Suppression of the Bending Vibration of Drill Strings via an Adjustable Vibration Absorber

Hamed Moradi, Firooz Bakhtiari-Nejad and Mojtaba Sadighi

Department of Mechanical Engineering, Amirkabir Universtity of Technology, 424 Hafez Ave, 15875-4413 Tehran, Iran

(Received 15 December 2010; Provisionally Accepted 5 March 2012; Accepted 14 May 2012)

Vibration control of the drilling process in the gas and oil industries is of great importance. Applying an effective control system diminishes both costs and process time and increases work efficiency. Typically, the drill string vibrates in a combination of three distinct modes of transverse, torsional, and axial vibrations. Due to the importance of torsional vibration and the associated stick-slip phenomenon, many works have been devoted to this area. However, transverse vibration is another major source of vibration arisen from the long length of the drill string structure. In this paper, a tunable vibration absorber as a semiactive controller is designed to suppress the transverse vibration. After modeling the drill string as an Euler-Bernoulli beam and formulating the problem, the optimum specifications of the absorber, such as spring stiffness, absorber mass, and its position, are determined using an algorithm based on the mode summation method. The effect of bit rotational speed under the non-resonance and resonance condition is studied. It is shown that the best position of the absorber depends on the spring stiffness and bit rotational speed.

1. INTRODUCTION

Rotational drilling that constructs a borehole linking the earth surface to a reservoir of oil or gas was a major revolution in the drilling industry. Due to the buildup of damaging vibrations, the drilling process is usually associated with interruption and fatigue, diminished accuracy of the drilling process, and high cost of drill-bit failures.[1] Therefore, having knowledge of drill-string vibrations and exerting an effective control system leads to cost reduction, diminished process time, and consequently increased work efficiency. The existence of various types of dynamic forces and their rapid changes, the long length of the drill string, the effect of the mud pump, and mass unbalance cause the drill-string motion to be a combination of torsional (rotational), transverse (bending), and axial vibrations.[2]

Torsional (rotational) vibration, which is caused by the interaction between the bit and the rock or the drill string and the borehole well, has been studied extensively.[3–5] Torsional relaxation oscillations, or the stick-slip phenomenon, produced by the friction force between the bit and the well are a source of torsional vibration.[4,5] Velocity weakening in the friction force (Stribeck effect) caused by the contact between the bit and borehole is another source of torsional vibration.[3,6] The coupling between the torsional and axial dynamics that arises from the bit-rock interactions causes such velocity weakening.[7]

In addition, several authors have investigated transverse vibration caused by the axial force, contact with the well and pipe eccentricity leading to centripetal forces,[3,8] lateral motion of bottom-hole assembly (BHA),[9] axial vibrations due to rock cutting process, and coupled nonlinear axial-transverse and axial-torsional vibrations of drill strings.[8,10] Moreover, lumped parameter models including nonlinear expressions for the forces-torques interactions with the rock formation have been developed.[11,12] In another study, the influence of geometrical nonlinearities on the coupled axial-transversal vibrations of drill strings was investigated.[13]

Although many control efforts have been made to suppress these vibrations, a detailed dynamic model of drill strings has not been presented yet because of complex modeling, limitations caused by neglecting the coupling between the transverse, torsional, and axial modes of vibration and other external influences.[14,15] The interactions of the drill bit with the rock face and the drill string with the environment, interactions induced by stabilizers on the BHA, and forces and torques transmitted by the top drive are some external factors affecting the process.[16]

Several control approaches have been applied to suppress drill-string vibrations. Various feedback devices have been designed to control the speed and torque of the drive at the well head.[17,18] Torque feedback controllers improve the sustained excitation associated with the stick-slip phenomenon by reducing the effective reflection coefficient for torsional energy at the rotary.[16] Using active dampers to suppress self-excited torsional vibration (without active torque monitoring),[4] utilizing a nonlinear energy sink, and transferring targeted energy to a lightweight attachment as a passive control method[3] are some of the studies carried out in this area. In addition, the field method in conjunction with torque feedback has been used to control the torsional vibration.[14,17] Various control techniques, such as linear control,[19] cascade and decentralized control based on modelling error compensation,[20] H_∞ control,[21] nonlinear control,[22] optimal feedback control,[23] and sliding mode control,[24] have been used to suppress stick slip.

Transverse vibration is one of the most significant causes of failure in drill strings. Vibration induced by the mud pump, the contact between the drill string and the well, pipe eccentricity leading to centripetal forces, and lateral motion of BHA are the major sources of transverse excitation.[8,16,25] Lateral instabilities associated with dynamic behavior of the drill string have been investigated.[26] However, in spite of the importance of transverse vibration, less research has been devoted to controlling such vibration.

In this paper, the drill string is modeled as a cantilever Euler-