

Optimization of energy consumption in a designed prototype vehicle in an advanced engineering environment

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Abstract. Nowadays one of the main issues in developing modern automotive solutions is the energy consumption of mechanical transmission systems. Mechanical transmission systems are designed to provide power, usually between the driven machine and the motor. The transfer of energy can be accompanied by a change of forces, torques and speeds. During the transfer of energy also occurs the change of the nature of motion e.g. from reciprocating to pivotal or from periodical to continuous one. The construction of mechanical transmission consists of at least two wheels, which are interrelated with a flexible connector or which being directly in contact. Mechanical gear ratio can be varied by leaps and bounds, fixed or variable continuously i.e. CVT (Continuously Variable Transmission). The aim of the paper is to analyse the efficiency of engines and powertrain of vehicles using energy-saving solutions using engineering software of the CAE class. The paper aims to present a synergy that occurs in a technical environment of energy solving vehicles. One of the tasks is to develop an analysis of the drives used in industry and energy-efficient vehicles with hydrogen engines and fuel cells. The analysis bases on the investigations conducted in a virtual environment, which uses the 3D model of a test stand for energy consumption measuring for vehicle engines.

1. Introduction

Mechanical gears are designed to provide energy, most often between the working machine and the engine. During the transport of energy, it may be accompanied by changes in forces, torques and speed. There is also a change in the nature of the movement during transfer of energy, e.g. from reciprocating to rotary, from periodic to continuous [1].

The construction of a mechanical transmission consists of two wheels or more connected with each other by a tie or touching each other. At the moment when the rotational speed of the input shaft (driving) is higher than the speed of the output shaft (driven), one deals with the reducer, otherwise with a gearbox that increases the rotational speed, i.e. the multiplier. The transmission ratio of mechanical transmission can be variable in steps, constant or variable continuously – CVT [1, 2].

The next division may be due to the possibility of changing the direction of the drive. On the other hand one can distinguish self-locking mechanisms, and when this is not possible, the drive is unstable.

The gearing is called a three-link mechanism, which consists of two moving links, i.e. gears, forming with the immobilized element a progressive or rotational kinematics pair. The gears can be divided due to the type of rim on cones, cylinders, snails, gears and scrolls. The gears are divided depending on the position of the wheel axles on: angular, parallel and warped parallel. The next



division depends on the gears used: single-stage or multi-stage. The next possibility of division results from the displacement of the axis of rotation on the gears with fixed or planetary axes. In gears with fixed axles, the axes of rotation of all wheels are stationary in relation to the body, and in planetary gears at least one wheel has an axis of rotation that moves relative to the body [3].

The belt transmission has two or more wheels with links in the form of belts. The belt can be toothed or smooth due to their shape. In the case of smooth belts, the drive is transferred from the drive wheel to the wheel driven by the belt as a result of the belt tension between it and the wheels. In the case of toothed belts, the drive is transferred in the gears by shape engagement of the toothed belt with the wheels. Belt transmissions have many advantages over chain transmissions, including: silent running, smooth motion, the ability to relieve impulsive load changes, vibration damping, simplicity, cheap construction, work without lubrication, the ability to transfer traffic when the shafts are not parallel, low sensitivity for shaft pitch errors, low sensitivity to the accuracy of assembly and execution, as well as the ability to obtain variable ratios by using stepped wheels [1].

2. Theoretical aspects of the problem

The purpose of the work is to analyse the efficiency of engines and drive system in energy-saving vehicles using engineering software. The work is to present the synergy occurring in the technical environment. One of the tasks is to develop a review of literature on drives used in industry and energy-saving vehicles with engines and fuel cells. Then the objective is to create the model of the possible modernization of the test stand. The next stage of the work is to analyse the efficiency of the engines, discussing the results obtained.

The design of the car is characterized by its aerodynamic appearance while maintaining the ergonomics of the shape with a sufficiently small turning circle. The steering system allows the turning of the two-wheeled front axle of the vehicle. The steering construction is made of aluminium alloy and steel, and composite stand bearings are also used. The steering wheel was created by 3D printing in FDM technology. The braking system is divided into a set of two brakes. The Avid BB5 bicycle brakes are mounted on the front axle and are mounted directly to the switches and ultra-light discs with a diameter of 160mm, while the rear axle is secured with a V-brake mechanical brake. The drive system uses a high-efficiency, brushless BLDC motor, which drives the wheel using a gear with a toothed belt, which is characterized by low weight. The motor controller has power transistors with low conduction resistance. The car uses 4 microprocessors with a computing power of 72 million operations per second. By using a given controller, the efficiency of the engine has been increased by 11.7%. The drive is transmitted through a quiet transmission with a Gates GT3 gear belt. The freewheel of the bicycle hub was also used. It is a toothed-ratchet mechanism connecting the toothed belt gears with teeth to the rear wheel. The purpose of using a given mechanism is to allow driving while not pressing the gas pedal. The drive from a technical point of view is a one-way clutch that allows the drive to be transferred from the transmission to the wheel, and the wheel can be rotated freely in the direction of travel with the sprocket stopped or even spinning in the opposite direction. Figure 1 shows a given drive system for an energy-efficient car.

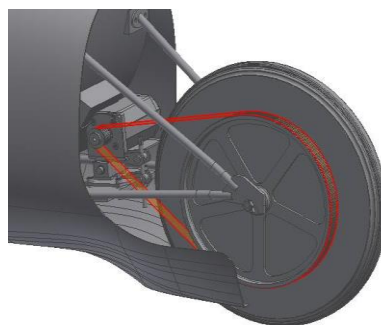


Figure 1. Model of the analysed drive system.

The solution of the propulsion system is the use of a planetary gear that has been arranged in Chapter 2.7. It is characterized by a low mass compared to the gear ratio. Two Dunkermotoren Bg 75x75 engines were used. Figure 2 shows the model of the transmission used in the prototype vehicle. In the car, a PEM type fuel cell was used.

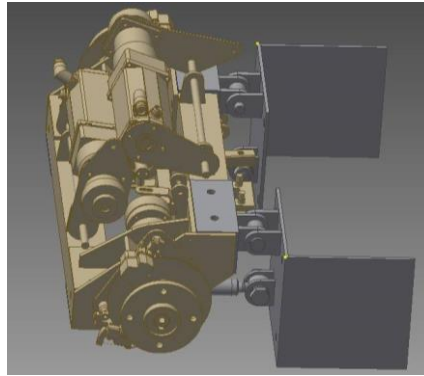


Figure 2. Model of the analysed gear system.

The Dunkermotoren BG BG 75 PI engines were used in research facilities. They are brushless AC motors with actuators with built-in motion controller and a convenient interface for computers. Drives of this series can be easily parameterized for different operating modes. With the exception of ball bearings that can be worn, the other components are ideal for continuous operation.

3. Test stand

In figure 3 is presented a 3D model of the engine test bed prepared in advanced software of the CAD/CAE class [4,5].

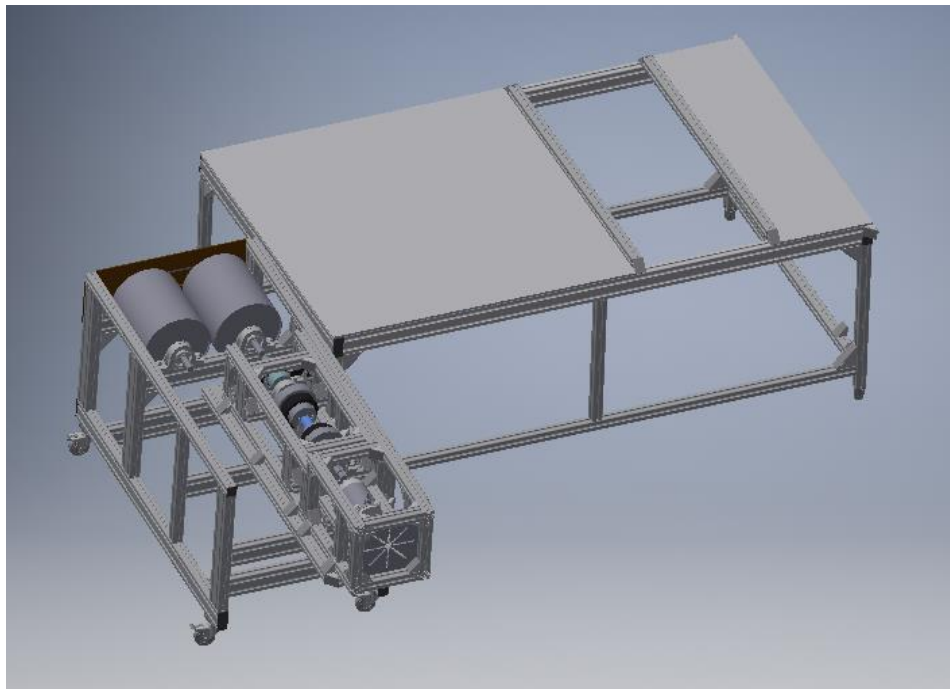


Figure 3. Model of the engine test bed.

All elements are connected with each other by sheet metal constructions, which act as the basis with the use of SKF bearing housings. It was proposed to change the construction of the dynamometer to facilitate the possibility of testing specific electric motors. The test stand consists of a motor introducing the shaft into motion, and the encoder together with the torque meter is asked to register the generated data. The power transferred to the other shaft is by means of a belt. On the second shaft, a brake is installed in the form of an engine that generates the set loads registered by the torque sensor. The actuator, located at a 180° angle to the shafts, is responsible for adjusting the belt tension.

The measuring station is divided into four sub-assemblies: drive system, braking module, table and module realizing the belt tension. The braking system is stationary because it has been fixed to the table with screws. The drive was mounted on tin elements, and subsequently mounted on trolleys and linear guides Hiwin (figure 4). The entire system is put in motion by the TIMOTION electric actuator. The force sensor was mounted between the table attachment and the actuator housing. The pressure of the piston is read from the sensor by means of a computer, which is related to the force applied in the cable. The drive system with the braking module was coupled with a toothed belt.

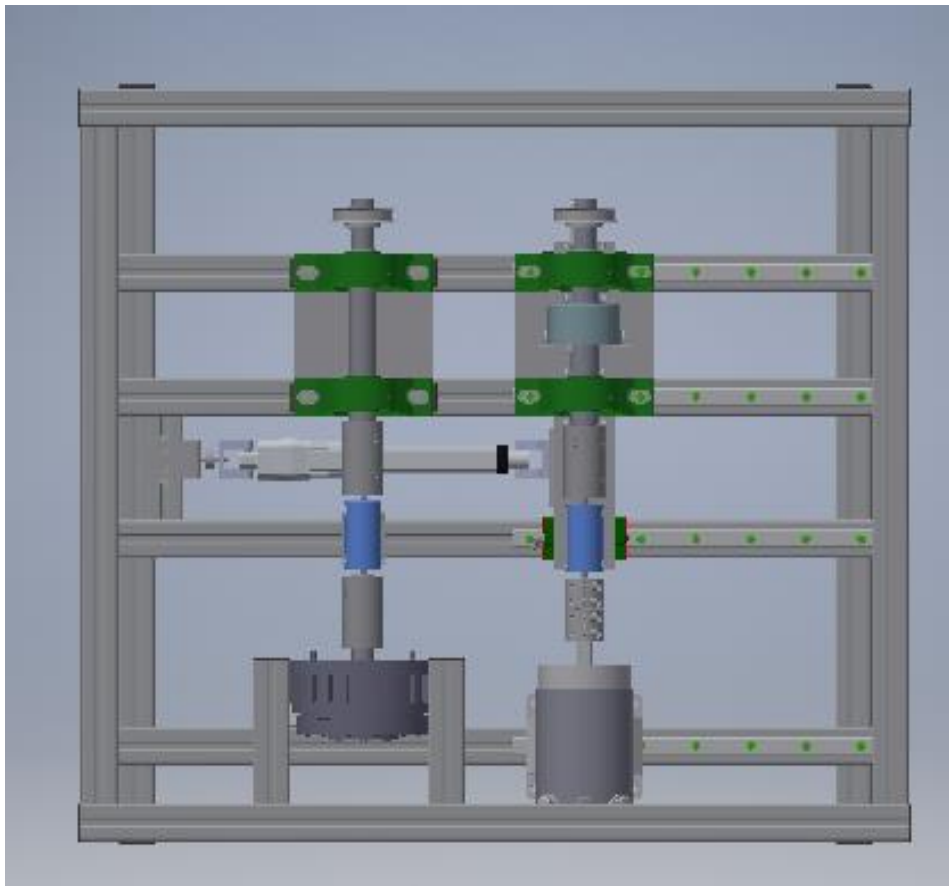


Figure 4. Model of the measuring stand.

Due to the high costs and limited time, the dynamometer was not completely modernized. The results of measurements were analysed using developed Matlab software. The elaborated script allows computing graphs of engine characteristics.

4. Results of measurements

The tests consisting in analysing data obtained from the virtual test stand. The stand was tuned basing on parameters obtained from the real test stand and from measurements of the vehicle. The sampling

rate is 2048. The first samples signals are not taken into considerations because it is the starting period of engine operation. In figures 5 – 7 are presented graphs presenting the efficiency of the investigated drive at different loads.

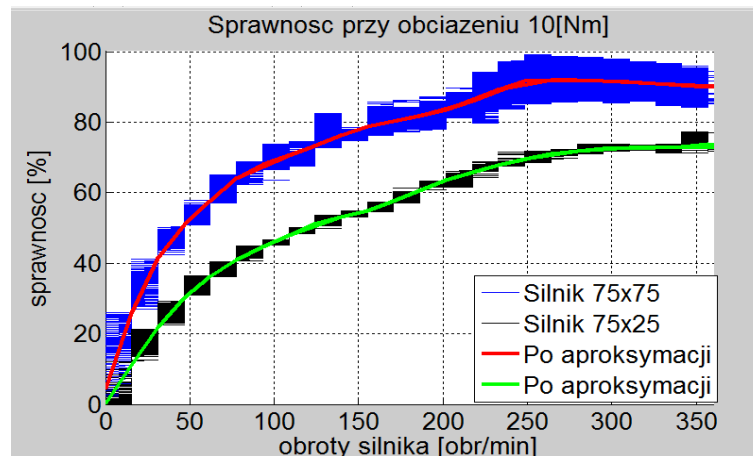


Figure 5. Graph of engine efficiency at load of 10 Nm.

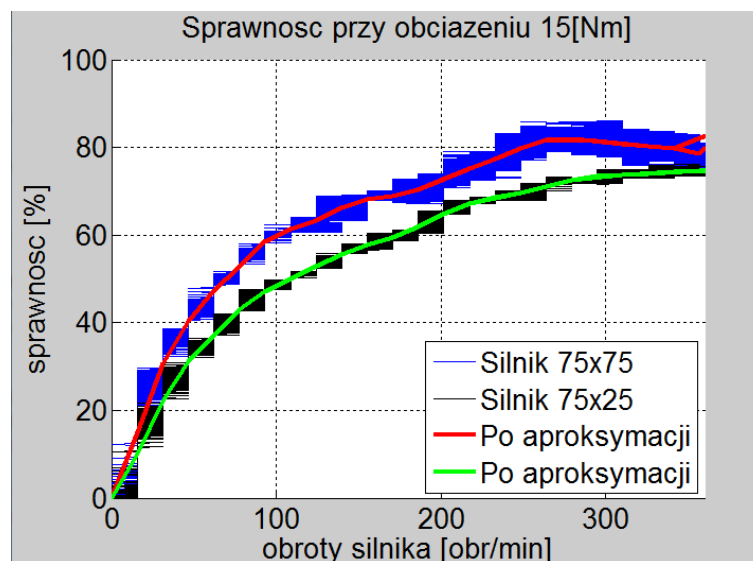


Figure 6. Graph of engine efficiency at load of 15 Nm.

Better performance is characterized by the Dunkermotoren BG75x75 PI engine. Its maximum efficiency is 80.34%, while the Dunkermotoren 75x25 type is about 75%. Along with the increase in the efficiency of the engines, they decrease. In the case of a load of 30Nm, the engine 75x75 is 68.42%, while for the second engine the value is 45.24%. Once again it has been proven that the use of a larger size engine works well in this type of drive. The load is related to the resistance of movement.

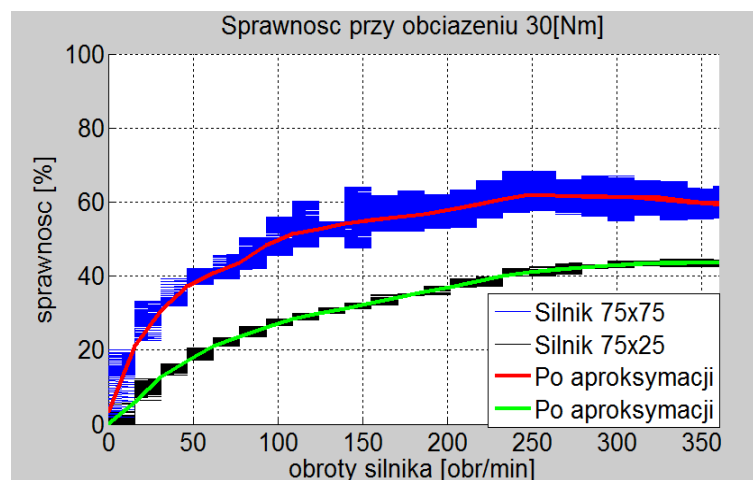


Figure 7. Graph of engine efficiency at load of 30 Nm.

5. Conclusions

The modelled virtual stand is the model of an engine test bed. It consists of an electric engine, transmission system and a braking wheel. Using the software, adapted to use in the engine braking stand, the obtained results were later developed. Generally the calculation have been made using MatLab script. All elements were linked using Internet bus and IPC technique [6]. It allows determining many of the characteristics of the analysed engine. For different load values, corresponding to the different conditions on the road, it was generated individual plots of energy consumption. The research was carried out for the limited engine power, at the engine rotational speed of about 350 rev/ min. After conducting the series of tests, the graphs have been prepared for 3 different types of loads corresponding to the rolling resistance.

One should point that many of such solutions must take into consideration both the terrain configuration as well as the influence of environmental factors on the drive system components [7,8]. This factors are the subject of future researches.

6. References

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