SELECTION AND EVALUATION OF MARINE SHAFTING TORSIONAL VIBRATIONS CALCULATION SOFTWARE

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ABSTRACT

Calculation of torsional vibrations shall be performed in an early phase of designing a ship propulsion system, immediately after defining the ship propeller, selection of the main propulsion engine, eventual reduction gearbox and dimensioning of each particular shaft cross section. Both the shipyard designer and the classification society technical specialist, approving technical documentation, are to have on their disposal appropriate computer software for this purpose. The paper presents the procedure that has been done in the Croatian Register of Shipping (CRS) with the aim to select and adopt the computer program for review of marine shafting torsional vibrations calculations, within the plan approval process. After that, an extensive evaluation of the selected program was performed, by testing on selected examples of two-stroke and four-stroke engine systems. On the basis of this evaluation, it was recommended that the CRS chooses SimulationX software program, capable of practical and correct modelling of excitation, various types of damping, non-linear characteristics of flexible couplings and propeller behavior in ice. Several modifications were also needed in terms of developing new elements. Results of testing showed satisfactory program capabilities and achieved precision of its results. In addition to this, based upon experience gained at the CRS, the Faculty of Maritime Studies decided to use SimulationX in education to enable the students and researchers simulating various technical systems.

KEY WORDS

marine propulsion system, shafting , torsional vibrations, SimulationX

1. INTRODUCTION

The main task of any ship propulsion system designer in the earliest design phase is to select the propeller that enables the ship to achieve contracted speed for the given ship hull form, as well as to select the proper main propulsion prime mover (e.g. Diesel engine, steam or gas turbine plant and reduction gearbox) to drive this propeller transmitting the required power through the main propulsion shafting [1], [2].

The ship classification society technical specialist has also a very important task: to check out whether the designed main propulsion shafting meets the approval criteria required by the classification society rules. These are the low cycle and the high cycle fatigue criteria [3], [4].

The low cycle fatigue criterion (with typical number of loading cycles below than 10^4) is essential for the basic dimensioning of thrust, intermediate and propeller shaft(s). This criterion, representing the primary loading cycles represented by zero to full load and back to zero, including reversing torque, is expressed by well-known classification rules simple formulae for dimensioning the propeller and intermediate shafts, in e.g. [4]. Basically the formula determines shaft diameters upon engine maximal continuous rating power, relevant engine speed and the shaft material static strength properties.

The high cycle fatigue criterion (with a typical number of loading cycles highly above 10^7) takes into account the torsional vibration stresses permitted for continuous operation, as well as reverse bending stresses. It is defined by the limits of torsional vibrations stresses vs. shafting speed (rpm), as specified in [3] and [4], separately for continuous operation and quick transition within a selected interval of shafting speed range. In order to check this criterion it is necessary to perform a very complex task: calculation of propulsion shafting torsional vibrations.

The present paper deals with the software applicable for the shafting torsional vibrations calculations. The aim of the paper is to encourage classification societies technical specialists, engaged in review and approval of the torsional vibrations calculations, to enable themselves to get the necessary competencies to perform complex calculations such as the mentioned one by means of modern software packages (like SimulationX) [5], no matter what the effort may be required to achieve proficiency in using such programs. Achieving this aim will certainly contribute to better functionality and even safety of ship, due to a more reliable propulsion shafting system.

The tasks of the paper are the following: to briefly describe the background for the torsional vibrations calculations, then to explain the basis for the selection of SimulationX as the most appropriate software for these calculations at the CRS. The next task was to present methodology how to judge what additional steps were required to implement the program (selecting the engine modelling approach with a different level of complexity and even to develop own additional elements to model damping expressed by dynamic magnification) [5]. Finally, the tasks were to present the results obtained by the program testing, setting the reference values by [6] and [7], compare the results with these values and draw out conclusions about the best applicable approach for the evaluation of the steady state torsional stress response at various shafting speeds. The tests, their results and conclusions, presented hereafter, focus primarily on two-stroke low-speed Diesel engine propulsion systems with normal firing in engine cylinders.

Hopefully, the paper will, by achieving the stated tasks, help future users of SimulationX (technical specialists) in small classification societies similar to the CRS, machinery installation plan approval offices to resolve certain ambiguities, doubts and questions they may be faced with in their everyday work. The last task was to encourage marine engineering MSc course students and younger faculty researchers to get familiar with powerful capabilities of SimulationX software product.

2. TORSIONAL VIBRATIONS CALCULATIONS: THE WHYS AND HOWS

Preliminary dimensions, i.e. external and internal diameters of particular shafts may be easily determined by the ship propulsion system designer on the basis of MCR power, relevant rotational speed and mechanical properties of the selected material by implementing classification Rules [4]. These classification Rules are generally based upon IACS Unified Requirement UR M68 [3], comprising simple formulae applied to the calculation of these diameters.

2.1. Torsional vibrations calculations review by class society - why

After initial dimensioning, i.e. defining shaft diameters based upon the nominal torque transmitted and shaft material strength, the designer has to determine final design form, select final dimensions, material and service loading for each shaft itself [2].

However, in this very first design phase it is very important to determine the shafting steady state response to the engine excitation and propeller variable torque excitation around the shafting axis, i.e. torsional vibrations response. It is a difficult task, because the entire shafting system has not been completely defined in this phase yet. Unfortunately, in case of improper design concept, there is not much that can be done in later phases, other than providing and installing a torsional vibration damper. For this reason, proper calculation of torsional vibrational response is needed in the initial phase of the marine shafting design [1].

2.2. Torsional vibrations calculations review by class society – how

On the other hand, the classification society technical specialists face this problem also in an early approval phase of the ship machinery documentation, immediately after the approval of shafting general plan. In accordance with the IACS Quality Systems Certification Scheme (QSCS) the review calculations shall be based upon different methods to those that were already used by designers in the originally submitted calculations [8]. For this reason, selection of powerful simulation modelling software, based upon general concept, may be considered a reasonable option.
In general, torsional vibrational response of shafting depends by all means upon its design form, dimensions, material and service loading [2]. The most appropriate model for the analysis of shafting system torsional vibrations is the model with lumped masses (represented by their mass moments of inertia around the shafting axes), massless shafts (representing stiffness and damping of parts of the system) and engine loading [2].
Considering steady-state response in terms of angular, torque and stress amplitudes for various shafting rotational speeds in the operational speed range, the particular necessary data to be provided are the mass moments of inertia for each concentrated mass, the torsional stiffness of shafts, structural damping in the shafts, damping of propellers, flexible couplings and torques due to cylinder pressures and inertial forces of the reciprocating parts of engine systems for a single engine cycle (two-stroke or four stroke) [1], [2].

2.3. Requirements to be met by the software

The software program shall by all means be capable of using mentioned input data in any form and to provide all the necessary types of results: natural frequencies, vibratory modes, steady state responses in terms of mass rotation angles, angular velocities, accelerations, torques, stresses and power loss.

The selected software is to be extensively tested on carefully selected examples common to the ships classed by the classification society. In general, these examples are to comprise both two-stroke direct drive engines, as well as four-stroke propulsion systems with a reduction gearbox. It is also important that the program can accept damping in any form of its definition (physical, Lehr's damping factor, dynamic magnifier, etc.). Further on, the program shall be capable of entering the engine excitation data in form of cylinder pressure vs. crank angle, crank torque vs. crank angle, or crank torque trigonometric approximation (Fourier's) coefficients. The calculations for comparison may be taken from the class society archives as performed in the past, or they can be readily obtained by few of available freeware programs that could have been found.

3. METHODS FOR SOFTWARE SELECTION, ITS AMENDING AND FINDING BEST PRACTICE MODELING TECHNIQUES

3.1. Requirements for the torsional vibrations calculation software

The task of a classification society technical specialist is not to design the ship propulsion system. That is the task of the shipyard's machinery equipment designer that has already been previously preliminary completed. The actual class technical specialist's job is to evaluate the designer's proposal against the classification society technical rules [8]. So, the class society has the torsional vibration calculation available on disposal and aims to review the calculation itself, formulating and imposing class remarks and notes within the approval process, as well to define the calculation approval status.
For this reason the software to be used for review does not need to be that extensive as the one for the design. A feasible idea would be that the software is based upon general multiphysics approach to cover generalized similar problems. Ease of use, meaning ease of data preparation, entry, as well as ease of obtaining and interpreting of the output results is also essential.
In addition to this, the calculation procedure is to be based upon the state-of-the-art technical rules, with built-in acceptance criteria and the possibility

of taking into account all the actual influences (such as the non-linearity of highly-flexible couplings stiffness, as in e.g. [9]). It is important to obtain all of the results required by the technical rules, for all of the required calculation cases, correctly visualized, understandable and comparable to the acceptance criteria for all the propulsion systems possible service operating configurations.

3.2. Selection of candidate software for class purpose

To develop own class society software was rejected by the CRS as an idea on the very beginning. The reason was obvious: it would take a lot of effort, in terms of time and money, with a doubtful final result. A small class society, such as CRS, cannot devote time of its technical specialists to the development of such a complex software package. Ship classification is in fact a commercial job, performed on a highly demanding international market, consuming almost all of the available work load of the classification technical specialists, so a ready-made software was preferred and had to be found.

The selected software was also to be based upon a modern operating system computer platform, so that it can be easily transferred to the newest version of (e.g. MS Windows) operating system once it becomes the only-choice-left. However, some of the software programs found-in-the-wilderness, were based upon obsolete operating systems (e.g. PC DOS) belonging today into the category freeware (or better: abandonware), with the possibility of being used as invaluable tools for testing of a modern software program, rather than the first choice for the class review software.

For all of the reasons specified above SimulationX by ESI Group, Dresden, drew the authors' attention to be the most fit-for-purpose, as a general analysis tool, against several other designer-oriented programs available on the market, e.g. [10].

3.3. Required tests for the selected software

However, SimulationX requires a testing procedure, not to test the program itself, but to test the correct understanding and interpretation of input data and the results by the future users. It was also necessary to find out which modifications, or even new elements, had to be developed to implement the software in a proper way.

In accordance with [11], a software product is defined as the set of computer programs, procedures, and possibly associated documentation and data, where *software* is synonymous with *software product*.

There is no doubt that the producer of such an extensive software product, as the SimulationX, has passed all the essential stages in its design and development specified by [11]: review, verification and validation. The hereafter testing of SimulationX may be in some aspects understood as similar to its validation performed by the producer. The most important issue to be resolved was to find out whether the user of the software would be capable of correct understanding and interpreting on certain presumptions in input data preparation, correct selection of processing type, as well as correct interpretation of final output results.

3.4. Additional elements that needed to be developed and implemented

CRS testing and evaluation of the SimulationX revealed at the start that the system with four-stroke high- or medium-speed Diesel engine(s), commonly with highly-flexible coupling(s) and reduction gearbox(es) do not impose any practical doubts how to model the system. The only issue was whether to model the propeller damping by Frahm's model, Archer's model, or Lehr's damping factor. A very good agreement of the results with the reference ones was easily obtained by the now-obsolete program used by the CRS, developed long ago by the esteemed third-party producer in Fortran, operating on MS DOS operating system [6].

So, the actual problem, to be dealt with, was the modeling procedure for conventional two-stroke slow-speed Diesel engine systems directly coupled to the fixed-pitch propeller by means of intermediate shaft(s) and a single propeller shaft. The analyses in question were both free-undamped vibrations and the steady-state torsional stress response. Free vibration results needed to be expressed by the system natural frequencies. Forced vibrations calculations results of interest were the torsional stress amplitude harmonic

components for a selected shafting section, their mean value and summation vs. shafting speed.
In these two-stroke engine systems usually every lumped mass model component has its damping expressed as dynamic magnification value. This value has to be related with the inertial moment (i.e. "rotational mass" of the component, thus requiring a new modeling element [12].

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SimulationX allows special additional elements to be either directly developed by means of Modelica programming language for physical systems modeling [13], or by assembling the new compound elements by means of the basic ones, or as the combination of Modelica and compound elements [5]. Figure 1 shows the schematic layout of the newly developed special element of absolute damping [12]

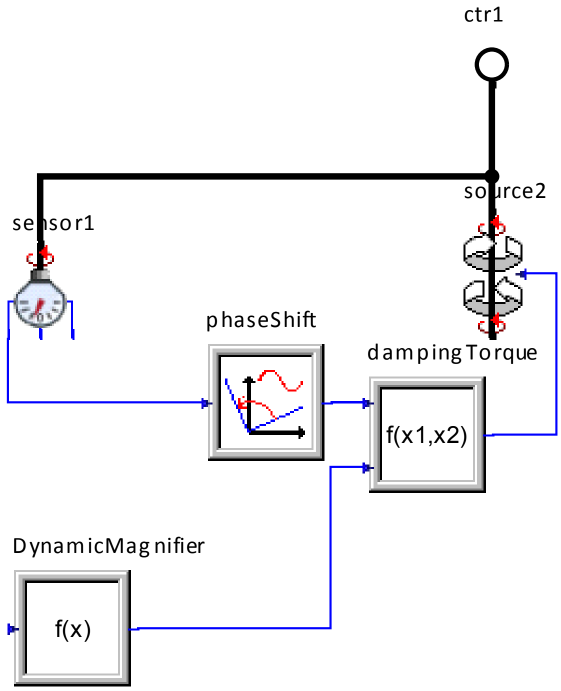

Figure 1. Special element of absolute damping

The developed element describes absolute frequency dependent damping. This separately developed SimulationX compound element is used to model damping expressed by the dynamic magnification factor, *M*, and it consists of the several basic elements.
This damping may be expressed by complex mass in the frequency area, proportional to the acceleration.
Torque for frequency independent damping is expressed as:

$$T_D = b \cdot \Delta\omega \quad \rightarrow \quad b = const. \qquad (1)$$

On the other hand, the torque for frequency dependent damping originates from the dynamic magnification factor, *M* [12]:

An additional issue, found out to be very practically essential to the calculation results was whether the connecting rod modeling in each and every cylinder model should have been based upon so called "physical modeling" or the "crank angle approach" [5].

$$M = \frac{\omega \cdot J}{b(\omega)} \quad \rightarrow \quad b(\omega) = \frac{\omega \cdot J}{M} \qquad (2)$$

Torque for frequency dependent damping by means of complex properties [12]:

$$T_E = -\omega^2 \cdot \left(J - j \cdot \frac{J}{M} \right) \cdot \varphi(j\omega) + k \cdot \varphi(j\omega) \qquad (3)$$

The derived equation (3) was directly implemented in the compound element presented in Figure 1.

3.5. Engine modeling approach of various levels

In general, main propulsion engine modeling in SimulationX torsional vibration calculation models can be based upon the following model levels [5]:

- Compact engine model (Figure 2),
- Individual torsional vibrations analysis cylinder models (Figure 3),
- Power transmition cylinder models, with a separate model for combustion pressure space or crank torque (Figure 4).

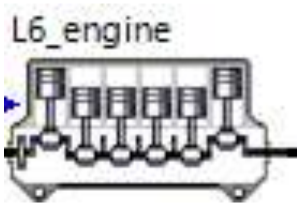

Figure 2. Compact engine model

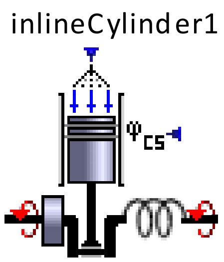

Figure 3. Individual TVA cylinder model

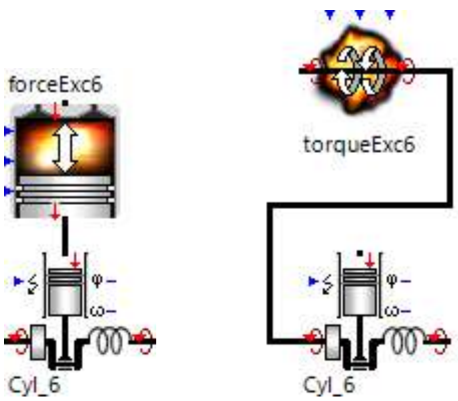

Figure 4. Power transmition models

4. RESULTS AND DISCUSSION

Steady-state torsional vibration analysis by SimulationX torsional vibrations modeling package has been selected as the most important one to be reviewed by the CRS as the possible future user. So, the transient analysis is not of a significant practical value for the classification society technical specialists. Test calculations have been performed on several 5- 6- or 7-cylinder engine systems. For the presentation of typical results hereafter the 5-cilinder engine system has been selected, with a typical model configuration shown in Figure 5.

Acceptance criteria were separately defined for the analysis of free undamped vibrations (natural frequencies and mode shapes) and for forced damped vibrations (torsional twist angles, shear strains, internal torque moments and torsional stresses).

The testing results have been presented in the Table 1 for the free vibrations and in Table 2 for the steady state forced torsional vibrations response in terms of peak stresses at the critical speeds.

The reference results were obtained by the freely available (but today obsolete and therefore also abandonware) MAN B&W program GTorsi [7] and also now-obsolete version of the powerful program TorVic purchased by the CRS very long ago, but today still in use [6].

The presented results refer solely to the case of normal firing in each of the engine cylinders.

The Figure 5 shows also the newly developed elements as described in section 3.4) in their compact symbolic representation. They are all denoted as "dynMagn" in the Figure 5 (with their expanded presentation in Figure 1). These damping elements were essential to be applied in order to obtain the proper calculation results.

The calculation results presented in Tables 1 and 2 achieve the best match to the reference values by implementing crank torque model in power cylinder engine model (in which the excitation torque is applied by a separate concentrated torque element, Figure 4, right). It is important to note that the 2nd match (with not any significant difference to the best one) has been obtained by a more practical model with crank torque TVA cylinders (elements in Figure 3 and the system in Figure 5).

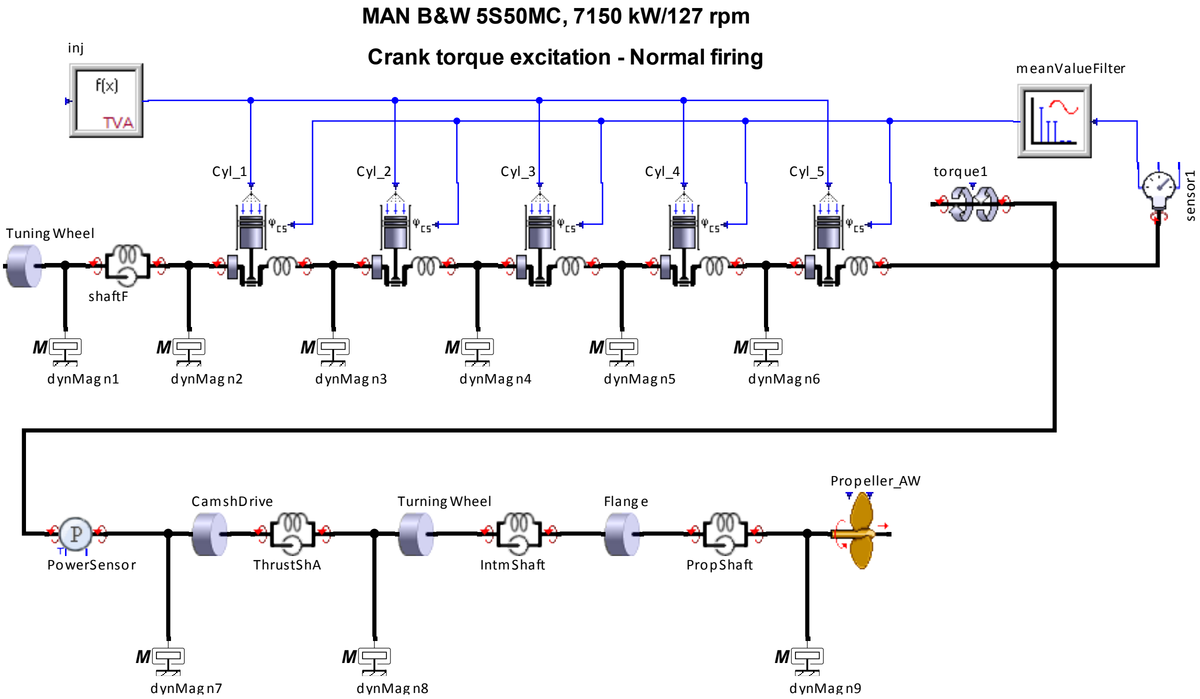

Figure 5. Typical testing system configuration with individual TVA engine cylinders

Table 1. Free vibrations results

Absolute values		crit. speed		
		n1	*n2*	*n3*
case	*program*	[rpm]	[rpm]	[rpm]
1.	TorVic, v1.1	**310,7**	**1587,0**	**3222**
2.	GTORSI, v3.6.1	310,6	1587,0	3222
3.	TVA cyl's, crnk_torq	309,5	1588,0	3222
4.	TVA cyl's, cyl_press	309,4	1586,6	3222
5.	Pow cyl's, crnk_torq	**309,6**	**1588,0**	**3222**
6.	Pow cyl's, crnk_torq	309,4	1586,6	3222
7.	5L engine, crnk_torq	309,5	1588,0	3222
8.	5L engine, cyl_press	309,4	1586,6	3222

Relative values [%]

case	*program*	*n1*	*n2*	*n3*
1.	TorVic, v1.1	0,0%	0,0%	0,0%
2.	GTORSI, v3.6.1	0,0%	0,0%	0,0%
3.	TVA cyl's, crnk_torq	-0,4%	0,1%	0,0%
4.	TVA cyl's, cyl_press	-0,4%	0,0%	0,0%
5.	Pow cyl's, crnk_torq	-0,4%	0,1%	0,0%
6.	Pow cyl's, crnk_torq	-0,4%	0,0%	0,0%
7.	5L engine, crnk_torq	-0,4%	0,1%	0,0%
8.	5L engine, cyl_press	-0,4%	0,0%	0,0%

Table 2. Forced vibrations results

Absolute values		*tot. tors. stress max. amp.*			
		critical speed	*thrust shaft*	*intm. shaft*	*prop. shaft*
case	*program*	[rpm]	[MPa]	[MPa]	[MPa]
1.	TorVic, v1.1	**62,0**	**25,9**	**106,5**	**58,8**
2.	GTORSI, v3.6.1	62,1	27,9	114,5	63,2
3.	TVA cyl's, crnk_torq	62,1	26,2	108,0	59,6
4.	TVA cyl's, cyl_press	61,8	25,5	104,9	57,9
5.	Pow cyl's, crnk_torq	**62,1**	**25,8**	**106,2**	**58,6**
6.	Pow cyl's, crnk_torq	61,8	25,4	104,6	57,8
7.	5L engine, crnk_torq	62,1	27,3	112,4	62,1
8.	5L engine, cyl_press	61,8	26,5	109,0	60,2

5. CONCLUSION

SimulationX has been selected and evaluated software product by the presented procedure as an excellent choice to be used by the CRS technical specialists. Presenting all details of this extensive evaluation would be much above the scope of this paper.

SimulationX has been proven its fitness-for purpose, being capable of modeling special situations requiring non-linear incremental-iterative calculations, originating from e.g. progressive elastic characteristic of highly-flexible couplings, e.g. in [9].

The program allows detailed modeling of elastic and damping characteristics of system components, e.g. engine cylinders, avoiding any possible misinterpretation in the model (f.i. modeling of engine connecting rod, where several models may be used) [5].

Damping can be entered in any form that the designers would have used (absolute damping, relative damping, Lehr's damping factor, dynamic magnification factor, etc.). Special elements needed to be developed for this purpose.

Cylinder excitation loading can be entered in several possible forms such as cylinder pressures or crank torques vs. crank angle, or harmonic components of crank angles. This has a certain non-neglectable influence to the final results.

Propeller loading can also be modeled for ship operations in ice, based upon Finnish-Swedish Ice Class Rules [14] (this was not actually tested, but the propeller model is declared capable of this by the SimulationX producer).

The amount of practice needed to transfer to the new modern software from the old well-known obsolete platform, avoiding all the possible errors and misunderstandings with the propulsion shafting designers and the authors of the torsional vibrations calculations is rather demanding and high, but it may be considered as an attractive challenge to the class technical specialists.

Ambiguities in selecting model for the engine connecting rod was not deeply investigated. The authors have chosen to rather recommend implementing the simpler and direct "approach by crank angle (nonreactive)", as denoted by the SimulationX producer, against the "physical model" [5].

Developed damping elements proved also to be correct, owing to the demonstrated satisfactory comparison with the reference results. If this had failed, the SimulationX would not have been rated that high as a candidate software.

Higher discrepancies in misfiring modelling, were actually found, but have not been presented here. They will be a matter of future work.

Owing to the above specified reasons it can be finally concluded that the CRS technical specialists should with no hesitation rely on SimulationX modeling, procedures and results in their reviews of propulsion systems torsional vibrations calculations, which are being submitted for approval by shipyards' machinery installation designers.

Another valuable consequence of this evaluation was the decision to implement the SimulationX software product (based upon its academic license) in the simulation modelling courses at the Marine Engineering MSc degree studies at the Faculty of Maritime Studies, Split, Croatia as an interesting challenge to students and junior researchers.

If and when students and the faculty researchers accept this challenge and decide to get really acquainted in deep with the details of torsional vibrations calculations by SimulationX, there is no doubt that classification societies (such as the CRS) will benefit employing them as technical specialists in charge of review and approval of torsional vibrations calculations.

This expectable benefit strongly depends upon the amount of cooperation among ship machinery designers, classification society technical specialists, as well as their educators (such as maritime faculties). Future will certainly show the final outcome.

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REFERENCES

1. Batrak, Y., Torsional vibration calculation issues with propulsion systems, www.shaftdesigner.com, accessed 31.12.2011
2. Vulić, N., Dobrota, Đ., Komar,I., Damping and excitation in the torsional vibrations calculation of ship propulsion systems (paper TR03_ID73) CIET 2016 Contemporary Issues in Economy & Technology, Split, 16-18.06.2016.
3. ... Unified Requirement (UR) M68 Dimensions of propulsion shafts and their permissible torsional vibration stresses, (Rev.2, Apr 2015), IACS International Association of Classification Societies, London, 2015
4. ... Rules for the Classification of Ships, Part 7-Machinery Installation, Croatian Register of Shipping, Split, 2013
5. ... SimulationX, Library Manual-Torsional Vibration Analysis, ITI-Software GmbH, Dresden, 2015
6. ... TorViC, version 1.11 User's Manual, CADEA, Split, 2000
7. ... Torsional Vibration Calculation Program GTORSI, Version 3.6.1 External, User's Manual, MAN Diesel & Turbo, Copenhagen, 2012
8. ... IACS Quality System Certification Scheme (QSCS), Rev. 1, IACS International Association of Classification Societies, London, 2012
9. ... The Highly Flexible VULASTIK-L Coupling, edition 03/2013, Vulkan Kupplungs- und Getriebebau, Herne, 2013.
10. ... ShaftDesigner - The Shaft Calculation Software, SKF Solution Factory, website: www.shaftdesigner.com, accessed May 2015
11. ... ISO/IEC 90003:2014, Software engineering - Guidelines for the application of ISO 9001:2008 to computer software, International Organization for Standardization, Geneve, 2014
12. Abel, A., Direct communication, e-mail ITI-Software GmbH, May 2015
13. ... Modelica-A Unified Object-Oriented Language for Physical Systems Modeling-Language Specification, Version 3.2, Revision 2, Modelica Association, 2013
14. ... Guidelines for the Application of the Finnish-Swedish Ice Class Rules, TraFi, Helsinki, 2011.

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