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Conceptual Test Rig for Real-Time Analysis of Operation of Thermostatic System of High-Voltage Components of Electric Vehicle Traction Drive

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ABSTRACT

This article describes conceptual test rig for real-time analysis of operation of thermostatic system of high-voltage components of electric vehicle traction drive in X-in-the loop tests. Integration architecture of test rigs located in European countries is discussed aiming at analysis of processes occurring in various systems of electric vehicle, such as anti-lock system, motor–wheel, suspension, thermostatic system of high-voltage components. Test modes are also described, which are required for studies of various components and systems of electric vehicles under various conditions. A set of various scenarios was required to demonstrate flexibility and speed of response of X-in-the-loop environment, as well as analysis of operation of specific systems in overall vehicle. The article describes a method to control actuators of thermostatic system implemented on test rig as well as devices for simulation of thermal and hydraulic properties of cooled objects (motor-wheels and invertors) in real time.

Key words: vehicle, electric vehicle, test rig, virtual object, thermostatic system, tests, XIL.

1. INTRODUCTION

It is possible to state for sure that the sales of new electric vehicles will increase from 2 million in 2020 to 44 million in 2025 (for a total of Russia, EU, US, and China). Electric vehicles should achieve economic competitiveness regarding conventional vehicles already in 2030, which is promoted by traffic code, especially in major cities, where vehicle traffic with harmful emissions of waste gases is restricted more and more [1]. Automotive industry faces new problems in electric vehicle segment, in particular regarding adaptation to rapidly developing technologies together with decrease in profitability as well as high dependence of operation of various systems on each other [2, 3, 4]. For instance, in order to perform motion with increased efficiency of electric vehicle, combined control of electric motors, thermostatic systems, and chassis units is necessary. Therefore, integrated studies of various vehicle systems are important in common virtual–physical environment, which would allow to integrate high amount of test rigs located all over the World. In the scope of these studies, common virtual–physical environment has been developed referred to as X-in-the-loop [5, 6, 7].

2. DESCRIPTION OF TEST RIG CONCEPT

In the scope of XILforEV international project, the concept was implemented allowing to perform virtual–physical studies in cooperation with other research and production centers in Europe.

The concept stipulates combined activation and use of multipurpose test-bench equipment, software simulators, driving simulators, etc., located in various countries aiming at integrated studies of components and systems of electric vehicles. Peculiar feature of this concept is that overall simulation of motion cycle of electric vehicle is performed in real time using all connected devices with similar parameters of involved models and environments.

In this work NAMI institution developed test rig for analysis of operation of thermostatic system of high-voltage components of electric vehicle traction drive. The test rig provides physical simulation of high-voltage components of electric vehicle traction drive in terms of temperature and hydraulic regime of the components studied on other test rigs included into XIL tests. The test was performed under the conditions simulating ambient temperature from–40°C to +50°C. The conceptual flowchart of the test rig is illustrated in Fig. 1.

During the XIL experiment, NAMI received in real time the input data from X-in-the-loop environment of European research centers. The data were transmitted using VPN and reflected current thermal and hydraulic state at output from cooling objects participating in the test as well as information about ambient environment: temperature, moisture, motion speed of electric vehicle.

The circuit of thermostatic system of high-voltage components of electric vehicle traction drive (Fig. 2), implemented on test-bench equipment, provides temperature control of devices simulating cooling objects with regard to preset limits of temperature variations of cooling fluid by variation of fluid flowrate as well as air flow passing through heat exchanger of the system by means of rpm variation of thermostatic system ventilator [8, 9, 10].

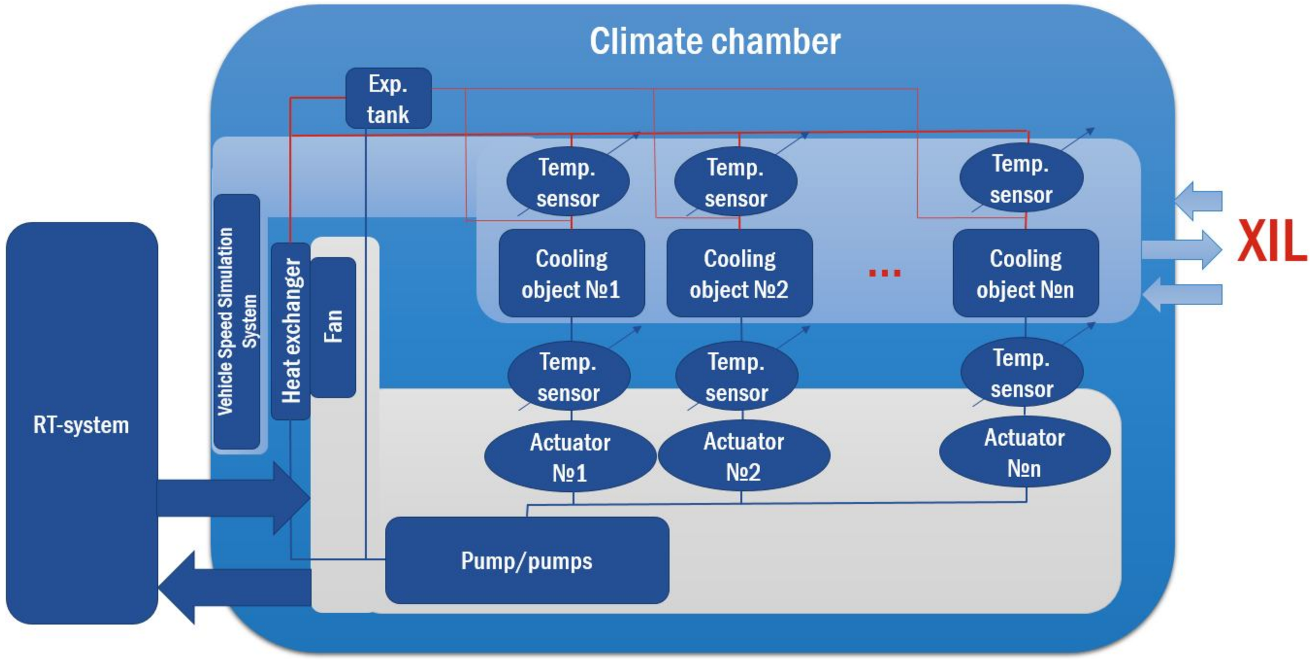

Figure 1: Conceptual test rig for analysis of thermostatic system of high-voltage components of electric vehicle traction drive

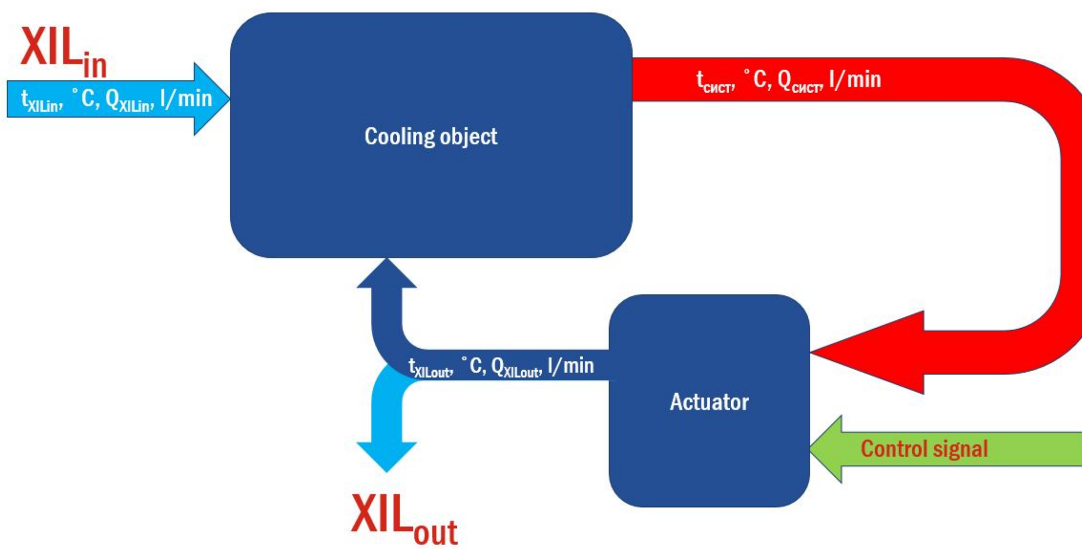

Figure 2: Circuit of thermostatic system of high-voltage components of electric vehicle traction drive

3. TEST RIG OPERATION MODES IN XIL EXPERIMENTS

During the studies a set of tests was performed aiming at demonstration of flexibility and speed of the X-in-the-loop environment, as well as analysis of operation of specific systems of integrated vehicle system. The following operation modes of the test rigs were studied in real time:

1) Mixed braking. In this scenario, a set of tests was performed aimed at analysis of mixed regenerative braking by electric motors and friction braking mechanisms as during regular and during emergency braking. In this operation mode, sharp increase of thermal energy in cooling jackets of electric motors and invertors was observed, which directly affected thermostatic system of high-voltage components of electric vehicle traction drive.

2) Mixed motion. In this scenario, a set of tests was performed aimed at analysis of integration of vehicle active suspension and electric motors to obtain high smooth ride of electric vehicle. This motion mode is also demanding to thermostatic system of high-voltage components of electric vehicle traction drive since during driving along highly rough roads, the amount of thermal energy evolved by each electric motor is different.

3) Integrated control of chassis. This scenario stipulates integration of two previous scenarios aiming at integrated

analysis of processes occurring in all considered systems. This mode allows to optimize operation algorithms of thermostatic system of high-voltage components of electric vehicle traction drive in order to obtain high efficiency of the system operation and to decrease power consumption.

4) Analysis of fault tolerance and reliability. This scenario is aimed at achievement of potential of XIL test regarding fault tolerance and reliability. This was aided by simulation of fault in one of the movers: loss of connection/reverse torque on rotor of electric motor, which exerted influence on all other components participating in the scenario comparable with behavior of actual electric vehicle. In terms of analysis of efficiency of thermostatic system of high-voltage components of electric vehicle traction drive, this scenario attracted great interest. It was required to prevent overheating of components in any variant of fault of a mover [11].

4. ELECTRON ARCHITECTURE OF TEST RIG CONTROL

The electron architecture of test rig for studying thermostatic system of high-voltage components of electric vehicle traction drive (Fig. 3) is comprised of main control unit (MCU) intended for control of operation of thermostatic system, load control units LCU1…LCUn intended for control of simulated devices, and ventilator control unit VCU.

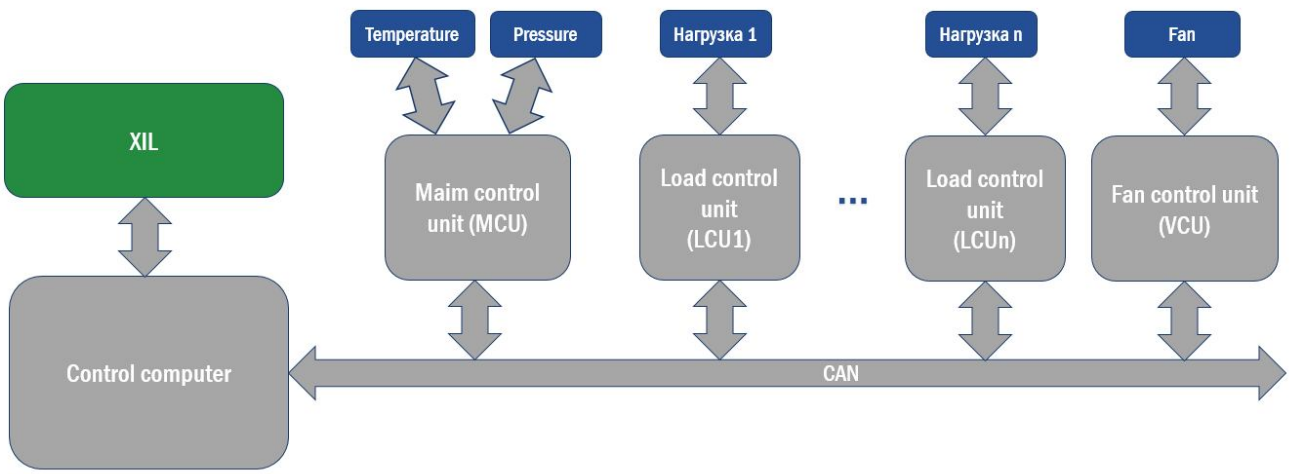

Figure 3: Electron architecture of test rig for analysis of thermostatic system of high-voltage components of electric vehicle traction drive.

MCU receives signals from temperature and pressure sensors, measures these signals and sends the measured values via communication interface (CAN) to control computer (CC). The unit receives from CC via communication interface the information about necessary states of valves and pump flowrate and sets these values.

LCU receives from CC via communication interface the information about necessary loading power (simulator) and sets this value.

VCU receives from CC via communication interface the information about necessary ventilator flowrate and sets this value.

The main information exchanged by virtual and physical parts of the system is comprised of temperature, flowrate, and pressure of fluid at input and output of the thermostatic system. The input parameters are measured and sent to the virtual part of the system in the form of signals. Interface between virtual and physical parts of XIL system is presented by the unit of data collection from sensors and the simulator (loading device) which generate physical output impacts: temperature, flowrate and pressure of working fluid. The values of these impacts are predicted by virtual model of thermostatted object and implemented by regulators and feedbacks of respective parameters.

Virtual part of XIL systems uses 1D models of thermal and hydraulic processes. Since they do not generate excessive computational loads, they can by predicted in real time, in its turn this provides acceptable adequacy of process reproduction in thermostatted components.

Regulatory control unit is the controlling part of XIL system, it calculates control signals for actuators of simulator [12]. Input variables of virtual part of XIL system are used as assigning signals for regulators. Measured values of output variables of thermostatted object, which are simulated physically, are used as feedbacks [13, 14].

5. CONCLUSION

This article presented the concept of integrated operation of the developed test rig with test rigs of European research centers including its operation modes. The developed conceptual test rig in the frames of the studies facilitated operation of thermostatic system of electric vehicle traction drive with accounting for real-time data exchange in X-in-the-loop environment including studies of European research centers. Operation of electric vehicle traction drive under various climatic conditions was demonstrated using efficient control of actuators of thermostatic system.

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