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Dynamic System Composed of Topdrive and Drill Pipe

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Abstract

Modern drilling rigs are equipped with a modern system of engagement of the upper part of the top drive system which is used to carry out special functions. A great importance in the dynamic study of a working system in technological drilling operation is given to the way in which the system structure is set. A first concern in this regard was to set the structure of the working system in order to design the dynamic simulation as a continuous system.

Key words: *drilling, dynamic study, working system, simulation*

Introduction

Modern drilling rigs are equipped with a modern system of engagement at the top of topdrive string for carrying out special functions such as rotating the drill string during the lifting operation, resulting in reducing the difficulties of taking out the drill string, maintaining in a controlled way the strokes of the drill string into the well axis in order to focus on specific operations (making up or breaking out a joint)automation and monitoring the state parameters of the operation of the operating surface to carry out directional drilling operations.

Of the need to develop and improve these systems the most important issue is how to approach their design in order to analyze and introduce solutions that meet the announced requirements.

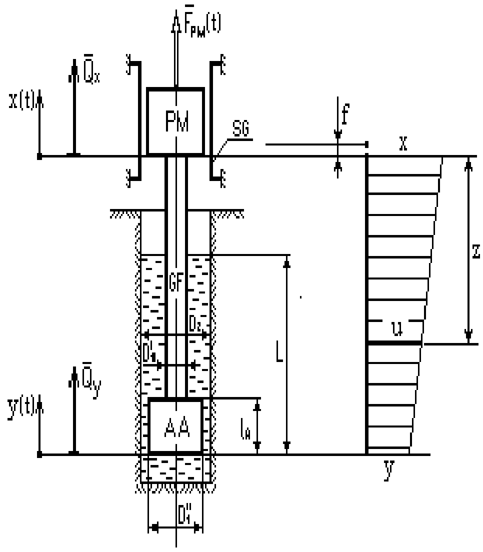
Methods for Modeling the Dynamics of the Drill String - Topdrive Operating System Assembly

It has also been considered that energy losses of the drill string result from viscous and dry amortization. More, a new element has been discovered, that is structural amortization. The load peak results from the system inertia, overcoming gel resistance and hydrodynamic pressure due to plunger effect.

Produced mechanical waves can become dangerous for both the drill string (area of threaded joints) and the surface guidance structure on which the waves have effect.

Identifying these types of variations of the variables of force and speed respectively makes possible the study of the induced effects in the structure of top drive rolling.

To establish the mathematical model of the handling operation of the drill string whose movement is run with a topdrive system, having as functions engagement and guidance of movement, the following scheme of calculation can be proposed, in which the following abbreviations can be noticed:



where:
M_{PM} represents mass of elements on the mobile platform;
F – active force, *F = F(t)*;
x(t) – movement of mobile platform(MP) ;
M_{AA} – concentrated mass at the bottom hole assembly level ;
y(*t*) – movement of bottom hole assembly;
f – elastic deformation due to static loads.

Fig. 1. The calculation scheme for establishing the mathematical model of the drill string.

Considering *x(t)* and *y(t)* as generalized coordinate movements and *u* the movement of a section at distance z, Lagrange equations for the considered model are:

$$\mathrm{m} = \mathrm{m}' \cdot \left(1 - \frac{\rho_f}{\rho_o}\right) \tag{1}$$

$$\frac{\mathrm{d}}{\mathrm{dt}}\left(\frac{\partial E}{\partial x}\right) - \frac{\partial E}{\partial x} + \frac{\partial V}{\partial x} + \frac{\partial D}{\partial x} = Q_x \tag{2}$$

$$\frac{\mathrm{d}}{\mathrm{dt}}\left(\frac{\partial E}{\partial y}\right) - \frac{\partial E}{\partial y} + \frac{\partial V}{\partial y} + \frac{\partial D}{\partial y} = Q_y \tag{3}$$

$$u = y + \frac{x - y + f}{L} \cdot (L - z) \tag{4}$$

Kinetic energy *E* of the system made up of mobile platform, drill string and the bottom hole assembly:

$$E = \frac{\mathrm{m_{EE}}}{2} \cdot \left(\frac{\partial u}{\partial t}\right)^2_{z=0} + \frac{\rho \cdot \mathrm{A}}{2} \cdot \int_0^l \left(\frac{\partial u}{\partial t}\right)^2 \mathrm{d}z + \frac{\mathrm{m_{AA}}}{2} \cdot \left(\frac{\partial u}{\partial t}\right)^2_{z=L} = \\ = \frac{\mathrm{m_{EE}} \cdot \dot{x}^2}{2} + \frac{\mathrm{m}}{3} \cdot \frac{\dot{x}^2 + \dot{x} \cdot \dot{y} + \dot{y}^2}{2} + \frac{\mathrm{m_{AA}} \cdot \dot{y}^2}{2} \tag{5}$$

V is the potential energy in the system platform, drill string bottom hole assembly.

$$V = V_1 + V_2 + \mathrm{m_{AA}} \cdot g \cdot y + \mathrm{m_{EE}} \cdot g \cdot x = \\ = \mathrm{G} \cdot \frac{x+y+f}{2} + \frac{\mathrm{k}}{2} \cdot (x-y+f)^2 + \mathrm{G_{AA}} \cdot y + \mathrm{G_{EE}} \cdot x \tag{6}$$

V_1 represents the variation of potential energy of the drill string as a result of movement:

$$V_1 = \mathrm{m} \cdot \mathrm{g} \cdot \int_0^{\mathrm{L}} u(z)\mathrm{d}z = \mathrm{m} \cdot g \cdot \int_0^{\mathrm{L}} \left[y + \frac{x-y+f}{L} \cdot (\mathrm{L}-z) \right] \mathrm{d}z = \mathrm{M} \cdot g \cdot \frac{x+y+f}{2} \tag{7}$$

V_2 – variation of the potential energy of the drill string as a result of elastic deformation:

$$V_2 = \frac{\mathrm{E}A}{2} \cdot \int_0^{\mathrm{L}} \left(\frac{\partial u}{\partial z} \right)^2 \mathrm{d}z = \frac{\mathrm{k}}{2} \cdot (x-y+f)^2 \tag{8}$$

$$k = \frac{EA}{L}\text{, elastic constant of the drill string}$$

f – elastic deformation due to static loads:

$$f = \frac{1}{\mathrm{k}} \cdot \left(m_{AA} \cdot g + \frac{M \cdot g}{2} \right) \tag{9}$$

D – dissipation function in the drill string – bottom hole assembly system

It should be noted that in order to avoid non-linearity of expression in the Lagrange equation termsif there are internal forces of amortization, Lord Rayleigh defines a function that is canceled at zero speed and it is called the dissipation function D.

Thus, the generalized amortization force, corresponding to a virtual change of generalized coordinates can be obtained as a derivative of the dissipation function in a fraction with generalized speed:

$$Q_{xd} = \frac{\partial D}{\partial \dot{x}} \qquad Q_{yd} = \frac{\partial D}{\partial \dot{y}} \tag{10}$$

Dynamic analysis of a structure is carried out operating with specific notions of dynamics: mass, rigidity, amortization. Amortization plays an important role in determining the dynamic response of a stressed structure; uncertainty of 20 ... 30% in assessing amortization changes the response at a rate of 15 ... 40%.

Viscous amortization

Mechanical systems which oscillate in fluids, bodies that slide on lubricated areas, dissipate energy through viscous amortization.

The dissipation function is:

$$D = \frac{\mathrm{k} \cdot \mathrm{A}}{2} \cdot \int_0^{\mathrm{L}} \left[\frac{\partial}{\partial t} \left(\frac{\partial u}{\partial z} \right) \right]^2 \mathrm{d}z \tag{11}$$

Replacing (4) in (11), the result is:

$$D = \frac{\mathrm{k} \cdot \mathrm{A}}{2\mathrm{L}} \cdot (\dot{x} - \dot{y})^2 = \mathrm{c} \cdot \frac{(\dot{x} - \dot{y})^2}{2} \tag{12}$$

and the derivates:

$$\frac{\partial D}{\partial \dot{x}} = -\frac{\partial D}{\partial \dot{y}} = c \cdot (\dot{x} - \dot{y}) \tag{13}$$

Structural amortization

Structural amortization may take place due to the phenomena that occur inside the materials forming structures, that is drill string (non-elasticity, flow phenomena, viscous-elastic phenomena etc.) and also due to contact between these elements which make up the assembly well – drill string - structure guiding the movement. It can be concluded that the amortization force is proportional in intensity to the elastic force (return) and the opposite sense of speed, so it can be expressed as deriving from a potential:

$$F_d = -\mathrm{i} \cdot \mathrm{s} \cdot \frac{\partial W}{\partial q} \tag{14}$$

where:

F_d represents the structural amortization force;

q represents the generalized coordinates of the movement $q \in \{x,y\}$;

s – a constant; $\mathrm{i} = \sqrt{-1}$

D results in this case from the virtual mechanical work of the amortization forces:

$$\delta D = \delta L = F_d \cdot \delta q = -\mathrm{i} \cdot \mathrm{s} \cdot \frac{\partial W}{\partial q} \cdot \delta q \tag{15}$$

The table below shows some values of the loss coefficient (η).

Table 1. Loss coefficient η for various materials

Material	Loss coefficient η
General use steel	0.005… 0.010
Alloyed steel	0.001… 0.008
Cast iron	0.020… 0.050
Aluminum alloys	0.003

The normal unitary effort, in case of materials that behave structurally, can be expressed by introducing a complex elasticity module:

$$E' = \mathrm{E} \cdot (u + i \cdot v) \tag{16}$$

where E represents the elasticity module for steel:

$$u = \frac{1 - \frac{\eta^2}{4}}{1 + \frac{\eta^2}{4}} \quad ; \quad v = \frac{\eta}{1 + \frac{\eta^2}{4}} \tag{17}$$

Variation of potential energy as a result of the produced deformation:

$$V = \frac{E'\cdot A}{2}\cdot\int_0^L\left(\frac{\partial u}{\partial z}\right)^2 dz = \frac{u+i\cdot v}{2}\cdot EA\int_0^L\left(\frac{\partial u}{\partial z}\right)^2 dz \quad (19)$$

For η values corresponding to alloyed steel (table 1), it can be noticed $u \cong 1$. Relation (19) becomes:

$$V = (1+i\cdot v)\cdot\frac{EA}{2}\cdot\int_0^L\left(\frac{\partial u}{\partial z}\right)^2 dz = V_2 + i\cdot v\cdot V_2 \quad (20)$$

Taking into account (20), the variation of total potential energy *V*, in the system mobile platform – drill string – bottom hole assembly with structural amortization becomes:

$$V = G\cdot\frac{x+y+f}{2} + \left(1+i\cdot\frac{\eta}{1+\frac{\eta^2}{4}}\right)\cdot\frac{k}{2}\cdot(x-y+f)^2 + G_{AA}\cdot y + G_{EE}\cdot x \quad (21)$$

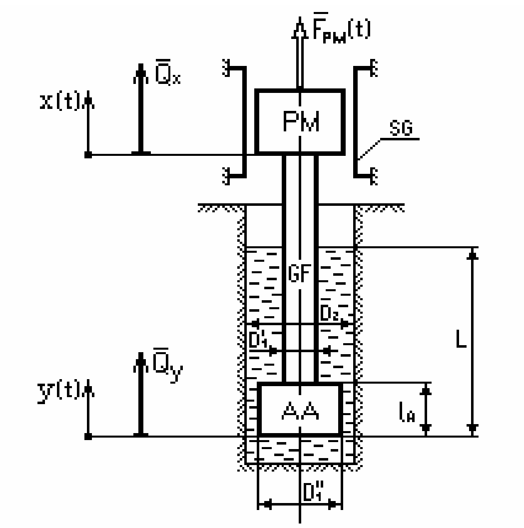
Coulumbian amortization

Dry friction or coulumbian amortization is a strong force that appears in the relative motion between the body and the surface, whose size is constant and depends only on the coefficient of sliding friction (f) and normal reaction of the surface (N) and the direction of this force is directed by the direction of the contact speed, but on the opposite sense:

$$F = -f\cdot N\cdot \mathrm{sgn}\left(\frac{\partial x}{\partial t}\right). \quad (22)$$

Modeling the Actions

In order to model the actions in the system (1.2,3) the following calculation scheme is proposed:



where:
MP mobile platform;
DS – drill string;
BHA – bottom hole assembly;
GS – guiding structure of the mobile platform;
D_1' – external diameter of the drill string;
D_1'' – external diameter of the bottom hole assembly
D_2 – well diameter.

Fig. 2. Calculation scheme for modeling the actions on the topdrive

Generalized functions are calculated using the following expressions:

$$Q_x = F_{PM}(t) + F_{f,PM} \tag{23}$$

where:

$F_{PM}(t)$ is the moving force that acts on the system mobile platform – bottom hole assembly;

$F_{f,PM}$ – the resultant of the friction forces corresponding to dry friction existence in the guiding elements of the mobile platform:

$$F_{f,PM} = -f \cdot N \cdot \mathrm{sgn}(\dot{u}) \quad ; \quad Q_y = -G_l - F_{f,AA} - F_{HS} \tag{24}$$

where:

G_l represents the weight of the mud engaged in movement when the bottom hole assembly is moved into the well:

$$G_l = \rho_f \cdot g \cdot L \cdot \frac{\pi}{4} \cdot \left(D_1^{"2} - D_1^{'2}\right) \tag{25a}$$

$F_{f,AA}$ - the resultant of the friction forces, at the bottom home assembly level:

$$F_{f,AF} = k \cdot \left(G + G_{AF}\right) \tag{25b}$$

F_{HS} - supplementary hydrodynamic force or supplementary force:

$$F_{HS} = F_{HS_1} + F_{HS_2} \tag{25c}$$

F_{HS_1} - component of the *supplementary force* resulted from overcoming the gel resistance when inducing the bottom hole assembly movement

F_{HS_2} - component of the *supplementary force,* due to supplementary pressure, that results from the *swabbing* of the bottom hole assembly in the well full of drilling mud

The equation system (2), (3), associated to the mathematical model becomes:

$$\begin{cases} m_1\ddot{x} + \frac{M}{6}\ddot{y} + c(\dot{x} - \dot{y}) + k(1 + is)(x - y + f) = F_{PM}(t) - f \cdot N \cdot \mathrm{sgn}(\dot{u}) - F_{f,PM} - \frac{G}{2} - G_{EE} \\ \frac{M}{6} \cdot \ddot{x} + m_2 \cdot \ddot{y} - c \cdot (\dot{x} - \dot{y}) - k \cdot (1 + i \cdot s) \cdot (x - y + f) = G_l - F_{f,AA} - F_{HS} - \frac{G}{2} - G_{AA} \end{cases} \tag{26}$$

where the following notations have been used: $m_1 = m_{EE} + \frac{M}{3}$ and $m_2 = m_{AA} + \frac{M}{3}$

The particularities of the mathematical model give a character of generality in the study of phenomena in accordance with the reality of modeling and studying the dynamic behavior of the considered system.

This system of equations represents the mathematical model of the complex determined by considering that energy is dissipated in the material (inside) with structural amortization, and externally by dry and viscous friction.

Using Computer Simulation Results

Below are simulated the graphic solutions of the system equations.

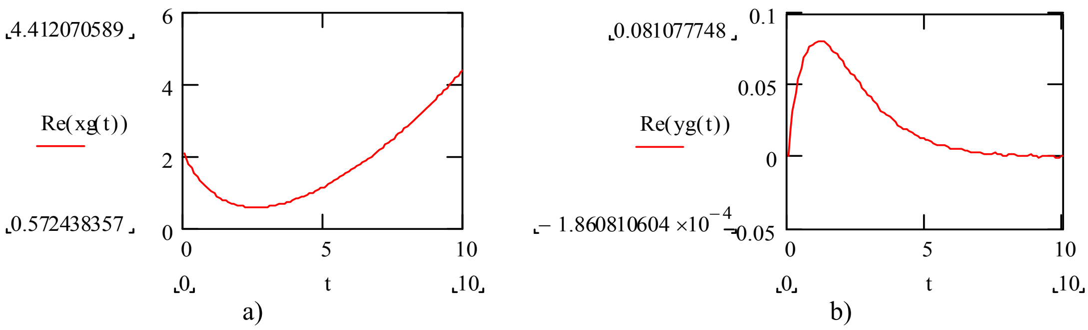


Fig. 3. Drilling head displacements [m]:
a) higer xg(t); b) lower yg(t) relative to starting position.

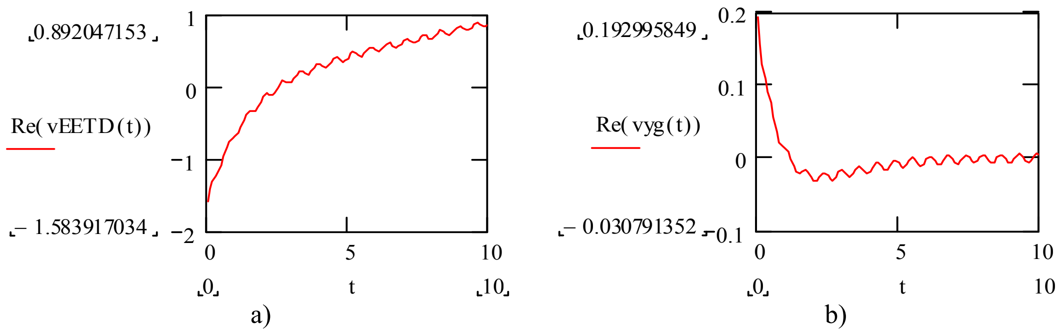


Fig. 4. Speed oscillation [m/s]:
a) higer vEETD(t); b) lower vyg(t).

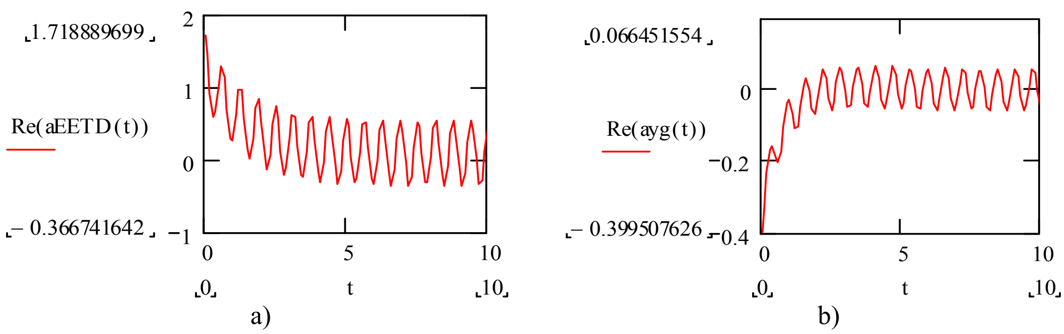


Fig. 5. Accelerations of the oscillating $[m/s^2]$:
a) higer aEETD(t); b) lower ayg(t).

Simulation conditions:
- 4500 m depth
- Drilling fluid density 1260 kg /
- Shear stress N / A
- 0.1143 m outside diameter of the rods
- 0.0925 m inner diameter rods.

Conclusions

Modern drilling rigs are equipped with a modern system of engagement of the upper part of the top drive system which is used to carry out special functions. A great importance in the dynamic study of a working system in technological drilling operation is given to the way in which the system structure is set. A first concern in this regard was to set the structure of the working system in order to design the dynamic simulation as a continuous system.

By comparison with mathematical models established by already existing energy method proposed by various researchers, some original contributions have been made by including the mathematical equations of the model, the effect given by the gel resistance of the drilling mud and of the "plunger" by additional hydrodynamic pressure occurrence during bit run back operation.

It has also been considered that energy losses of the drill string result from viscous and dry amortization. More, a new element has been discovered, that is structural amortization. The load peak results from the system inertia, overcoming gel resistance and hydrodynamic pressure due to plunger effect.

Produced mechanical waves can become dangerous for both the drill string (area of threaded joints) and the surface guidance structure on which the waves have effect.

Identifying these types of variations of the variables of force and speed respectively makes possible the study of the induced effects in the structure of top drive rolling.

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Dinamica sistemului alcătuit din topdrive şi garnitura de foraj

Rezumat

În cadrul acestui articol este prezentat modelul matematic al ansamblului compus din echipamentul de antrenare de la partea superioară a garniturii de foraj denumit topdrive şi ansamblul garnitură de foraj. Principalele elemente de noutate aduse modelului constau în considerarea amortizării structurale şi a presiunii suplimentare apărute la manevra garniturii de foraj în sondă. Rezultatele se materializează prin elaborarea unui program de calcul computerizat ale cărui rezultate grafice sunt prezentate în urma simulării operației de extragere a garniturii de la o anumita adâncime.