AN ENERGY EFFICIENT APPROACH ON AN ELECTRO-HYDRAULIC DRIVING SYSTEM FOR PUBLIC UTILITY WORKS VEHICLES

Iulian-Claudiu DUȚU[1], Tiberiu AXINTE[2], Ionaș-Cătălin DUMITRESCU[3],
Oana VLĂDUȚ[1], Mihaela-Florentina DUȚU[1]
[1]University Politehnica of Bucharest, Romania
[2]Research Center for Navy, Constanța, Romania
[3]Hydraulics and Pneumatics Research Institute, Bucharest, Romania

Abstract: *Energy efficiency is nowadays a very important criteria when developing industrial or mobile applications from various technical fields, requiring the engineers to use updated concepts, smart technologies and digital connectivity solutions. Regarding the improvement of energy efficiency for a certain technical application, in most of the cases the research and engineering teams must develop new modules or subsystems, retrofitting the existing ones may lead to undesirable complex circuits or installations, very difficult to maintain. In a narrower case, when referring to a public utility works vehicle, energy efficiency is a very sensitive aspect due to the limited number of resources available (diesel, petrol, electric) to generate energy on a mobile machinery. As a complex system, most of its key subsystems must be optimized regarding overall productivity, ease-of-use when interfacing the human operator, increased flexibility, high energy efficiency and reduced maintenance costs. In this paper the authors propose an energy efficient electro-hydraulic driving system used for the waste pressing module of a public utility works vehicle, as an alternative to the existing one. The modeling and simulation of the electro-hydraulic driving system was made using FESTO FluidSIM software environment.*

Keywords: *energy efficient, hydraulic drive, electric control, automation, FluidSIM.*

INTRODUCTION

Hydraulic driving systems are generally used in majority of fixed or mobile industrial applications, their technical advantages still cannot be overcame by other driving systems that use mechanical, pneumatic, electrical or hybrid solutions. The use of electro-hydraulic drive systems on public utility works vehicles is a common practice, but some cases a very good technical solution is not necessary an energy efficient one. Today's mobile hydraulic systems are often complex, perform different tasks and work under different load conditions, which makes it difficult to analyze energy losses, [1]. A part of the results presented in this paper were obtained within a national research and development project, which originated from a specific demand of a Romanian company acting in the field of design and manufacturing public utility works vehicles. The general application area relates to the improvement of overall energy efficiency of such vehicle through modifying or re-designing some major electric and hydraulic drive subsystems. In order to maximize energy efficiencies in hydraulic systems, mechanical and volumetric losses must be balanced so the sum of these losses is minimized, [2]. In this paper, the authors focus their work on a waste pressing module of the public utility works vehicle.

Nationally, state-of-the-art when regarding the field of manufacturing public utility works vehicles show that it cannot be found a professional company that is able to offer a full technical custom solution, client's demands are mostly covered with imported new or second-hand utility vehicles.

The novelty aspects that the authors would like to emphasize are regarding the structure of hydraulic driving and electric control subsystems. In this respect, the hydraulic drive will use an optimized schematic, thus reducing to a technological possible minimum the energy losses generated especially through throttling and inadequate topology of hydraulic equipment. A second research topic focuses on the possibility of storing hydraulic energy in a battery of accumulators when the vehicle is in passive working phases (such as moving to an intervention area) and transfer it back into the electro-hydraulic system when necessary in the active work phases.

Currently, research and engineering teams use modeling and simulation activities in most of their projects, testing and optimizing virtual experimental models before releasing them into development. On the market there is available a fair number of virtual tools offering professional software packages that target on a single field of engineering or on cross-field engineering. Computer simulation is a powerful and generally accepted practice to carry out research in the arm of fluid power, [3]. When intending to model an equipment or a system it must be taken into consideration some initial conditions or simplifying hypotheses, that can or cannot produce errors in the model itself. Generally, a simple equipment is relatively simple to be modeled, but when modeling a complex equipment or system there must be assumed the existence of some discrepancies between virtual and physical models – leading, sometimes, to significant errors when simulating the model. Another issue here is related to proper modeling of the physical environment where the equipment or system functions. It must be noted that another type of modeling errors may arise when defining constraints between the functional parts of a complex equipment. Powerful modeling and simulation software tools significantly reduce modeling errors by offering the user predefined and preconfigured part libraries that can be customized in a very high level of detail.

COMPONENTS OF THE ELECTRO-HYDRAULIC SYSTEM

1.1 Hydraulic driving subsystem

In numerous industrial solutions as well as in mobile machinery field, hydraulic driving is used due to its many technical advantages, such as: fast response, significant load stiffness, large power density, and superior stability, [4]. One major disadvantage of hydraulic driving is high energy consumption, [5], along with complex layout of the installation. Taking into consideration the energy efficiency related issues of the hydraulic systems, [6], in general, the authors propose a simplified schematic, transferring most of the control signals and their processing from hydraulic to electric field. As can be seen in Figure 1, the schematic of the hydraulics subsystem has a simple construction, using mostly standardized equipment thus having a positive financial impact on the overall cost when constructing the electro-hydraulic driving system.

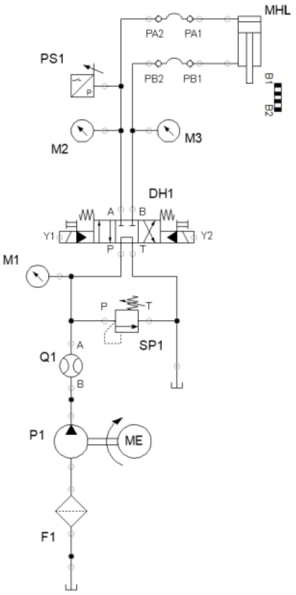

Figure 1: Schematic of the hydraulics subsystem

The hydraulic subsystem can be seen as consisting of several functional modules, as follows: power generation with a safety feature, directional fluid control, electronic/mechanical measurement and linear movement generation. Main components of the hydraulics subsystem are given in Table 1.

Table 1: Equipment used in hydraulics subsystem

No.	Equipment ID	Equipment name	Used	Functional module
1	F1	Hydraulic oil filter	1	Power generation
2	P1	Fixed-displacement pump	1	Power generation
3	ME	Electric motor	1	Power generation
4	Q1	Electronic flow-meter with display	1	Measurement
5	SP1	Pressure-relief valve	1	Safety
6	M1 … M3	Pressure gauge with dial	3	Measurement
7	DH1	Electro-hydraulic directional valve	1	Directional
8	PS1	Electrical, adjustable, pressure switch	1	Measurement
9	PA1/PA2, PB1/PB2	Flexible pressure line, with fittings	2	Directional
10	MHL	Double-acting hydraulic linear motor	1	Movement generation
11	Y1, Y2	DC solenoid valve coil	2	Directional
12	B1, B2	Electro-mechanical limit switch	2	Safety

1.2 Electric control subsystem

As stated before, authors tried to design the global schematic of the electro-hydraulic system in such a way that most of the control signals and their processing are transferred from hydraulics to electric subsystems. This implies that the electric control subsystem will have a much more complex schematic than the hydraulics subsystem. Processing control signals using specialized hydraulic equipment is not an easy task, certainly the schematic will be far more complex than using electric processing. In fact, when comparing a single functional task of a control algorithm for a public utility work vehicle, it can be seen that the electric processing is easier to implement, far more reliable than hydraulics, needs few maintenance procedures and the overall cost is significant lower. As future development, the authors intend to use a programmable logic controller (*PLC*) to control most of the functions available on the utility work vehicle.

There is given in Figure 2 the electrical control subsystem schematic and in Table 2 the electric parts used here. The authors used FESTO FluidSIM software environment, both hydraulic and electric modules, for modeling and simulating the relay-logic schematic designed to control the hydraulic subsystem.

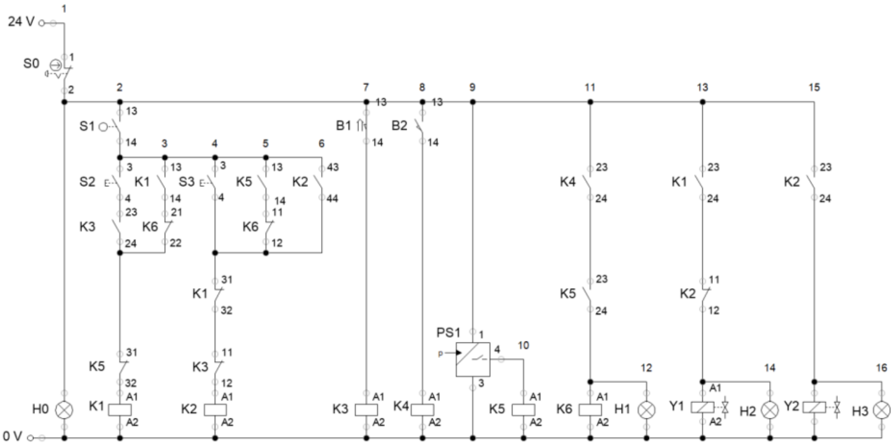

Figure 2: Schematic of the electric control subsystem

As can be seen in Figure 2, the authors designed a schematic that uses the electric power source already available on the public utility work vehicle (its battery pack) and common used parts in the automotive field in order to increase maintenance availability for the end-user and to lower the overall implementation cost. Special electrical parts are known to be not so easy to procure; besides, their procurement price will be significantly higher. On the other hand, it is energy efficient to use the same power source as the destination vehicle because when converting DC to DC or inverting DC to AC, it must be taken into consideration the energy losses that will occur in the process.

Table 2: Parts used in electric control subsystem

No.	Equipment ID	Equipment name	Used
1	S0	Safety STOP button, mushroom type	1
2	S1	Safety electro-mechanical roller switch	1
3	S2	START button for the automated cycle	1
4	S3	START button for the semi-automatic cycle	1
5	B1, B2	Electro-mechanical limit switch	2
6	PS1	Electrical, adjustable, pressure switch	1
7	K1 … K6	Automotive control relay	6
8	H0 … H3	Optical indicator lamp (LED)	4
9	Y1, Y2	DC solenoid valve coil	2

FUNCTIONAL DESCRIPTION

Power generation module structure uses a hydraulic oil tank that connects through pressure lines to filter *F1* inlet. Also, the oil tank is used for return lines connection. Filter *F1* is connected using pressure lines to pump *P1* inlet port, which can be regarded as a mechanical to hydraulic energy convertor. As a safety feature, the power generation module uses a pressure-relief valve *SP1* in order to limit the hydraulic working pressure value to a safe maximum. *SP1* is self-mechanically operated in case of a fault that causes the pressure to increase to an abnormal value.

The pressurized hydraulic fluid flows from the oil tank through filter *F1* and pump *P1 and* it is being directed by fixed pressure lines to the input of the *Q1* flow-meter. Current flow value can be read on a local digital display. *DH1* is a 4 ports/3way bypass in mid-position electro-hydraulic directional valve that unloads the pump *P1* in the power generation module while *DH1* is set on its central position, both *Y1* and *Y2* solenoids being not energized, while the rod of *MHL* hydraulic motor is locked onto its current position. It must be noted that due to manufacturing reasons, *DH1* cannot totally block the fluid flow towards *MHL*, even in its central position, having *A* and *B* ports closed. In this case, assuming that an external force will be exerted, *MHL*'s rod will slowly move. The directional valve *DH1* uses *P* as the pressure inlet port, *T* as the pressure return port (tank port), *A* and *B* as pressure in or out ports for supplying the hydraulic linear motor through *PA1/PA2* and *PB1/PB2* flexible pressure lines. The directional valve *DH1* use two helical springs in order to center its spool in the absence (or loss) of an electric control signal, converted into mechanical displacement by *Y1* and *Y2* solenoid valve coils. Displacement of the *DH1*'s spool is controlled through manual or electric commands connecting hydraulic ports *P-A*, *B-T* when energizing *Y1* and ports *P-B*, *A-T* when energizing *Y2*.

Pressure gauges *M1*, *M2* and *M3* are used to measure and display on their individual dials current pressure values in the respective circuits, for maintenance purposes. *PS1* is an electrical, adjustable, pressure switch used in the electric control subsystem to trigger a stop command for the waste pressing cycle, thus returning the pressing platter in its initial position.

Referring to the schematic in Figure 1, it can be seen that *DH1* uses *Y1* and *Y2*, two DC solenoid valve coils, in order to move its spool. The solenoids must be controlled alternatively in operational (active) phases of the waste pressing cycle. In figure 2, *S0* is a mushroom type safety STOP button, with a normally-closed (NC) electric contact, used for emergency STOP of the waste pressing cycle. There are used electromagnetic control relays, *K1 … K6*, along with other electric circuit parts in order to materialize the operation logic of the pressing cycle as given below in Table 3, where *0* mean no operation/retraction of *MHL*'s rod, *1* mean operation/extension of *MHL*'s rod, *X* is an indifferent (not taken into consideration) state, whereas *CP* mean that *MHL*'s rod is locked onto its current position.

Table 3: Pressing cycle operational logic

		Electric schematic symbols									
No.	**Functional phase**	**S0**	**S1**	**S2**	**S3**	**B1**	**B2**	**PS1**	**Y1**	**Y2**	**MHL**
1	Emergency STOP (manual)	1	X	X	X	X	X	X	X	X	CP
2	Stand-by	0	0	0	0	1	0	0	0	0	0
3	START pressing cycle (automatic)	0	1	1	0	1	0	0	1	0	1
4	Press plate retraction (automatic)	0	1	0	0	0	X	1	0	1	1
5	Press plate retraction (semi-automatic)	0	1	0	1	0	X	X	0	1	1
6	Pressing complete (automatic STOP)	0	1	0	0	0	1	1	0	0	CP

In Figure 2, *S1* is a safety electro-mechanical roller switch that is used to disable the manual operating mode when pressing chamber safety latch is open. As can be seen from Table 3, the pressing plate is descending when *Y1* solenoid is energized and ascending when *Y2* solenoid is energized. The solenoids are alternately energized, is not allowed to energize both *Y1* and *Y2* solenoids in the same time – this will be regarded as an electric control system failure – because when referring to the hydraulic driving schematic given in Figure 1, energizing both solenoids would mean that the *DH1*'s spool should move in opposite directions in the same time. As an additional safety function, when pressing chamber safety latch is accidentally opened, the electric control subsystem will trigger an emergency STOP command, enabling the *CP* functional mode.

In Figure 2, button *S2* enables the automated pressing cycle if there are met two conditions: pressing chamber safety latch is closed and pressing plate is fully retracted. Self-latching of START pressing cycle (automatic) command is made using a simple series electric circuit with one normally-open contact of relay *K1* and one normally-closed contact of relay *K6*. Again, as an additional safety function, START pressing cycle (automatic) command is inhibited when the pressing chamber safety latch is opened and the pressing plate is in movement.

Press plate retraction (semi-automatic) command is enabled by pressing *S3* button. This will cause the press plate to return in its fully-retracted position, being validated only when pressing complete (automatic STOP) mode is activated – limit switch *B2* and pressure switch *PS1* are both active in the same time – or pressing chamber safety latch is opened while pressing plate is still in motion and needs to return to fully-retracted position. The press plate retraction (semi-automatic) command is self-latching using one normally-open contact of relay *K2*.

Press plate retraction (automatic) command is used to fully retract the pressing plate after the cycle was enabled by pressing button *S2*. In the process of pressing, there are encountered two opposing forces given by the resistant force of the waste against pressing and the friction force between waste and side walls of the pressing chamber. Hydraulic driving subsystem must counterbalance these two types of forces, causing the pressure value in the active chamber of *MHL* to increase to a maximum determined by the hydraulic working pressure value and the desired degree of waste compaction. In this case, a pressure peak value will trigger *PS1* causing the press plate to return to fully retracted position, unless pressing complete (automatic STOP) mode is already active. The desired degree of waste compaction can be easily modified by proportionally adjusting the setpoint value of *PS1*, but there must be taken into consideration that a high degree of waste compaction is also dependent on the maximum working pressure of the hydraulic driving subsystem and safety regulations.

Pressing complete (automatic STOP) functional phase will be enabled automatic when *PS1* is triggered and *B2* is self-latched. The optical indicator lamp *H1* will signal the human operation that the electro-hydraulic system has entered pressing complete phase, *Y1* and *Y2* solenoids being not energized. When binding the compacted waste, the press plate is still exerting force; in order to evacuate, the press plate must return to its fully retracted position by, first, closing the pressing chamber safety latch and afterwards pressing button *S3*. The electric control subsystem will now enter in stand-by functional phase, pressing chamber safety latch can be opened and bound compacted waste can be unloaded. New pressing cycle can be started by closing the pressing chamber safety latch and afterwards pressing button *S2*.

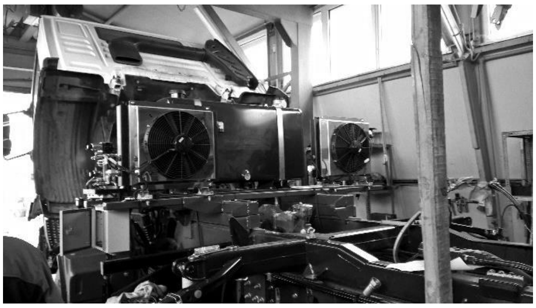

Figure 3: General view of the electro-hydraulic driving system mounted on the vehicle

As can be seen in Figure 3, the experimental model of the public utility work vehicle is in development, being in-line with the time planning of the activities provided by the project implementation plan. The general view given in Figure 3 show the backside of vehicle’s cabin, for driver and passenger, where are mounted the hydraulic driving subsystem (middle-left) and the electric control subsystem (bottom-left) together with other functional subsystems of the vehicle.

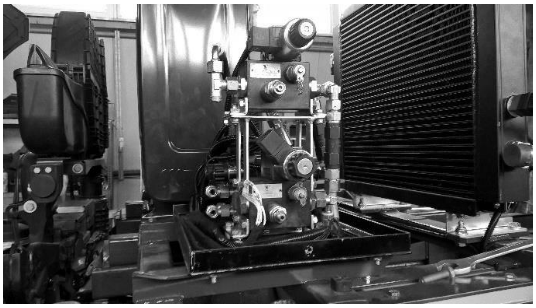

Figure 4: Detail view of the hydraulic driving subsystem mounted on the vehicle

In Figure 4 is given a detailed view of the hydraulic driving subsystem where can be seen the directional valve *DH1* and one solenoid valve coil *Y2* (both top-center). In Figure 5 is given a detailed view of the electric control subsystem where can be seen the electromagnetic relays (top-center), DIN-rail mounted electrical connectors (bottom-center) and some electric circuitry.

Figure 5: Detail view of the electric control subsystem mounted on the vehicle

CONCLUSIONS AND FUTURE WORK

The engineering field of electro-hydraulic drives has developed more on the energy efficiency in the past years. New and rapid technology advances, especially in the field of control electronics – leading to IT development – improved the overall energy management of such driving systems. However, not only the field of control electronics encountered significant developments, but worldwide is starting to gain more and more attention from the researchers a scientific concept known as digital hydraulics. This concept is considered to be revolutionary for the development of electro-hydraulics field, being noted several research trends in both fundamental and applicative research. In this paper the authors presented a simple, energy efficient and cost effective electro-hydraulic driving system for a specific technical application. The technical solution presented can be even more improved after performing on-site experimental researches on the public utility work vehicle, in different working cycles with load variations.

As future work, the authors propose themselves to investigate other approaches on the energy efficiency of the electro-hydraulic driving system for the presented particular case of a waste pressing module in a public utility work vehicle. There can be depicted two future research directions, one on the control electronics field, thus investigating the opportunity to use a programmable logic controller, replacing mechanical or electro-mechanical measuring equipment with sensors or, if necessary, adding new types of transducers; the second direction is related to the hydraulic driving subsystem by studying the opportunity to use digital hydraulics concept.

ACKNOWLEDGEMENT

This research was supported by the Executive Unit for Financing Higher Education, Research, Development and Innovation, UEFISCDI, under the PNCDI III – Programme 2, sub-programme 2.1, submission code PN-III-P2-2.1-PTE-2019-0446, funding contract no. 53PTE/23.09.2020, project title “Hydrophilic auto-chassis for high energy efficiency operation of interchangeable equipment intended for performing public utility work”, acronym ASHEUP, research direction 3.Econano-technologies and advanced materials, subdomain Advanced materials.

REFERENCES

[1] Berne, L.-J., et al.; Multi-Point-of-View Energy Loss Analysis in a Refuse Truck Hydraulic System, *Energies Journal*, Vol. 14 (2021) No. 9, eISSN 1996-1073

[2] Rydberg, K.-E.; Hydraulic Fluid Properties and their Impact on Energy Efficiency, Proceedings of 13th Scandinavian International Conference on Fluid Power (SICFP2013), Krus, P., et al. (Ed.), pp. 447-453, ISBN 978-91-7519-572-8, Linköping, Sweden, June 2013, Linköping University Electronic Press, Sweden, (2013)

[3] Kappi, T., et al.; Simulation study of a mobile machine with special reference to energy efficiency, Proceedings of the Fifth International Conference on Fluid Power Transmission and Control (ICFP'2001), YongXiang, L., Ying, C. (Ed.), pp. 378-382, ISBN 7-5062-4955-3, Zhejiang University, Hangzhou, Rep. of China, April 2001, International Academic Publishers Ltd. unit 1205, 12 Floor, Sino Plaza, 255 Gloucester Road, Hong Kong, Causeway Bay, China, (2001)

[4] Dai, J., et al.; Signal-Based Intelligent Hydraulic Fault Diagnosis Methods: Review and Prospects. Chin. J. Mech. Eng. 32, 75, (2019), *Available from* https://doi.org/10.1186/s10033-019-0388-9, *Accessed:* 2021-09-06

[5] Popescu, T.-C., et al; Increasing energy efficiency and flow rate regularity in facilities, machinery and equipment provided with high operating pressure and low flow rate hydraulic systems, Proceedings of the18th International Multidisciplinary Scientific GeoConference (SGEM 2018), pp. 401-408, ISBN 978-619-7408-44-7, Publisher STEF92 Technology Ltd., 14 Kl. Ohrdiski Blvd., Sofia, Bulgaria, (2018)

[6] Chirita, P.-Al., et al; Improving the energy efficiency of multifunction motor vehicles by equipping them with hydrostatic pumps with load sensing, Proceedings of the18th International Multidisciplinary Scientific GeoConference (SGEM 2018), pp. 393-400, ISBN 978-619-7408-44-7, Publisher STEF92 Technology Ltd., 14 Kl. Ohrdiski Blvd., Sofia, Bulgaria, (2018)

Corresponding author:

Corresponding Author: Iulian Claudiu DUȚU, Lecturer, Ph.D. Eng.
Full address: no.313 Splaiul Independentei, Faculty of Biotechnical Systems Engineering, Department of Biotechnical Systems, Laboratory of Biotechnical Process Automation, D-007
Email: iulian_claudiu.dutu@upb.ro