METHODOLOGY OF HYDRAULIC SYSTEM DEVELOPMENT USING EXPERIMENTAL STAND AND COMPUTER MODELING

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This paper deals with creation of methodology that can be effectively used in design and development of a more complex hydrostatic system. In future, the designed hydraulic system should fulfill given functions respecting the given parameters. It is usually possible to create such a system using several methods but not all of them lead to a full success without a risk of failure. It is not possible to create clear-cut directions for reliable option of design methodology but in dependence on the type of solved problem and demands on the results, a suitable choice of methodology can be shown e. g. by means of an example of verified and successful process of system designing.

Using the concrete example, the paper shows a methodology of successful development of a hydraulic system where demanding research claims had to be fulfilled. To carry out this research, it was necessary to use a special experimental stand and computer modeling to gain the optimum effectiveness.

KEYWORDS
methodology, project, design, development, hydraulic, system

1. INTRODUCTION

A development of a more complex hydraulic system represents a number of steps of sequential solution of partial stages, reaching of partial goals by their suitable combination until the final goal is at last reached. This goal is a functional hydraulic system meeting the determined requirements.

When developing a more sophisticated hydraulic system, it is necessary to choose a suitable advancement – methodology -to reach the necessary results in usually a limited time. Creation or choice of such methodology is of basic influence on the whole course and result of the work which can consist of activities of a number of institutions, teams and also individual specialists. The methodology of how to solve the task is often a part of grant application; therefore the methodology preparation offers a more extensive use. A successfully defended international grant project presented in this article can serve as an example of applied methodology.

2. DEMANDS ON PROJECTS OF HYDRAULIC SYSTEMS

A design of any technical system is connected with demands corresponding to specific properties of the type of designed system. Different demands can be found in connection with e. g. electric systems in comparison to mechanical or hydraulic ones, etc. In the case of design of hydraulic systems, it is necessary to take into consideration their particularities [Pourmovahed 1992], e. g.: compressibility of liquid transfer medium and variability of its compressibility module in dependence on pressure, elasticity of elements of pipes, necessity of experimental determination of size or function dependences of some loss coefficients both in stationary end dynamic processes, hydraulic impact, cavitation, necessity to include the solution to the related mechanical or electric problems in the design, a final speed of propagation of pressure excitement in liquid, leeks of liquid and leakage problems, specific software for modeling and simulation of activities of designed hydraulic system as well as software for its graphics, measuring and evaluation of sizes and courses of measured hydraulic quantities, etc. [Pourmovahed 1992a], [Stecki 2002], [Nevrly 2005].

3. FORMS OF DESIGN OF HYDRAULIC SYSTEMS

According to the demands on the problem solution, the variants of design of hydraulic systems can occur; these include a potential use of the experimental stand and a computer for modeling [Zavadinka 2012], [Nevrly 2011] and simulation, and for graphic processing of the design.

Let us consider e. g. the regimes referred to in the following table where the presence or absence of corresponding item is marked by a sign.

regime	1	2	3	4	5	6	7	8
with laboratory stand	–	–	–	–	+	+	+	+
with computer modeling and simulation	–	–	+	+	–	–	+	+
with final realization of design	–	+	–	+	–	+	–	+

Tab. 1. An example of possible methodology regimes

Let us notice the properties of some regimes referred to in Table 1.

Regime No. 1:
This proposal is performed without the use of laboratory stand, computer modeling, and final realization of design.

This type of proposal can be found e. g. during the work on basic studies, preliminary indicative solutions, etc. It is not necessary to use a stand; costs are reasonably low, the design is not physically realized.

Regime No. 2:
This proposal is performed without the use of laboratory stand and computer modeling, with final realization of design.

This proposal is focused on final design realization; its solution is so accessible that the use of laboratory stand and modeling is not necessary; costs can be higher in comparison with the previous regime owing to the corrections or amendments related to the design realization.

Regime No. 5:
This proposal uses a laboratory stand without final realization of design.

In this case, as it is necessary to use a laboratory stand, the proposal claims are more demanding. Standard methods are not sufficient here and it is necessary to use the experiment. Costs, time and staffing demands are adequately raised.

Regime No. 8:
This proposal uses a laboratory stand, modeling, and final design realization.

This case is the most demanding one [Wei 2014], [Nevrly 2015], because the final realization of design is required. A number of activities are connected with this realization. Costs, time and staffing demands on the design are the highest ones in comparison to other cases.

A growing complexity of the design brings about growing demands on the methodology of design solutions which represent a basis and a necessary prerequisite for coordination of the whole project. The best way how to show the whole process is to introduce a particular example. The last mentioned type of design methodology, using a laboratory stand, computer modeling and final design realization, can serve as an example.

4. EXAMPLE OF DESIGN METHODOLOGY OF REALIZED HYDRAULIC SYSTEM USING EXPERIMENTAL STAND AND MODELING

The design methodology of the international project of EUREKA entitled "Hydrostatic system for energy recovery in commercial vehicles" solved by Brno University of Technology and partners (2012-2014) was chosen as an example of design methodology of realized hydraulic system using an experimental stand and modeling. This project was focused on research and development of a new product – a recovery hydrostatic module – for energy recovery through breaking and acceleration of commercial vehicles using a control for energy transfer optimization based on mathematical modeling of the system functions.

Figure 1. The road roller AMMANN AP 240 H

The principal idea of this system is to use the kinetic energy of the braked vehicle which is commonly lost by braking and changed ineffectively into heat and wear of brakes. This was realized by the change of kinetic energy to hydraulic energy that is used through the following acceleration of the vehicle. In this way, the load of the combustion engine is reduced; savings of fuel can reach up to 25 % together with the increase in economical effectiveness and ecology of operation. This system is especially suitable for vehicles working in frequent cycle of acceleration-deceleration as e. g. forklift trucks, rollers, etc.

The result of the project is a prototype of the recovery hydrostatic module which was tested in real conditions on a selected vehicle – the roller Ammann AP 240 H (Fig. 1). The economic importance of the project follows from the possibility of wide use of project output as a new kind of efficient and ecological drive on the global market.

Owing to the complexity of the project, it was necessary to select a suitable variant according to Tab. 1 and to create a suitable design methodology. The regime No. 8 described in Tab. 1 was chosen as the only suitable variant for the project solution.

4.1 Main goals and results of the project

The project was focused on research and development of a new product – a hydrostatic system for energy recovery through breaking and acceleration of commercial vehicles using a control for optimum energy transfer based on computer modeling of the system functions. This project brought about marked economic contributions for the operation of mobile working equipment with cyclic operational regime – about up to ¼ savings of fuel consumption of the vehicles – as well as the increase in their ecology and reliability.

Technical principle of solution

A special valve block is connected between a pump and a hydrostatic converter (hydraulic motor/pump) in the stand (and finally in the road roller), and a high-pressure hydro-pneumatic accumulator of a suitable size and also a low-pressure hydro-pneumatic accumulator are connected to the circle. During breaking, kinetic energy is accumulated in the high-pressure accumulator. The exchange of oil takes place between these accumulators during breaking or acceleration of the vehicle. This energy is used during the following acceleration and in such a way the fuel used to drive the combustion engine is saved. The whole process of energy recovery is electronically controlled.

The introductory part of the project is first of all oriented at the analysis of activity of the equipment for energy recovery and its application. Conceptual design solutions of hydrostatic recovery module and its parts were continuously verified and optimized during this stage of research by means of simulations of hydraulic processes taking place in the designed experimental stand. Simulation results became a basis for the design of resulting solution variant.

Due to the necessity to perform experiments using the experimental stand and experimental vehicle whose full weight reaches 24 tons e. g. during measurements of its rolling resistance coefficient, weighting, etc., the analysis of safety risks with the aim to eliminate a potential risk of injury was carried out Simulation models of parts and also mounting of the hydraulic system in the road roller were built up in order to optimize the energy efficiency, valve timing of the valve block of recovery hydrostatic module, sizes of accumulators and other technical parameters and to minimize the pressure and energy losses. These models were built up in connection with numerous measuring results of hydraulic, mechanic, electric and pneumatic quantities taking part in static and, first of all, dynamic processes taking place in the explored regimes of road roller operation.

Prior to measurements, measurement requirements on the roller for simulation and optimization purposes were determined, a methodology of measurement and evaluation of results was created, measuring devices were prepared measurements and their evaluations were repeatedly carried out, mostly in electronic form. Data from significant measurements were continuously saved.

The recovery hydrostatic module (RHM) was built up as a result of research activities; it was implemented in the mobile working machine and tested in real operational conditions.

4.2 Methodology of design solution, main stages of design

Stage 1
- – E1-1 – Conceptual draft proposal
- – E1-2 – Design of experimental stand and computer models
- – E1-3 – Simulation and testing of models

Stage 2
- – E2-1 – Design of prototype of recovery hydrostatic module
- – E2-2 – Design of adjustments of mobile machine
- – E2-3 – Production and mounting of RHM prototype in the mobile machine
- – E2-4 – Testing of RHM prototype

Stage 3
- – E3-1 – Operational tests of the prototype in real conditions

5. MORE DETAILED METHODOLOGICAL SCHEDULE OF MAIN STAGES

For greater clarity, this chapter will illustrate selected graphic displays – charts, graphs, photographs, etc., allowing a better follow-up of the methodology of design solutions and the schedule of solved tasks.

5.1 Methodology of design solution during Stage 1

E1–1 – Conceptual draft proposal

time of realization	1/2012 – 6/2012
subject of solution	An analysis of previous technical solutions, principles and possible solutions, conceptual draft design, basic mathematical and simulation models of functions of the experimental stand and RHM, which was developed and used as an prototype in particular mobile working land machine.
output	a) literature and patent search, conceptual draft design applicable to the analysis of functioning of real equipment for energy recovery and search for methods of optimum control b) design of basic computer models of processes in the proposed stand c) basic design of measuring, control and software equipment for simulation of processes in the stand

E1-2 – Design of experimental stand and computer models

time of realization	6/2012 – 9/2012
subject of solution	design of the stand (Fig. 2) and specification of mathematical models for simulation of processes and ongoing optimization of control
output	a) constructional design of stand b) specification of computer models according to the constructional design a) design of control system including software and hardware equipment

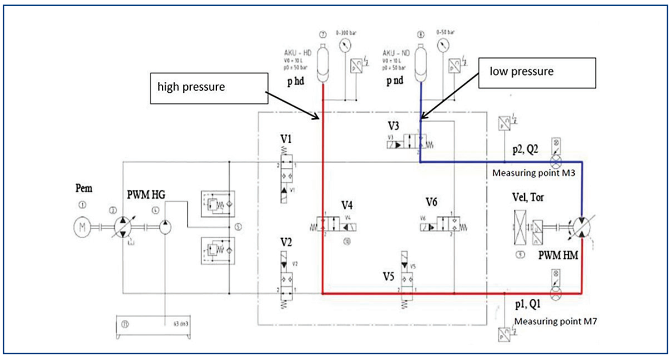

Figure 2. Simplified scheme of the stand for deceleration operational regime

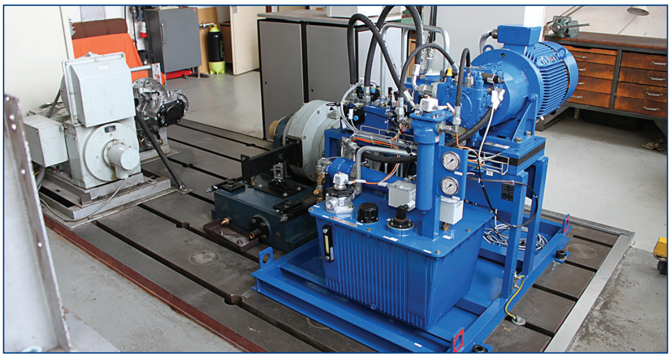

Figure 3. Experimental recovery stand

E1-3 – Testing of mathematical models and simulation

time of realization	9/2012 – 12/2012
subject of solution	The goal of this stage is testing of functionality of computer models of energy recovery processes under laboratory conditions in different operational regimes, specification of computer models, optimization of stand elements, optimization of recovery control, building up of algorithms of optimized control
output	a) composition of laboratory hydraulic stand (Fig. 3) b) results of measurements on the stand c) verified computer models of processes under different conditions of stand operation (Fig. 4, Fig. 5), optimized configuration of stand elements, optimum control of recovery in the stand, publications

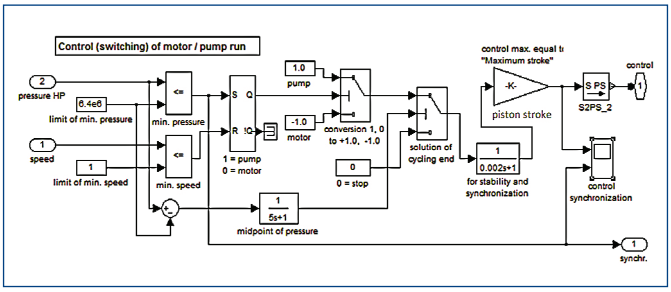

Figure 4. Simulation model of control for cyclic recovery regime

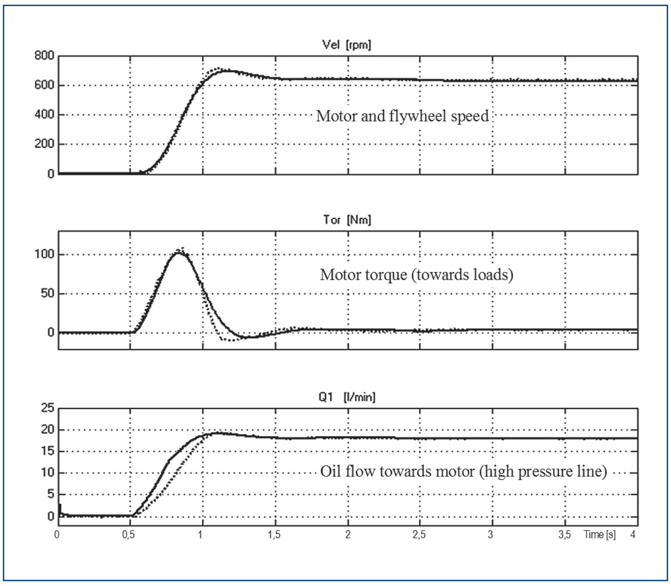

Figure 5. Comparison of simulation results (continuous curves) of hydraulic circuit and measuring results (dashed curves)

5.2 Methodology of solution during the Stage 2

E2-1 – Design of prototype of recovery hydrostatic module (RHM)

The recovery hydrostatic module was designed and produced due to the application of results gained in laboratory conditions and it was used in the selected working land machine in the form of functional sample.

time of realization	1/2013 – 2/2013
subject of solution	The goal of this stage is the application of results from the previous stage in the constructional design of RHM prototype, design of measuring and software equipment.
output	a) constructional design documentation of RHM for energy recovery in mobile working machine for the analysis of different operational conditions and for verification of methods of optimum control (Fig. 6) b) design of measuring and software equipment. c) algorithms of simulation models of processes [Filipi 2010] studied on the real equipment

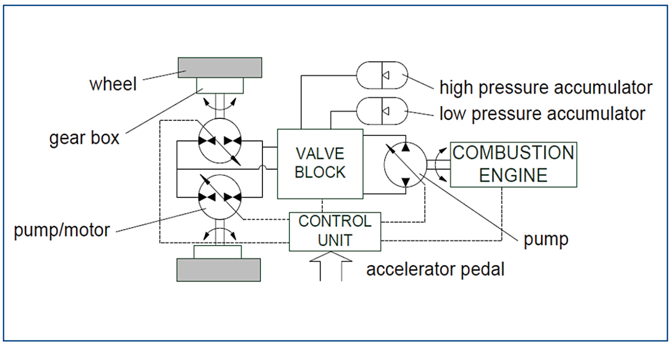

Figure 6. Simplified diagram of the vehicle with hydrostatic recovery drive

E2-2 – Constructional design of mobile machine adjustments

time of realization	3/2013 – 5/2013
subject of solution	Subject of this stage is a constructional design of adjustments of selected real machine where the RHM will be installed and tested.
output	a) constructional design of RHM (Fig. 7, Fig. 8), constructional adjustment of the mobile machine b) specification of simulation models in connection to the constructional design of RHM

E2-3 – Production and mounting of RHM prototype in the mobile machine

time of realization	6/2013 – 9/2013
subject of solution	The subject of this stage is mounting of RHM in the adjusted mobile machine (Fig. 9).
output	RHM mounted in the selected mobile machine. Basic algorithms of optimized control [Wang 2009] of the entire system of energy recovery using computer models of recovery processes.

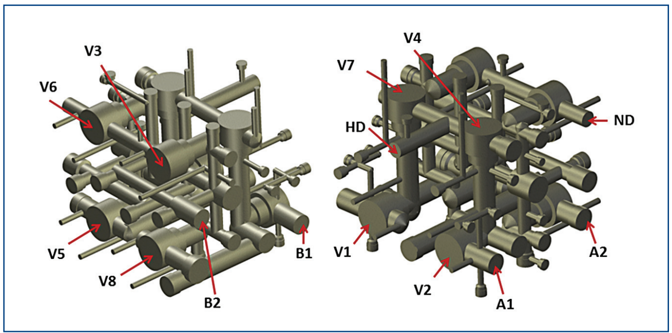

Figure 7. Borings in the valve block

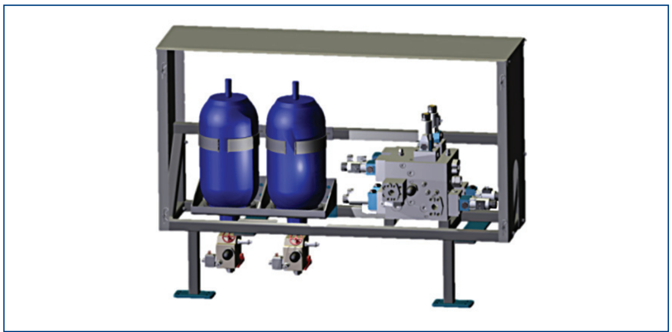

Figure 8. Recovery hydraulic module

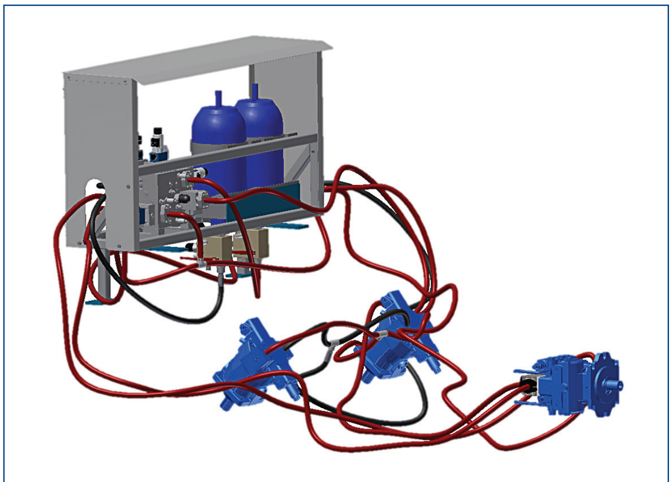

Figure 9. The set of recovery hydraulic system with pump and hydraulic motors

E2-4 – Testing of RHM prototype on the vehicle

Basic regimes of experiment and measurements

Following operational regimes were selected for evaluation and verification of correctness of simulated processes:

a) drive at constant speed
b) acceleration
c) breaking

time of realization	10/2013 – 12/2013
subject of solution	The goal of this stage is testing of functionality of the basic set for energy recovery in the adjusted vehicle.
output	Results of RHM functionality tests on the adjusted vehicle.

5.3 Methodology of solution during the Stage 3

E2-1 – Operational tests in real conditions – optimization of parameters

time of realization	1/2014 – 12/2014
subject of solution	The subject of this stage is to fine-tune [Heikkilä 2013], [Nevrly 2014a], [Nevrly 2014b] and on the vehicle to test the RHM for hydraulic energy recovery with optimized control (Fig. 10).
output	Results of operational tests of the recovery system with optimized control (Fig. 11), publications [Nemec 2014], [Nevrly 2014c], [Nevrly 2014d], functional sample, presentation materials.

Figure 10. Borings in the valve block

This newly developed recovery hydrostatic module [tv-news report] is considered to be the first worldwide equipment which is able to effectively operate in common vehicles working at low speeds up to 9 km/hour, e. g. road rollers. Savings of fuel can reach up to 25 % together with the increase in economic effectiveness and ecology of operation.

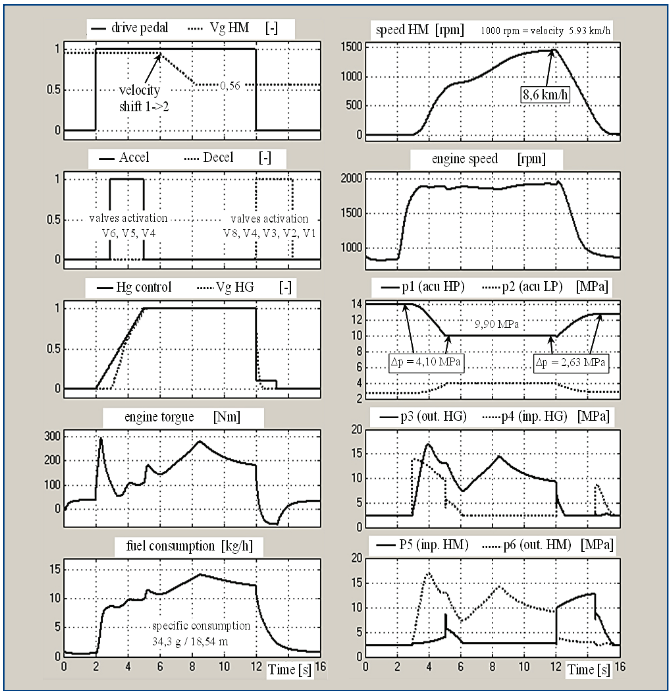

Figure 11. Example of start and stop courses: energy recovery with weight load

6. CONCLUSION

The methodology of development of a hydraulic system has, especially in more sophisticated cases, a principal influence on time course, costs and quality of solution. Therefore it is a factor that should not be neglected and a needful attention should be paid to it to avoid pointless losses.

As mentioned in this paper, it is possible to use different methods for determination of correct methodology; it depends on the nature of the solved problem, time, financial, technical and other conditions as well as on the experience which variant to select. Of course, for simple cases, it is not necessary to build up and use the experimental stand or simulation models, and vice versa.

As in the simplified example shown in this article, it is obvious that it is necessary not only to choose the correct methods of solution but also to respect the relevant and in advance planned relations, time and space sequences of activities to reach a quality, well-timed and cost-saving development of hydraulic system. The role of proper methodology is irreplaceable for the design of a more complex hydraulic system.

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