STUDYING INFLUENCE OF THE MATHEMATICAL MODEL ERROR ON THE RESULTS OF CALCULATING FREEDOM TORSIONAL VIBRATION FOR MARINE DIESEL PROPULSION SYSTEM

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Received: 25 Dec. 2023; Revised: 11 Jan. 2024; Accepted: 20 Mar. 2024

ABSTRACT

The Freedom Torsional Vibrations (FTV) Calculation (FTVC) for the marine main propulsion plant (MPP) to determine the freedom frequencies and the FTV formations of the mechanical system. Normally, the MPP is dynamically modeled as a finite n concentrated masses with the parameters of: Mass moment of inertia J_k (kgm^2, $k = 1 \div n$) and the torsional stiffness $C_{k,k+1}$ (Nm/rad) between the k and k+1 concentrated masses. This paper studies the influence of the number of concentrated masses n as well as the accuracy of determining J_p (Moment of inertia of the propeller) on the solution of the MPP's FTVC. The research verifies to the MMP on the Korean ship XXX-XXX-XXX, using the MDE 6G70MEC.

***Keywords**: Freedom Torsional Vibration (FTV); Mathematic model of the FTV; Exactness of the FTV calculation.*

I. INTRODUCTION

In the designing and building a new or renew sea-going ship, the torsional vibration calculation and measurement (TVC, TVM) of the main propulsion plant (MPP) is compulsory. The maritime registration organization approves the results of the TVC and TVM [1]. In practice for TVC, we usually model the MPP as a system of n lumped masses with the constant inertial moments of masses, and the massless coefficients of the torsional weightless stiffness (torsional spring) for connecting these masses.

The math models for torsional vibration of MPP mechanical system always come with an error rate. With regard to a technical problem, this error rate must be in a permitted range so that the model as close to the real system as possible. The competency maritime register considers and approves the TVC and sea-trial test results under the Rules for the classification and construction of sea-going ships.

For the free torsional vibration calculation (FTVC), we solve following equations:

$$\boldsymbol{J\ddot{\varphi} + C\varphi = 0} \qquad (1)$$

Where: J =*diag*(J_1, J_2,…,J_n) - Diagonal matrix of inertial moments; *C*- Stiffness matrix; φ - TV state vector, $\varphi = [\varphi_1 \ldots \varphi_n]^T$; n – Equation's number of system (1).

In the last years of XX century, the calculation speed on the computers was so slow. Therefore, the classical, simple methods (Tole and Holtz methods [6]) were used to compute approximately the roots w^2 of the equation: det(C-Aw^2) = 0, where det() is symbol of matrix determinant.

We normally are interested in two first non-zero w_{01} and w_{02} frequencies. Then, the dynamical - math torsional vibration's model of the MPP has 03 concentrated masses. For example, the MPP model consists of following three masses with the moments of inertia, respectively: J_1 (modeled for engine); J_2 - for flywheel and J_3 - for transmission shaft system with propeller. Today, with the grow of the information technology and software with modern calculation methods, the solution det(C-Aw^2) = 0 is solved very quick and easy [**1**,**3**]. However, concern with the error rate of the models we must research to find out the number of concentrated-masses a model should have and analyze the effect of an error-rate (incorrect measurement, insufficient unity) of certain of parameters to result of FTVC.

Table 1. Number of n in FTV calculation model for MPP on marine ships.

№ (n)	ME side + Flywheel ($kg.m^2$)	Shaft line & Propeller ($kg.m^2$)	MV name & MDE
1 (12)	1:FLW (16800); 2:FLG+M (6789); 3-8:CYL-6(42716); 9:CH.DRIVER+M (13322) 10:TURN.WHEEL (15608)	11:FLANGE (IMS+PRS) (962.8); 12:PROPELLER (177443)	XXX-XXX-XXX-1 (KOREA) HYUDAI- MAN-B&W 6G70ME-C9.2
2 (13)	1:FLW1 (34800); 2:FLG+M (3334); 3-9:CYL-7(72009); 10:Camdrive+Thrst (18200) 11:TURN.WHEEL (34221)	12:FLANGE (IMS+PRS) (2749); 13:PROPELLER (473314)	XXX-XXX-XXX-2 (KOREA) HYUDAI- MAN-B&W 7G80ME-C9.5
3 (12)	1:FLW1 (24300); 2:FLG+M (11634); 3-8:CYL-6(72009); 9:Camdrive+Thrst (26570) 10:TURN.WHEEL (30545.6)	11:FLANGE (IMS+PRS) (2291.4); 12:PROPELLER (429425.9)	XXX-XXX-XXX-2 (KOREA) HYUDAI- MAN-B&W 6G80ME-C9.5
4 (12)	1:FLW1 (8696); 2-7:CYL-6(4920); 8:Camdrive+Thrst (735) 9:TURN.WHEEL (8136)	10: (IMS) (94.3); 11:(PrS) –(224.5) 12:PROPELLER (27554)	F56-NT01/02 (Nam Trieu –Vietnam) SULZER 6RT- Flex50
5 (12)	1:CounterWeight (30.2); 2:Camdrive (49.9); 3-9:CYL.-7(614.6); 10:Thrst (68.0) 11: TURN.WHEEL (481.5)	12:FLANGE (IMS+PRS) (71.0); 13:PROPELLER (7385)	VINASHINSKY, 15000DWT – PR (Vietnam, 2007) MAN-B&W 7S35MCC
6 (13)	1:FLW1 (104.0); 2-9:CYL-8(342.1); 10:Camdrive+Thrst (68) 11:TURN.WHEEL (230.3)	12:FLANGE (IMS+PRS) (75.7); 13:PROPELLER (5997.4)	CV-Fortune Navigation (VOSCO, Vietnam) MAN-B&W 8L35MCC
7 (13)	1:FLW1 (7000.0); 2:FLANGER(121.0) 3-8:CYL-6(3256.0); 9:Camdrive+Thrst (882.0) 10:Moment Compstr(316.0) 11:TURN.WHEEL (3095.0)	12:FLANGE (IMS+PRS) (221.9); 13:PROPELLER (21757.0)	MV-HR34000 DWT (FR, Vietnam, 2007) MAN-B&W 6S46MCC
8 (11)	1:FLW1+FLG (5121.0); 2-7:CYL-6(3487.0); 8: FLG+FLW (4610.0)	10:FLANGE (IMS+PRS) (213.0); 11:PROPELLER (24556.0)	MV. SANTA SERENA (Nippon Steel,Japan) MAN-B&W 6S46MCC

Lech Murawski and M Dereszewski [4] modeled MPP as two concentrated masses: J_1- for all components in torsional vibration system of engine and flywheel; J_2- for immediate shaft, propeller shaft and propeller. The authors were interested in the basic parameters of FTV at node-1.

Yuriy Batrak [6] presented the result of FTVC on marine MPP using two-strokes, 6-cylinders main engine with different number of masses: 2, 4, 8 and 16. The influence of discretization number n on natural frequencies of FTVC decreased considerably (and related errors ≤10 %). In addition, the author considers that dividing immediate shaft, propeller shaft and propeller of MPP into separate parts while modeling is unnecessary.

To make the research problem to be clearer, the authors list a number of FTVC models, approved by maritime register organizations (Table 1).

As we see on the above - mentioned Table 1: The concentrated masse number n varied on configuration of mechanical system and the viewpoint of the constructor. In addition, the inertia moment of the propeller (IPM) in water J_{wp} has a considerable vary range: $J_{w.p} = (1.15 \div 1.35) J_{a.p}$; where, J_{ap} - IPM in air (without water).

In this paper, the authors analyze the difference of FTVC result (free vibration frequencies and the corresponding vibration form) while changing the number of concentrated masses and the Jwp value of the IPM. The paper would consider FTVC, and comparison of the FTVC with the sea-trial results.

II. MATERIALS AND METHODS

1. DoE for Freedom TVC of the MPP with MDE

Design of Experriments is made in accordance with the dynamic-math model of the MPP using the z-cylinder marine two-stroke diesel engine (MDE) shown in Table 2 (for the №1 in Table 1).

Table 2. DoE for FTVC of the MPP on MV.XXX-XXX-XXX-1 with the MDE HYUDAI-MAN-B&W 6G70ME-C9.2.

№(n)	ME side + Flywheel (kg.m^2)	Shaft line & Propeller
1 (12)	1:FLW (16800); 2:FLG+M (6789); 3-8:CYL-6(42716); 9:CH.DRIVER+M (13322) 10:TURN.WHEEL (15608)	11:FLANGE (IMS+PRS) (962.8); 12:PROPELLER (177443) And corrected J_{pc} to receive the exact FTV frequency n_{01}, as well as TVM.
2 (11)	1:FLW + FLG+M (J_{e1}); 2-7:CYL-6(42716); 8:CH.DRIVER+M (13322) 9:TURN.WHEEL (15608)	10:FLANGE (IMS+PRS) (962.8); 11:PROPELLER (J_{pc})
3 (10)	1:FLW + FLG+M (J_{e1}); 2-7:CYL-6(42716); 8:CH.DRIVER+M + TURN.WH. (J_{e8})	9:FLANGE (IMS+PRS) (962.8); 10:PROPELLER (J_{pc})
4 (9)	1:FLW + FLG+M (J_{e1}); 2-7:CYL-6(42716); 8:CH.DRIVER+M + TURN.WH. ()	9:FLG (IMS+PRS)+PROPELLER (J_{e9} theo J_{pc})
5 (12)	1:FLW (16800); 2:FLG+M (6789); 3-8:CYL-6(42716); 9:CH.DRIVER+M (13322) 10:TURN.WHEEL (15608)	11:FLANGE (IMS+PRS) (962.8); 12:PROPELLER (J_{pc}) J_{pc}=104% *J_{pc}(Case 1)
6 (12)	1:FLW (16800); 2:FLG+M (6789); 3-8:CYL-6(42716); 9:CH.DRIVER+M (13322) 10:TURN.WHEEL (15608)	11:FLANGE (IMS+PRS) (962.8); 12:PROPELLER (J_{pc}) J_{pc}=96% *J_{pc}(Case 1)

2. Equivalent polar moment of mass inertia (Je) and torsional stiffness (Ce) from m lumped masses

Suppose that from m masses with inetia moments: $J_{r+1},\ldots,J_{r+m}$, we convert to 1 mass with an equivalent inetia moment: J_{er}, (kg.m^2) using the equation (2) below:

$$J_{er} = \sum_{k=1}^{m} J_{r+k} \qquad (2)$$

and placed in the center of the flexibilities L_e (in accordance with the last mass) [5]:

$$L_{er} = \sum_{k=1}^{m} J_{r+k} L_{r+k} / J_{er}; L_{p,p+1} = 1/C_{p,p+1}; p = r+k;$$

$$L_p = L_{p,p+1} + L_{p+1,p+2} + ... L_{n-1,n} = \sum_{h=p}^{n-1} 1/C_{h,h+1} \quad (3)$$

Where: $C_{h,\,h+1}$ – torsional stiffness coefficient between h^{-th} and $(h+1)^{-th}$ mass.

3. Software module for freedom TVC

The software to compute FTV was developed based on LabVIEW [3]. Normally, we take interest in two first frequencies w_{01}, w_{02} as well as the vector of relative root: α_{kj}, k=1…n; j=1 or 2.

4. Verified studying FTV on the MPP, using MAN-B&W 6G70ME-C9.2

The MPP on MV.XXX-XXX-XXX using a DME MAN-B&W6G70 MEC-9.2 [2]. The MV was built in South Korea (Because of copyright reasons, the authors couldn't provide the specific name of the ship).

Table 3. Model for TVC of the MPP using 6G70ME-C9.2 [2].

№	Mass Name	Moment of Inertia kgm^2	Stiffness MNm/rad
1	D290.OUT	16800.00	
2	D.IN+FLG+M	6789.00	9.00
3	CYLINDER 1	42716.00	3717.47
4	CYLINDER 2	42716.00	3205.13
5	CYLINDER 3	42716.00	3236.25
6	CYLINDER 4	42716.00	3154.57
7	CYLINDER 5	42716.00	3225.81
8	CYLINDER 6	42716.00	3344.48
9	CH.DRIVER+M	13322.00	4444.44
10	TURN.WHEEL	15608.14	6666.67
11	FLANGE	962.79	90.87
12	PROPELLER	177442.75	190.60

In the resonance n = 36 rpm, the TVs are big and unstable. In contrast, on the near-resonance, n=34 rpm, the TVs are not so big, and stable. Therefore, the measurement results show that $n_{01} \approx 6*36 = 216$ (rpm); or $w_{01} \approx pi*n_{01}/30 = 22.61$ rad/s.

III. RESULTS AND DISCUSSION

The TVC and results of the torsional

Table 4. FTVs study of the MPP using the ME: 6G70ME-C9.2.

DoE №1 (FTV Model 0, in Fig.1)						
TVC	n_{01} =205.7; k=6, n_r = 34.2 rpm			Selected J_p = 177443 kgm^2		
TVM	$n_r \approx 36$; k=6; $n_{01} \approx 216$ rpm			-		
TVC	n_{01} =214.289; n_r = 35.72 rpm n_{02} =248.837; n_r = 41.5 rpm			Corrected J_{pc}=0.88*J_p; Jcc=0.95*Jc, the repeatation calculates the TVs		
E№	Masses	n_{01}(rpm)	δ_{01}%	n_{02}(rpm)	δ_{02}%	Note Merged
2	11	214.288	0.000	248.831	0.002	(2&3)
3	11	212.308	0.920	253.844	2.010	(1&2)
4	10	212.308	0.920	253.842	2.010	(1&2;9&10)
5	9	212.241	0.960	253.787	1.990	(1&2;9&10;11&12)

vibration measurements (TVM) at the sea-trial tests are obtained and shown in Table 4, in accordance with the input data showing in the FTV Models on the Fig.1.

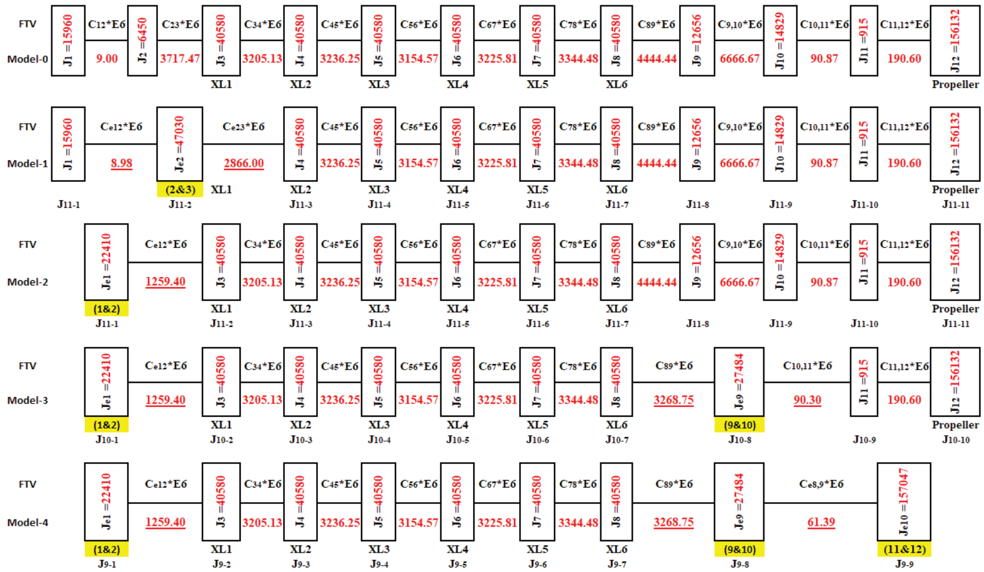

Figure 1. Equivalent models for the verified FTVC studying.

IV. CONCLUSION

The difference of the results, obtained from FTVC and sea-trial tests on the verified Korean marine vessel using MAN-B&W 6G70ME-C9.2, as main engine was proved that it is necessary to adjust input values for TVC (the inertia moment coefficients of mechanical system).

This paper analyzed the influence of changing the number of the finite lumped masses in FTVC models on the calculated free vibration frequencies of marine MPP using two strokes main diesel engine. The original model with n=12 masses was altered to corresponding models with number of masses n=11, 10 or n=9 in succession. The results showed that the relative deviations $\boldsymbol{\delta}_{01} < 1\%$ and $\boldsymbol{\delta}_{01} < 2.2\%$ for the first frequency $\mathbf{w}_{01}$ and the second frequency $\mathbf{w}_{02}$ respectively. Therefore, the numbers of the equivalent lumped masses from the diesel's ends and propeller's transmission shafts play a minor effect in the FTVC results on the MPP.

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