1
General introduction

1.1
Oil well drilling system

Oil and other hydrocarbons are the primary source of global energy. However, the exploration of these hydrocarbons presents a myriad of challenges resulting mainly from lithological variation and other unanticipated natural phenomena. Among these challenges, the occurrence of vibrations generated during the drilling process is of great importance and poses several associated risks.

Roughly, the drilling system consists of a motor (electric or hydraulic) located at the top end position which imposes rotational motion in the drilling system. The bottom end position comprises the Bottom Hole Assembly (BHA) and the drill bit. Between these ends the top-down torque transmitting element called drill string (connection of a series of pipes) is situated. At the top end, the top drive rotates with a constant angular velocity (Surface RPM - $SRPM$). Next, an axial force called Weight On Bit (WOB) is imposed. This combination of WOB and $SRPM$ provides the needed Torque On Bit (TOB) to induce rock failures (crushing, shearing or grinding). These failures depend on the drill bit used in the rotary drilling process. The system operation is more thoroughly described in references [2, 5, 10, 16, 31]. Figure 1.1 illustrates the system of oil extraction. Figure 1.2 illustrates the top-down torque transmitting element - drill string.

Due to the nonlinear complexity arising from the boundary conditions, bit-rock interaction, and drill string-wellbore wall interaction the drilling system presents complex vibration phenomena. Thus, the drill strings undergo axial (longitudinal motion), lateral (whirl motion) and torsional (angular fluctuation) vibrations (see Figure 1.3). The damage from this undesired behavior is worrisome, such as the premature wear or failures of parts of the drill string and bit, downhole motors, and the interference of transmission signals measured data. This results in increased time and cost of the process. Figure 1.4 illustrates types of failures that are commonly encountered in drill pipes and threaded connections. Drill string vibrations may also cause

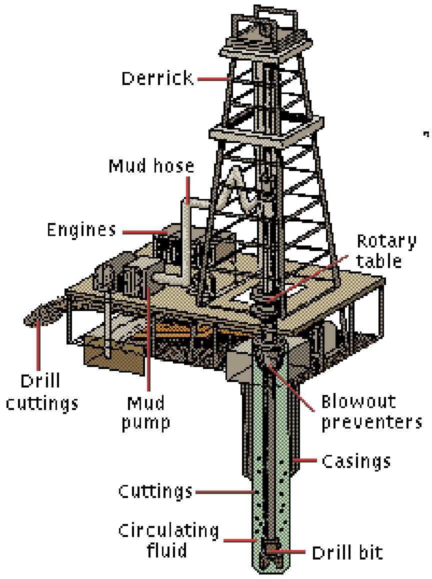

Figure 1.1: Drilling system.

problems with directional control of the string during deviated drilling and BHA instability [9], reduce the rate of penetration, and cause damage to the borehole wall resulting in a collapsed or vastly oversize borehole [16]. Therefore, a better understanding of these phenomena is necessary to avoid repair cost, since this is two times higher than cost of prevention [31]. All the problems present in drilling systems are further described in references [5, 14, 16, 24].

Measurements of drill string rotation both at surface and at the bit have revealed that the drill string often behaves as a rotating torsional pendulum, i.e. the top end rotates with a constant rotary speed, whereas the bit performs a rotation with varying rotary speed consisting of a constant part and a superimposed torsional vibration [8]. In its most drastic form, the bit comes to a standstill while the top end rotates with a constant rotary speed, and then increasing the torque in the drill string until the bit suddenly comes loose again [16]: this phenomenon is called stick-slip. The high angular velocity of the bottom end in the slip phase can generate severe axial and lateral vibrations and instability of the BHA [33]. This phenomenon is an auto-excited drilling dysfunction that is characterized by large oscillations of the angular velocity of the bit [29] and it arises mainly from the nonlinear relationship between the resistive torque and angular velocity of the bit. In general the auto-excited systems performs periodic motions which are held by external non-harmonic sources [12]. According to the oil company *Elf-Aquitaine* (*apud* Franca [10]), stick-slip occurrence in drilling processes reaches 50 % of the drilled wells with PDC (Polycrystalline Diamond Compact) bit.

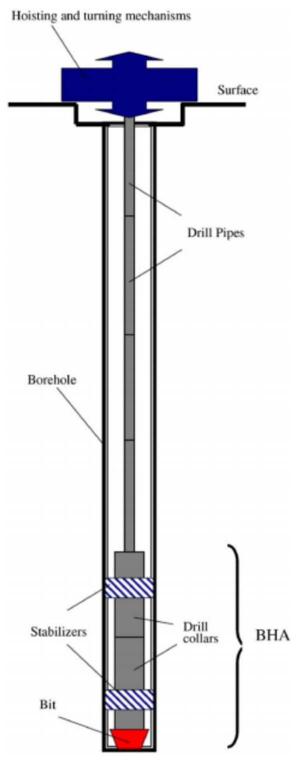

Figure 1.2: Torque transmitting element called drill string. Source: Khulief *et al* [21].

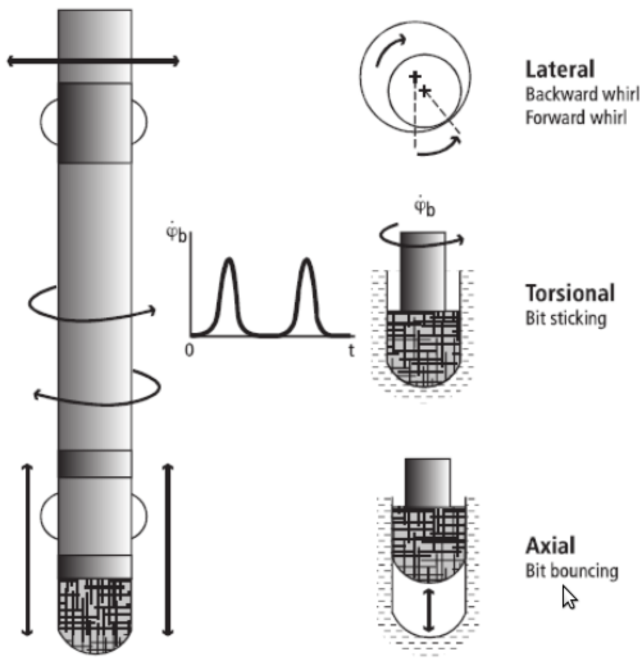

Figure 1.3: Types of vibration on drill string. Source: López [27].

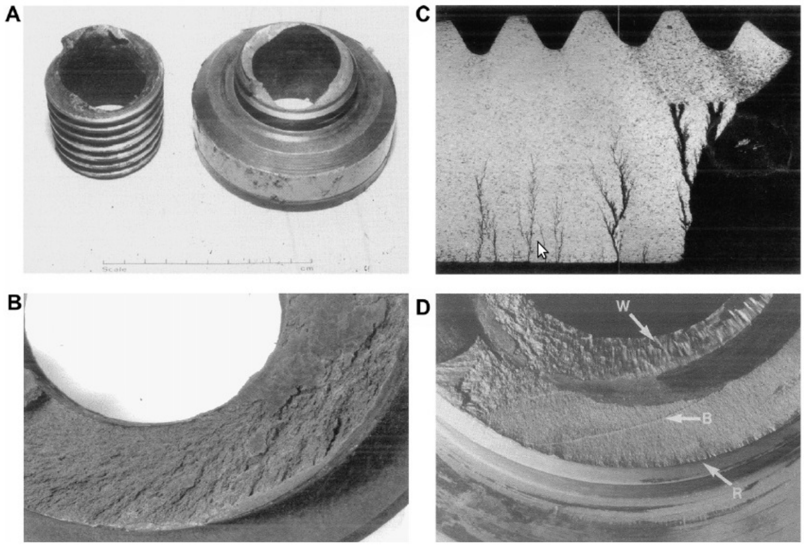

Figure 1.4: Types of failures: (A) ductile; (B) fragile; (C) stress corrosion cracking and (D) fatigue. Source: Macdonald *et al.* [22].

1.2
Overview and objectives

Due to the complex behavior of the drill string, the drilling operation is one of the main challenge of oil and gas exploitation. The rotary drilling presents undesired vibrations arising from multiple sources, for example, nonlinear bit-rock interaction, mass imbalance, misalignment, mud motor, and interaction between the drill pipe and borehole wall. These phenomena may excite axial, lateral and torsional vibrations which may increase costs and time of the exploration process due to non efficient drilling, equipment failures, and premature detrimental wear of the drilling equipments.

Specifically torsional vibrations are often regarded as the most damaging modes of vibration when drilling with low rotary speed [4] and they may also excite axial and lateral vibrations. Thus, the need to reduce and/or avoid the stick-slip while drilling in order to prevent increased costs and time is clearly evident. Therefore, several researches have been conducted and approaches have been proposed to model the torsional oscillations problems, as referenced in the biography of this work.

In this study, a numerical and experimental torsional analysis of the drill string is performed to provide grounds for deciding the optimal way to mitigate or eliminate the stick-slip phenomenon. First, sensitivity analysis of the friction models, sensitivity analysis of the drilling system parameters (length of the drill pipes and BHA, diameters of the drill pipe), and multi-degrees of freedom modeling, are performed. In this goal, resistive friction torque models are applied and then their influence on the drill string dynamical response are analyzed.

Afterwards, the modeling complexity of the drill string is increased in order to identify the proper discretization of the drill string.

Finally, an experimental apparatus is designed and manufactured in order to validate the numerical model.

1.3 Organization of the master dissertation

The organization of this master dissertation is done as follows. First, Chapter 2 contains the literature review about drill string vibrations. Most part of the listed papers include torsional vibrations and proposed solutions for this undesired behavior. Also in the second chapter, some preliminary concepts are presented in order to provide a theoretical base to understand the topics that will be presented. In Chapter 3, the numerical dynamic model for a full scale drilling system and the friction models for the resistive torque in downhole are discussed. The test rig description, parameter estimations and numerical model of the test rig are described in Chapter 4, as well as there the analysis the results test rig models. Finally, Chapter 5 comprises the conclusions of this work and topics for future works are discussed.