NEW SYSTEMS OF ENERGY RECOVERY AND ELECTRIC-HYDRAULIC BATTERY MOBILE DRIVE

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The article presents a brief overview of new electric-hydraulic systems of three selected earthmoving machines developed by means of mathematical modeling and simulation. These machines were as follows: a road tire roller, an excavator and a wheel loader. Their common feature was that a special innovative system was developed for each of them by Bosch Rexroth company (Brno) in cooperation with BUT (Brno University of Technology) using mathematical modeling of hydraulic, mechanical and electrical processes in the machines. Each of these machines represents an innovation: a module for the recovery of kinetic ("braking") energy was developed for the road roller, and an emission-free electric battery drive for the excavator and the loader as a replacement for the diesel engine drive.

KEYWORDS

hydraulic, electric, drive, system, modeling, simulation

1 INTRODUCTION

In an effort to reduce the fuel consumption of the engine of working machines, according to specific conditions, a solution can be sought, for example, in the recovery of the kinetic energy of the roller. On the other hand, elimination of chemical emissions and reduction of acoustic emissions can be achieved by substitutionn of an internal combustion engine with an electric motor. Hydraulic systems must then be re-adapted so that they can perform their function in new conditions. To do this, it is necessary to carry out an analysis [Pourmovahed 1992a], [Pourmovahed 1992b] to create mathematical-physical models and optimize solutions by simulation. In our case, it was the Amann road tire roller E19.

excavator up to 2 tons produced by the company Bobcat Doosan and the Dapper 5000 wheel loader manufactured by VOP, s. p., CZ.

2 THE ROAD ROLLER AMMANN AP 240 H

For the first of these machines - the Ammann road tire roller (Fig. 1) manufactured by Ammann Nove Mesto nad Metuji – the solution was the recovery of kinetic energy during its cyclical working movement back and forth.

Figure 1. The road roller Ammann AP 240 H

Figure 2. The experimental stand

With standard brakes, this energy is wasted during regular braking and uselessly converted into heat escaping into the surroundings. The purpose of our research was to recover this energy and convert it into the pressure energy of the gas in the hydraulic-pneumatic accumulator and use it for the subsequent start of the roller.

The experimental stand (Fig. 2) [Nevrly 2015] for research of kinetic energy recovery consists of the following main parts: electric motor, axial piston pump, hydraulic motor, valve block, high pressure bladder accumulator, low pressure bladder accumulator, dynamometer as a load, tank, measuring system, control system, and connecting elements (piping, hoses).

The stand served as a physical miniature of the technical core of the twenty tons weighing road roller, on which it was possible to perform experiments and their analysis in laboratory conditions and verify the created mathematical models of events that took place on a larger scale on the road roller itself. The aim was to use mathematical models and simulations to find a method of how to capture the kinetic energy of the braking roller, which is unnecessarily wasted by the brakes of standard road rollers, and use it for the subsequent start of the machine.

The recovered kinetic energy of the innovated road roller is thus used cyclically when the cylinder starts. It is cyclically stored and pumped from hydro-pneumatic accumulators, where nitrogen gas serves as a gas spring.

As an experimental vehicle demonstrating the kinetic energy recovery, a hydromobile [Mikula 2012], [Stodolak 2012] (Fig.3, 5) was built as a miniature garbage truck. Using the recovered energy, it raised imitation of trash cans.

Figure 3. The hydromobile in the International Engineering Faire in Brno

The design of the important valve block (Fig. 4, 6) for the distribution of pressure oil was developed in several steps. In the first stage, a simplified model of the distribution block was created with the design of individual main flow branches and drilling for built-in valves. After verifying the design in accordance with the hydraulic scheme, additional holes were drilled in the valve block for logical control of individual valves. The design of drilled holes related to two-way valves was created in accordance with the ISO 4401 standard, dealing with the layout of individual ports (Hydraulic fluid power-Mounting surfaces).

Figure 5. Inside of the hydromobile

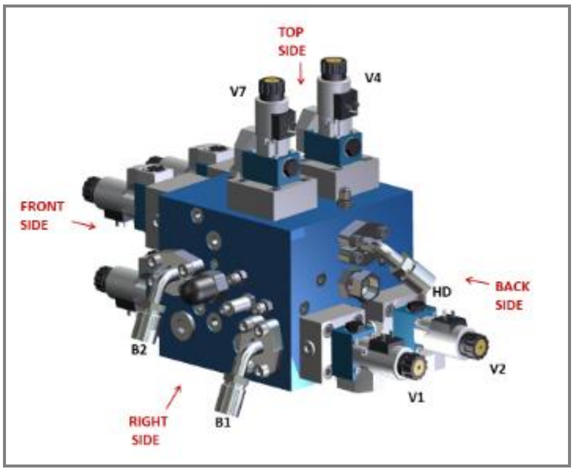

Figure 6. The final design of the valve block

Flanges from VOSS, which are commonly applied by Bosch Rexroth and meet the required compatibility criteria for connection to the AP 240 H road roller, were used to connect the individual inputs and outputs of the main branches. In order to meet the safety requirements, two safety valves were integrated in the circuit.

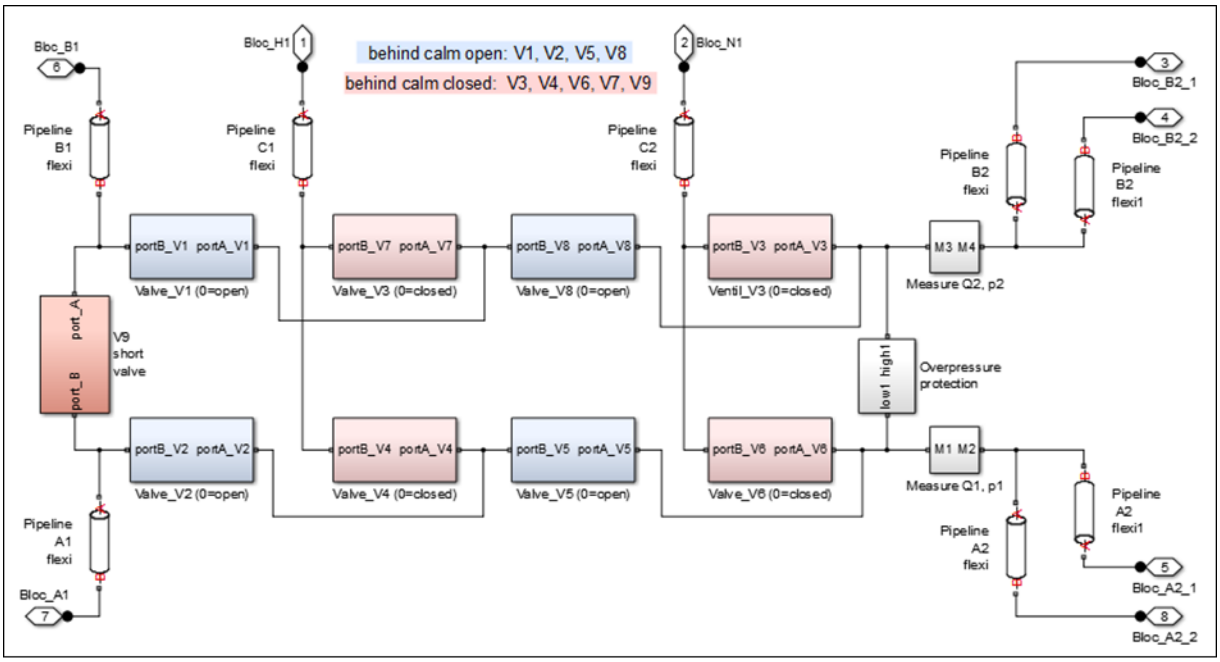

Figure 4. The structure of the model of the valve block

Figure 7. The Ammann roller with recuperation module

Achieved results:

Fuel savings: up to 26.6 %, lowering of CO2 and NOx emissions, prolongation of braking system lifetime, improvement of machine acceleration.

3 ELECTRIC-HYDRAULIC EXCAVATOR E19

In the second case, mathematical modeling and simulation were used, but this time to help to replace the internal combustion engine with an electric motor at the excavator.

The electric drive powered by electric accumulator as a single source of energy was a fundamental innovation in contradiction to the traditional drive of excavator equipped with an internal combustion engine. In our case, we innovated the excavator E19 up to 2 tons produced by the company Bobcat Doosan. To simulate the electric motor, the power and torque behaviour during excavator working cycles were analysed.

The system with the electric motor consists of the following main parts (Fig. 8): battery charger, battery, control system [Vorel 2016], electric motor with controller and hydraulic motors. Testing of machine functions was performed by a system of targeted measurements of excavator parameters with subsequent data processing and verification of mathematical models. Mathematical models of subsystems in the Matlab/Simulink environment were compiled using the industry-oriented toolboxes Simscape, SimHydaulics etc.

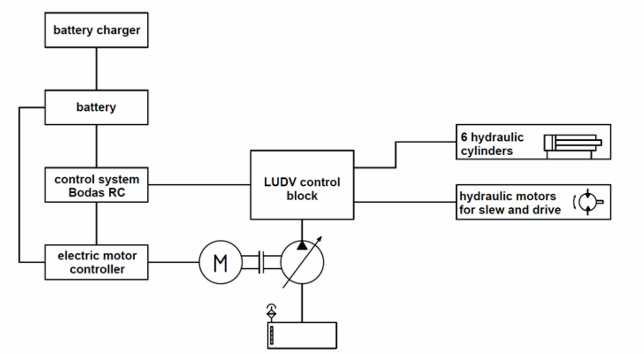

Figure 8. The system with electric motor and single axial piston pump

Figure 9. The excavator E19

- Type: LLiFePO4
- Nominal voltage: 48 V
- Electric charge: 180 Ah
- Maximum output current: 200 A

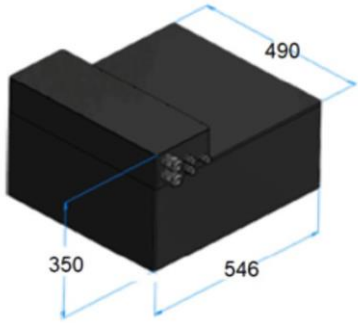

Figure 10. Electric battery

(dimensions in mm)

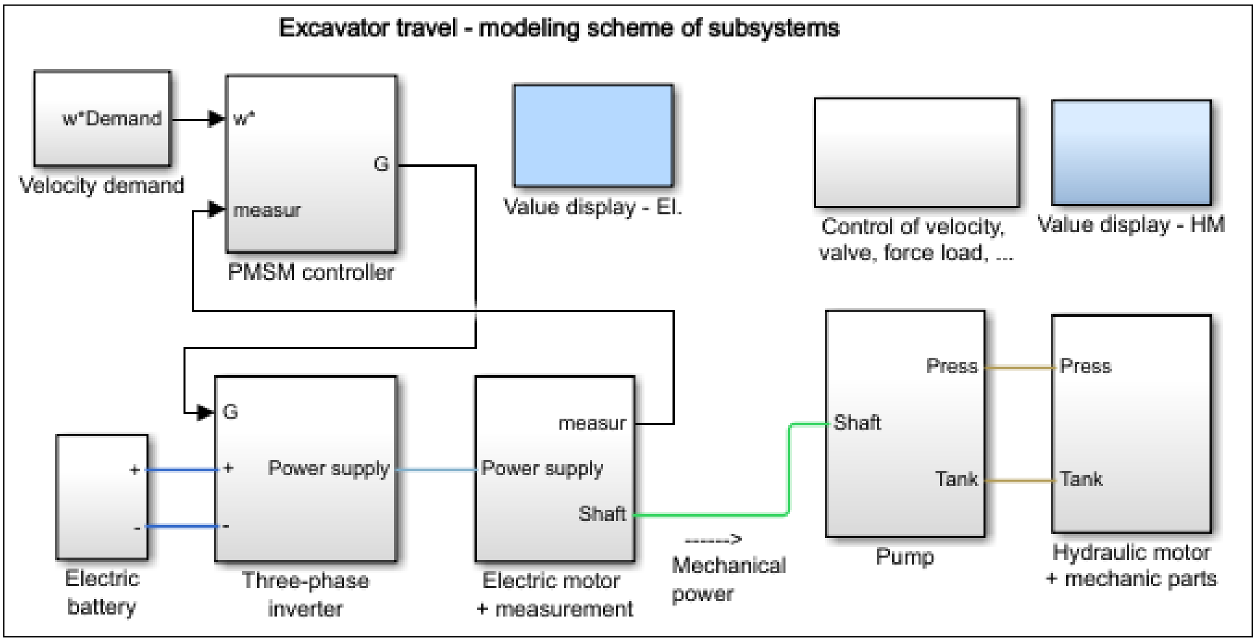

Figure 11. The structure of the model of electric drive of the excavator

The former combustion engine was replaced by an electric motor [Vorel 2016] chosen according to a large set of measured data application with the combustion engine. The model was then used for prediction of dynamic and static requirements on the electric drive given by the excavator operational diagram. Because the PMSM electric motor was manufactured as a prototype, it was necessary to properly measure the motor parameters to build a realistic motor model. The structure of the model of electric drive of the excavator is shown in Fig. 11 [Nevrly 2020]. Some simulation results are shown in Fig. 12.

The electric drive of the excavator was created with a patented control system of its subsystems, the operation of which is free of gaseous and, to a large extent, also noise emissions, unlike the original drive using an internal combustion diesel engine.

4 THE DAPPER 5000 LOADER

Even in the third case of described earth moving machines, mathematical modeling and simulations were used. As in the previous case, it is a replacement of an internal combustion engine with an electric motor. The intention was to switch to an electric motor powered by a rechargeable electrochemical source (hereinafter: battery). This requires a new approach to drive design, but it can also benefit from new loader features - better movement dynamics, emission-free operation, less noise, etc. The drive is divided into two circuits - the first supplies the necessary energy for the four-wheel drive and the second supplies the oil with a hydraulic switchboard, which supplies the upper part of the machine with pressurized oil.

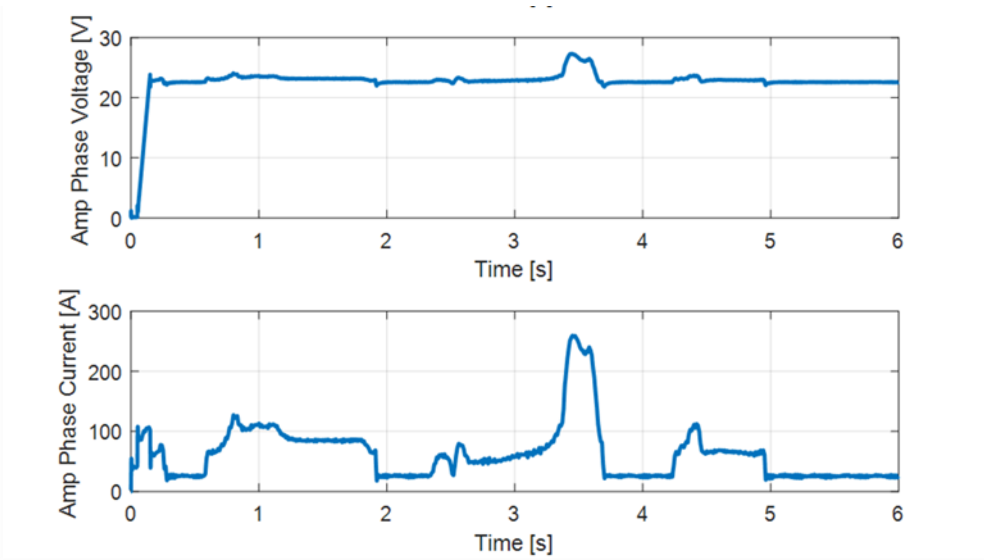

Figure 12. Example or time courses of simulated quantities

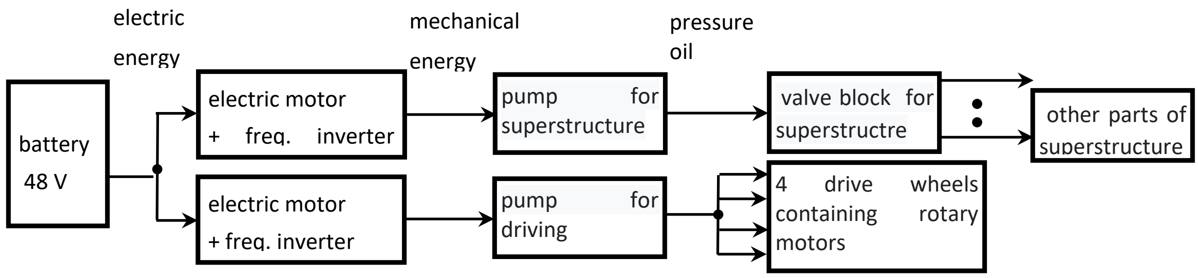

Figure 13. Drive in terms of energy flow

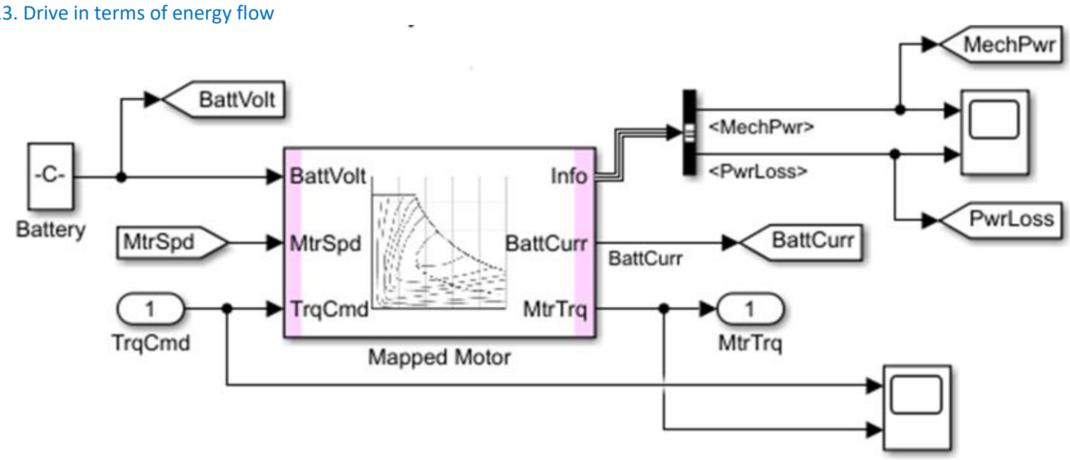

Figure 14. The structure of the model of the electric motor

A battery with a nominal voltage of 48 VDC and a three-phase synchronous motor with permanent magnets - PMSM (nominal power 12 kW, maximum power 20 kW, nominal speed 3000 rpm) were used for the tests. The frequency converter is a control unit that implements the vector speed control of the connected three-phase motor. The axial piston pump is a product of Bosch Rexroth. The structure of the model of the electric motor with connections is shown in Fig. 14. The specialized "Mapped Motor" block is a sophisticated universal block with many internal setting (configuration) options. Speed control is part of the function of the electric motor controller. The correct setting of the controller has a fundamental effect on the driving behavior and must be given due consideration during commissioning.

Figure 15. Electric motor control, part with speed and torque control

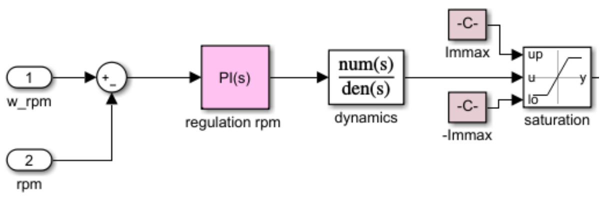

Figure 16. The Dapper 5000 wheel loader

Fig. 15 shows a part of motor speed control and torque setpoint generation [Nemec 2020]. This is a part that affects the stability of the drive. The influence of nonlinearity limiting the current to the motor as well as the variable moments of inertia in loads are important for stability. The Dapper 5000 wheel loader is shown in various working positions in Fig. 16. The models were verified by tests, an example can be seen in Fig. 17.

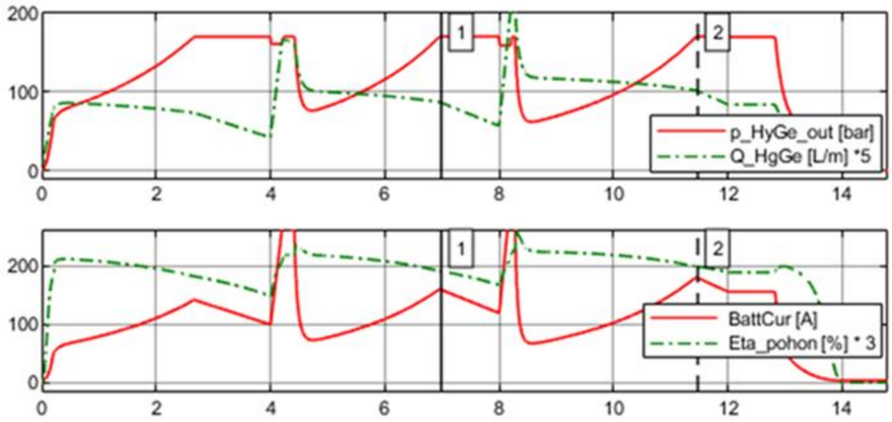

Figure17. A sample from model verification tests

Time [s[]

5 CONCLUSIONS

In all three described earth moving machines, the use of mathematical modeling was crucial, e.g., in the design of the road roller valve block in kinetic energy recovery, in the adjustment of the speed controller for the Dapper 5000 loader and in the investigation of various combined problems. Without the use of mathematical modeling in the developed machines, the fuel consumption of the Ammann road roller would not have decreased by as much as 26.6% and the described electrification of the E19 excavator would not have been awarded a Gold medal in 2018 at the International Engineering Fair in Brno.

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