ARC '16

مؤتمر مؤسسة قطر
السنوي للبحوث

QATAR FOUNDATION
ANNUAL RESEARCH
CONFERENCE

Towards World-class
Research and Innovation



Energy and Environment Pillar

http://dx.doi.org/10.5339/qfarc.2016.EESP2073

# Influence of Sinusoidal Drive Speed Modulation on Rotor with Continuous Stator Contact

**Abdullah Alzibdeh[1], Mohamed Y. Al-Qaradawi[2], Balakumar Balachandran[1]**

[1]University of Maryland, US
[2]Qatar University, QA

Email: azibdeh@umd.edu

## Abstract

Torsional vibrations experienced by drill strings can be detrimental to drilling operations. With a goal of understanding torsional vibrations experienced by drill strings and determining means to attenuate undesired vibrations, the authors have studied the effect of adding a sinusoidal modulation to a constant rotation speed of a drill string. A combination of modeling, analysis, and experiments is used to explore the influence of this rotation input modulation on the system response. The drill string is modeled as a modified Jeffcott rotor, which is described by a system with three degrees of freedom. Considering the case of forward whirling of a rotor in continuous contact with a stator, the equations of motion are reduced to a single degree-of-freedom nonlinear oscillator describing the torsional motions. In order to understand the fast time scale and slow time scale components of the motion, the method of direct partitions of motions is used to determine an approximate response to the nonlinear oscillator. The obtained results of the analysis illustrate that with the sinusoidal modulation of the rotor drive speed, the equivalent torsion stiffness can be enhanced and the character of the friction force at the contact can be made smooth. The analyses helps bring forth the stabilizing influence of the added sinusoidal input to the rotor drive speed. Over the considered parameter ranges, the numerical results obtained with the full three degree-of-freedom model and the reduced single degree-of-freedom model are found to be in agreement with each other. Furthermore, the results from these models are found to compare well with those obtained by using the method of direct partition of motions. Experiments with a laboratory scale drill-string arrangement are to be carried out to validate the analytical and numerical findings and further explore the effectiveness of the drive speed modulation on the rotor dynamics.

**Cite this article as:** Alzibdeh A, Al-Qaradawi MY, Balachandran B. (2016). Influence of Sinusoidal Drive Speed Modulation on Rotor with Continuous Stator Contact. Qatar Foundation Annual Research Conference Proceedings 2016: EESP2073 http://dx.doi.org/10.5339/qfarc.2016.EESP2073.

## Introduction

Slender rotating structures are used in many engineering applications. Drill strings are long rotating slender structures, which are used in drilling operations. A schematic of a rotary drill rig is shown in Figure 1 (e.g., Liao, Balachandran, Karkoub, and Abdel-Magid, 2011). Drill strings experience different types of vibrations (axial, torsional, and lateral vibrations) that may lead to detrimental failures of a drilling system. Drill-string vibrations have attracted the attention of many researchers, and many models have been developed to understand them. Since drill strings have a large length-to-diameter ratio, typically, the first torsional natural frequency and first lateral natural frequency are close to each other. This frequency proximity and the nature of the system allows for coupling and energy transfer between the associated vibration modes. Here, as a step towards developing further understanding, a drill string is modeled as an extended planar Jeffcott rotor with gravity acting normal to the rotor. Due to the planar motions, no gyroscopic effects are considered. The extended model, which was earlier considered in the work of Vlajic, Liu, Karki, and Balachandran (2014), is shown in Figure 2. The model is described with three degrees of freedom (DOF), namely, x and y to account for lateral motions, and theta to account for torsional motion. A large number of research efforts have focused on controlling drill-string vibrations by using different feedback control algorithms, which need measurements along the drill string. In this work, the authors propose a different control approach to mitigate whirling motions during continuous rotor-stator contact. This can be compared to a situation of a drill string being in continuous contact with the borehole. The approach is open loop in implementation and this approach is based on adding a high frequency input to the drive speed of the drill string. Given the open-loop nature, the method does not depend on any measurements along the drill string or rotary table, which could be attractive for a practical stand point. Although the current focus is on motions of a rotor with continuous stator contact, it is planned to study stick-slip and non-contact cases in the future.

## System Modeling, Studies, and Results

As previously mentioned, the drill string is modelled as a Jeffcott rotor with three DOF. Proceeding along the lines of the group's prior work (Vlajic, Liu, Karki, and Balachandran, 2014), after some approximations for the continuous rotor-stator contact case, the 3 DOF system is reduced to a single second-order nonlinear differential equation governing the torsional motion. In Figure 3, for a representative case with a constant drive speed, the torsional state histories obtained for the full model and the reduced model are plotted. It is noted that the final state of the motion is captured quite well. To further analyze the response during forward whirling, the reduced-order model was nondimensionalized and an approximate solution was obtained by using the method of direct partitions. This method allows one to separate slow scale motions from fast scale motions. As discussed, in the group's prior work, this method can be useful to examine whirling motions. The results obtained by directly integrating the full model as well as the reduced-order model have been compared with that obtained by using the method of direct partitions of motions. It is seen that the perturbation analyses is able to provide an approximate solution that compares well with the numerical results obtained through direct integrations. Next, this analysis is used to examine the influence of the addition of secondary frequency component. It is seen that the addition of the secondary frequency, a high-frequency one, helps smooth out the friction coefficient variation with respect to the relative speed at contact. This is found to have a beneficial effect on the motion and helps suppress large-amplitude torsional motions. Stability analysis was also conducted to examine this effect.

## Concluding Remarks

A study has been conducted to examine the influence of sinusoidal modulation of rotor drive speed in a system, wherein the rotor experiences continuous stator contact. A single degree of-freedom reduced model is developed to study the torsion response and it is found that the addition of a high frequency input can be beneficial in attenuating rotor motions. This is believed to be useful for developing open-loop control schemes for attenuating forward whirling motions of drill strings. Results obtained from a lab scale experimental arrangement will be used to examine the effect of this drive speed modulation further and they will be reported in the conference presentation. Future studies could build on the current effort to examine cases of backward whirling.

## Acknowledgment

The authors would like to gratefully acknowledge the support received from the Qatar National Research Fund for NPRP Project 7-083-2-041, to pursue this collaborative work between the University of Maryland, College Park, MD, USA and Qatar University, Doha, Qatar.

## References

1. Liao, C.-M., Balachandran, B., Karkoub, M., and Abdel-Magid, Y., Drill-String Dynamics: Reduced-Order Models and Experimental Studies, ASME Journal of Vibration and Acoustics, Vol. 133, 2011, pp. 041008-1-041008-8.
2. Vlajic, N., Liu, X., Karki, H., and Balachandran, B., Torsion Oscillations of a Rotor with Continuous Stator Contact, International Journal of Mechanical Sciences, Vol. 83, pp. 65–75, 2014.