Analysis of Torsional Vibration of Diesel Shaft System using Hard Coupling with Working Machine

Phân tích dao động xoắn hệ trục động cơ diesel và máy công tác sử dụng khớp nối động

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Abstract: The model is built to analyze and calculate the torsional vibration of the internal combustion engine shaft system and the generator connected by hard coupling to assess the response to the free and forced vibration of the shaft system, thereby serving as a basis for devising a suitable plan to reduce or avoid the problem of shaft torsion vibration. The results of the research include: modeling and building a separate calculation program for shaft torsion vibrations using MATLAB software; free vibration response analysis including calculating the vibration mode frequency and corresponding vibration forms; analyzing the forced vibration response including the amplitude of vibration of the degrees of freedom and the torsion stress of each element.

Keywords: *Amplitude of vibration; Forced vibration; Free vibration; Torsional vibration*

Tóm tắt: Mô hình được xây dựng nhằm phân tích, tính toán dao động xoắn của hệ trục động cơ đốt trong và máy phát điện được nối với nhau bằng khớp nối cứng nhằm đánh giá sự phản hồi với dao động tự do và dao động cưỡng bức của hệ trục, từ đó làm cơ sở đưa ra phương án phù hợp. để giảm hoặc tránh vấn đề dao động xoắn trục. Kết quả của đề tài bao gồm: mô hình hóa và xây dựng chương trình tính riêng dao động xoắn trục bằng phần mềm MATLAB; phân tích phản hồi dao động tự do bao gồm tính toán tần số dao động và các dạng dao động tương ứng; phân tích dao động cưỡng bức phản hồi bao gồm biên độ dao động bậc tự do và ứng suất xoắn của từng phần tử.

Từ khóa: *Biên độ dao động; Dao động cưỡng bức; Dao động tự do; Dao động xoắn*

1. Introduction

In order to calculate and produce optimal simulation results with the response forms of the torsional vibration problem, the first step is to build a physical model that is true to the system; the work of mass regulation of mass disks and length regulation of axial segments, construction of elemental matrices and overall matrices of mass, anti-torsion rigidity, damping coefficients with figures that must be close to the actual structure. The forced moments over time acting on the system including the excitation moment of the diesel engine and the resistance moment of the generator should be calculated with actual data or obtained from the equipment supplier. These data will be fed into a program written in MATLAB software to calculate and find free vibration responses including: the system's own vibration frequency, the vibration forms corresponding to the natural frequency; forced vibration responses include: the amplitude of fluctuations of masses at the corresponding revolutions and power of the motor from which the shear stress on each shaft segment is calculated. These results serve to assess the ability of the shaft system to work with safe conditions of torsional vibration, thereby providing a method to reduce the impact of torsional vibrations by making unsafe speed range recommendations or installing additional torsional dampers for the shaft system.

2. Building of calculation model

2.1. Physical model building

Proceed to convert the actual system shaft into the equivalence system shaft by regulating the length and the leading to the mass. The post-process shaft system is considered a smooth cylindrical axis with a constant cross-section, with rigidity, elasticity, masslessness, and concentrated mass disks located in the corresponding positions. When conducting the equivalent length of the axle system, it must ensure the balance of the energy of the shaft when subjected to the same torque. That is, the anti-torsion rigidity of the equivalent shaft segments must be equal to the anti-torsion rigidity of the real axis. Replace the moving masses with disks with equivalent mass moments of inertia and set in the equivalent position. The equivalent shaft system after regulation consists of disks with mass inertial moment J_i placed on smooth axes of stiffness k_i, with a damping coefficient c_i in the corresponding position. The shaft system consists of n degrees of freedom corresponding to n disks of mass and (n – 1) elements corresponding to (n – 1) shaft segments [1].

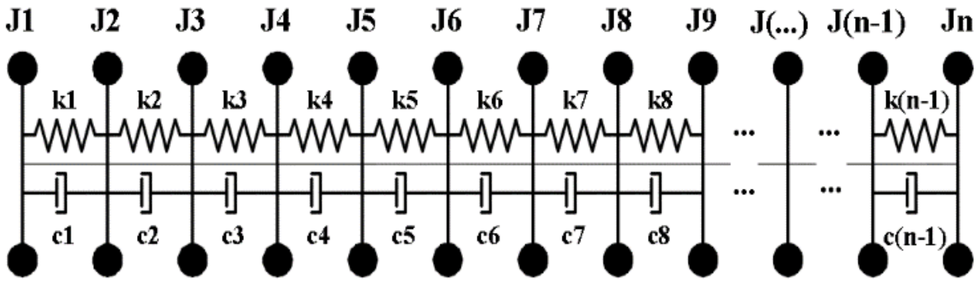


Figure 1. Shaft torsion vibration modeling diagram

2.2. Free vibration response analysis [1], [2]

The free vibration equation of a multi-degree axis system, including the damping coefficient, is a system of differential equations written in general form as follows:

$$J\ddot{\theta} + C\dot{\theta} + K\theta = 0. \text{ where:}$$

$$J = \begin{bmatrix} J_1 & 0 & 0 & 0 \\ 0 & J_2 & 0 & 0 \\ 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & J_n \end{bmatrix}$$ is the overall mass inertial moment matrix

$$K = \begin{bmatrix} k_1 & -k_1 & 0 & 0 & 0 \\ -k_1 & k_1 + k_2 & -k_2 & 0 & 0 \\ 0 & -k_2 & k_2 + 3 & \ddots & 0 \\ 0 & 0 & \ddots & k_{n-1} + k_n & -k_{n-1} \\ 0 & 0 & 0 & -k_{n-1} & k_n \end{bmatrix}$$

is the overall stiffness matrix.

$$k_i = \begin{bmatrix} k_i & -k_i \\ -k_i & k_i \end{bmatrix} \text{ and } \quad J_i = \begin{bmatrix} J_i & 0 \\ 0 & J_{i+1} \end{bmatrix}$$

are the element stiffness matrices and mass inertial moment matrices of the i-th element.

The damping coefficients of the system appear in the row elements or at the compound block. Experimentally, one can select damping matrices as a ratio of as a combination of mass inertial moment matrices and stiffness matrices $C = \alpha J + \beta K$. where: α, β are empirical coefficients and $\theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \cdots \\ \theta_n \end{bmatrix}$ overall torsion angle matrix.

2.3. Forced vibration response analysis [1],[3]

The forced vibration equation of a multi-degree axis system of degrees of freedom including damper coefficient one is a system of differential equations written in general form as follows

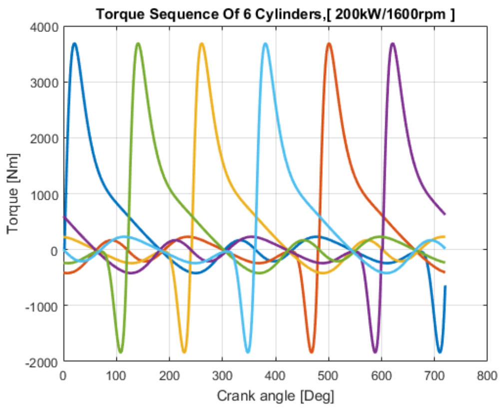
$J\ddot{\theta} + C\dot{\theta} + K\theta = F(t)$, in which: F(t) are torque acting on the shaft system including: excitation torque of 6 cylinders (torque on the crankshaft generated by the force of combustion gas in the cylinder and forced torque due to the inertial force of the transmission mechanism group) and the electromagnetic resistance moment of the generator.

3. Conduct calculation and analysis of results

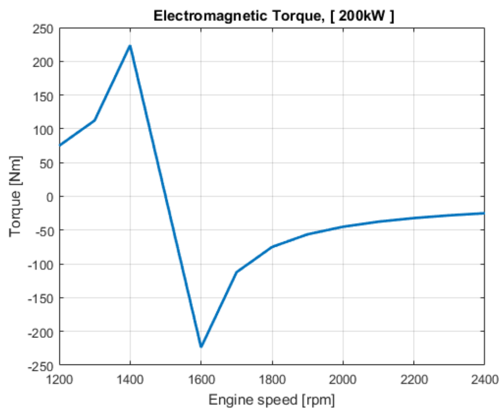
The calculations in the study conducted are a generator set consisting of a 4-stroke 6-cylinder diesel engine with a rated power of 200kW at 1800 rpm, a 3-phase generator with a rated power of 200kW at 1800 rpm connected by a hard disk shaft connection presented in the table below.

Table 1. Data table of shaft system parameters used in torsional vibration calculation

STT	Detailed name	Momentum calculating mass [kgm2]	Stiffness axle [MNm/rad]
1	Damping ring	0.079	0.126
2	Dampers Puli	0.035 0.015	1.261
3	Cylinder Assembly 1	0.043	1.519
4	Cylinder Assembly 2	0.028	1.519
5	Cylinder Assembly 3	0.043	1.519
6	Cylinder Assembly 5	0.043	1.519
7	Cylinder Assembly 5	0.028	1.519
8	Cylinder Assembly 6	0.043	1.386
9	Cogwheel	0.033	9.550
10	Flywheel, Shaft coupling disk	0.708 0.042	20.081
11	Disk captured with disk shaft joining	0.174	3.35674
12	Cooling impellers	0.1887	2.75013
13	Main Rotor	1.4085	1.22522
14	Rotor excitation	0.0874	



a) Moment of excitation of diesel engines



b) Electromagnetic moment of the generator

Figure 2. Excitation moment of the engin and 3-phase generator

After using the calculation program with the axis parameters in table 1, 14 vibrations corresponding to the vibration mode frequency and corresponding rotational speed are obtained (Figure 3:) underneath. Based on the results of the analysis of free vibrations of the shaft system, it is shown that the speed ranges at which resonance occurs have a much greater frequency than the normal operating speed range of the motor, during the actual operation of the motor cannot run to these speeds. However, in practical conditions, not only when the shaft system operates at the speed ranges corresponding to the natural frequency, there is a resonance problem and poses a danger to the shaft system, but the cooperation of the harmonic force systems, the value of the combined load is much greater than the load when resonance occurs. Therefore, it is necessary to calculate the forced vibration responses from which to calculate the shear stress on each axle segment to evaluate the ability of the shaft system to twist load when working.

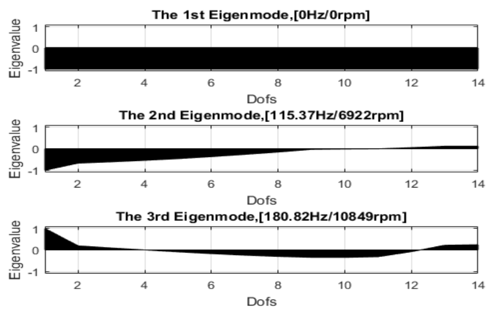


Figure 3. Result of 3 vibration modes corresponding to the natural frequencies of the shaft system

Forced vibration responses consist of the amplitude of vibration of each degree of freedom at the corresponding revolutions of the engine. From there, the stress for each axis segment is determined and compared with standards. Figure 4 shows the anguler amplitude results of the 10th degree of freedom (flywheel and axial coupling disk) in modes of 200kW/1200rpm, 200kW/1400rpm and 200kW/1600 rpm. These torsional amplitude results allow to assess the abnormal working capacity of the free order, whether the co-operation of the harmonic forces causes a large shear stress on the axis.

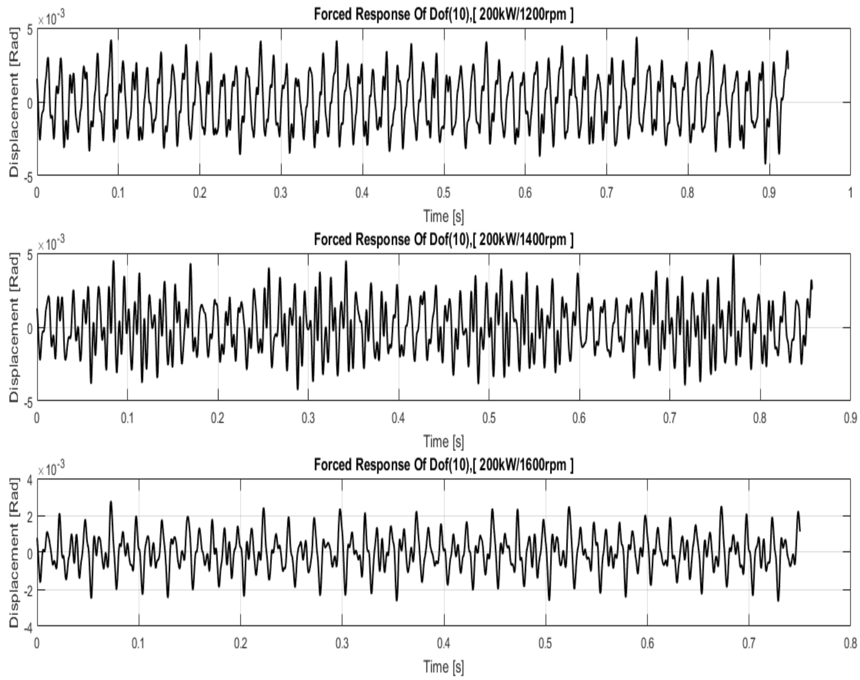


Figure 4. Vibration amplitude results of the 10th degree of freedom (flywheel and shaft connecting disk)

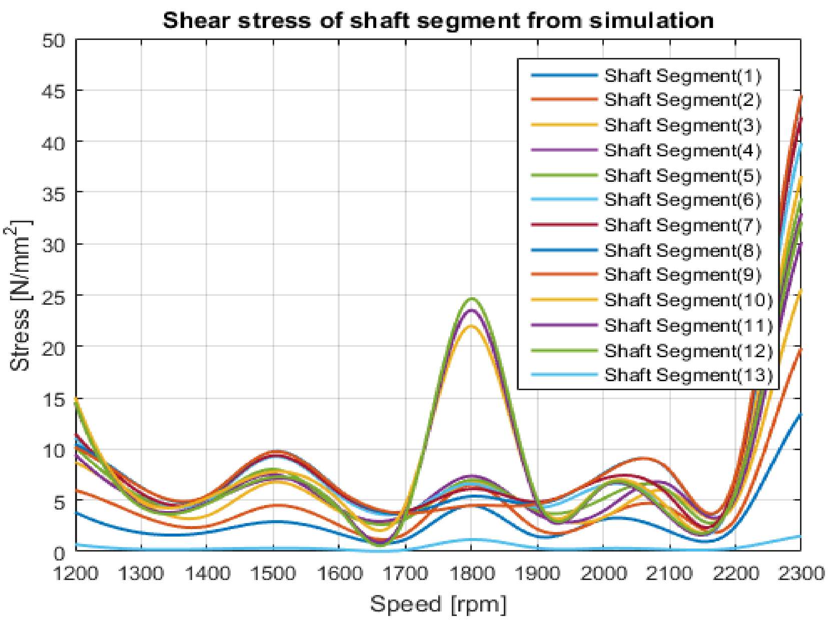


Figure 5. Shear stress results of component shaft segments

The results showed that in some shaft segments 10, 11 and 12 of the generator there was an abnormal increase in shear stress at 1800rpm revolutions. This is due to the problem of co-operation of regulatory excitation moments that cause great stress on the component shaft segment. Through analysis and calculation of shaft torsion vibration, some technical comments have been made to the problem of calculating shaft torsion vibration as follows:

- The higher the natural frequency, the more complex the stress response in the shaft system. When the frequency of the forced force (excitation moment) is close to the natural frequency of the axial system, resonance will occur.

- To predict the results of the calculation of torsional vibrations accurately: firstly, it is necessary to correctly determine the inertial moment and torsional rigidity of the system, and secondly, the method of determining the stress of torsional vibrations on each shaft segment under working conditions.

- In the process of calculating and testing different coefficients, noting the prediction of dangerous speed, the damping coefficient does not need to be determined more accurately.

4. Conclusions

The study focused on modeling and calculating torsional vibrations of diesel engine shafts and working machines connected by rigid coupling with the results calculated and expressed from the program including: free vibration responses and forced vibration responses from which to determine the shear stress on each component shaft segment. part. The calculation results from the program will allow to predict the occurrence of resonance phenomena in the axle system at what power number of revolutions of the motor and also the problem of cooperation of the moments of harmonic excitation causing great stress on the shaft.

References

[1] William T.Thomson. *Theory of Vibration with Applications*. Prentice – Hall International Edition, 1998.

[2] Sigiresu S.Rao, *Mechanical Vibration*. Addision – Wesley Publishing Company, Massachusetts, 1990.

[3] Joseph Edward Shigley, Jonh Joseph Uicker. *Theory of Mechines and Machanisms*. McGraw – Hill international editions, 1995.

[4] Wladyslaw Mitianiec, Konrad Buczek, "Torsional Vibration Analysis Of Crankshaft In Heavy Duty Six Cylinder Inline Engine," Institute of Automobiles and Internal Combustion Engines, Cracow University of Technology. 2008.

[5] B Y Yu, Q K Feng, X L Yu, "Modal And Vibration Analysis Of Reciprocating Compressor Crankshaft System," Institute of Compressor, Xi'an Jiaotong University, P R China. 2011.

[6] Fikre E. Boru (Dr.-Ing.), Johann Lenz (Dr.-Ing.). "Torsional Vibration Problem in Reciprocating Compressor – Case Study," *SIRM 2015 – 11th International Conference on Vibrations in Rotating Machines*, Magdeburg, Germany, 23 – 25, February. 2015.

[7] Xiaolin Tang, Wei Yang, Xiaosong Hu, Dejiu Zhang, "A Novel Simplified Model For Torsional Vibration Analysis Of A Series - Parallel Hybrid Electric Vehicle," *Elsevier*, Mechanical Systems and Signal Processing 85 (2017) 329–338. 2017

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