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Measurement and analysis of instantaneous torque and angular velocity variations of a low speed two stroke diesel engine

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ABSTRACT

This paper presents an investigation into the potential of using direct measurement of engine torque for diagnostic purposes in large engines – in this case applied to power generation. The procedures for measuring and analyzing the instantaneous torque, the angular displacement on the generator output end and the angular displacement on its free end for a ten-cylinder, low speed two stroke diesel engine are presented. Angular speed oscillations are frequently used for combustion engine diagnostics although they cannot be used to measure engine power directly. In addition, and for engines with huge inertia generators such as those used in power plants, speed oscillations are very low and this reduces the signal to noise ratio and makes the evaluation of the instantaneous angular speed very noisy. In the work described here, torque and angular displacement measurements carried out at the same point and with the same engine conditions are compared and the superior performance of torque is demonstrated. Harmonic analysis of instantaneous torque allowed the identification of the dynamic characteristics of the power train of the diesel group and clearly suggests that this signal can be used as a diagnostic tool for excitation, combustion malfunctions, or for the mechanical characteristics of the system and crankshaft stiffness. The torque distortion introduced by the generator due to the discontinuity imposed by the pole pairs is also observed in the torque signal, suggesting that the torque signal can be used to identify generator malfunction.

1. Introduction

Low speed two stroke diesel engines are used for propulsion and power generation in ships. In relation to the installed power around the world, and although the ratio of diesel power to total installed power is low, these engines are frequently used on islands and in most cases they are the only type of prime mover available. In the case of large ships, low speed diesel engines represent almost all of the propulsion solution, although alternative gas engines are growing as the prime mover [1]. The efficiency of diesel engines is typically close to 50% and some models surpass this level. Only combined cycle plants

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with a rated power higher than 100–150 MW can provide efficiencies greater than those of two stroke diesel engines [2], which is much higher than the maximum power attainable today in large diesel engines. In addition, these engines have a low sensitivity to atmospheric changes, low efficiency reduction when they are operated at low loads, burn low-cost heavy fuels and have such advantageous characteristics that they can be fed with pure vegetable oil [3]. Combined cycle plants or gas turbines have clear disadvantages in these respects.

However, and from the point of view of exploitation, these engines do suffer from drawbacks:

- Maintenance is usually based on corrective or preventive actions, which clearly increases the operational cost.
- Catastrophic failures are relatively common, although a good preventive plan can be implemented [4–6].

Internal combustion engines at stationary running do not have a constant angular displacement as it is variable within the engine cycle [7]. The magnitude of the oscillations, angular positions of the relative maximum of the angular displacement and the general form of this speed depend on the load characteristics of the engine and the load, the engine design and the dynamics of the torsional system [8]. This relationship between instantaneous angular displacement and torsional system dynamics has led to a lot of research work in this area and this trend will continue in order to extract information from instantaneous angular speed for engine diagnosis [8–10].

In the case of low speed diesel engines with a very long stroke, such as those used for power generation, the huge inertia of the alternator means that the amplitude of the oscillations of the part of the shaft engaged to the alternator is very low and therefore the angular displacement signal presents a low signal to noise ratio. In contrast, the shaft experiences a large torsion and therefore high shear loads produce high strains at the shaft surface. These strains can be measured through strain gauges when they are oriented to measure principal stresses. If parasitic deformation is cancelled out correctly, it is possible to measure dynamic engine torque. This signal (instantaneous engine torque) contains information that can be used for diagnostic purposes. Although both torque and angular displacement or speed contain closely related information about the dynamics of the system, engine torque also contains the absolute magnitude and this makes this signal more appropriate for system identification applications [11]. This property, in conjunction with the measurement of the instantaneous angular displacement, also allows an evaluation of the mechanical power transferred from the engine to the generator and therefore completes the energy balance of the engine. If combustion pressures in every cylinder are measured, the total energy delivered by the cylinders is known and therefore the measured torque can be used to estimate the mechanical losses of the engine.

This paper presents an investigation into the oscillations of the shaft of a two stroke, low speed diesel engine used for power generation. For this purpose the angular displacement at the front and at the free end of the crankshaft were measured simultaneously along with the torque at the front. The simultaneous measurement of both angular displacements indicated that the system cannot be considered as rigid from the point of view of torsional dynamics [12].

If trend monitoring techniques are applied to the crankshaft vibration characteristics in terms of torque and angular displacement, the comparison of these with templates for the engine in a healthy state can be employed for system diagnosis.

2. Plant layout and description

The research was carried out on a two stroke low speed diesel engine, on line ten cylinders, crosshead arrangement, and the main data are given in Table 1. These engines performs a complete cycle in one crankshaft turn, this is, 360°. The

Table 1
Main engine data.

	Magnitude	Units
Number of cylinders	10	
Engine speed	125.00	rpm
Piston diameter (D)	0.67	m
Connecting rod length (L)	2.538	m
Stroke ($2R$)	1.70	m
Mean piston speed (c)	7.10	m/s
Number of compression rings (nc)	5	–
Ring thickness (e)	18	mm
Mass of piston, rod and crosshead per cylinder (m_p)	4550	kg
Maximum power	15.50	MW
Maximum efficiency	48.00	percent
Mean effective pressure	12.40	bar
Sequential firing	1-9-4-6-3-10-2-7-5-8	