Mechanical Systems and Signal Processing 94 (2017) 1–13

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Diesel engine torsional vibration control coupling with speed control system

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ARTICLE INFO

Article history:
Received 17 September 2016
Received in revised form 26 November 2016
Accepted 11 January 2017
Available online 24 February 2017

Keywords:
Coupling model
Shafting torsional vibration
Speed control
Speed oscillation

ABSTRACT

The coupling problems between shafting torsional vibration and speed control system of diesel engine are very common. Neglecting the coupling problems sometimes lead to serious oscillation and vibration during the operation of engines. For example, during the propulsion shafting operation of a diesel engine, the oscillation of engine speed and the severe vibration of gear box occur which cause the engine is unable to operate. To find the cause of the malfunctions, a simulation model coupling the speed control system with the torsional vibration of deformable shafting is proposed and investigated. In the coupling model, the shafting is simplified to be a deformable one which consists of several inertias and shaft sections and with characteristics of torsional vibration. The results of instantaneous rotation speed from this proposed model agree with the test results very well and are successful in reflecting the real oscillation state of the engine operation. Furthermore, using the proposed model, the speed control parameters can be tuned up to predict the diesel engine a stable and safe running. The results from the tests on the diesel engine with a set of tuned control parameters are consistent with the simulation results very well.

1. Introduction

Diesel engines are commonly used in the field of the ship, and the reliability of the diesel engine is relative to the safety of maritime. There is a typical coupling problem which affects the operation of the diesel engine. During the operation of a diesel engine with 9 cylinders and power of 4500-kW, the oscillation of engine speed and the severe vibration of gear box occur. From the start of 400 r/min, the speed of the engine is increasing gradually. When it approaches to about 450 r/min, the governor arm starts vibrating and the fluctuation of the speed starts increasing. When it approaches to about 540 r/min, the range of fluctuation reaches 20 r/min and the oscillation of engine speed occurs which leads the engine unable to operate normally. This phenomenon is caused by the coupling of the dynamics of the driven shafting and the control system of the diesel engine.

The coupling issues have gained wide attention especially in the research fields of industries where the reliability is highly required such as in electric power industry or in helicopter industry. The self-oscillations occurring during the process of turbo unit connected into electronic network have been successfully explained not only theoretically but also experimen-

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http://dx.doi.org/10.1016/j.ymssp.2017.01.017

tally. Along with that, many mathematical coupling models were developed to solve the issue of self-oscillations, such as, the electro-mechanical coupling model, the analysis model coupling shafting torsional vibration to electronic network and the torsional vibration simulation model coupling gas steam combined cycle unit with electronic network, etc. [1,2]. Gao [3] presented a theoretical study and proposed an active vibration control scheme for controlling torsional vibration of a rotor shaft in large steam turbine generator sets, and the results show that full state feedback control has significant effectiveness on attenuation of torsional vibration energy and response of turbo-generator shaft system. Hall [4,5] established wind turbine model including the gear and shaft model to study how the wind capture capability of a fixed-speed wind turbine can be improved through the implementation of a variable ratio gearbox (VRG). White [6] investigated the reduction of rotor shaft torsional vibrations through active control of the generator torque, where the drive train consists of the rotor with its mass and inertia, and the rotor shaft with its stiffness and damping. In the helicopter research field, many simulation models were developed to deal with the coupling issues between transmission chain and speed control system in order to solve torsional vibration problems. Among the models, there are the model coupling torsional vibration of transmission chain system to speed control system and the coupling model among human, helicopter and speed control system in which the human effect is taken into coupling account [7–9]. Pavel [10] gave an overview on the state-of-the-art in rotorcraft pilot coupling (RPC) problem, underlining the future challenges in this field. Zhang [11] established a helicopter/turbo-shaft engines system which has complex coupling relationships, including four parts: open-loop model of helicopter, flight controller, open-loop model of turbo-shaft engine and engine controller. Sun [12] focused on the aeroelasticity analysis of rotor blade and rotor control systems, and the results show the inertia of the swashplate has significant effects on high-frequency harmonics of the servo loads.

However, in the field of reciprocating machinery such as diesel engine, the problems of coupling oscillation in diesel engine are very common but there are a few researches focusing on the coupling issues. Usually, speed control part and torsional vibration part are studied separately. The classification society rules only make requirements for the two parts individually and have no requirements for the coupling issues at all [13]. While studying the simulation of speed control system, usually the shafting is treated as a rigid one with single inertia, neglecting that the shafting is deformable [14–16]. Tao [17] proposed an adaptive neutral network control for elastic marine shafting using dynamic surface control in order to reduce the shafting torsional vibration due to fluid incentives of propeller, and the limitation in that study is without considering the coupling between the torsional vibration of whole shafting system and the control system. Östman [18] presented a method for reducing the torsional vibration of the crankshaft by balancing the cylinder-wise torque contributions with the measured angular speeds of the crankshaft system, which leads to a significant reduction of the thermal load of the flexible coupling. Tang [19] established a novel simplified torsional vibration model to study the torsional vibration characteristics of a compound planetary hybrid propulsion system, and the simplified model can be used to accurately describe the low-frequency vibration property. This study provides a basis for the coupling simulation of vibration-control system to ensure the real-time performance of the coupling model. By and large, among the published literatures, one can hardly find the coupling models on shaft system vibration with control system.

In this paper, aiming at the oscillation of the propulsion system, firstly, the torsional vibration is calculated and the speed control is simulated based on the traditional simulation method with a rigid shaft. The two parts (the torsional vibration and the speed control) are analyzed separately to check if the results satisfy the classification society rules. Then, a coupling simulation model by combining deformable shaft torsional vibration with speed control system is proposed which has never been studied before. The coupling model was built by substituting the deformable shafting model for the rigid one into the speed control simulation model. The coupling model can be used to explain the cause of the malfunction as fault problems. Such problems are sometimes not simply design problems of parts but rather than coupling problems among all parts in a system such as shafting, controller, etc.

2. Shafting torsional vibration

2.1. Free torsional vibration

The shafting of a diesel engine studied in this paper consists of crankshaft, gearbox gear shaft, propeller shaft and generator shaft as shown in Fig. 1, where the power of the propeller is 2800 kW, and the power of the generator is 500 kW.

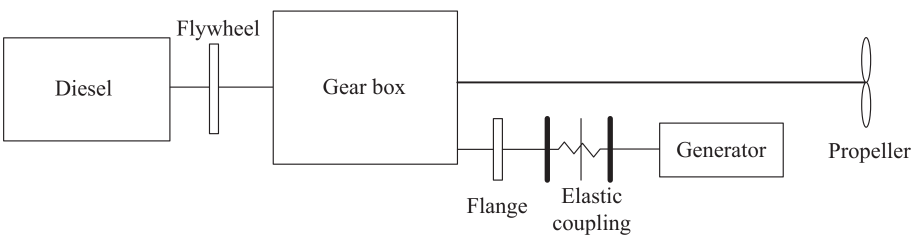

Fig. 1. Shafting system.