THE CHANCES FOR REDUCTION OF VIBRATIONS IN MECHANICAL SYSTEM WITH LOW-EMISSION SHIPS COMBUSTION ENGINES

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SUMMARY

Development of diesel engines is focused on reduction of exhaust gas emissions, increase of efficiency of the fuel mixture combustion and decrease of fuel consumption. Such engines are referred to as low-emission engines. Low-engines trends bring higher engine power outputs, torques and also increase of vibrations and noisiness level. In order to reduce these vibrations of diesel engines, it is necessary to apply different dynamical elements, which are able to increase an adverse impact of exciting amplitudes. One of the results is application of a pneumatic dual-mass flywheel. The pneumatic dual-mass flywheel is a dynamical element that consists of two masses (the primary and the secondary mass), which are jointed together by means of a flexible interconnection. This kind of the flywheel solution enables to change resonance areas of the mechanical system which consequently leads to reduction of vibrations.

1. INTRODUCTION

In combustion engines applications, a great emphasis on reduction of emissions is put by the legislation. The emphasis is put mainly on reduction of CO_2, NO_x, SO_x and dust particles [1], [2]. It is also ship transportation where the legislation defines strict emission levels [3]. The producers of combustion engines need to respond to these legislative requirements flexibly. In general, it is observed that the development of engines with reduced emissions is characterized by following features.

A downsizing is considered as the first trend. Engine downsizing is the use of smaller version of cylinder of combustion engine. In particular, downsizing means to reduce the displacement and number of cylinders. This will minimize a layout dimension of engine but it also increases production costs. The reduction of cylinder count also brings significant negative impacts on the dynamics, expressed in increased level of vibrations and noisiness. Due to reduced count of cylinders, the main harmonic component of engine is changed. The main harmonic component is replaced by another, lower harmonic component.

The second feature is referred to as down-speeding. Down-speeding is matching the gearing of the transmission and differential to the engine so that the engine turns at lower revolutions per minute. The maximum engine torques turns in the area of lower engine revolutions. Mechanical systems in which the combustion engines are located, they are designed to work in over-resonance area. It means a resonance area arising from the main harmonic component is already eliminated during a starting or stopping of combustion engine. Downspeeding will cause a moving of working area of an engine to mentioned resonance area. Figure 1 shows a trend of down-speeding. The down-speeded diesel engine could have a main negative impact on the increase of exciting amplitude in resonance area.

In development of combustion engines, the third new technology is Cylinder deactivation. Cylinder deactivation shuts down a number of the engine's cylinders when they are not needed. When the engine shuts down a cylinder, this has a negative impact on the dynamics within whole propulsion system. The impact is followed by a change in torsional spectrum and exciting harmonic component, but it is also seen in the increase of secondary exciting harmonic component.

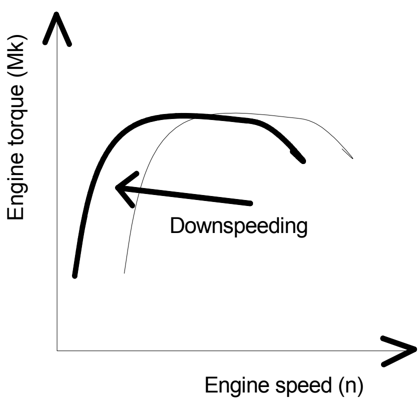

Figure. 1 Downspeeding

Turbocharging is considered to be the last trend in engine development. Turbochargers are fans with the variable geometry of blades. They allow more compressed air to go into engine chambers. This mass in needed to ensure a higher torque of engine to generate more power outputs. While using turbochargers, the exciting amplitudes are increased.

All these trends mentioned above bring significant positive results in lowering of emission level, increasing combustion efficiency and achieving more engine outputs and torques. These technologies will contribute significantly to higher efficiency of combustion engine mixture and minimalization of exhausted gases by the use of mechatronical systems [4], [5]. The regulation of combustion in engines is accompanied by vibrations within engine [6], [7]. In a controlled combustion process, all the legislative requirements and operation parameters are achieved. Therefore, both legislative and transport operators are satisfied. The legislation is satisfied thanks to lower level of emissions and the operator in the form of lower costs of the fuel consumption. The application of the measures and mentioned positive results is accompanied by indispensable dynamical change of propulsion. Torsional vibrations caused by dynamical change transmitted within whole propulsive system are the cause of strain of gear tooth wheels, transmission shaft and other propulsive elements[8], [9], [10], [11], [12]. The most disadvantageous impact of the process is transmission of vibrations and nosiness all around the environment.

2. CHARACTERISTIC OF THE MECHANICAL SYSTEM

Every drive, as seen in Figure 2, is defined as a mechanical system consisting of propulsive and driven elements joined by connecting elements. Figure 2 indicates the mechanical system of combustion engine that drives the primary (propeller) and the secondary drive. On the basis of torsional oscillation theory, it is possible to define the mechanical system as a substitutional torsional oscillated mechanical system with n-masses. Consequently, such torsional oscillated mechanical system of masses has n-1 natural frequencies. At a certain moment, each of these natural frequencies can become identical with exciting frequency which causes resonance.

Danger of the resonance rests in damages of particular system elements. Therefore, it is needed to define exact solutions of the mechanical system to avoid undesired resonance areas. Throughout the planning of the mechanical system and its protection, it is important to regard dominant exciting frequencies causing the most expressive vibrations. In case of the mechanical system with piston´s mechanisms, whose motion can be characterized by harmonic components, we talk about resonance of harmonic components. Exciting harmonic components are divided into primary (dominant) and secondary harmonic components. During dynamical control of the mechanical system, we currently pay attention to resonance arising from the primary harmonic component. Consequently, the measures are focused against the mentioned resonances in the drive. The resonance protection of the mechanical system is properly shown in the following Campbell diagram (see Figure 3).

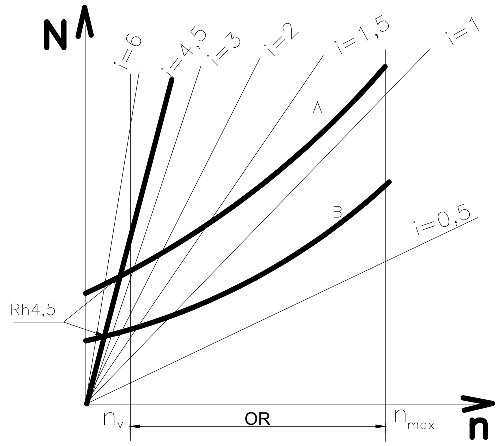

Figure 3 The Campbell diagram

In the Campbell diagram, the lines marked from i=0,5 to i=6 represent harmonic components of the mechanical system. Thick line marked as i=4,5 represents primary harmonic component. As a protection of the mechanical system are used pneumatic flexible couplings, which are located on the primary drive of the mechanical system as it can be seen in Figure 2. In the mentioned Campbell diagram, the lines marked as A and B represent natural frequencies of the mechanical system. In the working area of torque of the mechanical system (marked as OR) in shown diagram, there is no point of intersection of lines which represents a natural frequency and a primary harmonic component (marked as Rh 4,5). In summary, the mechanical system sets forth above is sufficient in terms of primary harmonic component resonance.

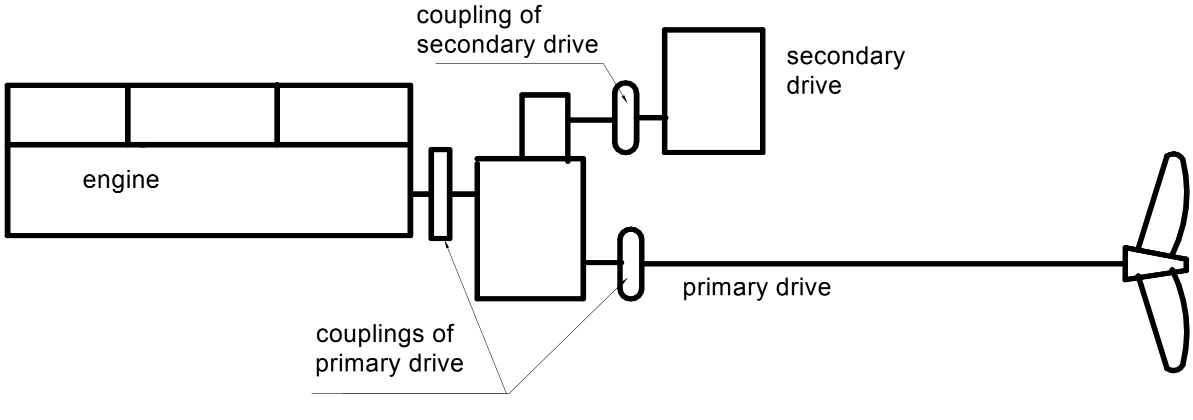

Figure. 2 The mechanical system

The involuntary problem in the mechanical system occurs when a low-emission combustion engine is used. Essential features of this type of engine are namely a low-emission level, economical working and it also obtains all trends, mentioned in chapter 1., such as Downsizing, Downspeeding, Cylinder deactivation, Turbocharging but also an individual combustion control in cylinders. Consequently, after application all those trends into an engine, it becomes a complicated dynamical exciter. For that, another secondary harmonic component, that impact on dynamical system is not significant; may turn to primary harmonic component. If the impact of the secondary harmonic component is arising, it is needed to make a provision for resonance originated in secondary harmonic component in a planning phase of particular elements. The mechanical system with the low-emission engine is plotted in Campbell diagram seen in Figure 4.

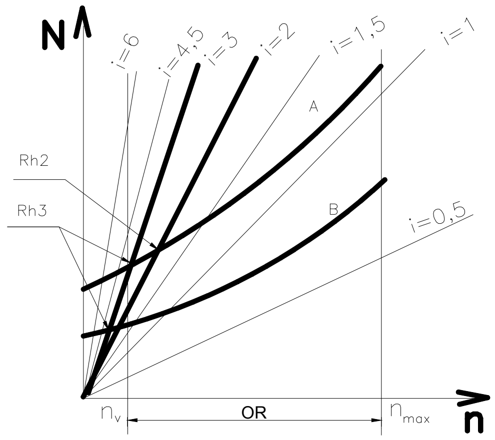

Figure 4 The Campbell diagram of the mechanical system with low-emission engine

Comparing Figure 3 and Figure 4, it is visible that the primary harmonic component is changed after application of Downsizing (represented by thick line marked as i=3 in Figure.4). During steady running of the engine, after application of Cylinder deactivation, the secondary harmonic components become dominant in terms of excitement (represented by thick line marked as i=2 in Figure.4). In Figure 4 is plotted a resonance that originated from the third harmonic component (seen as Rh3) and the second harmonic component (seen as Rh2). It stands to reason of resonance creation in working area of the mechanical system (seen as Rh2). Except the specification described above, increase of exciting amplitudes of other harmonic components could occur.

The application of flexible couplings or variant dynamical elements to avoid natural resonance origination in engine with Cylinder deactivation is the appropriate solution for the mechanical system. To reach the satisfying state of the mechanical system, the exacting solutions in dynamics are required. It is necessary to note the fact that combustion engine propels besides the primary drive as well as the secondary drive in the engine. The wrong proposal of dynamical elements in the mechanical system causes resonances during the low-emission engine running. In this regard, it is required to pay attention to other feeding elements of the secondary drive in combustion engine.

The secondary drive of the mechanical system is excited by the same spectrum of exciting frequencies as the primary drive is excited. Thereby the secondary drive removes lower mean value of the torque compared to the primary drive; it can seem that its strain level gets lower. Even during the design of components of the secondary drive, it is needed to regard creation of dangerous resonances. One of the appropriate solutions to avoid the resonance during the low-emission engine running is the application of component which is able to react to dynamical changes in drive. That implies the application of a component able to tune up its natural frequency. The following Campbell diagram (Figure 5) presents the impact of the tuning component, mentioned above.

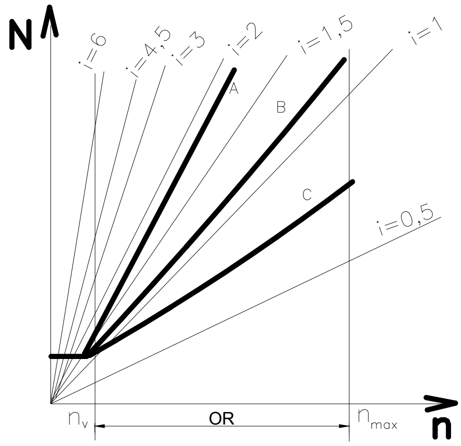

Figure 5 The Campbell diagram with tuning component applied into the mechanical system

Diagram of the mechanical system of low-emission engine serves as a basis for the plotted Campbell diagram. The application of the tuning component allows changes of the natural frequency in order to avoid the resonances of dominant harmonic components. In Figure 5, there are also shown three natural frequencies in progress, represented by thick lines marked by letter A, B, and C. Particular progresses represent the natural frequencies, which alternate as necessary, to avoid the recurrence of natural frequencies originating in operation mode of the mechanical system.

3. THE APPLICATION OF A PNEUMATIC DUAL-MASS FLYWHEEL

As mentioned in the chapter above, the mechanical system is able to prevent resonances and variable natural frequencies. The change of the natural frequency of the mechanical system is relatively achievable by using of two basic principles. The first principle allowed changing the moment of inertia of the mechanical system. It is applicable in shut-down state of the mechanical system only; meanwhile the rotating masses are applied or removed. The second one allowed realizing the changes in running state of the mechanical system. The principle rests in change of stiffness and dumping properties of components in the mechanical system [16], [17], [18], [19], [20]. For that purpose, the pneumatic dual-mass flywheel is applied (seen in Figure 6). The suggested pneumatic dual-mass flywheel consists of primary (1) and secondary mass (2), which are interconnected with pneumatic flexible bags (3). They are able to alternate the air pressure during the rotation of the mechanical system.

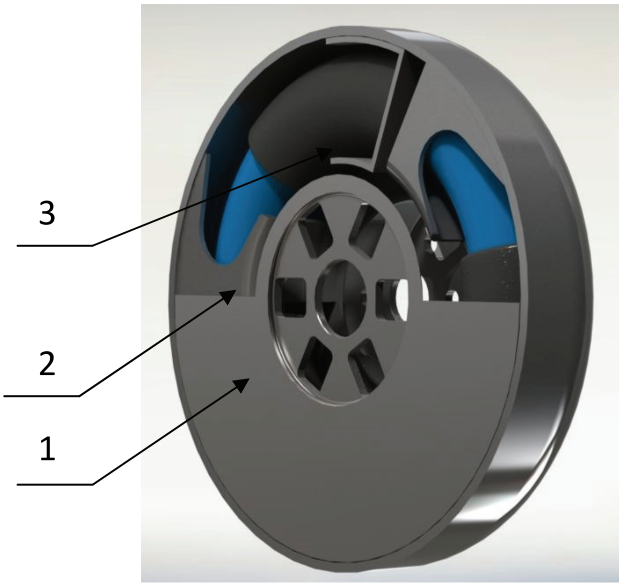

Figure 6 Pneumatic dual-mass flywheel

The air pressure in the pneumatic dual-mass flywheel can be changed from the 100 kPa up to 800 kPa. Basic area of loading characteristics of the pneumatic dual-mass flywheel were defined (seen in Figure 7), specifying the characteristics of torsional stiffness of the designed pneumatic dual-mass flywheel, shown in Figure 8.

As seen in Figure 8, the pneumatic dual-mass flywheel disposes of the set of characteristics depending on air pressure and torsional stiffness. As it has been stated, the pneumatic dual-mass flywheel allows the torsional stiffness in dependence on the air pressure.

For the tuning of the mechanical system, two ways of use of the pneumatic dual-mass flywheel are possible to apply. The first way rests in suggestion of the primary and the secondary mass of pneumatic dual-mass flywheel to tune the mechanical system basically. Consequently, during the operation of the mechanical system, the pressure as well as the torsional stiffness of the pneumatic dual-mass flywheel change. After the change, the torsional stiffness ensures the change in the natural frequency of the mechanical system, according to characteristics marked A, B and C presented in Figure 6.

To reach the required tuning of the natural frequency of the mechanical system, a regulation system is needed, which provides necessary air pressure in the pneumatic dual-mass flywheel and appropriate torsional stiffness of the pneumatic dual-mass flywheel.

The regulation system of the pneumatic dual-mass flywheel should be interconnected with a regulation system of the combustion engine and a result should be controlled by monitoring system of vibrations. The proposed interconnection of systems (see Figure 9) allows the use of low-emission engines as well as to reaching of a needed dynamic tuning of the secondary drive.

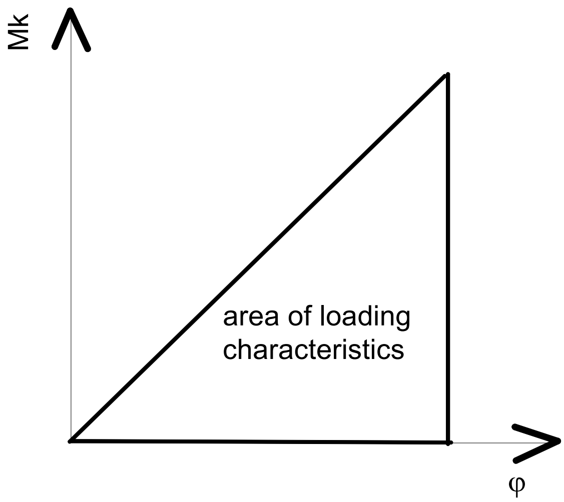

Figure 7 Area of loading characteristics of the pneumatic dual-mass flywheel for pressure from 100kPa up to 800 kPa

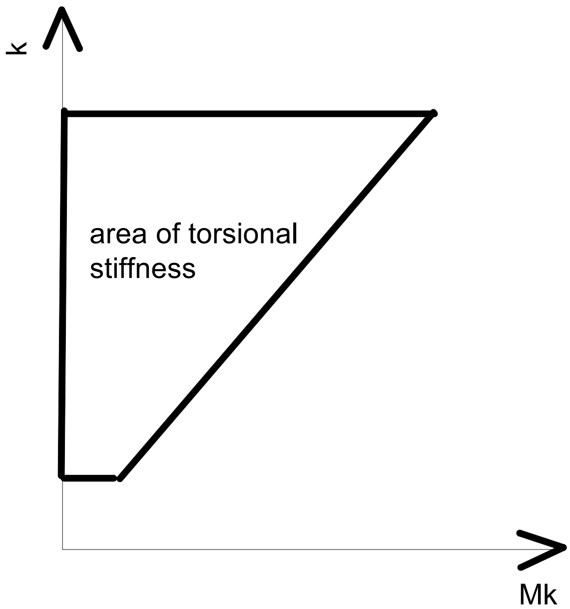

Figure 8 Area of characteristics of torsional stiffness of the pneumatic dual mass-flywheel for pressure from 100kPa up to 800 kPa

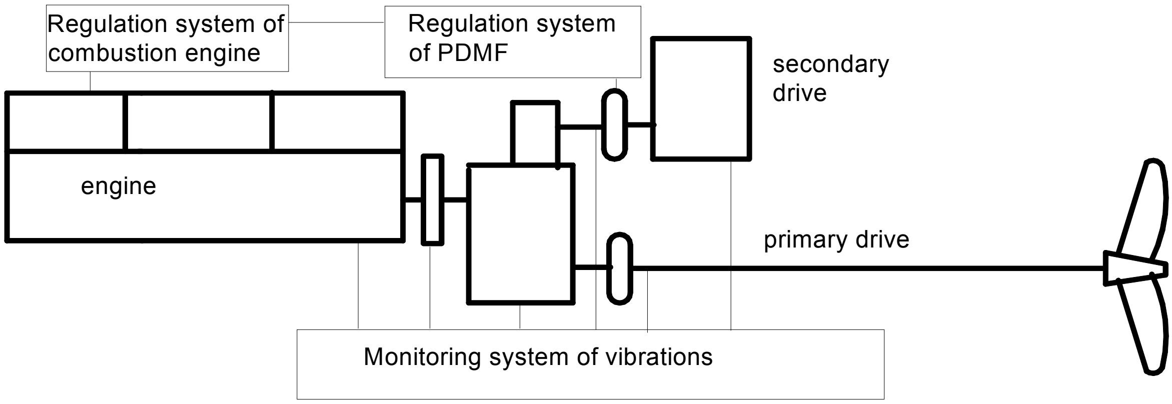

Figure 9 Scheme of management of the tuning of the secondary drive

4. SUMMARY

To fulfill the emission legislative requirements, gases exhausted by the combustion engines have many negative impacts on drive dynamics. For that, a complex dynamical analysis and the application of dynamical components are required. Evidently, the change of drive dynamics caused by the low-emissions combustion engines requires an application of components which are able to provide the dynamical parameters of drive in order to achieve low vibration and noisiness level. It is necessary to design components which can be subsequently regulated and applied into the mechanical system. In the article, the Campbell diagrams present differences in dynamical analysis of the drive constructed before the development of the low-emission engines, which are considered to be exciting systems. Consequently, we pay attention on the use of the tuning of natural frequencies of the mechanical system with the applied pneumatic dual-mass flywheel and regulation system. On the basis of theoretical analysis, the use of the pneumatic dual-mass flywheel interconnected with regulation and monitoring vibration system contributes to the solutions in dynamics in the mechanical system with low-emission engine. It is necessary to state that detailed dynamical calculations of the mechanical system are required with all needed relevant parameters. On the basis of detailed dynamical analysis of the mechanical system, it is possible to construct the pneumatic dual-mass flywheel which fulfils the conditions for proper tuning of natural frequencies in the mechanical system. In the end we recommend the application of the pneumatic dual-mass flywheel in combination with application of the regulation system in all mechanical systems with the low-emission engines.

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