Tests of Electrical Motor for Installation in the Wheel Hub of an Electric Car

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Abstract. The article presents the construction of test stand for testing an electric permanent magnet synchronous motor (PMSM) with an external rotor. The results of laboratory tests such as temperature rise tests for various motor parameters (such tests allow to determine temperatures in important motor components during different driving conditions - calculated for Fiat Panda III) and load tests with the determination of efficiency maps in the entire range have been presented. It was assumed that the car's drive is fitted with two motor in the rear axle.

1. Introduction
In recent years, the KOMEL Institute of Drives and Electrical Machines has carried out a number of design and research works in the field of drives for various types of electric vehicles [1-4]. One of the currently realized projects in the field of e-mobility concerns the direct drive motor installed in the wheel hubs of vehicles, which is related to the need to carry out research in wide range. Among the issues of construction and experimental works aimed at developing and manufacturing the product, it can be distinguished the most important ones: defining design assumptions, modeling and computer simulation, developing design documentation, making a prototype and experimental verification. The individual process steps are strictly interdependent. Particular importance for the assessment of the effectiveness of the design process are the results of the real model tests. They allow to assess the correctness of computational and design work as well as to verify initial assumptions.

As part of the project carried out at the KOMEL Institute, a PMSM motor with an external for installation in the wheel hub was designed and manufactured [5]. One of the prototypes is shown in Fig. 1 and Fig. 2. In order to determine the parameters of the motor (electromechanical and thermal), a number of tests were carried out to analyze the conformity of the real and design characteristics.

2. 3D model of the tested motor
The drive system equipped with two motors of this type should ensure dynamic driving of a Fiat Panda type car. For cars with a larger weight, in order to obtain sufficiently high driving parameters, it is preferable to use a 4-wheel drive system. The overall dimensions of the developed motor have been adapted to the 17 "rim. The available design space is limited by the outer diameter of the rim, its shape, rim shoulder (ET) and the brake drum (if included in the braking system). The presented motor has an external rotor. The rotating element is the body in which the magnetic core is installed with fixed permanent magnets. The fixed element is an anchor disc with a supporting structure, a labyrinth cooling system and a stator with windings. The rotor position sensor is necessary to control the motor.
3. Description of the test bench

The motor tests were carried out on the prepared test stand, which is shown in Figure 3.

Tested motor was coupled through torque meter with an auxiliary DC machine. The tested object was powered from the Sevcon Gen4 Size8 controller dedicated to the drives of electric vehicles. During the tests, the inverter was supplied with a constant voltage of nominal value. As the necessary rotor angular position sensor, a magnetic absolute encoder with an analogue Sin-Cos output was used. Control of the motor controller was carried out by a control and measurement computer with a dedicated application.

For the measurement of electromechanical parameters, a high-performance power analyzer with a current transducer was used. Such a system enabled measurement of motor voltages and currents (and determination of active power and power factor), voltage and current consumed by the inverter (and determination of the power consumed by the entire electric drive) as well as mechanical quantities: torque and speed. On the basis of the obtained results for each static point, the efficiency of the motor, controller and the entire electric drive was determined. Archiving of measured parameters was carried out on a control and measurement computer using dedicated software. The tested motor, as a prototype object, was equipped with a series of resistive temperature sensors placed in strategic and most important places in terms of thermal analysis such as: stator windings (winding in slot and end winding) stator core and water cooling system jacket. The sensors have been connected to a multi-channel recorder enabling the archiving of temperature changes at individual points. Due to the fact that this motor is characterized by high values of the supply voltage frequency, it was decided to measure the temperature of permanent magnets placed in the external rotor.

Due to the fact that this motor is characterized by high values of the supply voltage frequency, it was decided to measure the temperature of permanent magnets placed in the external rotor [6]. For this purpose, a small wireless temperature logger was developed, which after installing on the surface of the rotor and connecting the sensor placed on the magnet enables continuous temperature recording. Block diagram of the recorder is shown in Fig. 4. The main element of the system is a microcontroller (μC) powered by lithium-ion battery (BAT) and voltage regulator (VR). The resistance of a small foil PT100 sensor placed on the magnet is converted to a digital by 15-bit RTD-to-digital converter (RTD-Conv) and goes to the microcontroller (μC) where it is converted into temperature. The temperature results are recorded at the specified time on the microSD card. The microcontroller used is a small size 32-bit module with ARM Cortex M0 + core. It is characterized by low power consumption with good technical parameters - for this reason it is often chosen for use in mobile electronic devices, among
others according to the concept of the Internet of Things. The described measurement module together with the battery has been mounted on the part of the shaft. In order to limit the disturbances that could affect the system, a ferrite tape was used between the shaft and the recorder and all connections were made through shielded lines (in particular the RTD sensor lines). The use of a small Li-Ion battery with a capacity allows to perform long tests with measurement of the magnets temperature without charging.

![Figure 3. Schematic diagram of the test bench](image1)

**Figure 3.** Schematic diagram of the test bench

![Figure 4. Diagram of temperature logger](image2)

**Figure 4.** Diagram of temperature logger

### 4. Measurement results

In the case of motors intended for applications in the broadly understood electromobility, the significant parameter of the motor is its maximum torque and instantaneous overload (in order to ensure good dynamics of the vehicle). The motor should also be characterized by high efficiency in a wide range of speed [7].

Figure 5 shows the map of the efficiency of the motor made on the basis of the laboratory tests results. The map covers the full range of torque up to the maximum motor torque of 750 Nm and the full speed range up to 1400 rpm, which is equivalent to the vehicle speed (Fiat Panda, wheels with 17" rims) equal to approx. 155 km/h. The following figures show the heating characteristics for various work points resulting from the actual driving parameters of the Fiat Panda.

The results of laboratory tests showed that the motor meets the requirements of the work parameters specified in table 1. With the speed of 1360 rpm, which is equivalent to the car's speed of 150 km/h, the motor is able to work for a long time with a much higher torque than it is required to overcome the motion resistance of the vehicle (Fig. 6). Such a torque reserve can be beneficial when driving in adverse weather conditions, e.g. in strong winds.

The operating temperature of the winding and permanent magnets are safe and are set at a level lower than the insulation class (180°C) and for permanent magnet during field weakening (120°C) [8].
Table 1 presents the calculated motor operation parameters for different driving conditions of the Fiat Panda with two motors built in the rear axle. Figures 7 and 8 show the temperature changes during operation under other conditions.

**Table 1. Specification of motor operation parameters for various driving conditions**

| Case                                                                 | $P_m$ (kW) | $T$ (Nm) | $n$ (rpm) | Comments                          |
|---------------------------------------------------------------------|-------------|----------|-----------|-----------------------------------|
| 1. The maximum speed of the vehicle on a flat surface - 150 km/h   | 21.4        | 150      | 1362      | The calculated power is continuous |
| 2. Vehicle speed 50 km/h - 20% elevation in the distance of 1 km    | 23.5        | 495      | 454       | Time needed - about 1.5 minutes   |
| 3. Vehicle speed 70 km/h - 15% elevation in the distance of 5 km    | 26.3        | 395      | 635       | Time needed - about 4.5 minutes   |
| 4. Vehicle speed 100 km/h - 10% elevation in the distance of 10 km  | 29.4        | 309      | 908       | Time needed – about 6 minutes     |
| 5a. Acceleration of the vehicle 0-100 km/h                         | 69.5        | 730      | 908       | Acceleration in 10s               |
| 5b. Acceleration of the vehicle 0-100 km/h                         | 59.0        | 620      | 908       | Acceleration in 12s               |
| 5c. Acceleration of the vehicle 0-100 km/h                         | 48.7        | 512      | 908       | Acceleration in 15s               |

**Figure 5. Motor efficiency map based on measurements**

**Figure 6. Temperature during the heating test: 1360 rpm, 150 Nm, 21.3 kW, 10 dm$^3$/min**

**Figure 7. Temperature during the heating test: 950 rpm, 400 Nm, 40 kW, 10 dm$^3$/min**

**Figure 8. Temperature during the heating test: 1060 rpm, 450 Nm, 50 kW, 10 dm$^3$/min**
5. Summary

The developed test stand allows for testing traction motor for installation in wheel hubs of cars in the full load and speed range. One of the most important tests are heating tests that allow to determine the time in which the motor can work with given parameters. Such tests allow to determine temperatures in important motor components during different driving conditions, e.g. when driving at maximum speed, during acceleration or when driving on a slope. The measurement of the temperature of permanent magnets is also important for developing motor for installation in the wheel hub. Neodymium magnets have an acceptable range of operating temperature which, if exceeded, may cause demagnetization of the magnets. For this reason, at certain work points, it is the temperature of permanent magnets that can limit the range of the motor's operation, not the temperature of the winding [9]. The design and testing of the electrical motor for mounting in the wheel hub should be complemented by research on the impact of the use of additional unsprung mass on the comfort of driving and the operation of the suspension system. Testing on the vehicle should allow to determine the maximum mass of motor, which has a significant impact on its design and operating parameters.

6. References

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