

Static modes of an electromagnetic working shaft (EMWSh) and an electro-electromagnetic working shaft (EEMWSh) with the inclusion of a capacitor in the rotor circuit of the motors

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Abstract. In this paper, the issues of ensuring the statically stable operation of a two-motor electric drive are considered, a fundamentally new system of coordinated rotation of asynchronous motors based on an electromagnetic working shaft (EMWSh) has been developed. A distinctive feature of EMWSh is the connection of the rotor windings of two or more motors to the power windings of an induction rheostat (IR) and capacitors. The issues of practical application of EMWSh and electro-electromagnetic working shaft EEMWSh with the inclusion of a capacitor in the rotor circuit of motor systems in multi-motor electric drives of crane movement mechanisms and long conveyor lines are studied.

1 Introduction

A multi-motor AC electric drive is currently widely used in many industrial mechanisms, providing synchronous rotation of mechanically unrelated units and assemblies. The most accurate synchronization of rotation speeds of drive motors in a wide range of load changes is achieved when they are switched on according to the electric working shaft (EWSH) scheme [1-3]. However, EWSHs are characterized by such disadvantages as the need for pre-start synchronization of the angular positions of the rotors, the impossibility of "synchronization on the go", the impossibility of reverse. These shortcomings to a certain extent hinder the widespread use of EWSH and necessitate the development of other systems of synchronous rotation, in certain respects inferior to EWSH, but with better performance [6, 16].

2 Methods

A fundamentally new system of synchronous rotation of asynchronous motors - EMWSh has been developed. A distinctive feature of EMWSh is the connection of the rotor windings of two or more motors to the power windings of an induction rheostat (IR). IR is an electromagnetic energy converter and is characterized by the ability to change its active and inductive resistance as a function of the rotor current frequency, which in turn is

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directly proportional to the motor slip [4, 10]. The EEMWSh study shows the possibility of increasing the motor speed control zone, which can be seen from characteristic 2 in Fig. 1. Comparative characteristics of EMWSh, EEMWSh and EWSh with IR for the same parameters of IR and engines.

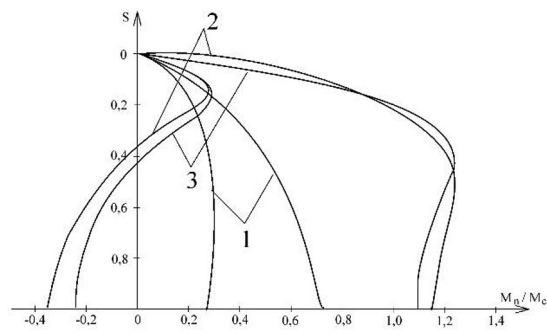
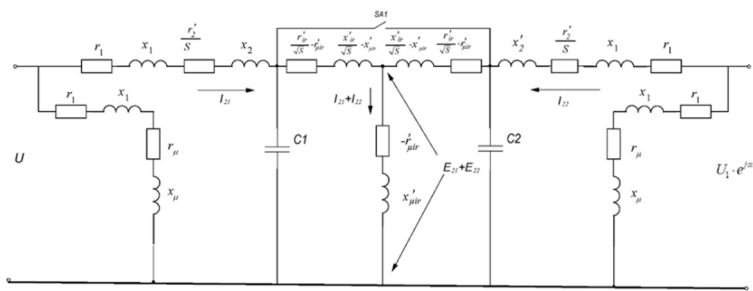


Fig. 1. $k_2=1.0$ $\alpha=90^\circ$ $\beta_2=0.5$ $\beta_1=1.0$: 1- EMWSh, 2- EEMWSh, 3- EWSh with IR

However, as can be tentatively assumed, the inclusion of a capacitor in a circuit containing an IR should lead to a significant increase in the control range; x_{ir} , which increases depending on $f\sqrt{S}$, is compensated to a greater extent by x_c , depending on $\frac{1}{\sqrt{S}}$. In this case, the inclusion of capacitors in parallel with the windings of the IR should be more efficient; in this case, the resonance of the currents in the circuit determines the value I_p and,



therefore, M_c .

Fig. 2. Equivalent circuit of EMWSh and EEMWSh with the inclusion of capacitors

The equivalent circuit when capacitors are turned on is shown in Fig. 2.

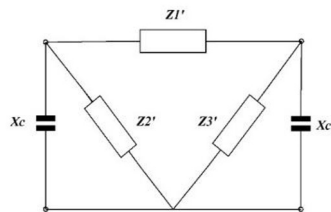


Fig. 3. First equivalent transformation (from Y to Δ).

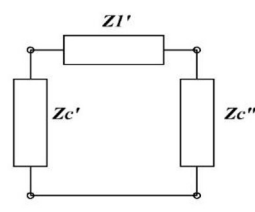


Fig. 4. Second equivalent transformation (addition//).

Additionally, at the 1st stage, we will transform the section of the circuit with EMR from a star Y into a triangle Δ , as shown in Fig. 2.
 Let us introduce the notation:

$$z'_{ir} = z_{ir} - z_M = \left(\frac{R_{ir}}{\sqrt{S}} - R_M \right) + \left(\frac{x_{ir}}{\sqrt{S}} - x_M \right) \quad (1)$$

Then we have according to the rules:

$$z'_2 = z'_3 = z'_{ir} + z_M + \frac{z'_{ir} \cdot z_M}{z'_{ir}} = z'_{ir} + 2z_M = z_{ir} + z_M$$

$$z'_1 = z'_{ir} + z'_{ir} + \frac{z'_{ir} \cdot z'_{ir}}{z_M} = 2(z_{ir} - z_M) + \frac{(z_{ir} - z_M)^2}{z_M} = (z_{ir}^2 - z_M^2) / z_M \quad (2)$$

At the 2nd stage, we perform addition in parallel z'_2 (or z'_3) with x_c . The elements shown in fig. 4. have the following parameters ($x_c = -jx_c / S^2$) denoted as z_c):

$$z'_c = z''_c = \frac{z_c \cdot (z_{ir} + z_M)}{z_c + z_{ir} + z_M} \quad (3)$$

At the 3rd stage, we transform Δ into Y. The elements shown in fig. 4. have the following parameters:

$$z''_1 = z''_2 = \frac{z_{ir}^2 - z_M^2}{z_M} \cdot \frac{z_c \cdot (z_{ir} + z_M)}{z_c + z_{ir} + z_M} \cdot \left[\frac{z_{ir}^2 - z_M^2}{z_M} + 2 \cdot \frac{z_c \cdot (z_{ir} + z_M)}{z_c + z_{ir} + z_M} \right] = \frac{(z_{ir} - z_M) \cdot z_c}{z_{ir} - z_M + z_c}$$

$$z''_3 = \frac{(z_{ir} + z_M)^2 \cdot z_c^2}{(z_c + z_{ir} + z_M)^2} \cdot \left[\frac{z_{ir}^2 - z_M^2}{z_M} + 2 \cdot \frac{z_c \cdot (z_{ir} + z_M)}{z_c + z_{ir} + z_M} \right] = \frac{z_M \cdot z_c^2}{(z_{ir} + z_c)^2 - z_M^2} \quad (4)$$

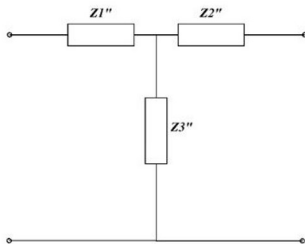


Fig. 5. Third equivalent transformation (from Δ to Y).

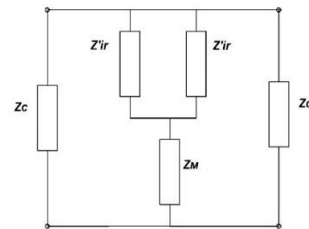


Fig. 6. Equivalent circuit plot EEMWSh with Z_c .

In the case of closing the ZK contact, the equivalent circuit of the EEMRV with capacitors for the same section has the form (Fig. 6). The transformation in this case is as follows.

$$z_{\text{con}} = \left(\frac{z'_{\text{ir}}}{2} + z_M \right) P \frac{z_c}{2} = \frac{(z'_{\text{ir}} + 2z_M) \cdot 2z_c}{4 \cdot (z'_{\text{ir}} + 2z_M + z_c)} = \frac{(z_{\text{ir}} + z_M) \cdot z_c}{2 \cdot (z_{\text{ir}} + z_M + z_c)} \quad (5)$$

Let us introduce an additional component $\gamma = \frac{x_c}{x_\kappa}$ and previously used $k_1, k_2, \beta_1, \beta_2$ and

find expressions for the active and reactive components z''_1 (or z''_2), z''_3 , and also z_{con} .

In final form:

$$\begin{aligned} R''_1 &= \frac{\frac{\gamma^2}{S^4} \cdot \left(\frac{k_1 \beta_1}{\sqrt{S}} - k_2 \beta_2 \right)}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} \cdot x_\kappa; \\ x''_1 &= \frac{-\frac{\gamma}{S^2} \cdot \left[\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 \right) \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right) \right]}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} \cdot x_\kappa; \\ R''_3 &= \frac{-\frac{\gamma^2}{S^4} \cdot \left\{ k_2 \beta_2 \cdot \left[k_1^2 \beta_1^2 / S - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \beta_2^2 \right] + 2 \beta_2 \cdot \right. \\ &\quad \left[k_1^2 \beta_1^2 / S - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \beta_2^2 \right]^2 + 4 \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \right. \\ &\quad \left. \left. \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right] \right\}}{\left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2} \right]^2} \cdot x_\kappa; \\ x''_3 &= \frac{\frac{\gamma^2}{S^4} \left\{ 2 k_2 \beta_2 \cdot \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right] - \beta_2 \cdot \right. \\ &\quad \left[k_1^2 \beta_1^2 / S - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \beta_2^2 \right]^2 + 4 \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \right. \\ &\quad \left. \left. \left[k_1^2 \beta_1^2 / S - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \beta_2^2 \right] \right\}}{\left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2} \right]^2} \cdot x_\kappa; \\ x_{\text{con}} &= \frac{-\frac{\gamma}{S^2} \cdot \left[\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2 \right) \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2 \right) \right]}{2 \left[\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2 \right)^2 \right]} \cdot x_\kappa \quad (6) \end{aligned}$$

Then the general expression for the moments of engines according to the type (1) and (6) will look like:

$$\frac{M_{1,2}}{M_M} = \left[\frac{\frac{S_m}{S} + \frac{\gamma^2 \cdot (k_1\beta_1/\sqrt{S} - k_2\beta_2)}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2}}{S} \right] \cdot (1 - \cos \alpha) \\ + \left[\frac{\frac{S_m}{S} + \frac{\gamma^2 \cdot (k_1\beta_1/\sqrt{S} - k_2\beta_2)}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2}}{S} \right]^2 + \left\{ \frac{\frac{S_m}{S} + \frac{\gamma}{S^2} \cdot \left[(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2 \right]}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} \right\}^2 + \left\{ \frac{\frac{S_m}{S} + \frac{\gamma}{S^2} \cdot \left[(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2 \right]}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} \right\} \\ + \frac{\frac{\gamma^2}{S^4} (k_1\beta_1/\sqrt{S} - k_2\beta_2)}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} - \frac{2\frac{\gamma^2}{S^4} \{k_2\beta_2 \cdot [k_1^2\beta_1^2/S - k_1^2\beta_1^2/S - (\beta_1/\sqrt{S} - \gamma/S^2)^2 - k_1^2\beta_1^2/S - (\beta_1/\sqrt{S} - \gamma/S^2)^2 - k_2^2\beta_2^2 + \beta_2^2]\}}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} \\ + \frac{\frac{\gamma^2}{S^4} (k_1\beta_1/\sqrt{S} - k_2\beta_2)}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} - \frac{2\frac{\gamma^2}{S^4} \{k_2\beta_2 \cdot [k_1^2\beta_1^2/S - (\beta_1/\sqrt{S} - \gamma/S^2)^2 - k_1^2\beta_1^2/S - (\beta_1/\sqrt{S} - \gamma/S^2)^2 - k_2^2\beta_2^2 + \beta_2^2]\}}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} \\ - \frac{(\beta_1/\sqrt{S} - \gamma/S^2)^2 - k_2^2\beta_2^2 + \beta_2^2}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} + 2\beta_2 \cdot [(k_1\beta_1/\sqrt{S}) \cdot (\beta_1/\sqrt{S} - \gamma/S^2) - k_2\beta_2^2] \\ + 4 \cdot [(k_1\beta_1/\sqrt{S}) \cdot (\beta_1/\sqrt{S} - \gamma/S^2) - k_2\beta_2^2]^2 \Bigg\} \cdot (1 + \cos \alpha) \\ + \left[\frac{-k_2\beta_2^2 + \beta_2^2}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} + 2\beta_2 \cdot [(k_1\beta_1/\sqrt{S}) \cdot (\beta_1/\sqrt{S} - \gamma/S^2) - k_2\beta_2^2] \right] \\ + 4 \cdot [(k_1\beta_1/\sqrt{S}) \cdot (\beta_1/\sqrt{S} - \gamma/S^2) - k_2\beta_2^2]^2 \Bigg\} + \left\{ 1 - \frac{\frac{\gamma}{S^2} \cdot [(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2]}{(k_1\beta_1/\sqrt{S} - k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} \right\} \\ + \frac{(-k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2)(\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)}{(-k_2\beta_2)^2 + (\beta_1/\sqrt{S} - \beta_2 - \gamma/S^2)^2} + \frac{2\frac{\gamma^2}{S^4} \cdot \{2k_2\beta_2 \cdot [(k_1\beta_1/\sqrt{S}) \cdot (\beta_1/\sqrt{S} - \gamma/S^2) - k_2\beta_2^2] + 4 \cdot [(k_1\beta_1/\sqrt{S}) \cdot (\beta_1/\sqrt{S} - \gamma/S^2) - k_2\beta_2^2]^2\}}{[k_1^2\beta_1^2/S - (\beta_1/\sqrt{S} - \gamma/S^2)^2 - k_2^2\beta_2^2 + \beta_2^2]^2} \\ + \frac{(-\gamma/S^2 - k_2\beta_2^2) - \beta_2 \cdot [k_1^2\beta_1^2/S - (\beta_1/\sqrt{S} - \gamma/S^2)^2 - k_2^2\beta_2^2 + \beta_2^2]}{+4 \cdot [(k_1\beta_1/\sqrt{S}) \cdot (\beta_1/\sqrt{S} - \gamma/S^2) - k_2\beta_2^2]^2} \Bigg\}^2 \mp$$

$$\begin{aligned}
& \pm \left\{ \frac{1 - \frac{\gamma}{S^2} \cdot \left[\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 \right) \cdot \left(\beta_1 / \sqrt{S} - \beta_2 + \beta_2^2 - \gamma / S^2 \right) \right]}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} \right. \\
& \quad \left. + \left\{ \frac{\frac{S_m}{S} + \frac{\gamma^2 \left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)}{S^4}}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} + 1 - \frac{\left\{ 1 - \frac{\gamma}{S^2} \left[\frac{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 \right) \cdot \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right) \right]}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} \right\}^2}{\left\{ \frac{S_m}{S} + \right.} \right. \\
& \quad \left. \left. - \frac{\frac{\gamma}{S^2} \cdot \left[\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 \right) \cdot \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right) \right]}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} \right\}^2} \right. \\
& \quad \left. - \frac{\frac{\gamma}{S^2} \cdot \left[\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 \right) \cdot \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right) \right]}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} \right\} + \frac{2 \gamma^2}{S^4} \cdot \frac{1}{\left[k_1^2 \beta_1^2 / \sqrt{S} - \right.} \\
& \quad \left. + \frac{\frac{\gamma^2}{S^4} \cdot \left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} - \frac{2 \gamma^2}{S^4} \left\{ k_2 \beta_2 \cdot \left[k_1^2 \beta_1^2 / \sqrt{S} - \left(\beta_1 / \sqrt{S} - \right. \right. \right. \\
& \quad \left. \left. \left. \left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2 \right] - k_2^2 \beta_2^2 + \right. \right. \\
& \quad \left. \left. \left. \left\{ 2 k_2 \beta_2 \cdot \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right] - \beta_2 \cdot \left[k_1^2 \beta_1^2 / S - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \right. \right. \right. \right. \\
& \quad \left. \left. \left. \left. - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \beta_2^2 \right] + 4 \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right]^2 \right. \right. \right. \\
& \quad \left. \left. \left. \left. - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \beta_2^2 \right] + 2 \beta_2 \cdot \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right] \right\}^2} \right. \\
& \quad \left. \left. \left. \frac{+ \beta_2^2 \right]^2 + 4 \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right]^2}{} \right\} + \right. \\
& \quad \left. \left. \left. \frac{+ \beta_2^2 \right] \right\} \right\} \right\} \\
& \quad + \left\{ 1 - \frac{\frac{\gamma}{S^2} \left[\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 \right) \cdot \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right) \right]}{\left(k_1 \beta_1 / \sqrt{S} - k_2 \beta_2 \right)^2 + \left(\beta_1 / \sqrt{S} - \beta_2 - \gamma / S^2 \right)^2} + \right. \\
& \quad \left. \frac{2 \gamma^2}{S^4} \left\{ 2 k_2 \beta_2 \cdot \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right] - \beta_2 \cdot \left[k_1^2 \beta_1^2 / S - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - \right. \right. \right. \\
& \quad \left. \left. \left. \left[k_1^2 \beta_1^2 / S - \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right)^2 - k_2^2 \beta_2^2 + \beta_2^2 \right]^2 + 4 \cdot \left[\left(k_1 \beta_1 / \sqrt{S} \right) \cdot \left(\beta_1 / \sqrt{S} - \gamma / S^2 \right) - k_2 \beta_2^2 \right]^2 \right. \right. \right. \\
& \quad \left. \left. \left. \left. - k_2 \beta_2^2 + \beta_2^2 \right] \right\}^2 \right\} \cdot \sin \alpha \right. \\
& \quad \left. \left. \left. \frac{- k_2 \beta_2^2 + \beta_2^2 \right] \right\}^2 \right\} \right\} \cdot \sin \alpha
\end{aligned}
\tag{7}$$

For EEMWSh, the view will be as follows:

$$\begin{aligned} \frac{M_{1,2}}{M_M} = & \frac{\frac{S_m}{S} \cdot (1 - \cos \alpha)}{\left(\frac{S_m}{S}\right)^2 + 1} + \frac{\left[\frac{\frac{S_m}{S} + \frac{\frac{\gamma^2}{S^4} \cdot (k_1 \beta_1 / \sqrt{S} + k_2 \beta_2)}{S^4}}{\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2\right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2\right)^2} \right]}{\left[\frac{\frac{S_m}{S} + \frac{\frac{\gamma^2}{S^4} \cdot (k_1 \beta_1 / \sqrt{S} + k_2 \beta_2)}{S^4}}{\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2\right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2\right)^2} \right]^2 +} \\ & \cdot (1 + \cos \alpha) \\ & + \left\{ 1 - \frac{\frac{\gamma}{S^2} \cdot \left[\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2\right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2\right) \cdot \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2\right)^2 \right]}{\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2\right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2\right)^2} \right\}^2 \mp \\ & \mp \left\{ \frac{1}{\left(\frac{S_m}{S}\right)^2 + 1} - \frac{1 - \frac{\gamma}{S^2} \cdot \left[\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2\right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2\right) \cdot \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2\right)^2 \right]}{\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2\right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2\right)^2} \right. \\ & \left. - \frac{\left[\frac{\frac{S_m}{S} + \frac{\frac{\gamma^2}{S^4} \cdot (k_1 \beta_1 / \sqrt{S} + k_2 \beta_2)}{S^4}}{\left(k_1 \beta_1 / \sqrt{S} + k_2 \beta_2\right)^2 + \left(\beta_1 / \sqrt{S} + \beta_2 - \gamma / S^2\right)^2} \right]^2 +} \right\} \cdot \sin \alpha \end{aligned} \quad (8)$$

The values typical for this electric drive circuit, as in the case of EMRV, are determined by (7) ÷ (8) using (6). They do not make sense to give here because of the volume of expressions.

3 Results and Discussion

Now it is necessary to analyze the families of ERW and EMRE characteristics with the inclusion of C and compare them with previously obtained characteristics [4, 12]. First of all, it should be noted that an increase in the coefficients γ , k_2 , β_1 , β_2 leads to a linearization of the load characteristic, but at the same time to an unacceptable overload of the motor ($M_n > 2M_M$). Therefore, we consider the characteristics with a low value of the listed parameters, shown in Fig. 7 and 8.

Characteristics of EMWSh and EEMWSh with the inclusion of a capacitor.

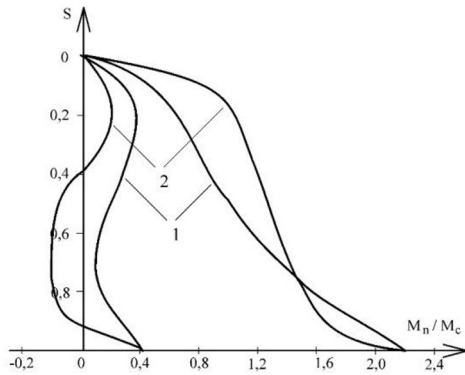


Fig. 7. $\gamma=1.0$ $k_2=1.0$ $\beta_1=0.5$ $\beta_2=0.5$
 1- EMWSH with C. 2-EEMWSH with C.

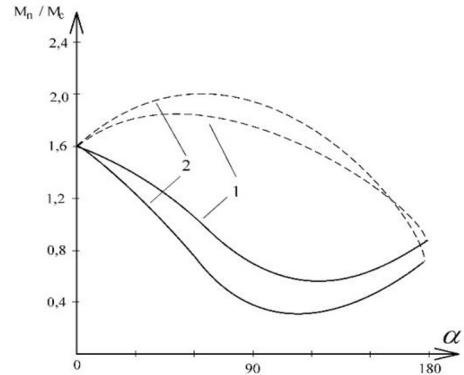


Fig. 8. $\gamma=1.0$ $k_2=1.0$ $\beta_1=0.5$ $\beta_2=0.5$.
 1- EMWSH with C. 2- EEMWSH with C.

It can be seen from them that, just as in the previous cases, the range covered by the EMRV is wider than the load range of the EMRV. It can also be concluded that for values of x_c , R_M , x_M , x'_{ir} not exceeding , we obtain the desired characteristic, which in the general case has the properties of both crane and traction. As can be seen from Fig. 7, for EMWSH, the characteristic is almost linear, therefore, this type of electric drive circuit can be recommended for conveyors, individual machines, wherever precise control of the speed of motors is required. EEMWSH is characterized by the presence of a flat and sloping section, which makes it possible to use such a scheme for crane engines. In general, the use of such schemes seems to be very promising [3, 5, 13-21].

4 Conclusions

A new multi-motor electric drive based on the principle of an electromagnetic working shaft is proposed, which eliminates some of the disadvantages of the known principle of an electric working shaft.

The schemes of electromagnetic and electro-electromagnetic working shaft with and without the use of capacitances have been studied theoretically and by calculation, and the best schemes and combinations of parameters have been found [10, 13, 14].

Prerequisites have been created for further research in the direction of new designs, calculation and analysis of dynamic modes and automation of full cycle calculations for EMWSH.

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