



Design and construction of an experimental test bench for the study of a mechanical system used for coupling power sources

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Abstract: This study investigates the experimental test bench specially created for testing a planetary mechanism with two degrees of freedom in the configuration of hybrid electric vehicle powertrain. For the experimental study, it was necessary to build a test bench that consists of a metal frame on which other mechanical and electrical components are positioned: the mechanical coupling system, the thermal engine, a three-phase electric motor and an alternator. The test bench can simulate road load, during which time it is measured with the help of a torque sensor the mechanical moment developed by the electric motor used in this configuration.

Keywords: hybrid vehicle, planetary mechanism, test bench

1. Introduction

Planetary gear trains (PGTs) are widely used in automobiles, heavy trucks, aerospace applications and other complex systems due to its numerous advantages. [1]

They reach large transmission ratios at small dimensions, are compact, and ensure the possibility of transmission ratios coupling without interrupting the power flow. [2].

There is a great variety of planetary gear trains, but the proper adoption of a planetary mechanism is done according to the transmission ratio, size, mass, and of course, efficiency..

Planetary gear trains composed of two central wheels and a planet carrier are used for coupling power sources due to their small size and mass.

The most commonly used planetary mechanism in coupling power sources is the Power Split Device with two degrees of freedom patented by Toyota [3].

Another option of coupling power sources is with the help of a planetary mechanism with two degrees of freedom, a double satellite and external meshing.

This paper presents the experimental test bench designed to study the behavior of such a planetary mechanism with a double satellite and external meshing, for power sources coupling for hybrid vehicles.

The test bench allows the analysis and evaluation of the kinematics and dynamic behavior of the planetary mechanism but also of the obtained performance.

The behavior of the planetary mechanism actually describes the behavior of the entire vehicle in all operating modes.

2. Test bench description

In a previous paper, it was presented a mechanical system that allows the coupling of three power

The thermal engine MT is located on the right side of the mechanical system. It is coupled to the mechanical system through the elastic coupling CE_1 . The electric motor ME is coupled to the mechanical system through a belt drive T_{C_2} , the belt wheels R_{C_4} and R_{C_5} are also driven by a Poly V belt, the tension in the belt being ensured by a tensioner (not shown in fig. 1).

At the right end of the ME shaft, by means of two elastic couplings, CE_2 , CE_3 , the torque transducer T_rC is mounted. Next to the elastic coupling CE_3 , by two radial roller bearings L_1 , L_2 , it is coupled a shaft on which the belt wheel R_{C_6} is mounted. Thus, through the belt drive T_{C_3} , transmits the movement to the braking system.

The belt wheel R_{C_7} is jointed in rotation with the brake drum F .

The brake drum F support, noted with ST is fixed on the test bench frame with the screws. The belt tension is provided by a tensioner who is not figured in fig. 1.

The drum shoes are operated by the handbrake lever M_F and the brake cable C_f connected to the brake shoes. By using the belt drive $T_{C_3}(R_{C_6} - R_{C_7})$ the angular velocity of the brake drum was reduced, the transmission ratio achieved by the two belt wheels being similar to the transmission ratio obtained by the vehicles main transmission.

Due to the considerable weight of the assembly: the brake drum F , the belt wheel R_{C_7} , as well as the assembly high speed at which it operates, it was necessary to protect it with a metal housing.

3. Test bench manufacturing

The test bench's frame is manufactured of a rectangular profile pipe in a welded construction. It has the dimensions: 1260x840x500. For ease of movement, 4 rollers are mounted at the bottom of the frame. Three metal plates are mounted on the frame with screws on which they will be mounted: the mechanical system, the thermal engine, the electric motor with the torque measuring system and the brake charging system. These are represented in Figure 2.

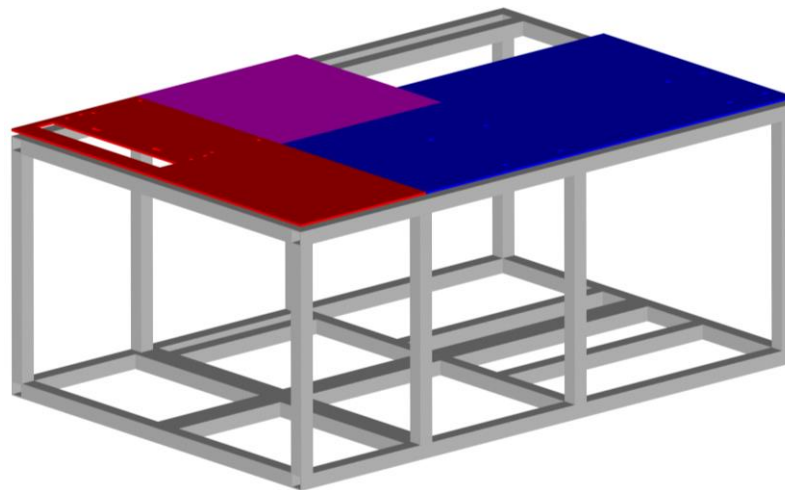


Figure 2. Positioning of the metal plates of the test bench.

The test bench has been designed to be used in any configuration of the coupling's system power sources. Also, the modular design, allows the installation of new components, electric or thermal engine, measuring systems, charging systems, etc.

The two alternators are also mounted on the metal plate containing the mechanical system. The mechanical system is fixed to the metal plate with 4 M10 screws. The metal plate has been cut-out to allow the assembly of the belt that transmits the movement to two alternators. They are positioned at the bottom of the plate, by means of two supports, one for each alternator, on either side of the axis of

symmetry of the mechanical system. The bracket is attached to one alternator ear, the other being used for a Poly V strap tensioning system.

The two alternators are charged by using headlight vehicle bulb systems that consume the power generated by the alternators. Thus it is simulated the charging of the traction battery.

The thermal engine is mounted on the metal plate with M10 screws on two parallel rails. Four spacers are mounted under the two rails to ensure the same distance of the axes for the two test benches components from the plate plane. The thermal engine is fixed to the two rails after the bolt coupling has been previously installed.

On the third metal plate are fixed: the electric motor, the torque transducer by means of two elastic couplings, the bearings and the belt wheel shaft and also the drum - wheel belt system that ensures the loading of the test bench.

The electric motor is mounted with 4 M12 screws. At the left end of the electric motor, the Poly V belt wheel is fitted with a wedge, which is coupled to the belt wheel of the mechanical system.

The BKC 300 94 elastic coupling is mounted on the right end of the electric motor. It is specially designed to be coupled to the T20WN torque transducer.

The coupling also has the role of protecting the torque transducer. The fixing on the shaft of the electric motor is done with a wedge and the coupling with the torque transducer through an elastic bracelet.

The second BKC 300 94 elastic coupling couples the output of the torque transducer with the belt wheel shaft. As in the previous case, the fastening is done with an elastic bracelet for the torque transducer and with a wedge for the belt wheel shaft.

The brake drum is a drum that equips Dacia Logan vehicles. Instead of the classical wheel, a Poly V belt wheel is mounted on the brake drum with 4 screws.

Due to its size and cumulative mass (drum - wheel) the assembly it balances itself dynamically.

Mounting is done by two U-shaped brackets. When mounting, the alignment of the two belt wheels must be taken into account.

The belt tension is provided by a roller tensioner.

The brake cable is attached to the top of the drum, passed through a hole in the metal plate, below it to the left, where the parking brake support is mounted (from the same vehicle model as the brake drum).

The parking brake support is mounted with screws, using the vehicle's fastening system.

The thermal engine's fuel tank is mounted above the carburetor level by through two closed profiles, this because the thermal engine is not equipped with a fuel pump. The profiles are fastened with screws on the test bench's frame in the right rear area, near the thermal engine area.

Figure 3 shows a view of the assembled test bench.



Figure 3. Top view of the test bench.

4. Test bench electrical wiring diagram

The electrical diagram with the low voltage electrical connections (12 V) is shown in Figure 4. The components are:

- Alt1, Alt2 – alternator,
- RT1, RT2 – alternator voltage regulator relay,
- RTM - thermal engine voltage regulator relay,
- BA1, BA2, BA3 – battery packs,
- K_M – engine start contact,
- RA – starter power relay,
- Starter – thermal engine starter.

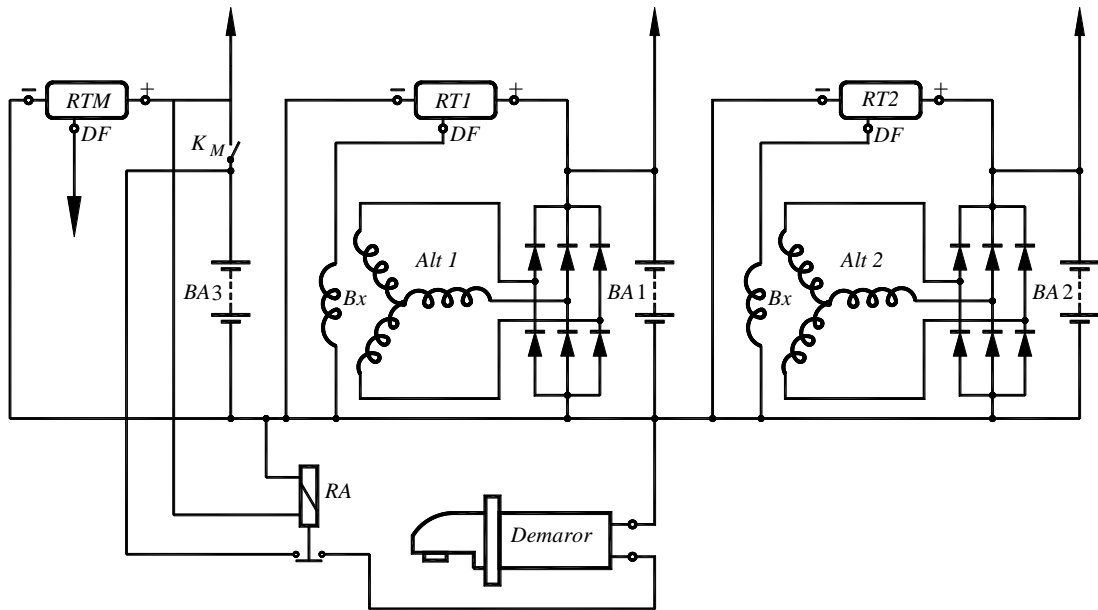


Figure 4. Test bench wiring diagram for 12 V.

The test bench has three 12V batteries. A battery (BA3) is used in the thermal engine circuit, which has a built-in starter and a battery charging system. The voltage relay (RTM) is outside the engine and the voltage regulating relays RT1, RT2 are mounted on the frame.

By operating the switch K_M , the thermal engine starter is coupled via the RA start relay. The two alternators (Alt1, Alt2) each charge a battery (BA1, BA2).

Because each electric vehicle has its own regulating relay, it was avoided to connect the three on a single battery.

The voltages generated by alternators go to consumers. The consumers are 6 columns of 5 12V vehicle headlight bulbs, each bulb having a power of 100 W. They are mounted on a metal plate with the dimensions of 580x500mm.

The metal plate is 2mm thick and is mounted with M5 screws on the side of the test bench.

Holes are made in the metal plate to pass the glass part of the headlight bulbs. the tightening and at the same time a good electrical contact is made with 5 clamps positioned horizontally, each clamp being fastened with 6 M4 screws.

The headlight bulbs are thus clamped between the metal plate and the mounting clamps.

Figure 5 shows the positioning of the headlight bulbs and the electrical connections of the 30 bulbs. The headlight bulbs on a column are placed in parallel, so it sum's up to a 500W consumer.

At the end of each column was mounted a socket that allows the connection of an ammeter with consumers or the mounting of a shunt.

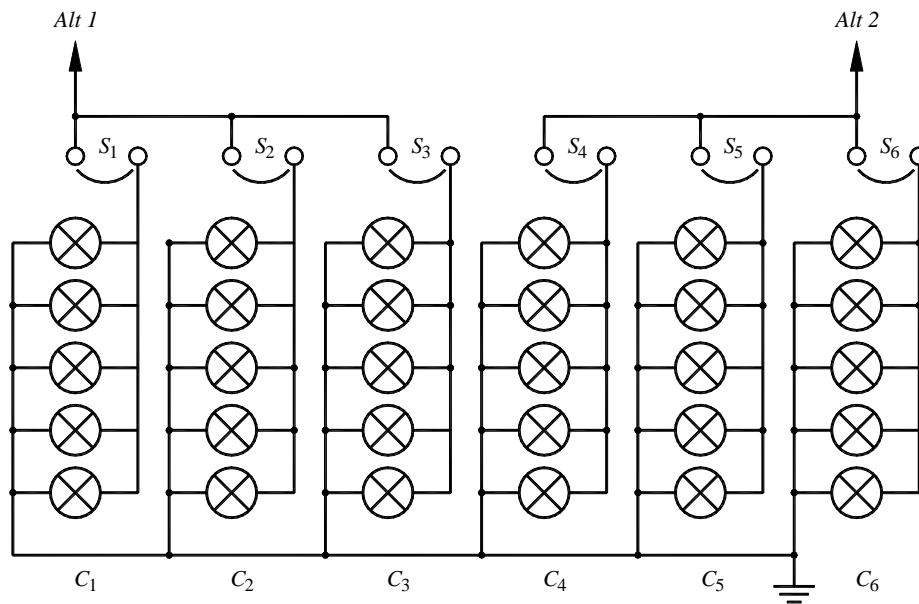


Figure 5. Wiring diagram of the headlight bulb panel.

Each alternator powers 3 such columns of headlight bulbs. The alternators have separate electrical wiring, each charging on its own network of consumers.

Due to the fact that the light bulbs releases high thermal power, a protective metal grille has been installed in front of them. The grille also has the role of protecting the bulbs from accidental blows. The connections were made with several types of multi-wire copper conductors with diameters of 1.5 mm, 2.5 mm, 4 mm and 8 mm, depending on the rated current in the circuit.

It is possible that the voltages of the 3 batteries enter an inverter module that transforms the DC voltage into three-phase AC voltage required for the electric motor. No such module was used, the three-phase voltage being available in the electrical network of the test laboratory.

The ME electric motor is powered from the three-phase network of the laboratory. The speed variation of the ME electric motor is done with a control module.

The electrical connecting cables are four-wire multi-wire copper cables with a diameter of 3.5 mm.

The control module of the three-phase electric motor consists of the SINAMICS power inverter and the CU 240S control module. The SINAMICS power module allows the control of the asynchronous electric motor speed both by changing the supply voltage and by varying the frequency. For correct operation, the voltage, maximum speed and power data of the electric motor are entered in the CU240S control module from the beginning.

The speed can be changed both by means of a potentiometer and also by means of computer programming the operation of the control mode.

The CU 240 control module detaches from the power module. It is programmed by setting the module switches either by attaching a memory in which the operating parameters are entered.

A feature of the control module is the energy recovery during the braking period of the electric motor.

The speed of the electric motor can also be adjusted manually by means of a potentiometer (5 k Ω).

The CU240S module can also be controlled in real time via the RS485 interface.

The control module is mounted on the side of the test bench on two vertical strips. The flat strips are fixed in advance on the frame with four M6 screws.

Figure 6 presents a side view of the test bench.



Figure 6. Lateral view of the test bench.

5. Conclusions

The dynamic behavior of the planetary mechanism with double satellite and external meshing was also studied from a theoretical point of view and the results showed that it can be used successfully in the configuration of hybrid vehicles.

In order to validate the experimental results, it was necessary to create and assemble a test bench, which meant:

- design of a test bench to study the dynamics of the mechanical system previously designed and used for the coupling of a three-phase electric motor with a power of 7.5 kW, a thermal engine with a maximum power of 15.3 kW and two alternators with a power of 1.5 kW each,
- design and construction of a test bench loading system with a drum brake and a load of alternators consisting of 6 columns, each with 5 headlight bulbs of 12V - 100W,
- design of low and medium voltage electrical diagrams for the electrical equipment of the test bench,
- programming the electronic control module of the three-phase electric motor that ensures the variation of the motor speed at a constant torque.

The study of the dynamic behavior on the experimental test bench is performed by measuring the torque and engine speeds in various working regimes. This will simulate the operating cycles of a hybrid vehicle, thus comparing the values obtained from mathematical calculations with those obtained experimentally.

In conclusion, the experiments performed on the test bench, and which will be the subject of future research, will validate or invalidate the solution regarding the use of using a planetary mechanism with double satellite and external meshing for hybrid vehicles.

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