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Drillstring Vibrations and Vibration Modeling

Vibration types

Drillstring vibrations can be divided into three types, or modes: axial, torsional, and lateral (Fig. 1)[1]. The destructive nature of each type of vibration is different.

Axial vibrations can cause bit bounce, which may damage bit cutters and bearings.

Torsional vibrations can cause irregular downhole rotation. Stick/slip is often seen while drilling and is a severe form of drillstring torsional oscillation in which the bit becomes stationary for a period. As the severity of stick/slip increases, the length of the stuck period increases, as do the rotational accelerations as the bit breaks free (Fig. 2). Torsional fluctuations fatigue drill collar connections and can damage bits. The use of a mud motor may help to address stick/slip if the main source of excitation is from the bit, but the presence of a motor does not prevent stick/slip. The drillstring and BHA above the motor can enter into a stick/slip motion even when the motor is turning the bit at a steady rate.

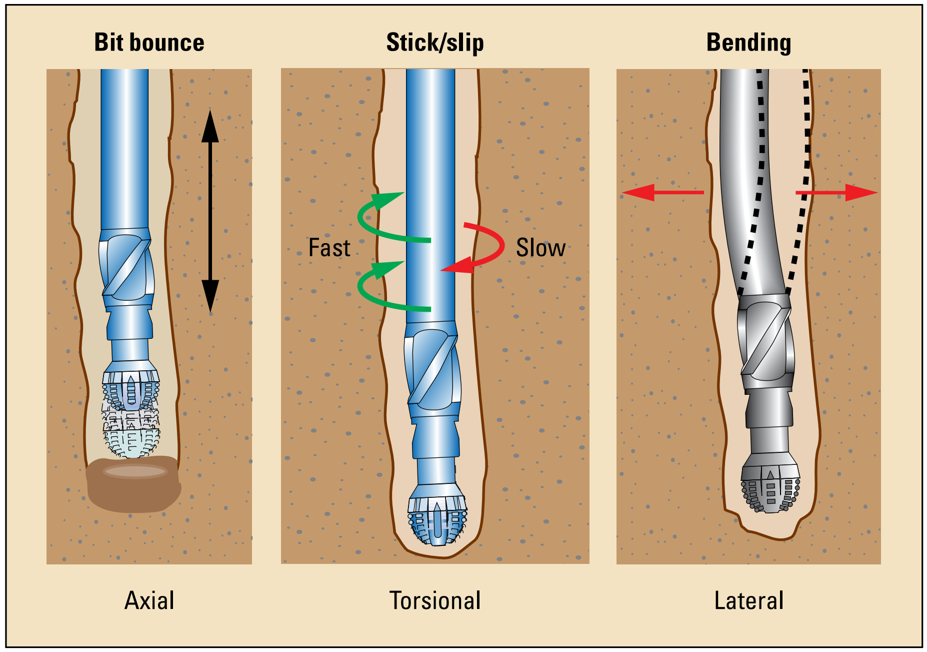

Figure 1. Vibration types.

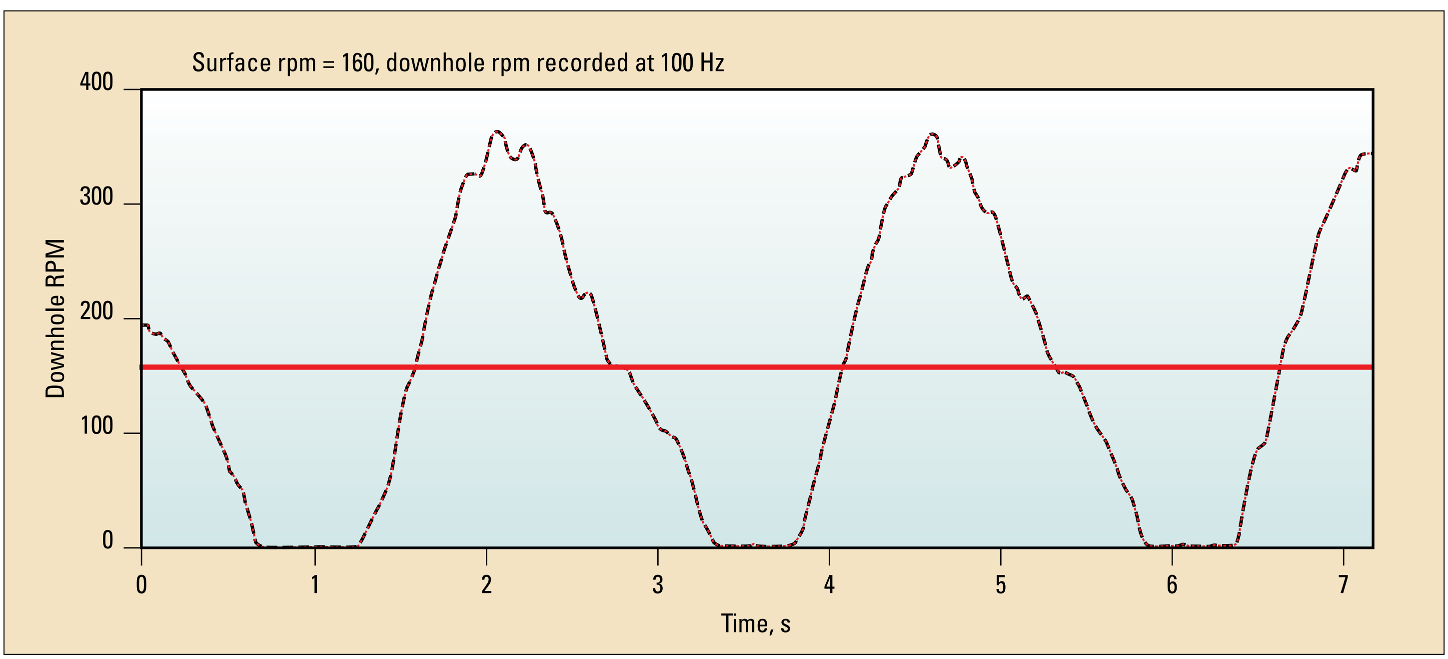

Figure 2. Fully developed stick/slip.

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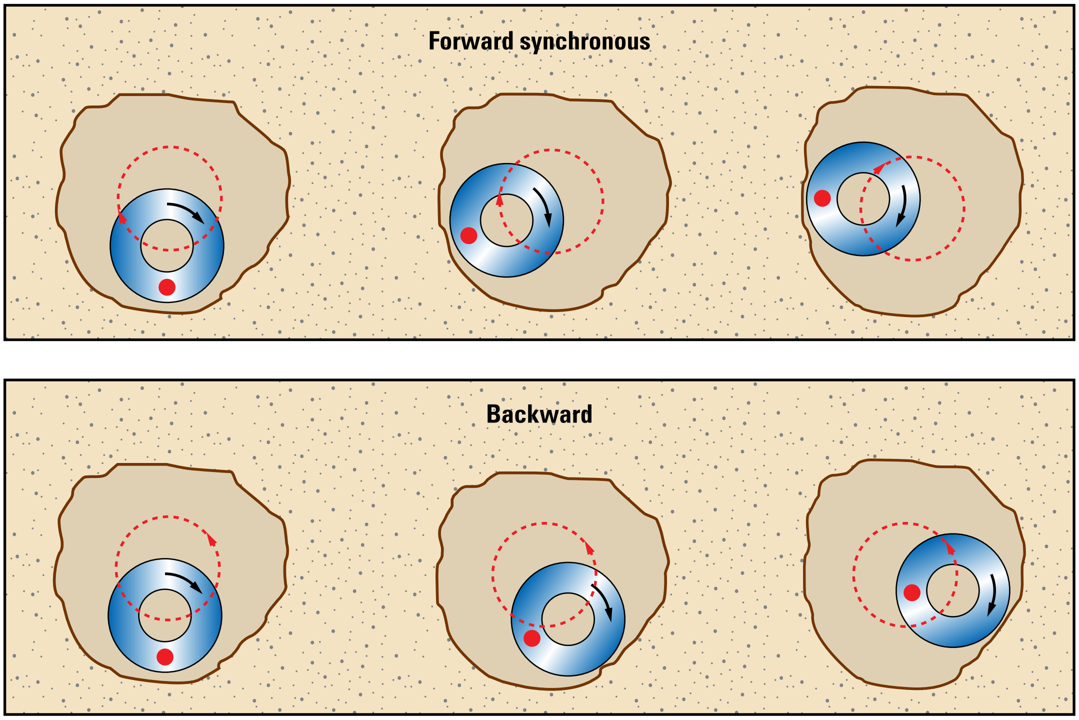

Figure 3. BHA whirl.

Lateral vibrations are the most destructive type of vibration and can create large shocks as the BHA impacts the wellbore wall. The interaction between BHA and drillstring contact points may, in certain circumstances, drive the system into backward whirl. Backward whirl is the most severe form of vibration, creating high-frequency large-magnitude bending moment fluctuations that result in high rates of component and connection fatigue. Imbalance in an assembly will cause centrifugally induced bowing of the drillstring, which may produce forward whirl and result in one-sided wear of components (Fig. 3).

Vibrations of all three types (axial, torsional, and lateral) may occur during rotary drilling and are coupled. Induced axial vibrations at the bit can lead to lateral vibrations in the BHA, and axial and torsional vibrations observed at the rig floor may actually be related to severe lateral vibrations downhole near the bit. At other times, severe axial vibrations near the bit may show no visible vibrations at the surface.

Axial and lateral vibrations are more violent in vertical or low-angle wells, and the displacements and bending moments introduced by lateral vibrations increase as the ratio of hole size to BHA collar size increases.

Natural frequencies and resonances

Natural frequencies are frequencies at which a structure likes to move and vibrate. Each natural frequency has an associated mode shape (Fig. 4). If the structure is excited at one of its natural frequencies, then resonance is encountered and large amplitude oscillations may result.[2] The largest amplitude displacements tend to occur at the first (fundamental) natural frequency.

Excitation sources

A drillstring vibrates as a result of load or displacement excitations applied at various locations and at various frequencies.

There is a wide range of potential excitation sources: mass imbalance, misalignment and kinks or bends, the cutting action of the drill bit, stabilizer blades (especially if they are straight), mud motors (nutation, or wobbling, of the rotor within the stator), and the friction factor between the drillstring and borehole wall.

Vibration modeling

There are two main types of vibration models: frequency domain and time domain.

Frequency domain models, such as the Schlumberger BHAV model, are fast running. A static model is used to compute BHA touch points and this information is used to compute the natural frequencies of the drillstring and BHA.

The user is asked to select the excitation sources expected (for example, imbalance and bit blades) and a critical rpm is computed for each source. The critical rpm is the surface rotational speed at which the frequency of the excitation source is expected to coincide with natural frequencies of the BHA. Interaction between the drillstring and the borehole wall is not taken into consideration.

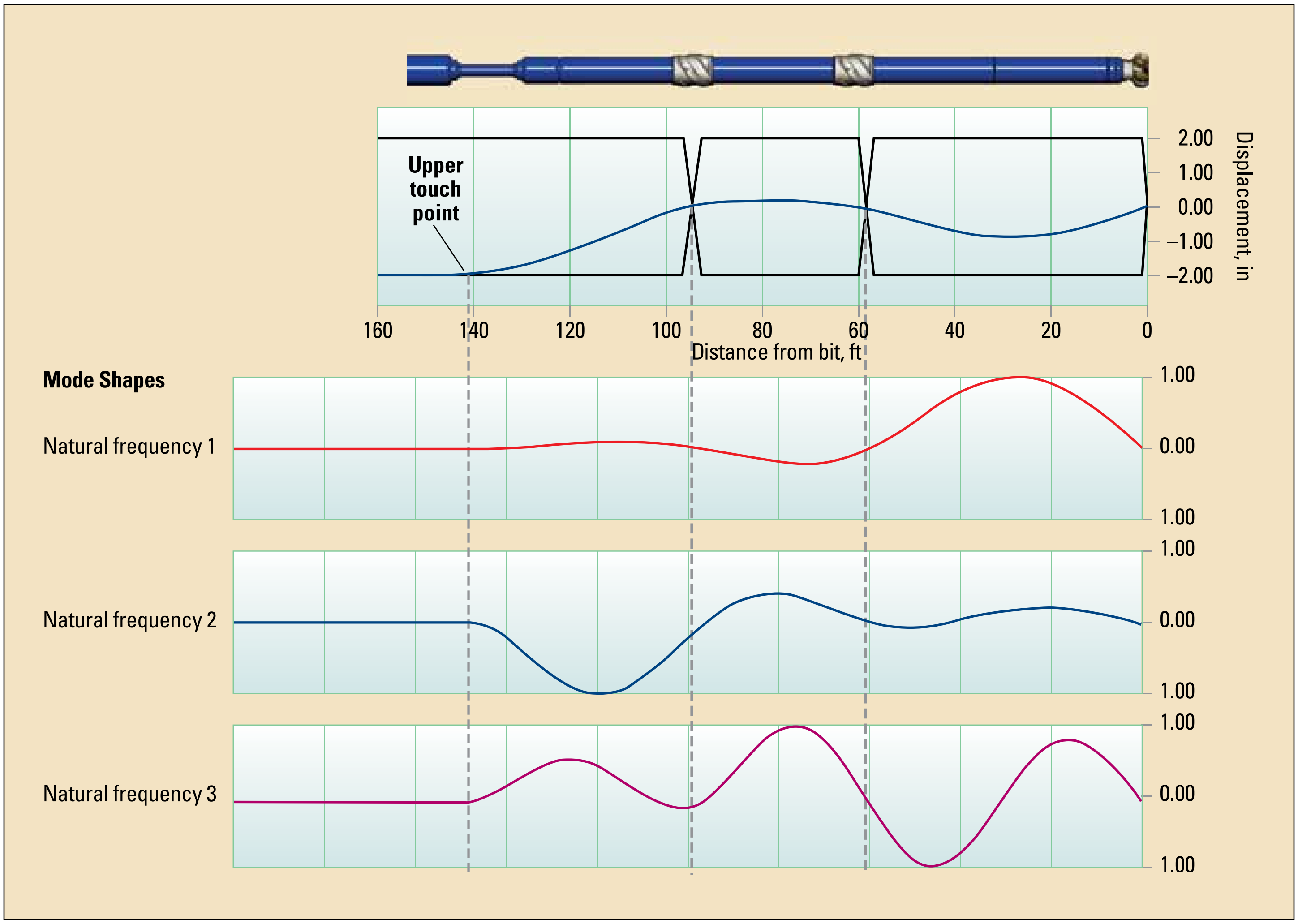

Figure 4. Lateral vibration mode shapes. The upper portion of this figure shows the static displacements of a restricted pendulum assembly in an inclined borehole. Static analysis is used to define the BHA contact points, which are used as an input to the computation of the structures' natural frequencies and mode shapes, shown in the lower portion of the figure.

Time domain (transient) models, such as the Schlumberger BHATV model, are more computationally intensive and, typically, drill forward in time and model the interaction between the drillstring and the borehole wall. This allows the models to capture mechanisms, such as forward and backward whirl, and provide a better representation of the excitation because of rotation of bends and kinks and to mud motor nutation.

Modeling limitations

It is important to bear in mind that vibration models require inputs that are commonly unknown or not available in real time, including formation properties and heterogeneity, BHA component imbalance and orientation, BHA misalignment (bent collars), downhole damping, and the friction factor at contact points (transient models). Models are also sensitive to hole diameter or stabilizer clearance.[3]

For these reasons, models are most powerful when used to compare the sensitivity of different BHA options to vibrations, and their accuracy improves when calibrated using offset well information and experiences. Because of the wide range of factors that influence vibration models, the models should be viewed as guidelines and used in conjunction with real-time measurements.

Summary

Vibration models are a valuable tool as part of an engineered approach[3,4,5,6] incorporating prejob analysis of offset well information, prejob modeling, real-time shock and vibration measurements, and postjob analysis and modeling[6], but it is important to understand their limitations.

References

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