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A generalized quasi-static model of drill string system

Wenjun Huang*, Deli Gao*, Shaolei Wei, Xin Li

Key Laboratory for Petroleum Engineering of the Ministry of Education, China University of Petroleum, Beijing 102249, China

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ABSTRACT

Accurate prediction of the drilling status needs an effective inversion calculation of the relevant parameters of the drill string system. In the previous studies, the inversion calculation was done by a trial and error method of low efficiency. To overcome this shortcoming, an automatic generalized quasi-static model of high efficiency of the drill string system is proposed in this paper. Firstly, the general form of the quasi-static model of drill string system (forward model) is given. However, practice has proven that the calculated results from the forward model are usually not consistent with the measured results of the drill string system. Then, the relevant deviations in the forward calculation are analyzed, and an inversion model is proposed to revise the model parameters. Different forms of the inversion models in the drilling design and actual drilling stages are given. Thirdly, the forward model and inversion model are further combined into a unity, namely generalized model. The generalized model is not only an advanced model depicting the drill string system, but also a powerful tool applied to practice. At last, the application of the generalized model to a real field is discussed.

1. Introduction

Systematic research on the drill string system has been undergone for more than half century since Lubinski's (Lubinski, 1950) outstanding work on the buckling of rotary drilling strings. Until now, a lot of mechanical models have been proposed to depict the drill string system. These mechanical models can be divided into quasi-static model and dynamic model, and also can be divided into bottom-hole-assembly (BHA) model and drill string model. In thermodynamics, a quasi-static process means a system changes so slowly that the system can be analyzed by static method at any moment. In quasi static model, the drill string is assumed to be at stable equilibrium status at any time when the drill string moves. The dynamic model means that the drill string vibrates periodically around the equilibrium position or randomly. BHA model is focused on studying the bottom hole assembly, which is the lower part of the drill string. The drill string model takes the whole drill string from ground to drill bit as the research object. Until now, only the quasi-static BHA model and quasi-static drill string model and mature and have been successfully applied to actual fields.

The quasi-static BHA model is the most classic part of drill string mechanics. The studies of quasi-static BHA develop from two-dimensional analysis (Lubinski, 1950) to three-dimensional analysis (Walker and Friedman, 1977), from small deflection assumption (Liu and Gao, 1988) to large deflection assumption (Ho, 1986; Gao and Xu, 1995; Li and Liu, 1994), and from vertical, inclined straight wellbore to curved or even arbitrary wellbore (Gao, 1994; Bai and Su, 1990). The model is widely used to predict well trajectory in actual drilling process. The predicted well trajectory with the BHA model usually deviates from the measured well trajectory, for the rock anisotropy is also another important factor affecting well trajectory (Deli, 2006). Considering that the rock anisotropy cannot be directly measured, an inversion model has been proposed to convert the actual drilling data to the rock anisotropy. Then the well trajectory can be predicted on the basis of the inversion rock anisotropy (Gao, 1994). The quasi-static drill string model is usually focused on the calculation of torque and drag of the drill string. The quasi-static drill string model includes soft rope (Brett et al., 1989; Lesage et al., 1988; Maidla and Wojtanowicz, 1987; Johancsik et al., 1984), stiff rod (Gao, 1994; Ho, 1988; Mitchell and Samuel, 2009; Li et al., 1993), the combination of soft rope and stiff rod (Qin et al., 2006), beam-column (Mcspadden and Newman, 2002; Grindhaug et al., 2013), gap element (Shuai et al., 1995; Zhang et al., 1992), and so on. Similar to the BHA model, the predicted torque and drag with the drill string model is usually not in consistent with the measured data, for the friction

* Corresponding authors.
E-mail addresses: huangwenjun1986@126.com (W. Huang), gaodeli@cast.org.cn (D. Gao).

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factor and wellbore tortuosity are also other important factors affecting the torque and drag (Lesage et al., 1988; Zhang et al., 1992). The friction factor and wellbore tortuosity cannot be measured directly, so the corresponding inversion model needs to be introduced. From the above analyses we can see that the inversion calculations of BHA and drilling string models can be seen as a problem of the same kind. In this paper, we mainly focus on the inversion quasi-static drilling string model.

In the previous studies, the traditional trial and error method is used to calculate the model parameters in the quasi-static drill string model. More specifically, the measured drilling data and calculated results from the quasi-static drill string model under a certain model parameter are simultaneously drawn in a same coordinate system. Different values of model parameter are continually substituted into the quasi-static drill string model until the calculated values are in good consistent with the average measured data (Adewuya and Pham, 1998; Mccormick and Wilcox, 2013; Rae et al., 2005). However, the above semi-automatic inversion calculation is of low efficiency, especially when it is applied to the actual drilling process. In the actual drilling process, the drilling status should be monitored in time with the quasi-static model (Rommetveit et al., 2004; Ugochukwu and Verity, 2014) to help the driller identify the possible down-hole troubles. Meanwhile, a trend of the drilling status should be predicted to help the driller avoid the impending drilling troubles (Kucs et al., 2008). The inversion and prediction calculations are continually done in the actual drilling process to improve the drilling efficiency. In order to realize this, a high-efficiency inversion quasi-static model needs to be proposed.

In this paper, the general form of the quasi-static drill string model (forward model) is given. The inversion quasi-static drill string model (inversion model) is proposed on the basis of the general theory of discrete inversion. The forward model and the inversion model are further combined into a unity called generalized model. The generalized model can do inversion and prediction calculations simultaneously in the actual drilling process. At last, the application of the generalized model in the actual drilling process is discussed.

2. Quasi-static mechanical forward model of drill string system

2.1. Description of the drill string system

The simple schematic of drilling rig system is shown in Fig. 1, in which the drill string is taken as a subsystem. The drill string system is closely related to the three systems: hoisting system, rotary system and circulating system. The drill string system is the most important part which connects the ground and underground components of the drilling rig system. The drill string system provides the external load of the hoisting system, the way of mechanical power transfer in the rotary system and the channel for

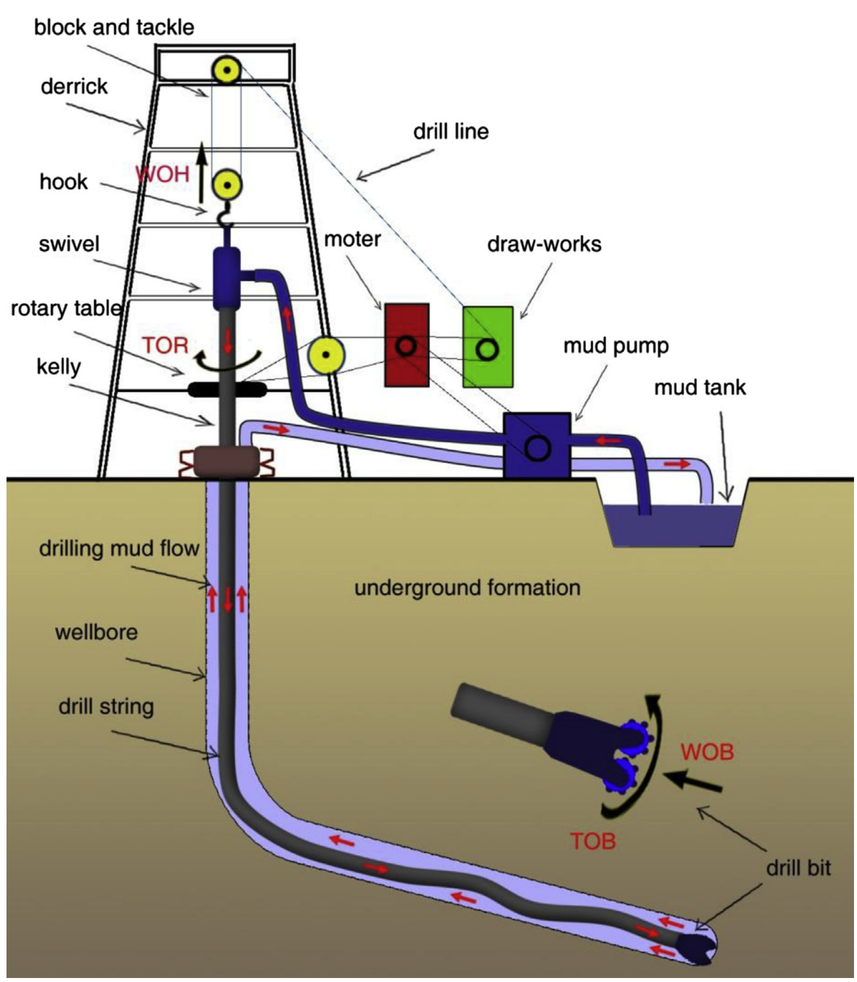

Fig. 1. Simple schematic of drilling rig system.