DOI: https://doi.org/10.53052/9788366249998.05

Matúš KAČÍR[1], Lucia ŽUĽOVÁ[2], Robert GREGA[3]

Supervisor: Robert GREGA

TRENDY W REDUKCJI DRGAŃ SKRĘTNYCH W NAPĘDACH KOMERCYJNYCH POJAZDÓW HYBRYDOWYCH

Streszczenie: Badania, rozwój oraz produkcja środków transportu charakteryzujących się zero emisyjnością mają wysoki priorytet w ekonomii Unii Europejskiej. Napędy hybrydowe są alternatywnymi rodzajami napędu pojazdów. Napędy hybrydowe są szczególnie wrażliwe na drgania skrętne. Celem tego artykułu jest omówienie możliwości redukcji drgań skrętnych w napędach hybrydowych.

Słowa kluczowe: sztywność skrętna, napęd hybrydowy, pneumatyczne dwumasowe koło zamachowe

TRENDS IN TORSIONAL VIBRATION REDUCTION IN DRIVES OF COMMERCIAL HYBRID VEHICLES

Summary: Research, development and production of mobile transport equipment with zero emissions has a high priority in the EU economy. Hybrid drives are one of the alternative drive systems. Hybrid drives are particularly sensitive to torsional vibrations. The aim of the article is to point out the possibilities of reducing torsional vibrations in hybrid drives.

Keywords: torsional stiffness, hybrid drive, pneumatic dual mass flywheel

1. Introduction

Drives form the basic skeleton of equipment for transportation, handling of goods, transportation of people, but also for supporting service activities in other industries.

[1] Ing. Technical University of Košice, Faculty of Mechanical Engineering, Department of Engineering for design of machines and Transport Equipment, e-mail: matus.kacir@tuke.sk

[2]Ing. Technical University of Košice, Faculty of Mechanical Engineering, Department of Engineering for design of machines and Transport Equipment: e-mail: lucia.zulova@tuke.sk

[3]prof. Ing. PhD. Technical University of Košice, Faculty of Mechanical Engineering, Department of Engineering for design of machines and Transport Equipment, e-mail: robert.grega@tuke.sk

Combustion engines are primarily used as an energy source in mobile drives. Long-term experience with the use of combustion engines in drives, long-term development and modernization of combustion engines have created a drive that is used in all sectors of the economies of the countries of the world and Europe (transport, agriculture, forestry, construction, etc.). In the context of new realities, new strategies and statements of the governing authorities, increasingly strict criteria are imposed on drive systems with combustion engines. Combustion engines installed in vehicles account for 16.2% of the total emissions on planet. Of this, 73% (11.9% of the total package of 16.2%) is allocated to road transport. Another division state that 60% of the mentioned 11.9% is responsible for passenger transport, 40% for freight transport. The tightening of the criteria in the field of drives with combustion engines can be observed since 1991, when the EURO 1 emission standard came into force. The emission standards tighten the conditions for the operation of drives with combustion engines. From the beginning, this tightening led to the modernization and development of internal combustion engines. However, the upcoming EURO 7 standard, which should enter into force in 2025, brings significant concerns. It is clear from the statements of representatives of the German Automobile Industry Association (VDA) that the proposed standard would prevent a new generation of low-emission cars from hitting the roads and it would instead promote the extension of the life cycle of older drives with combustion engines with worse emission parameters. The representatives of the VDA are interceding to use the next period for a more significant diversification of drives and to promote the use of low-emission fuels in the EU within the framework of the use of internal combustion engines, so-called e-fuel. This proposal by VDA representatives is based on the knowledge that the source of emissions and the problem for the climate is not the combustion engine itself, but the fossil fuels that these combustion engines burn and the way they burn it. source.

Radical solutions aimed at disadvantage of drives with combustion engines also result from the fact that the current insufficient fulfilment of current obligations to reduce greenhouse gas emissions will lead to an increase in the temperature on Earth by 2.7 degrees Celsius by the end of the century and not by 1.5°C as originally assumed. The current efforts of the states are completely insufficient and the world continues to be on the path to climate catastrophe (Climate Conference COP26, Glasgow 2021).

As one of the global economies, the European Union wants to continue to be a dominant economic power with a transformed economy. Economic growth must be supported by efficient transport. In the European Union, transport emissions account for approximately 25% of total greenhouse gas emissions and they have been increasing in recent years. Achieving a 90% reduction in transport-related greenhouse gas emissions by 2050 is a significantly ambitious target.

It is assumed that the new propulsion systems will be diversified, as defined by the measures of the Green Deal in the field of transport. The development of drive systems in the field of transport is expected in three directions, namely road transport, air transport and ship transport. A combination of measures is needed against the increase in emissions in road transport. Stricter standards regarding CO_2 emissions, especially the upcoming EURO 7 standard, are intended to accelerate the transition to zero-emission mobility. All new cars registered from 2035 are expected to have zero emissions.

The fulfilment of this expectation creates space for the development of drive systems using electricity, hydrogen, or alternative low-emission fuels as an energy carrier. At the same time, this growing legislative pressure offers a broad platform for the development of hybrid drives, primarily for the field of commercial vehicles.
The aim of the article is to point out the problem of torsional vibrations in hybrid drives and at the same time indicate the possible direction of the development of devices for reducing torsional vibrations in hybrid drives.

2. Defining the problem

Hybrid vehicle drives are one of the suitable solutions for drive systems in the transport of the future. A hybrid system can be created by combining at least two different drive systems. At present, the term hybrid drive system primarily means a combination of an internal combustion engine and an electric drive.
The following Fig.1 and Fig.2 show the basic concepts of hybrid drives designed for commercial vehicles.

A hybrid drive consisting of a combustion engine and an electric motor can be created in two basic versions, as a series drive or as a parallel drive.
In both cases, as we can see in Fig. 1 and Fig. 2, an electric machine is connected to the combustion engine in the drive. And the main clutch is also located in the drive. The main problem occurs if the drive is dynamically designed inappropriately and higher torsional oscillations occur. Torsional oscillation that was acceptable in traditional drives is unacceptable in hybrid drives. Torsional oscillation disrupts the rotating magnetic field of electric drives and generators and limits the control range of such a drive.

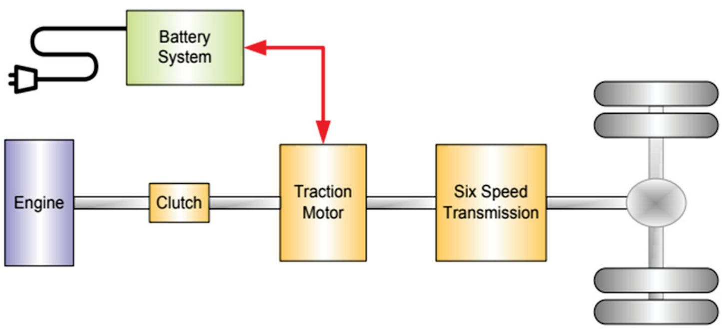


Figure 1. Series connection of the electric motor

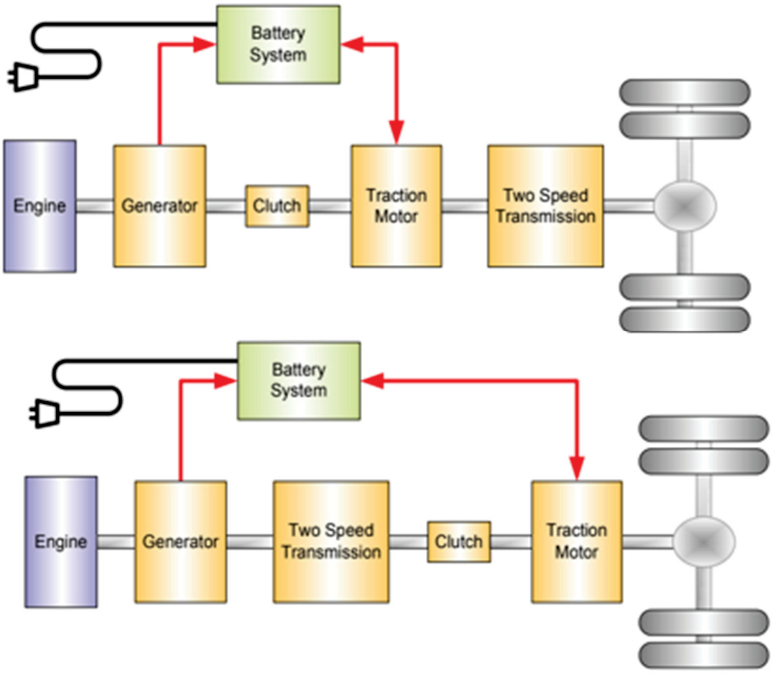


Figure 2. Series-parallel connection of the electric motor

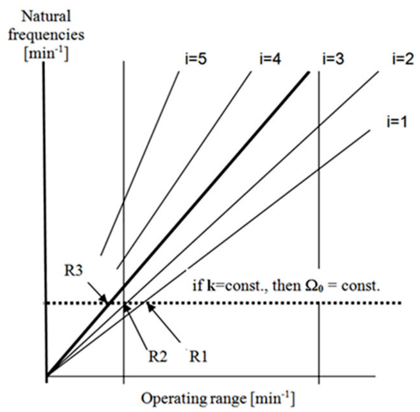
We can also define a hybrid drive as a mechanical system that transfers energy from the driving machine to the driven device.
Based on the theory of torsional oscillation, a mechanical system can be defined as a torsionally oscillating mechanical system with n-masses. We describe the undamped n-mass system in matrix form by equations of motion (1):

$$I.\ddot{\varphi} + k.\varphi = M_k \quad (1)$$

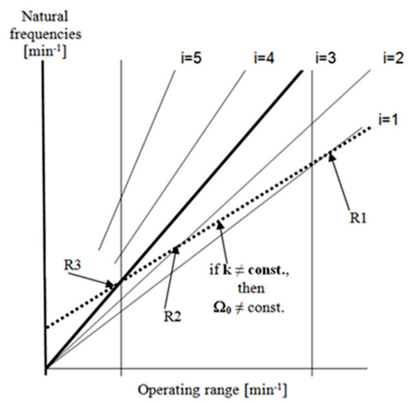
where: I – mass moment of inertia matrix,
k – stiffness matrix,
M_k - matrix of loading torques,
φ – twist angle,
$\ddot{\varphi}$ – angular acceleration.

A torsionally oscillating mechanical system consisting of n- masses then has n-1 natural frequencies. Each of these natural frequencies can be in a certain extent identical to the excitation frequency, which results in the occuration of resonances.
Through the dynamic analysis of the drive system, we come to the conclusion that the resulting value of the natural frequency is influenced by the material moments of inertia and the torsional stiffness of the system. The torsional stiffness of the system is affected by the torsional stiffness of the flexible link located in the drive. In current drives, it is primarily a dual-mass flywheel (DMF). Mass moments of inertia are usually constant. In the case of torsional stiffness, it is possible to achieve a torsional stiffness constant at DMF whose characteristics are linear. If the DMF has a non-linear

characteristic, the value of the torsional stiffness is also not constant and therefore the mechanical system will also have its own frequency course.
Dynamic ratios in a drive with an internal combustion engine can be conveniently expressed using a Campbell diagram. We will use Campbell's diagrams as follows: In the Campbell's diagram, the i-th harmonic components of the mechanical system will be displayed, marked with numbers 1 to 5. The main harmonic component will be marked with the thick line "i". The course of the natural frequency will be indicated by the dashed line. The intersection of the natural frequency and the i-th harmonic component will represent the resonance from the i-th harmonic component and will be labeled "Ri".
The negative impact of the application of trends for reducing engine emissions on vibrations is caused by the creation of a resonance area in the working area of the combustion engine.
Figure 3 shows two cases of the effect of torsional stiffness on the natural frequency and the resulting resonances. The case of Fig. 3a is a case where the DMF has a linear charter and therefore has a constant torsional stiffness. The case of Fig.3b is a DMF that has a non-linear charter and thus its torsional stiffness is not constant. As can be seen from Fig.3a, the R3 resonance caused by the main harmonic component is located below the working speed of the engine. This resonance is passed through when starting and stopping the engine, and the emergence of resonant oscillation is very short. Resonances marked as R2 and R1 are resonances that arise from secondary harmonic components, which, however, do not have a significant contribution to the formation of unwanted vibrations. A significant problem is while the engine is running, the hybrid management of the drive is applied, resulting in a change in the main harmonic component of the drive. Such a change would resonate for us in the working area of the drive. A more suitable solution is then the use of a DMF whose torsional stiffness will not be constant (Fig.3b). In such a case, it is possible to ensure protection from resonances and secondary harmonic components of the excitation with a suitably designed torsional stiffness of the DMF.



a.)



b.)

Figure 3. Campbell diagram

3. Trends in problem solving

Designing DMFs that will not have a constant torsional stiffness is very challenging. It is required that the DMF has a non-linear load characteristic. Currently constructed DMFs with coiled springs have several disadvantages due to their geometry and operating conditions. In addition, the stiffness and damping changes dramatically at increased engine speeds, and as a result of friction, the number of active coils of the spring is reduced, which leads to an increase in the actual stiffness of the spring and a decrease in damping.

Authors Maffiodo et al. in their work present a new DMF design that replaces classic compression coil springs with spiral springs. This DMF design is expected to be characterized by elastic spring deformation that will almost exclusively define the stiffness of the coil springs, which will be marginally affected by torque and revolutions. In addition, the system operates without requiring any lubrication, so there is no need to create a seal by welding.

As we mentioned in chapter 2, it is advisable to have a component applied in the drive that would be able to respond appropriately to changes in dynamic conditions. This means applying a component that would be able to tune (change) its own frequency during the operation of the drive. A suitable solution appears to be a pneumatic dual-mass flywheel (PDMF), which would have a torsional rigidity continuously variable according to the dynamic conditions in the drive.

The operational range of the PDMF can be seen on the Campbell diagram (Fig.4). When applying PDMF, we want to respond appropriately to the operating modes of the drive. The goal is to achieve a state of low vibration through tuning, i.e. using a smooth change in torsional stiffness to smoothly change the natural frequency of the system. In Fig.4 on the left, in the Campbell diagram, we have shown three different natural frequency curves marked A, B, C, which will be required in the working ranges of the hybrid drive. As we can see in Fig.4 on the right, these three courses can be achieved by changing the torsional stiffness accordingly. The pneumatic two-mass flywheel, with the help of a suitable control system, will allow us to smoothly change the torsional stiffness, so that we reach the desired value of the torsional stiffness. The resulting value of the course of torsional stiffness can be constant (characteristic A) or variable. The variable characteristic can be linear (characteristic B) or non-linear (characteristic C). A great advantage of PDMF is the possibility of this smooth change of torsional stiffness during the working mode of the drive.

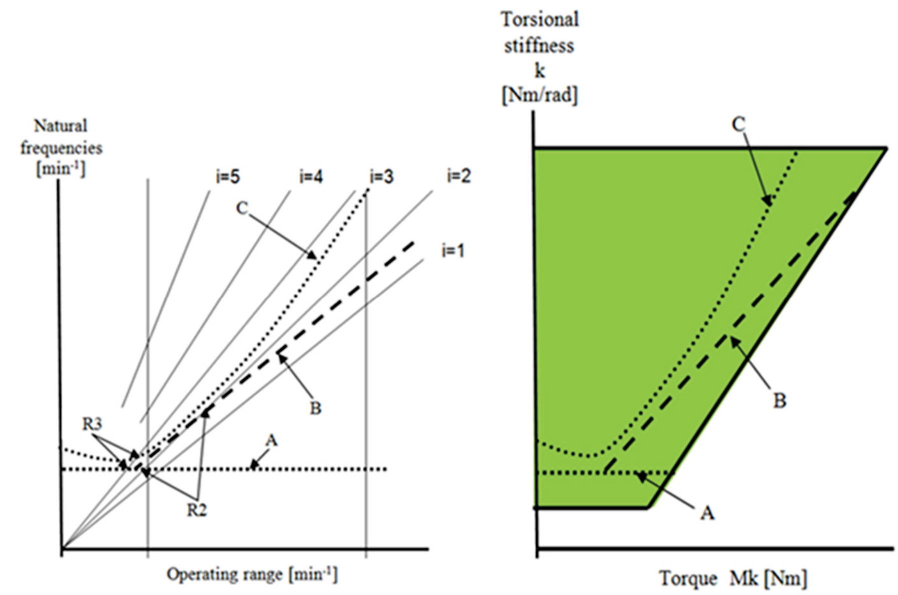


Figure 4. Natural frequency in Campbell diagram and controlled torsional stiffness of PDMF

4. Conclusion

Current DMFs have several limitations and are very narrowly designed for traditional propulsion systems. In the case of hybrid drives, it is necessary to pay attention to new types of DMF, namely those that will be able to adapt their properties to the working modes of the drive.

By theoretical contradiction using Campell diagrams, it was demonstrated that an effective protection of resonance areas is an active change of the own frequency. Changing the natural frequency of a mechanical system is relatively easy to achieve with two basic principles. The first principle consists of changing the moments of inertia of the mechanical system. The second principle is a change in the stiffness and damping properties of some of the drive components. This principle can be implemented even during the working mode of the drive, without the need to shut it down, but such a component must be applied where a smooth change of its stiffness is possible.

In the article, one of the DMF solutions was presented, namely PDMF. As we further demonstrated, PDMF is an element that can fulfill the demanding expectations for reducing the vibrations of hybrid drives.

Acknowledgments

This work is a part of these projects: **VEGA** 1/0528/20, **KEGA** 029TUKE-4/2021.

REFERENCES

1. Green Deal EU, 2021
2. GREGA R. [et al.]: Failure analysis of driveshaft of truck body caused by vibrations. In: Engineering Failure Analysis. Vol. 79. (2017) ISSN 1350-6307.
3. JAKUBOVIČOVÁ L., SÁGA M., VAŠKO M.: Impact analysis of mutual rotation of roller bearing rings on the process of contact stresses in rolling elements, Manuf. Technol. 13 50–54 (2013)
4. YÜCEŞAN A., SEZER S.: Vibration isolation with clutch disk pre-damper mechanism for the idle rattle phenomenon. Journal of Vibration and Control 24, (2016) 1518–1534.
5. MIYASATO M., KOSOWSKI M.: Plug-in hybrid medium-duty truck demonstration and evaluation., (2015) doi:10.2172/1234437.
6. LEE H.J., SHIM J.K.: Multi-objective optimization of a dual mass flywheel with centrifugal pendulum vibration absorbers in a single-shaft parallel hybrid electric vehicle powertrain for torsional vibration reduction. Mechanical Systems and Signal Processing 163(2022).
7. LOKHANDE S, SONAWANE P., LONDHE C.P.: Revive on design and manufacturing of dual mass flywheel, (2015).
8. WEDIN A.: Reduction of Vibrations in Engines using Centrifugal Pendulum Vibration Absorbers, Chalmers University of Technology, 2011.
9. CHARLES P., SINHA J. K., GU F., LIDSTONE L., BALL A. D., 2009 Detecting the crankshaft torsional vibration of diesel engines for combustion related diagnosis, J. Sound Vib. 321 1171–1185 (2008).
10. SUN W., LI Y., HUANG J., SAE INT. J.: Passenger Cars - Mech. Syst. 4(2011), 1050–1057.
11. HARIS A., MOTATO E., THEODOSSIADES S., RAHNEJAT H., KELLY P., VAKAKIS A., BERGMAN L. A., MCFARLAND D. M.: A study on torsional vibration attenuation in automotive drivetrains using absorbers with smooth and non-smooth nonlinearities. Applied Mathematical Modelling 46(2017),
12. GREGA R. [et al.]: Experimental Identification of Failures of High-Pressure Pump Drive. In: Applied Mechanics and Materials volume 816: Applied Mechanics and Mechatronics 2. - Zurich: TTP, 2015 P. 421-425. - ISBN 978-3-03835-602-8 - ISSN 1662-7482,
13. GREGA R, KRAJŇÁK J, BARAN P.: The Reduction of Vibrations in A Car - The Principle of Pneumatic Dual Mass Flywheel. In: Zeszyty naukowe Politechniki Śląskiej. No. 84. ISSN 0209-3324 (2014),
14. GREGA R. [et al.]: The chances for reduction of vibrations in mechanical system with low-emission ships combustion engines. In: International Journal of Maritime Engineering. Vol. 157, no. A4. ISSN 1479-8751 (2015),
15. HOMIŠIN J[et al.]: Continuous tuning of ship propulsion system by means of pneumatic tuner of torsional oscillation. In: International Journal of Maritime Engineering: Transactions of The Royal Institution of Naval Architects. Vol. 158, no. Part A3. ISSN 1479-8751 (2016),
16. GREGA R [et al.]: Analysis of the impact of flexible couplings on gearbox vibrations. In: Zeszyty naukowe politechniky Śląskiej: Seria Transport. Vol. 91, ISSN 0209-3324 (2016),