifting mechanisms.

Work point	1	1'	2	2'	3	3'	4	4'
|Mc*|	0,1	0,1	0,1	0,1	0,15	0,15	0,1	0,1
JmΣ*	30	30	16	16	30	30	16	16
Calculate	0	0	0	0	1	1	1	1

Relative duration with 0,1In_nom	$(\Sigma\Delta A)_i - (\Sigma\Delta A)_{R\,\mathrm{var}}$ / year, kWth			
5%	0	849	-11 229	-11 629
10%	0	823	-11 296	-11 696
20%	0	773	-11 428	-11 828

Fig. 5. Source data and calculated results for a swinging mechanism.

3. Conclusions

A software system for technical and economic comparison of crane drives with the main features of their operating modes – the ratio of the static and dynamic modes, load and inertia moments with / without a load, the relative running time with low speed. Notable capital and depreciation costs and annually total consumption of electricity determined by the program provide possibility to make a better informed decision on the choice of an electric drive or its reconstruction.

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ПРОГРАМНИЙ КОМПЛЕКС ДЛЯ ТЕХНІКО-ЕКОНОМІЧНОГО ПОРІВНЯННЯ КРАНОВИХ ЕЛЕКТРОПРИВОДІВ

Ростислав Герасим'як, Віктор Бушер,
Світлана Савіч, Людмила Швец

Розроблено програмний комплекс для техніко-економічного порівняння кранових електроприводів з урахуванням співвідношення статичних і динамічних режимів, навантаження і моментів інерції, відносного часу роботи зі зниженою швидкістю. Це надає змогу прийняти зважене рішення щодо вибору або реконструкції електропривода.

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