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IFAC-PapersOnLine 48-11 (2015) 700–705

Hidden oscillations in drilling systems with salient pole synchronous motor

M.A. Kiseleva N.V. Kondratyeva N.V. Kuznetsov G.A. Leonov

Saint Petersburg State University, Saint Petersburg, Russia, University of Jyväskylä, Jyväskylä, Finland Saint-Petersburg State Polytechnic University, Saint-Petersburg, Russia
e-mail: nkuznetsov239@gmail.com

Abstract: Recently the question on drilling rigs failures due to hidden oscillations was actively discussed. For instance, it was shown by the scientific group from Eindhoven University of Technology that such oscillations may appear in drilling rigs actuated by DC motor. In the works of the authors same effect was found for models of rigs with induction motor. Here a new mathematical model of a drilling rig activated by a salient pole synchronous motor is considered. Numerical modelling of the obtained model is performed.

Keywords: drilling system, salient pole synchronous motor, hidden oscillations

1. INTRODUCTION

Drilling rigs at an early stage of their development were often powered by diesel engines, which were later replaced by electric drive. As experience has shown, the rigs driven by electric motor have better performance than diesel rigs due to the higher reliability of the drive, the best adjustment properties and less time on maintenance and repair.

In serial production of drilling rigs different motors are used as an electric drive: induction motors with squirrel-cage and phase-wound rotor, synchronous motors, DC motors and electromagnetic brakes. Each of these types of motors has its advantages and disadvantages.

Many years of operating experience of drilling equipment in oil and gas industry reveals a whole range of reasons for which failures of drilling equipment appear. One important reason for failure is a sudden breakdown of the electrical part of the drilling rig. The problem of preventing catastrophic failures of oil and gas drilling equipment is extremely relevant. The construction and study of adequate mathematical models of drilling rigs contributes to this problem.

Rig undergoes various types of vibration (rotational, axial, torsional) during its operation. Torsional vibrations are regarded as the most damaging type of vibrations appearing in drilling system (Omojuwa et al., 2011; Rajnauth, 2003). These vibrations may lead to failures of the drill-string or even the drilling system itself. All these problems lead to unacceptably high cost and time losses for the drilling industry.

Mathematical models of drilling rigs represent complex nonlinear dynamic systems. Study of oscillations and stability of such systems by numerical integration of differential equations is extremely limited. Therefore, the results concerning the mechanism of occurrence of vibrations and hidden oscillations[1] in these systems are often obtained using computer modelling.

In (Kiseleva et al., 2014; Leonov et al., 2014b), an electromechanical model of drilling rig driven by induction motor drive is built. This model takes into account torsional deformation of the drill. This model is a modification of the model suggested by researchers from the Eindhoven

[1] An oscillation in dynamical system can be easily localized numerically if the initial conditions from its open neighborhood lead to the long-time behavior that approaches the oscillation. Thus, from a computational point of view, it is natural to suggest the following classification of attractors, based on the simplicity of finding the basin of attraction in the phase space: Kuznetsov et al. (2010); Leonov et al. (2011, 2012); Leonov and Kuznetsov (2013): *An attractor is called a* self-excited attractor *if its basin of attraction intersects with any open neighborhood of a stationary state (an equilibrium), otherwise it is called a* hidden attractor. For a *self-excited attractor* its basin of attraction is connected with an unstable equilibrium and, therefore, self-excited attractors can be localized numerically by the *standard computational procedure* in which after a transient process a trajectory, started in a neighborhood of an unstable equilibrium, is attracted to the state of oscillation and traces it. For a hidden attractor its basin of attraction is not connected with equilibria. The hidden attractors, for example, are the attractors in the systems with no equilibria or with only one stable equilibrium (a special case of multistability – multistable systems and coexistence of attractors). The well-known examples of the hidden oscillations are nested limit cycles in the papers on the 16th Hilbert problem (see, e.g., Kuznetsov et al. (2013a)) and counterexamples to the Aizerman and Kalman conjectures on the absolute stability of nonlinear control systems Leonov et al. (2010); Leonov and Kuznetsov (2011); Bragin et al. (2011). Recent examples of hidden attractors can be found in Kiseleva et al. (2012); Andrievsky et al. (2013b,a); Pham et al. (2014a,b); Wei et al. (2014b); Li and Sprott (2014); Zhusubaliyev and Mosekilde (2015); Wei et al. (2014a); Leonov et al. (2014a); Kuznetsov et al. (2013b, 2015); Burkin and Khien (2014); Li et al. (2014); Zhao et al. (2014); Lao et al. (2014); Chaudhuri and Prasad (2014); Leonov et al. (2015).

10.1016/j.ifacol.2015.09.270