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Streszczenie: Obecnie, w przemyśle samochodowym, szeroko i wnikliwie rozważa się problem wzbudzania oraz eliminacji drgań w pojazdach. Omawiane są także wszelkie technologie mające na celu eliminację drgań. W niniejszym artykule, rozważa się dwumasowe koło zamachowe jako jedno z rozwiązań służących do eliminacji tu omawianych wibracji. Proponowane dwumasowe koło zamachowe zostało zaprojektowane, aby bardziej efektywnie tłumić drgania niż innymi metodami. Omawiane są dwa innowacyjne rozwiązania konstrukcyjne polegające na pewnych zmianach strukturalnych elementów w dwumasowym kole zamachowym.

Słowa kluczowe: dwumasowe koło zamachowe, drgania, napęd pojazdu.

NEW DESIGN OF A DUAL-MASS FLYWHEEL WITH MULTI-STAGE CHARACTERISTICS

Summary: Currently, the production and elimination of vibrations in the automobile drive and related technologies for their elimination are a highly discussed topic in the automotive industry. The paper deals with the dual-mass flywheels as one of the solutions for eliminating these vibrations. The design for more effective vibration elimination includes 2 innovative solutions in the structural change of elements in the dual mass flywheel.

Keywords: dual-mass flywheel, vibrations, automotive drive

1. Introduction

From the very beginning, internal combustion engines were intended to drive equipment in transport, agriculture, but also in the field of energy production. Due to the improvement of efficiency, increase in performance and especially reduction

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in emissions of combustion engines, the design of individual parts of the engine was changed and various technological improvements were added. Over time, the Euro emission standard was introduced into the European standards, which determines the maximum number of emissions produced by automobile transport. As the automotive industry had to adapt to these conditions, engineers and developers made several changes to meet emission limits. Although these changes increased engine performance and reduced emission production, they also brought with them undesirable consequences as a by-product of the mentioned changes.
Technologies such as down speeding, downsizing, turbocharging or cylinder deactivation were indeed successful in reducing emissions, but they brought with them a more uneven engine operation called torsional oscillation, which manifests itself as vibrations in the vehicle. Torsional vibration not only affected the comfort of passengers, but also the life of vehicle components, such as shortening the life of transmission gears, the life of the crankshaft, and the life of the entire powertrain.
Currently, a dual-mass flywheel is used to eliminate torsional oscillation in internal combustion engines, the limits of which are limited. This paper deals with a dual-mass wheels as a possibility to eliminates torsional oscillation in combustion engines and the aim of the paper is new innovative conceptual proposals for more effective elimination of torsional oscillation by using a pneumatic two-mass flywheel with different connecting parts [1-4].

2. Dual-Mass Flywheel in Automotive Drive

The flywheel is considered as a rotating mechanical device with a significant moment of inertia, and it is used as a storage device for rotational energy. They are available on vehicles with internal combustion engines to provide a significant inertia for a regular regime in rotation motion. In basic, they are divided into rigid and flexible type. Rigid flywheels are most common on gasoline vehicle applications. It is a single mass made of cast iron and bolted over the crankshaft. One surface is machined to form the friction face [1].

A rigid flywheel is always fitted with a coupling and a dampened disc. It lets to perform the necessary following functions:

- Transmit full engine torque through the transmission;
- Allow the engagement and disengagement between engine and gearbox;
- Filter out dynamic vibrations between the engine and the gearbox;
- Dissipate the heat generated between friction surfaces;
- Provide engagement comfort & driver control;
- Enable flawless engine starting;
- Enable smooth gear changes [1].

Flywheels resist changes in their rotational speed, which helps steady the rotation of the shaft. Today's modern engines produce higher torques that can be driven at low engine speeds. As a result, the maximum engine torque to be transmitted increases thus resulting in an increase of noise and vibration.

Moving the damper springs from the conventional coupling plate to inside the flywheel allows the DMF (Dual-Mass Flywheel) to eliminate the torsional engine vibrations away from the gearbox and reduces the load on the transmission. The larger damper in the DMF is better suited for eliminating the engine vibrations (especially needed for turbo diesel engines). Gear shifting comfort is also improved with a low-inertia disc. The DMF allows driving at lower engine speeds increasing engine efficiency, thereby saving fuel and reducing CO_2 emissions [1], [5], [6].

2.1. Advantages of Dual-Mass Flywheel

The DMF takes advantage of its dual masses and long springs to lower the natural frequency of the vehicle's driveline to less than 400 rpm. This is a big advantage in comparison with conventional coupling systems where the natural frequency of the vehicle's driveline is usually in the driving range of 1500-2000 rpm. Therefore, with a DMF, the eliminating of the engine vibrations is insured at all driving speeds. The low stiffness of the DMF is made possible by moving the damper from the clutch disc assembly to inside the flywheel where there is much more space. The lighter clutch disc assembly also makes it easier to change gears. Dual Mass Flywheels significantly reduce perceived vibrations and gearbox noise. This represents a major step forward in power train filtration technologies. This advance is especially important because the fuel-saving engines now being developed have higher torque and, consequently, generate greater vibrations, especially at low speeds [1].

The main advantages includes:

Specifically designed for each vehicle application:

- Tuned with low stiffness for maximum noise reduction,
- Optimized eliminating performance,
- Applications from 200Nm up to 500Nm torque engines.

Improved driving comfort:

- Improved gear shift comfort and gearbox synchronizer durability by reduction of clutch disc inertia,
- Fuel consumption reduction is achieved by driving at lower speeds due to excellent noise reduction.

Designed for long lasting performance:

- High grade spring wire used,
- Long-life ball bearings and bushings (no maintenance needed),
- Added friction damping system design is stable for life [1].

2.2. Dual-Mass Flywheel Composition

The DMF is made up of two independent inertias/flywheels. The design splits the inertia between the engine and the transmission to keep the power train resonance below the engine idle speed. As a result, there is no transmission gear rattle in the normal speed range of the vehicle. Thereby, it increases the comfort of the vehicle's occupants [1]. The basics parts of DMF are shown in Fig. 1.

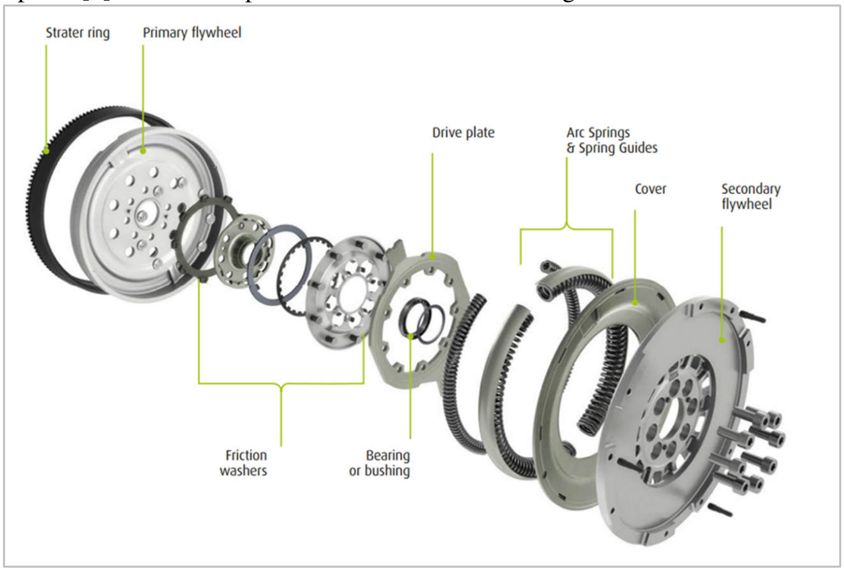


Figure 1. Parts of Dual-Mass Flywheel [1]

The primary flywheel is bolted directly to the crankshaft and contains the damping springs. The secondary flywheel is fitted with a conventional clutch cover and solid disc with a lower inertia, improving the gear shifting. There are two long curved springs between the flywheels that absorb the engine vibrations schematically shown in Fig.2). The main advantage is a greater angular damping which allows the maximum filtration [1].

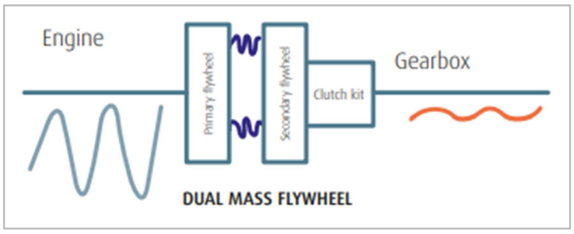


Figure 2. Schema of vibration absorption in automotive drive with DMF [1]

The curved springs are valve steel quality so that they can resist very high stress during wide angle compression when eliminating vibrations. The high curved spring load is supported by two hardened spring guides located inside the primary flywheel. A specific grease sustaining high operating temperature is added to lower friction between the springs and the spring guides. A curved DMF contains two sets of curved springs. Each set includes external and internal spring. The DMF could have one stage or two stages of springs (equal length or different length for internal and external springs). The two-stage spring enables two slopes with different stiffness [1], [7], [8].

Anyway, all DMF produced and applied at the same time are tuned to a certain type of engine according to its main parameters (power, volume, maximum torque). Modern low-emission engines work in several modes. In addition to driving modes such as ECO, Normal or Sport, one or more cylinders can be deactivated while the engine is running, while the engine characteristics also change. However, dual-mass flywheels produced at the same time cannot respond to this fact due to their characteristic, which is not possible while the engine is running. During engine operation, no changes can be influenced, therefore it would be advisable to change the characteristics of the dual-mass flywheel when changing the engine mode.

One of the alternatives to reduce the torsional vibration of the crankshaft is to replace the DMF while driving, or connect them also while driving, which is not possible with the current design of the engine and gearbox.

The basis of all currently used DMFs is the mathematical model in Fig. 3. This model consists of the primary mass I_P of DMF, the secondary mass I_S of DMF, which are connected by stiffness k_k and damping b. The shape and properties of the DMF parts, which is presented by the stiffness k_k, are usually characterized by constant stiffness properties. These constant stiffness properties are characterized by linear characteristics of DMF. DMF characteristics are therefore mostly linear and characterized as one-stage characteristics (Fig. 4a) or two-stage characteristics (Fig. 4b).

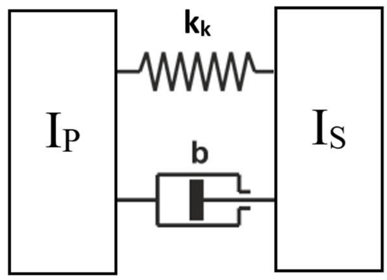
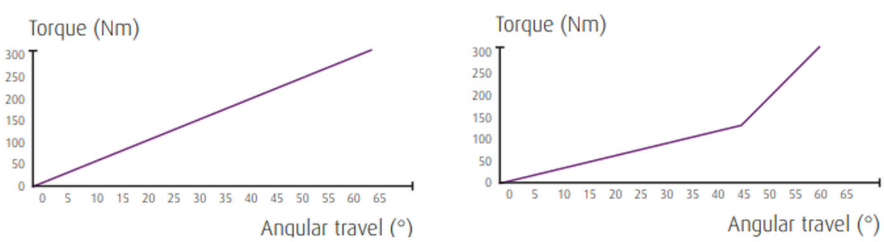


Figure 3. DMF mathematical model



a) DMF with one-stage curved spring

b) DMF with two-stage curved spring

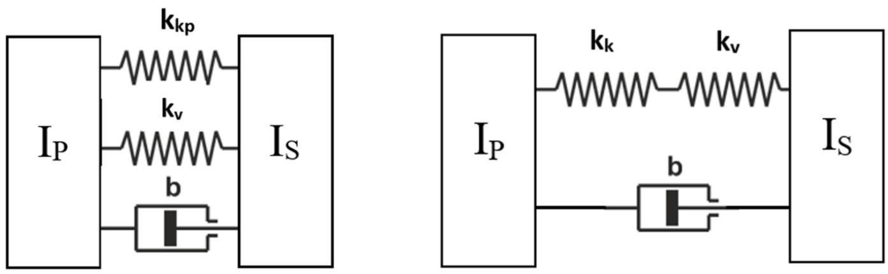
Figure 4. Torque transfer of DMF with different springs [1]

All mentioned above, in the single-purpose and tuning of the available two-mass flywheels only for a certain amplitude and frequency of torsional oscillations. This characteristic can also change while the engine is running, for example when deactivating the cylinders or during individual driving phases. For this reason, it would be appropriate to change the characteristics of the dual-mass flywheel according to the current conditions. This means applying an element, or elements, in which it is possible to smoothly change the load characteristics of the flexible element and thus achieve the lowest possible values of torsional oscillation in the entire drive train of the vehicle. One possibility is changing the characteristics of the DMF, or to change the stiffness of the elastic element so that the compression is not dependent on the force acting on the given elastic element. It means that the twist angle of the DMF would not depend on the torque generated between the individual flywheel masses.

3. New Design of Dual-Mass Flywheel

Modern engines run with lower idle speeds and higher torques, generating more vibrations. Therefore, it is necessary to improve the filtering capacity or to lower the point at which filtration begins without compromising the torque capacity. As vehicles are becoming more silent and the chassis is becoming lighter and more rigid, the level of vibration is becoming more apparent.

For innovative design of the DMF and the distribution of the masses of inertia make it possible to shift the resonance frequency under engine idle speed by changes in their parts that provide connection of these masses. In following chapters, the new designs od DMFs are presented. The new DMF design can be described by mathematical models Fig. 5a, b.



a b

Figure 5. Mathematical models of new DMF

In Figure 5a is a DMF model with parallel-ordered stiffnesses, and in Fig. 5b, the stiffnesses in DMF are ordered one after the other. Both mathematical models in fig. 5 are characterized by a pair of elements with two different stiffnesses. One of the elements is characterized by a constant stiffness k_k and the other element represents a variable stiffness k_v.

The variable stiffness k_v ensures better adaptability of the DMF to the operating conditions in which the drive works. The element with variable stiffness will be a pneumatic spring, in which the pressure can be changed from the p_{min} value to the

p_{max} value. Variable stiffness can therefore be achieved by using an elastic element in which the air pressure can be continuously changed and therefore the stiffness k_v can be changed in the range from k_{vmin} to k_{vmax}.

3.1. Pneumatic Dual-Mass Flywheel with a metal flexible unit

The design of the PDMF (Fig. 6) consists in the application of pneumatic metallic torsional vibration eliminators between the primary and secondary mass of the flywheel. The advantage of this design is the possibility of continuous regulation of the air pressure in the flexible elements. By regulation of the pressure in the spring elements of the flywheel, it is possible to change its characteristics, i.e., the dependence of the torque on the twist angle. It follows from this fact that the characteristic of the pneumatic dual-mass flywheel (PDMF) will not be graphically represented as a straight line or a curve, but as an area limited by the twist angle and the maximum torque, while the twist angle and basically the stiffness of the entire PDMF will be influenced by the pressure of the medium in the metal elastic unit.

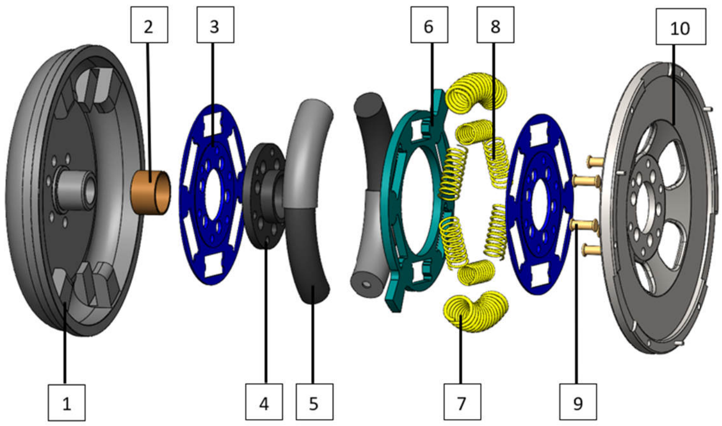


Figure 6. Parts of Pneumatic Dual-Mass Flywheel with a metal flexible unit

The construction consists of a primary mass (1), a casing (2), a pair of center plates (3), a hub (4), a pair of metal spring units (5), a center disc (6), a pair of curved coil springs (7), six compression springs (8), rivets (9) and secondary mass (10). All parts with positions are shown in Fig. 6.

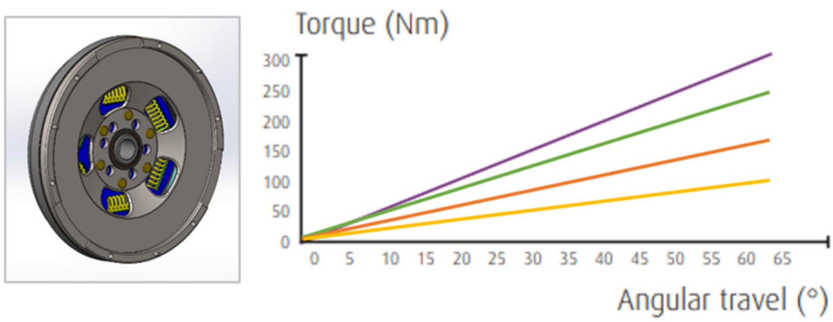


Figure 7. Pneumatic Dual-Mass Flywheel with a metal flexible unit and load characteristics

The advantage of the proposed DMF (Fig. 7) is multi-stage linear characteristics, which can be used in a wide range of excitation frequencies.

3.2. Pneumatic two-mass flywheel with rubber pneumatic bags

The construction of the pneumatic dual-mass flywheel with an air bag is similar to the construction of the pneumatic dual-mass flywheel with a metal spring unit. The difference is in the use of a flexible member of a different construction and a different material - rubber. The PDMF structure (Fig. 8) with air bags also consists of a primary mass (1), a casing (2), two centre plates (3), a hub (4), a pair of rubber pneumatic bags (5), a centre disc (6), a pair of bent coil springs (7), six compression springs (8), rivets (9) and secondary mass (10).

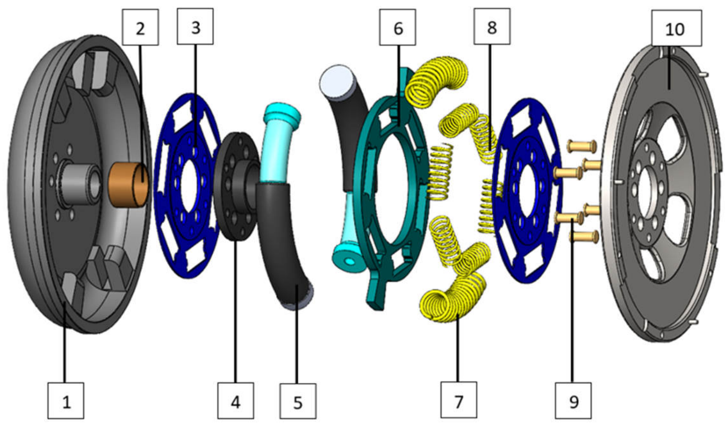
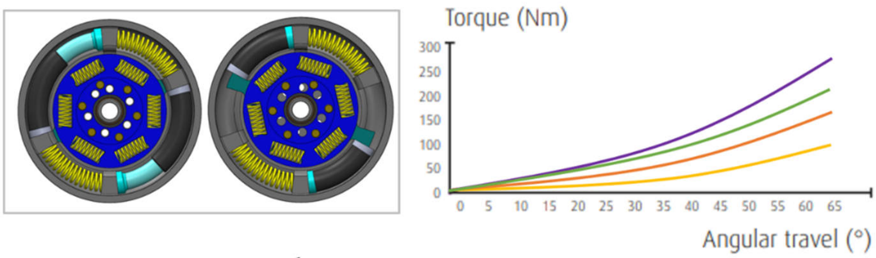


Figure 8. Parts of Pneumatic Dual-Mass Flywheel with rubber pneumatic bags

The principle of the proposed flywheel consists in the adjustable stiffness of the elastic elements, which ensures the possibility of optimal adaptation to the current conditions and requirements for the arising torsional vibration of the crankshaft. Pneumatic bags are placed between the primary mass and the central disk, which is flexibly placed against the secondary mass. Fig 9 shows the maximum (Fig. 9a) and minimum (Fig. 9b) twist angle. This alternative is characterized by non-linear characteristics and enables a twist angle up to 65° (Fig. 9c).



a b c

Figure 9. PDMF at maximum versus minimum twist angle and load characteristics

4. Results

Since the changes in the engine construction and the changes in the combustion process also brought negative consequences, it is necessary to eliminate these effects. One of the negative effects of technological and design changes is an increase in the magnitude of torsional oscillations and a shift of the resonance area to the engine's working revolutions. Designers and developers strive to eliminate these unwanted effects. To eliminate torsional oscillations and shift the resonance region outside the working speed of the engine, car manufacturers use a dual-mass flywheel, which has its limits such as flexibility of use, invariable characteristics, tuning for specific use. The currently used dual-mass flywheels are very close to their limits of use. After analysing the origin of torsional oscillation and the current possibilities of its elimination, two new innovative proposals were created. The properties of the designs and obtaining information about the possibility of application to vehicles will be the subject of further experimental research and testing of the designs.

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