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NUMERICAL SIMULATION OF TRANSIENTS PROCESSES IN NONLINEAR ELECTRIC DRIVE SYSTEM WITH INDUCTION ELECTROMAGNETIC CLUTCH

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Abstract- The new numerical method of simulation in nonlinear system of the drilling electric drive with induction electromagnetic clutch including the part with the distributed parameters is in view losses and presented in the paper.

Keywords: Computer Modeling, Nonlinear System, Drilling Electric Drive, Numerical Method, Electromagnetic Clutch.

I. INTRODUCTION

The problems of drilling oil wells operation results by necessity of studying of complex character of movement of all parts of drilling installation which takes place in case of rotary way of drilling [1].

Distinctive feature of drilling electric drives in case of rotary drilling is the presence of a boring column through which the rotating moment from drive of engine goes to the executive mechanism and a drilling instrument. It is necessary to note that coming on the input of system of the electric drive of the information about character of changing of loading on a drilling instrument occurs to some delay, owing to that circumstance, that the column of boring pipes is object with the distributed parameters. Therefore the studying of dynamics question in the electric drive which includes the part with distributed parameters represents doubtless scientific and practical interest [2].

In given article the further generalization on development of the specified numerical method for calculation of transients processes in nonlinear system of the drilling electric drive with induction electromagnetic clutch including the part with the distributed parameters is in view losses by the replacing operation of continuous integration by summation using the formula of trapezium. The essence of the offered numerical method is based on the using of discrete analogue of the integrated equation of convolution [3]. Advantage of the offered approach is that it allows finding transients in nonlinear system of the drilling electric drive with induction electromagnetic clutch with the distributed parameters, without finding of roots of the characteristic equation that considerably simplifies mathematical tricks and expands a circle of solved practical tasks.

II. THEORETICAL ASPECTS

The equation of movement of the electric drive and electromagnetic clutch is presented as:

$$I_{э}\frac{d\bar{\omega}_{э}(t)}{dt} = M_{э}(t) - M_{\mu}(t) \qquad (1)$$

$$I_{\mu}\frac{d\omega_{\mu}(t)}{dt} = M_{\mu}(t) - M_{c}(t) \qquad (2)$$

where $M_{э}(t)$, $M_{\mu}(t)$, $M_{c}(t)$ are the rotating moment of the electric motors, electromagnetic clutch and the moment of loading accordingly;

$I_{э}$, I_{μ} are the moment of inertia of a drive and electromagnetic clutch;

$\omega_{э}(t)$, $\omega_{\mu}(t)$ are angular speed electric drive and electromagnetic clutch.

In expression (1) rotating moment is nonlinear function $M_{э}(t) = \Phi\left[\omega_{э}(t)\right]$. We shall present nonlinear dependence $M_{э}(t)$ as approximate its piece-linear functions as:

$$M_{э}(t) = a_j \pm b_j \omega_{\omega}(t) \qquad (3)$$

where j = 1, 2, 3, ..., z; a_j, b_j are parameters of linearization for corresponding districts of mechanical characteristic of the engine.

$M_{\mu}(t)$ is presented as nonlinear dependence as approximate of piece-linear function as:

$$M_{\mu}(t) = a_2' - b_2'\omega_{\mu}(t) \qquad (4)$$

where a_2', b_2' are parameters of linearization for corresponding districts of mechanical characteristic of the electromagnetic clutch.

Expression (1) with the account (3) and (4) provided that prior to the beginning of transient angular speed of the engine $\omega_{эbeg}$ in the operational form, it is possible to present as:

$$\omega_{э}(s) = \left(\frac{a_s}{s} + I_{э}\omega_{эbeg}\right)k_1(s) - k_1(s)\left(\frac{a_2'}{s} - b_2'\omega_{\mu}(s)\right) \qquad (5)$$

where $\omega_э(s)$, $\omega_\mu(s)$ are Laplace image of functions $\omega_э(t)$, $\omega_\mu(t)$ and s is the operator of Laplace transformation; and $k_1(s)=\dfrac{1}{I_э s \pm b_j}$ is transient function.

Passing from the (5) in area of originals, we shall receive:

$$\omega_\omega(t)=\frac{a_j-a_2'}{b_j}\left(1-k_1'(t)\right)++\omega_{эbeg}k'(t)+ \\ +\frac{b_2'}{I_э}\int_0^1 k_1'(\theta)\omega_\mu(t-\theta)d\theta \tag{6}$$

where

$$k_1'(t)=e^{\pm\frac{b_j}{I_э}t}$$

Expression (2) with the account (4) in the operation form, it is possible to present as:

$$\left(I_\mu s+b_2\right)\omega_\mu(s)=\frac{a_2}{s}+I_\mu\omega_{\mu beg}-M_c(s) \tag{7}$$

where $\omega_\mu(s)$, $M_c(s)$ are the Laplace image of functions $\omega_\mu(t)$, $M_c(t)$.

Passing from the (7) in area of originals, who shall receive:

$$\omega_\mu(t)=\frac{a_2}{b_2}\left(1-k_2'(t)\right)+\omega_{\mu beg}k_2'(t)- \\ -\frac{1}{I_\mu}\int_0^t k_2'(\theta)M_c(t-\theta)d\theta \tag{8}$$

where $k_2'(t)=e^{-\frac{b_2}{I_\mu}t}$ and $M_c(t)$ is unknown function.

III. TECHNICAL FEATURES

Definition of the mentioned parameters is carried out by the following technique. The transients proceeding in a column of boring pipes as object with distributed parameters at rotation fluctuations without taking into account friction between a column of pipes and a clay solution are described by the wave equation [1, 3]:

$$-\frac{\partial\omega}{\partial x}=k_1\frac{\partial M}{\partial t}+k_3 M \\ -\frac{\partial M}{\partial x}=k_2\frac{\partial\omega}{\partial t}+\omega k_4,\quad 0\le x\le l \tag{9}$$

where $\omega=\omega(x,t)$, $M=M(x,t)$ are change of angular speed and he twisting moment to any point of a column of pipes during the any moment of time; k_1, k_2, k_3, k_4 are coefficients of constants; l is length of a column of boring pipes. By considering

$$\frac{k_3}{k_1}=\frac{k_4}{k_2}$$

entry conditions:

$$\omega(x,t)_{t=0}=0,\quad M(x,t)_{t=0}=0$$

And boundary conditions look like:

$$\omega(x,t)_{x=0}=\omega_\mu(t),\quad \omega(x,t)_{x=l}=\mu M(x,t)_{x=l}$$

where μ is the factor determining communication between angular speed $\omega(x,t)$ and the moment of torsion $M(x,t)$ in a final point of a link with the distributed parameters.

In a considered case a part the chisel of working face is represented as active loading of a shaft by resistance μ. For the free and fixed ends it accepts values accordingly $\mu=\infty$ and $\mu=0$.

The solution of system of the differential equations (9) under the accepted initial and boundary conditions allows to receive the full information on change of angular speed and the moment of torsion, both on length of a column of pipes, and on time. At the decision of a task in view at the first stage it is necessary to receive Laplace images for functions $\omega(x,t)$, $M(x,t)$.

By using this method, we shall receive expression for the specified functions in the operational form:

$$\omega(x,s)=\frac{e^{-(s+\alpha)\tau\frac{x}{l}}-e^{\varphi_1}\cdot e^{-2s\tau}e^{(s+\alpha)\tau\frac{x}{l}}}{1-e^{\varphi_1}\cdot e^{-2s\tau}}\omega_\mu(s) \tag{10}$$

$$M(x,s)=\frac{1}{\rho}\frac{e^{-(s+\alpha)\tau\frac{x}{l}}+e^{\varphi_1}\cdot e^{-2s\tau}e^{(s+\alpha)\tau\frac{x}{l}}}{1-e^{\varphi_1}\cdot e^{-2s\tau}}\omega_\mu(s) \tag{11}$$

where $\alpha=\dfrac{k_3}{k_1}$ is coefficient of losses, $e^{\varphi_1}=\dfrac{\rho-\mu}{\rho+\mu}$, $\rho=\sqrt{\dfrac{k_1}{k_2}}$ is wave loading; $\omega(x,s)$, $M(x,s)$ are Laplace images of functions $\omega(x,t)$, $M(x,t)$.

Expressions (10) and (11) it is possible to present as:

$$\omega(\delta,s)\left[\frac{1}{s}-e^{\varphi_1}k_1(s)\right]= \\ =\left[e^{-2\alpha\tau\delta}k_2(s)-e^{\varphi_1}e^{2\alpha\tau\delta}k_3(s)\right]\omega_\mu(s) \tag{12}$$

$$M(\delta,s)\left[\frac{1}{s}-e^{\varphi_1}k_1(s)\right]= \\ =\left[e^{-2\alpha\tau\delta}k_2(s)+e^{\varphi_1}e^{2\alpha\tau\delta}k_3(s)\right]\omega_\mu(s) \tag{13}$$

where

$$k_1(s)=\frac{1}{s}e^{-\frac{2l}{c}s},\quad k_2(s)=\frac{1}{s}e^{-\frac{2l\delta}{c}}$$

$$k_3(s)=\frac{1}{s}e^{-\frac{2l(1-\delta)}{c}},\quad \delta=\frac{x}{2l}$$

At the free end of a column of pipes $e^{\varphi_1}=-1$. For jammed on the end of a column of pipes $e^{\varphi_1}=1$. Transition from the equations (12) and (13) concerning images to the equation concerning originals, we shall receive:

$$\int_0^t \omega(t-\theta,\delta)1(\theta)d\theta - e^{\varphi_1}\int_{\frac{2l}{v}}^t \omega(t-\theta,\delta)k_1(\theta)d\theta =$$
$$= e^{-2\alpha\tau\delta}\int_{\frac{2l\delta}{v}}^t \tilde{\omega}_\mu(t-\theta)k_2(\theta)d\theta - \tag{14}$$
$$-e^{\varphi_1}e^{2\alpha\tau\delta}\int_{\frac{2l}{v}(1-\delta)}^t k_3(\theta)\tilde{\omega}_\mu(t-\theta)d\theta$$

$$\int_0^t M(t-\theta,\delta)l(\theta)d\theta -$$
$$-e^{\varphi_1}\int_{\frac{2l}{v}}^t M(t-\theta,\delta)k_1(\theta)d\theta =$$
$$= \frac{1}{\rho}(e^{-2\alpha\tau\delta}\int_{\frac{2l\delta}{v}}^t k_2(\theta)\tilde{\omega}_\mu(t-\theta)d\theta + \tag{15}$$
$$+e^{\varphi_1}e^{2\alpha\tau\delta}\int_{\frac{2l}{v}(1-\delta)}^t k_3(\theta)\tilde{\omega}_\mu(t-\theta)d\theta$$

The integrated equations (6), (8), (14) and (15) can be solved numerically if to replace integrals with the sums. In this connection, according to [1, 2], using communication between continuous time t and discrete n as $t = nT/\lambda$ (where λ is any integer), we make digitization of the integrated equations (6), (8), (14) and (15) at the chosen interval T/λ replacing operation of continuous integration by summation on a method of rectangular. Thus instead of (6), (8), (14) and (15) we shall receive:

$$\omega_\mu[n] = \frac{a_j - a_2'}{b_j}\left(1-k_1'[n]\right) + \omega_{эbeg}k_1'[n] +$$
$$-\frac{b_2'T}{\lambda I}\sum_{m=0}^{n}(k_1'[m]\omega_\mu[n-m] + \tag{16}$$
$$+k_1'[n-m+1]\omega_\mu[m-1])$$

where $k_1'[n] = e^{\pm\alpha n}$, $\alpha = \frac{Tb_j}{\lambda I_э}$ and

$$\omega_\mu[n] = \frac{a_2}{b_2}\left(1-k_2'[n]\right) + \omega_{\mu beg}k_2'[n] -$$
$$-\frac{T}{\lambda I_\mu}\sum_{m=0}^{n}(k_2'[m]M_c[n-m] + \tag{17}$$
$$+k_2'[n-m+1]M_c[m-1])$$

where $k_2'[n] = e^{-a_0'n}$, $a_0' = \frac{Tb_2}{\lambda I_\mu}$ and

$$\sum_{m=0}^{n}(1[m]\omega[n-m,\delta] +$$
$$+1[n-m+1]\omega[m-1,\delta]) -$$
$$-e^{\varphi_1}\sum_{m=\lambda}^{n}(1[m-\lambda]\omega[n-m,\delta] +$$
$$+1[n-m+\lambda+1]\omega[m-1,\delta]) =$$
$$= e^{-2\lambda T\delta}\sum_{m=\lambda\theta}^{n}(1[m-\lambda\delta]\omega_\mu[n-m] + \tag{18}$$
$$+1[n-m+\lambda\delta+1]\omega_{\mu[m-1]}) -$$
$$-e^{\varphi_1}e^{2\lambda T\delta}\sum_{m=\lambda(1-\delta)}^{n}(1[m-\lambda(1-\delta)]\omega_\mu[n-m] +$$
$$+1[n-m+\lambda(1-\delta)+1]\omega_\mu[m-1])$$

$$\sum_{m=0}^{n}(M[n-m,\delta]1[m] +$$
$$+1[n-m+1]M[m-1,\delta]) -$$
$$-e^{\varphi_1}\sum_{m=\lambda}^{n}(1[m-\lambda]M[n-m,\delta] +$$
$$+1[n-m+\lambda+1]M[m-1,\delta]) =$$
$$= \frac{1}{\rho}(e^{-2\lambda T\delta}\sum_{m=\lambda\delta}^{n}(1[m-\lambda\delta]\omega_\mu[n-m] + \tag{19}$$
$$+1[n-m+\lambda\delta+1]\omega_\mu[m-1]) +$$
$$+e^{\varphi_1}e^{2\lambda T\delta}\sum_{m=\lambda(1-\delta)}^{n}(1[m-\lambda(1-\delta)]\omega_\mu[n-m] +$$
$$+1[n-m+\lambda(1-\delta)+1]\omega_\mu[m-1])$$

where $\omega[n,\delta]$, $M[n,\delta]$ are the values of initial functions in the generalized form

$$\sum_{m=0}^{n}(1[m]\omega[n-m,\delta] +$$
$$+1[n-m+1]\omega[m-1,\delta]) =$$
$$= \omega[n,\delta] + \sum_{m=0}^{n-1}(1[n-m]\omega(m,\delta) + \tag{20}$$
$$+1[m-1]\omega[n-m+1,\delta])$$

$$\sum_{m=0}^{n}(1[m]M[n-m,\delta] +$$
$$+1[n-m+1]M(m-1,\delta)) =$$
$$= M[n,\delta] + \sum_{m=0}^{n-1}(1[n-m]M(m,\delta) + \tag{21}$$
$$+1[m-1]M(n-m+1,\delta))$$

Expression (18) with the account (20) will be:

$$\begin{aligned}
&\omega[n,\delta]+\\
&+\sum_{m=1}^{n}(\omega[n-m,\delta]1[m]+\\
&+1[n-m+1]\omega[m-1,\delta])-\\
&-e^{-\varphi_1}\sum_{m=\lambda}^{n}(1[m-\lambda]\omega[n-m,\delta]+\\
&+1[n-m+\lambda+1]\omega[m-1,\delta])=\\
&=e^{-2\lambda T\delta}\sum_{m=\lambda\delta}^{n}(1[m-\lambda\delta]\omega_\mu[n-m]+\\
&+1[n-m+\lambda\delta+1]\omega_\mu[m-1])-\\
&-e^{\varphi_1}e^{2\lambda T\delta}\sum_{m=\lambda(1-\delta)}^{n}(1[m-\lambda(1-\delta)]\omega_\mu[n-m]+\\
&+1[n-m+\lambda(1-\delta)+1]\omega_\mu[m-1])
\end{aligned}\tag{22}$$

We find the following recurrent ration allowing consistently calculating function

$$\begin{aligned}
&\omega[n,\delta]=\sum_{m=\lambda\delta}^{n}(1[m-\lambda\delta]\omega_\mu[n-m]+\\
&+\omega_\mu[m-1]1[n-m+\lambda\delta+1])-\\
&-e^{\phi}\sum_{m=\lambda(1-\delta)}^{n}(1[m-\lambda(1-\delta)]\omega_\mu[n-m]+\\
&+1[n-m+\lambda(1-\delta)+1]\omega_\mu[m-1])+\\
&+e^{\phi}\sum_{m=\lambda}^{n}(1[m-\lambda]\omega[n-m,\delta]+\\
&+1[n-m+\lambda+1]\omega[n-m,\delta])-\\
&-\sum_{m=0}^{n-1}(1[n-m]\omega[m,\delta]+1[m-1]\omega[n-m+1,\delta])
\end{aligned}\tag{23}$$

By carrying out of similar operations, we receive the following recurrent ration for definition value of trellised function $M[n,\delta]$:

$$\begin{aligned}
&M[n,\delta]=\frac{1}{\rho}(e^{-2\alpha\tau\delta}\sum_{m=\lambda\delta}^{n}(1[m-\lambda\delta]\omega_\mu[n-m]+\\
&+1[n-m+\lambda\delta+1]\omega_\mu[m-1]+\\
&+e^{\varphi_1}e^{2\alpha\tau\delta}\sum_{m=\lambda(1-\delta)}^{n}(1[m-\lambda(1-\delta)]\omega_\mu[n-m]+\\
&+1[n-m+\lambda(1-\delta)+1])-\\
&-\sum_{m=1}^{n}\left(1[m]M[n-m,\delta]+1[n-m+1]M[m-1,\delta]\right)
\end{aligned}\tag{24}$$

At $x=0$ from a recurrent relation (24), it is received the following expressions for trellised function $M_H[n]=M_c[n]$:

$$\begin{aligned}
&M_c[n]=\frac{1}{\rho}\sum_{m=0}^{n}(1[m]\omega_H[n-m]+\\
&+1[n-m+1]\omega_H[m-1])+\\
&+e^{\varphi_1}\sum_{m=\lambda}^{n}(1[m-\lambda]\omega_H[n-m]+\\
&+1[n-m+\lambda+1]\omega_H[m-1])+\\
&+e^{\varphi_1}\sum_{m=\lambda}^{n}(1[m-\lambda]M_H[n-m]+\\
&+1[n-m+\lambda+1]M_H[m-1])-\\
&-\sum_{m=0}^{n-1}(1[n-m]M_H[m]+\\
&+1[m-1]M_H[n-m+1])
\end{aligned}\tag{25}$$

Taking into account expression (25) in expression (17) we determine values of trellised function $\omega_\mu[n]$.

IV. CONCLUSION

The offered numerical method can be used at designing and operation of chisel systems at rotary drilling of oil wells.

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BIOGRAPHY

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