Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 55(6) (2023) 153-156
DOI: 10.22060/mej.2023.21883.7535

Two-three degree of freedom model for Anti Stick-Slip Tool of drill-string

A. Taraghi Osguei*, B. Mohammad Alizadeh, A. Dobakhti

Department of Mechanical Engineering, Sahand University of Technology, Tabriz, Iran

ABSTRACT: The drill-string experiences strong vibrations due to its length and interactions with the rock at the bit. The Anti Stick-Slip Tool (ASST), located at the end of the drill-string, effectively prevents the stick-slip and torsional vibrations. A new model has been proposed to analyze the tool, overcoming previous limitations. The model represents the system with two degrees of freedom in its non-activated state and three degrees of freedom when activated based on kinematic constraints. Simulations demonstrate the logical behavior of tools under external forces and torques. The model accurately depicts the effect of weight on bit and weight on the hook on the activation of tool. The proposed model enables researchers to study the nonlinear behavior of ASST resulting from switching between equations in specific operational conditions.

Review History:

Received: Oct. 27, 2022
Revised: May, 18, 2023
Accepted: Jun. 15, 2023
Available Online: Jul. 19, 2023

Keywords:

Torsional Vibration
Drill-string
Anti Stick-Slip Tool
Internal Friction

1- Introduction

During drilling operations, the drill-string experiences complex dynamic phenomena that result in undesirable oscillations. These phenomena are caused by various factors, such as the interaction forces between the drill bit and the rock or the well, as well as the forces acting on the drill-string. The vibrations can be categorized into torsional, axial, and transverse vibrations [1]. Several dynamic phenomena, including stick-slip [2] and bit bouncing [3], significantly impact drilling quality and lead to strong vibrations of the drill-string. Axial vibrations in drilling systems refer to oscillations along the direction of the drilling pipes [4]. Lateral vibrations, on the other hand, result in well wall expansion and can lead to damage to the drill-string and down-hole tools. Torsional vibrations [5], as the third type of vibrations in drilling systems, occur due to irregular rotation of the drill bit caused by torsional forces on the drill-string. One contributing factor to torsional vibration is the Stick-Slip phenomenon between the drill bit and the rock. These vibrations can pose challenges and impact drilling operations negatively. Active methods for controlling drill-string vibrations are costly due to equipment maintenance, data measurement, and sensor quality limitations. Therefore, non-active approaches, such as Anti Stick-Slip Tool of Tomax, are preferred by most drilling engineers to mitigate the stick-slip phenomenon. This tool reduces the length of drill-string to prevent stick-slip and ensure optimal performance. A new model with three degrees of freedom during activation and two degrees of freedom when deactivated has been proposed to overcome previous limitations[6,7]. The enhanced model provides more accurate information on the behavior of the drill string when using the Anti Stick-Slip tool, facilitating a better understanding of their performance in drilling operations.

2- Modeling of Anti Stick-Slip Tool

The Anti Stick-Slip Tool can be shown as below, this tool includes two active and non-active states. When the tool is in the non-active state, it acts as a rigid body with two degrees of freedom, and the axial and rotational displacements of the upper and the lower parts of the tool are the same.

In this case, the dynamic equations according to Newton's second law can be obtained for the axial and rotational displacement, and the equations are in the form of a matrix as follows:

$$M\ddot{\vec{q}} = \vec{F} \tag{1}$$

Where the matrix M and vectors $\vec{q}$ and $\vec{F}$ can be defined as follows:

*Corresponding author's email: taraghi@stu.ac.ir

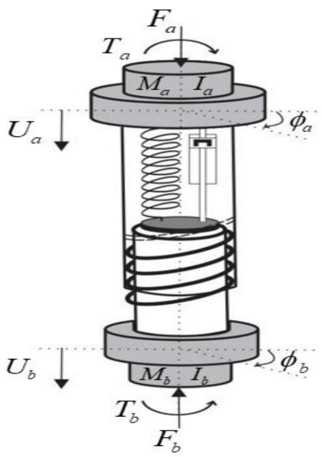

Fig. 1. Schematic structure of the Anti Stick-Slip Tool along with its internal parts

$$M=\begin{bmatrix} M_a+M_b & 0 \\ 0 & I_a+I_b \end{bmatrix},\quad \vec F=\begin{bmatrix} F_a-F_b+(M_a+M_b)g \\ T_a-T_b \end{bmatrix},\quad \vec q=\begin{Bmatrix} U_b \\ \phi_b \end{Bmatrix} \tag{2}$$

If the size of the external loads is greater than the internal resistance of the tool, this tool will be activated and will control the additional loads on the system by reducing the length of the tool. If the tool is activated, this system will have three degrees of freedom. In this case, the equations of motion related to the upper and lower parts of the tool are checked based on Newton's second law, whose final matrix state can be expressed as:

$$M\ddot{\vec q}+C\dot{\vec q}+K\vec q=\vec F \tag{3}$$

Where the matrices *M, C* and *K* and vectors $\vec q$ and $\vec F$ can be defined as follows:

$$M=\begin{bmatrix} I_a+\alpha r_i M_a & -\alpha r_i M_a & r_i M_a \\ -\alpha r_i M_a & I_b+\alpha r_i M_a & -r_i M_a \\ M_a\alpha & -M_a\alpha & M_a+M_b \end{bmatrix},\quad C=\begin{bmatrix} \alpha r_i C_b & -\alpha r_i C_b & 0 \\ -\alpha r_i C_b & \alpha r_i C_b & 0 \\ 0 & 0 & 0 \end{bmatrix}$$
$$K=\begin{bmatrix} \alpha r_i K_b & -\alpha r_i K_b & 0 \\ -\alpha r_i K_b & +\alpha r_i K_b & 0 \\ 0 & 0 & 0 \end{bmatrix},\quad \vec F=\begin{Bmatrix} (F_a-P-M_a g)r_i+T_b \\ r_i(-F_a+P-M_a g)-T_b \\ F_a-F_b+M_a g+M_b g \end{Bmatrix},\vec q=\begin{Bmatrix} \phi_a \\ \phi_b \\ U_b \end{Bmatrix} \tag{4}$$

When the system changes from the non-active state to the active state, the system is forced to follow a relationship between the internal forces based on the kinematic constraint in the threads, which can be written as:

$$(\bar I+\bar M r_i\alpha)\Delta\ddot\phi+r_i\alpha C_b\Delta\dot\phi+r_i\alpha K_b\Delta\phi= \bar I(\frac{T_a}{I_a}+\frac{T_b}{I_b})+\bar M r_i(\frac{F_a}{M_a}+\frac{F_b}{M_b})-r_i P \tag{5}$$

Based on the stated relation (5), external, internal, stored and activation torques can be defined to explain the activated and nonactivated conditions for operations of ASST.

Table 1. Conditions for describing states of ASST

First Condition	Second Condition	State
$T_{sto}>T_{act}$		Actived
$T_{sto}<T_{act}$		Non-actived
$T_{sto}=T_{act}$	$T_{ext}>T_{act}$	Actived
	$T_{ext}\le T_{act}$	Non-actived

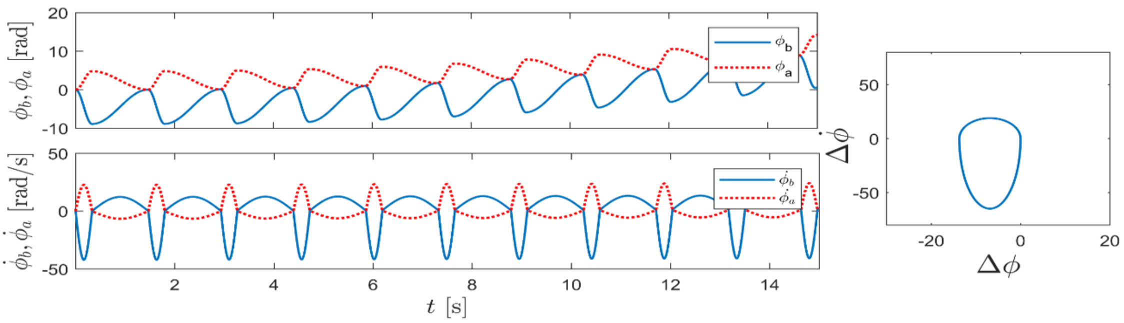

Fig. 2. Evolution of rotational displacement and rotational speed for two parts of the tool and phase portrait

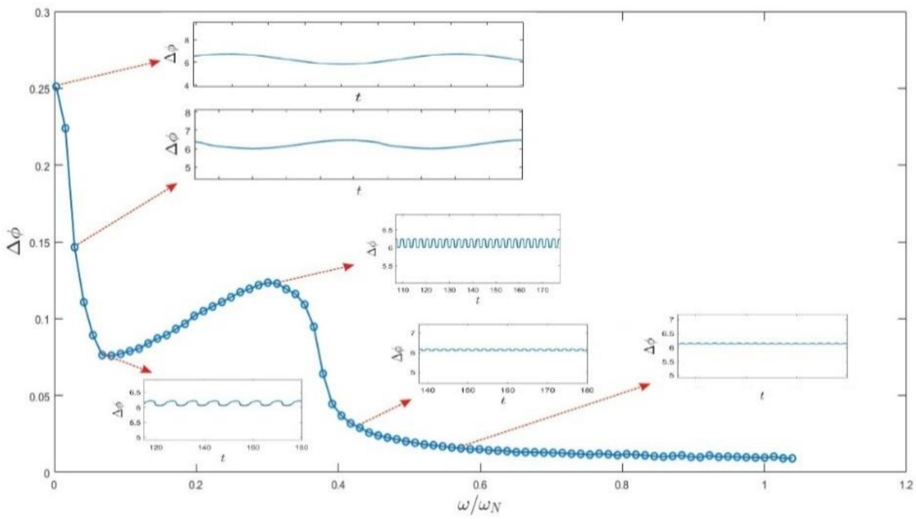

Fig. 3. Frequency response function diagram of the instrument for a specific case

3- Result

According to the results shown in Figure 2, it can be seen that the internal friction between two parts of ASST plays a crucial role in the behavior of ASST during the activation state and controls the start of activation. The phase portrait clearly shows the influence of internal friction on the compression and expansion state of ASST.

The dynamic behavior of the tool appears as a non-linear system due to the switches between two different linear equations of motion according to the inputs of the tool. Therefore, the frequency response curve of the ASST for a specified input is different from linear systems. Figure 3 shows that the amplitude of fluctuations for relative rotation of the two parts of the tool decreases by increasing the frequency ratio until it reaches about 0.07, and then the amplitude of the oscillations increases until the frequency ratio reaches 0.3. At this point, the frequency response curve shows a local maximum, beyond which the amplitude of the oscillations goes to zero. The range of constant and harmonic components of the input forces and torques used to derive the frequency response function is very important in determining the frequency response curve.

4- Conclusion

The Anti Stick-Slip Tool is an instrument to prevent destructive torsional vibrations during drilling operations. During the operation of this tool, there are two states named activated and non-activated. This research presents a model that overcomes the limitations of previous models and makes it possible to study the behavior of the drill-string in the presence of ASST. The proposed model accurately simulates the behavior of the tool through different states.

References

[1] T.G. Ritto, M. Ghandchi-Tehrani, Active control of stick-slip torsional vibrations in drill-strings, Journal of Vibration and Control, 25(1) (2019) 194-202.

[2] T. Richard, C. Germay, E. Detournay, A simplified model to explore the root cause of stick–slip vibrations in drilling systems with drag bits, Journal of sound and

vibration, 305(3) (2007) 432-456.

[3] W. QIU, H. FU, P. LI, Analysis on Drill String Vibration Signal of Stick Slip and Bit Bouncing, Advances in Petroleum Exploration and Development (S1925-5438), 8(2) (2014) 1-5.

[4] U.J.F. Aarsnes, N. van de Wouw, Axial and torsional self-excited vibrations of a distributed drill-string, Journal of Sound and Vibration, 444 (2019) 127-151.

[5] Z. Weiping, D. Qinfeng, Effect of prebent deflection on lateral vibration of stabilized drill collars, SPE Journal, 16(01) (2011) 200-216.

[6] A.T. Osguei, I. Khamoushi, M.K. Dehkordi, E. Pavlovskaia, M. Wiercigroch, Non-smooth dynamics of Anti Stick–Slip Tool, Physica D: Nonlinear Phenomena, 443 (2023) 133525.

[7] M.K. Dehkordi, A.T. Osguei, I. Khamoushi, E. Pavlovskaia, M. Wiercigroch, Internal mechanics of anti stick–slip tool, International Journal of Mechanical Sciences 221 (2022) 107188.

HOW TO CITE THIS ARTICLE

A. Taraghi Osguei, B. Mohammad Alizadeh, A. Dobakhti, Two-three degree of freedom model for Anti Stick-Slip Tool of drill-string, Amirkabir J. Mech Eng., 55(6) (2023) 153-156.

DOI: 10.22060/mej.2023.21883.7535