Study on the Use of Digital Hydraulics in P.E.T. Waste Baling Presses

Lect.Ph.D.Eng. **Iulian-Claudiu DUȚU[1]**,
Prof.Ph.D.Eng. **Sorin-Ștefan BIRIȘ[1]**, Prof.Ph.D.Eng. **Edmond MAICAN[1]**

[1] University Politehnica of Bucharest, iulian_claudiu.dutu@upb.ro

Abstract: *In the energy efficiency era, modern industry machinery demand now more than ever intelligent and efficient electronic control modules, in order to gradually increase their technical performances. Classic hydraulic driven machinery are complex and reliable but trying to reconfigure their schematic is a very hard to do process, in some cases impossible. Machine flexibility and energy efficiency are probably two of the most important concepts that govern the world of equipment – installation – machine design engineers. Solving this sort of demands certainly leads to a rapid increase in electronic control system complexity and designing new electro-hydraulic equipment that use modern concepts such as digital hydraulics. Nevertheless, complex electronic modules require adequate software development [1]. Referring to a narrower case, hydraulic P.E.T. waste presses, they are well acquainted for their productivity versus low cost classic hydraulics installation. Still, there remains another issue that needs to be taken into account: energy efficiency. In this paper, the authors have investigated the possibility of using the digital hydraulics concept in replacing classic electrohydraulic directional valves of a small capacity P.E.T. waste press from the energy consumption point of view. Also, there will be discussed main advantages and disadvantages of using digital hydraulics over classic hydraulics in the particular case of a P.E.T. waste press.*

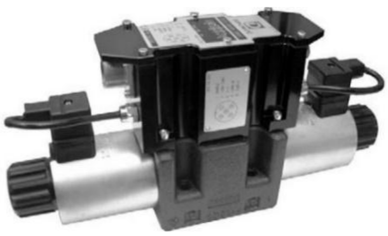
Keywords: *Digital, hydraulics, P.E.T. waste, press.*

1. Introduction

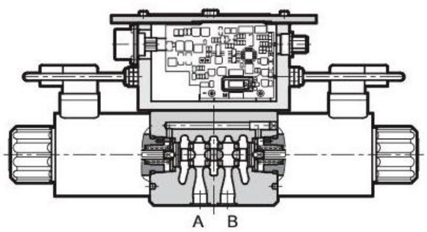
Digital hydraulics technical concept has entered the international scientific community around 1999, as an alternative to classic hydraulic driving circuits using proportional or servo equipment. However, strong inertia of the scientific community made the concept to develop very slowly. In present, digital hydraulic valves are slightly to be found in the commercial offer of traditional hydraulic manufacturers, but there are several functional models ready to be delivered to the market. There are a few among large hydraulic manufacturers have technical knowledge and capabilities to produce custom digital hydraulics equipment. Research laboratories of universities or institutes are continuously trying to optimize existing valves, but the greatest challenge still remains the development of capable software control algorithms or proper adjustment of certain constructive parameters of valves or their electromagnets – depending on which technical solution is adopted. Digital hydraulics have two alternative solutions to classic equipment both having the benefit of reducing general energy consumption of the hydraulic driving system: high frequency PWM switching or parallel connection of several 2/2 hydraulic directional valves (very similar to valve-islands) electrically controlled independently. In the second case, the valves are smaller, having reduced installation and maintenance costs over proportional equipment. They are also robust. In P.E.T. waste presses, the main problem is energy management due to the fact that the hydraulic pumping module must always operate at almost full capacity. This means high energy consumption in normal operating mode even if there are certain functional phases that does not require so much energy. There are made some experimental studies (Finland) on a fully functional digital hydraulic equipment, mounted on an excavator boom that revealed an energy consumption reduction up to 70%, in some phases of the actuation cycle. In that case, digital hydraulics equipment was used to replace classic hydraulic LS (Load-Sensing) system of the excavator.

2. State of the Art in Digital Hydraulics

The investigation starts from the idea of finding a technical solution to replace hydraulic proportional directional valves with new digital valve-islands, having equivalent operation principle, connected in parallel, with lower acquisition and maintenance costs, higher reliability and reduced overall energy consumption. It is a well-known fact that hydraulic proportional directional valves are expensive - looking, at least, from two points of view: acquisition and operation. This type of hydraulic valves is also very sensitive to the variations of some of the working environment parameters, but all of these have been somehow compensated using complex electronic modules and sensors. Furthermore, the reliability of hydraulic proportional valves is still a sensitive subject, referring mostly to the work cycle downtime, that in most cases require highly qualified personnel to diagnose and to repair – leading to increased personnel costs. Hydraulic proportional directional valves are demanding continuous operation of the pumping module in order to compensate internal losses of the directional valves. Besides these considerations, it must be taken into account that in most cases hydraulic proportional directional valves demand supplemental anti-cavitation or compensation equipment which are expensive and have complex internal structure, contributing significantly to the overall energy consumption of the hydraulic driving system.



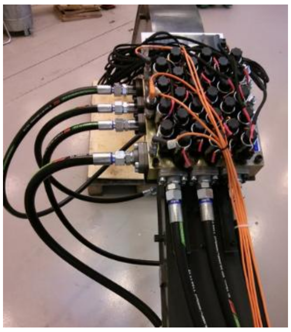
a. physical equipment



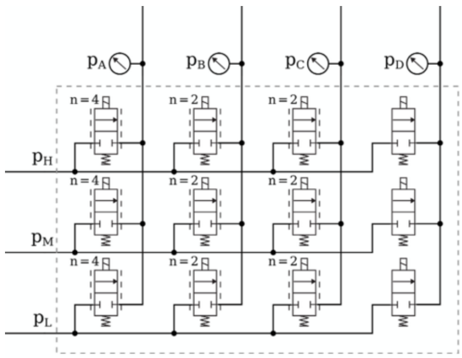
b. internal configuration

Fig. 1. Direct operated hydraulic proportional valve with integrated electronics proportional control [5]

As stated before, digital hydraulics valves are simpler being materialized by parallel connection of 2/2 poppet valves. In theory, these types of hydraulic directional valves have zero losses, leading to the idea that is not necessary for the pumping module to operate continuously, reducing overall energy consumption. There is not needed anymore a large, complex and low-energy efficiency pumping module, where digital hydraulics valves can properly operate with smaller pumping modules having in their structure one or more hydraulic accumulators (pressure storage reservoir). From the start we can observe an improvement of the energy efficiency of the system.



a. physical equipment

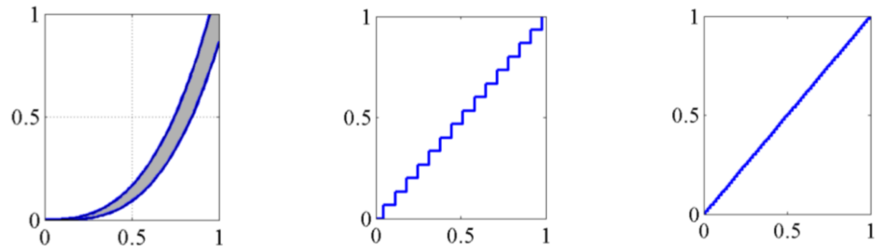


b. inner schematic

Fig. 2. Digital hydraulics valve [3]

Hydraulic 2/2 poppet valves, main components of the valve-islands, have small physical dimensions, they are robust and having lower acquisition, maintenance and operation costs than the proportional valves. Supposing that one of the poppet valves in the valve-island is not functional anymore, the automated electronic driving module will dynamically reconfigure the remaining operational valves of the valve-island in order to maintain process parameters near the setpoint values. Considering the case of hydraulic proportional directional valves, when one valve is defective, in most cases, the entire process will be shut down or can cause serious damages or life-threatening situations. Supplemental safety equipment is required to reduce the risks on the environment and human or animal life – adding even more costs to the initial system configuration.

Main technical challenges encountered in the discussion classic vs. digital valves will be described in the following. The size of digital hydraulic valves, as seen when comparing Fig. 1.a. and Fig. 2.a., is a delicate issue being approximated three times larger than regular hydraulic proportional directional valves. There is an obvious need for several parallel connected valves to make a valve-island in order to obtain the same operating function as in a hydraulic proportional directional valve [3]. A question arises over the reliability and cost factors of such a digital valve configuration. Being a relatively new concept, digital hydraulics equipment are highly priced and rare when referring to already existing models of hydraulic proportional valves. On long term this drawback will be overcame due to the benefits of mass production, but nowadays it is very important to take into consideration that digital hydraulics is a pioneering field of science and technology. Having a relatively large number of valves in the valve-island configuration that need to be controlled independently, it is required to develop a proper model control strategy, directly dependent to the number of poppet valves in the valve-island. Considering that n is the number of parallel poppet valves in the valve-island configuration, there will be a maximum of 2n possible control values for main digital valve's output. In the first place, main problem here will not be the value of n, but the speed of the electronic controller module when computing and trying to obtain an optimum combination of control values for a certain given state of the hydraulic system.



a. proportional valve | b. digital valve n = 4 | c. digital valve n = 6

Fig. 3. Influence of *n* on valve's output [2]

As can be seen in Fig.3, there is a direct correlation between the value of n and valve's output, a large number of parallel valves in the construction of the digital valve result in a large range of possible output values, in the same time directly influencing the characteristic curve of the digital valve. The digital valve will always have an exact number of outputs that will always be obtained in the same conditions thus improving precision. In Fig.3.a, the valve characteristic is affected by hysteresis, while in the case of digital valves, Fig.3.b and Fig.3.c, the hysteresis does not exist. Optimal control is also a delicate issue in digital hydraulics: when defining the objective functions it can be found that these are pursuing opposite goals, such as a short transient regime of the working pressures, higher output flow resolution, higher energy efficiency, lower market costs – still an important aspect due to the novelty degree of the digital hydraulics field (implying higher costs), lower noise and vibration generated by the poppet valves themselves, being in a continuous switching working regime – where the amplitude value of the switching noise is relatively close to the value of response time. Referring to the case of classic hydraulic proportional directional valves, the switching noise is given by the constructive particularities of those.

Probably one of the most important advantages of digital valves over classic valves is their programmability, meaning that same digital valve can be used for different purposes [2], by simply reprogramming its software controller. In the case of digital valves, available number of functions that a valve can perform depends mostly on the software than its mechanical structure. Control software can be easily updated to give new functionalities to the valve. This new concept of digital hydraulics, has the benefits of working in real time and hydraulic losses reducing, depending on the application, digital valve reduces losses 30-98% [2]. In the Figure below, it is shown a very short technological progress of the hydraulics field over the years. From the 1960's where the energy losses were significantly higher than the useful work, energy efficiency was at a maximum value of 10%, the technical field of hydraulics has progressed towards LS (Load Sensing) systems and officially starting from year 2006 towards Digital Hydraulics. A load-sensing hydraulic pump will always operate in a negative feedback control loop, establishing a new pressure drop every time the value of load pressure is changing.

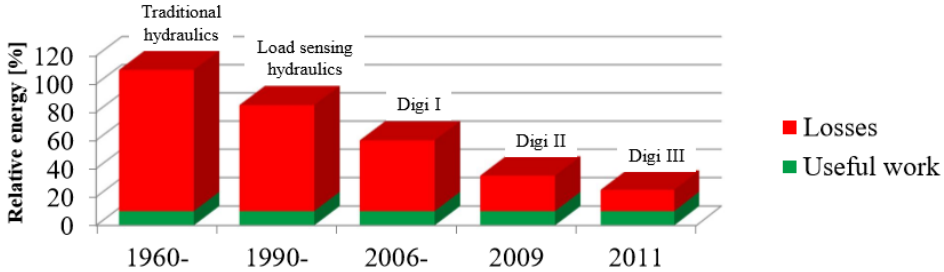


Fig. 4. Relative energy usage in hydraulics [2]

Digital hydraulics has already encountered three phases of scientific and technical development, progressively reducing the energy losses, obtained through scientific research and laboratory experiments. Limitations of current approaches in the digital hydraulics field are directly related to the novelty degree of the thematic, causing in the same time inertia in the scientific community, still adherent to classical hydraulics solutions. There are known very strong opinions that criticize the digital hydraulics field, on the difficulty to develop a highly intelligent control algorithms for digital hydraulics valves, on the limited valve resolution given by the limited number of directional valves in the valve-island, or on the still large physical dimensions vs. weight of the valve-islands or number of electrical wires and hydraulic hoses. The general trend of the industry is to miniaturize its equipment and digital hydraulics is not – nowadays – a part of that trend.
Some of the current technical approaches suggest instead of reinventing the field of hydraulics through digital hydraulics concept, to properly adjust the functional parameters of the existing hydraulic equipment available on the market, while promoting new functional models and intelligent control techniques in order to gain on the energy efficiency field. However, digital hydraulics tends to replace classic hydraulic circuits with their digital equivalent, using switching equipment and having significantly lower costs and higher efficiency. More or less, the limitations of the current approaches in digital hydraulics field are directly related to the costs of researches, still in the state of development and improvement, which implies the allocation of important funding of R&D departments of traditional hydraulic equipment manufacturers.

3. Digital Hydraulics and Baling Presses

Here, a question arises related to the necessity of retrofitting a hydraulic P.E.T. baling press when there are available on the market many constructive solutions with various degrees of automation and energy efficiency. In authors' opinion, baling presses are going to gain much more on the next years, knowing that every year thousands tones of used P.E.T. bottles from households of industry accumulate on waste management sites. The quantities are going to increase in the future, therefore the need of energy efficient pressing solutions will also increase, having direct impact on bales sizes, indirectly on pressed waste warehousing. Maximum working hydraulic pressure of a baling press is not always a fine measurement of its pressing efficiency, a more practical criteria is the compression degree of waste bales. Highly compressed bales can be stacked higher and safer in warehouses, also resulting in fewer bales, which reduces binding wire costs. On the logistics point of view, bales loading traffic and faster bales loading are also other benefits of energy efficient pressing.
The idea of replacing main hydraulic directional valve of one P.E.T. waste baling press, started from observing the functional cycle of an existing press in one of the laboratories of Faculty of Biotechnical Systems. The baling press construction is relatively simple, having a double metallic door design, self-latching closing technology, electro-hydraulic driving system, automated pressing cycle using sensors and microcontroller electronic board and a patented "rapid motion technology" that the manufacturer claim to reduce power consumption and to improve the cycle time by up to 40% compared to conventional drives [11]. There were made some improvements to the hydraulic power-pack, the pumping noise was reduced, with strong positive impact on both the human

operator and environment. Replacing the main hydraulic directional valve with a digital hydraulic valve (island-valve construction) it is supposed to overcome a major drawback of classic hydraulic directional valves as poor energy efficiency. Besides digital hydraulics, another solution is using load-sensing pumps, but these have high acquisition and operating costs. Of course, digital hydraulics is not probably the best cost-efficient solution (being an in-development technology), but in terms of energy it is. Another option in energy reduction is using distributed valves that are proven to reduce energy losses up to 50% in best cases.

Fig.5. Hydraulic baling press – studied model,
available in one laboratory of Faculty of Biotechnical Systems

When thinking in terms of baling press modernization, besides energy efficiency improvements it must be taken into consideration the period of time in which the investment amortization costs will payback [12]. Looking from the economic environment point of view, this period of time must be short and bring also an increased productivity. In addition, baling press downtime, that is the retrofitting time, must also be close to a minimum – the best solution here is using distributed valves, not load-sensing. This is implying parallel connected on/off directional valves [13], having the benefits of fast switching times and redundancy. Another positive issue of using 2/2 valves is their so-called "immunity" against hydraulic oil impurities. In hydraulic systems the power supply unit is centralized having, in most of the cases, the directional valves mounted nearby and transmitting power to system's motors, rotary or linear, through hoses or pipes that sometimes have considerable lengths. Statistics tell us that a large percent of hydraulic systems failures are related to hoses. Referring to Fig. 2.a, it can be seen that hydraulic hoses and digital hydraulics valves are very well acquainted to each other, meaning that in the digital case there will be used a significantly larger number of hydraulic hoses than the classic or proportional hydraulics case, to obtain a similar function. A larger number of hydraulic hoses implies a larger percent of failure.
Not only physical dimensions and number of hoses is the problem of a digital hydraulics system: each one of the 2/2 valves that are constructing the digital valve-island must be driven by an electromagnet. Available models of electromagnets used on commercial hydraulic equipment are not fast enough for digital hydraulics – opening and closing too slowly, far away from what it was intended to obtain. The electromagnets were redesigned in order to meet the speed demands of digital hydraulic valves. All led to an increase in control voltage. Again, referring to retrofitting the P.E.T. baling press, the electromagnets must be provided with voltage boosters and new control module. Wiring the electromagnets is another issue, both on the total electric cable length and total electrical current when all the electromagnets of the digital valve are switched on. Referring to Fig. 3 and considering a number of $n = 6$ parallel poppet valves in the valve-island configuration and knowing that each electromagnet draws from the electrical power supply a current of almost 1A, we have a total of 6A when all electromagnets are ON. In case of a larger digital valve, for example the one shown in Fig. 2.a, a total of 27 A are needed form the electrical power supply. These values of electrical current are fair, but an electromagnet of a hydraulic proportional directional valve draws up to 800mA maximum from the electrical power supply. Considering a larger number of n, the larger the current needed when all electromagnets are switched on, in a worst case

scenario, a digital valve with a number of 100 2/2 valves will require 100 A! In that case, usual cables are not an option, so they need to be redesigned.

4. Conclusions

Authors' current researches in the field of efficient P.E.T. waste pressing led to analyzing the idea of retrofitting a classic hydraulic baling press, using the digital hydraulics concept. Digital valve-islands made of 2/2 hydraulic directional valves seems to be a feasible solution over heavy and expensive load-sensing systems. The field of digital hydraulics is still in pioneering, researchers are still performing laboratory tests and formulating scientific hypotheses, their focus being on the development of optimal control strategies and valve development.Digital hydraulics can find the answer to some existing problems in hydraulics field, especially in energy efficiency and in the near future will replace available solutions. Still, digital hydraulics systems are using only one digital equipment in their configuration, such as directional valves, motors or pumps, and the others are classic or proportional equipment. When retrofitting an existing hydraulic system, fixed or mobile, it must be taken into account technical criteria such as available sensors, valves, power generators, functioning cycles, energy efficiency, control strategies, but also the economic criteria such as total cost control of the retrofitting and payback time. As a general conclusion, digital hydraulics has two strong advantages over classic hydraulics: energy efficiency and higher reliability.

Acknowledgments

This work has been funded by University Politehnica of Bucharest, through the "Excellence Research Grants" Program, UPB – GEX 2017. Identifier: UPB-GEX2017, contract no. 56/2017 (*DIGIPRESS*).

References

[1] P. Boström, M. Linjama, L. Morel, L. Siivonen, M. Walden, "Design and Validation of Digital Controllers for Hydraulics Systems", TUCS Technical Report, No 800, December 2006;
[2] M. Linjama, "Digital Hydraulics", Tampere University of Technology (TUT), Department of Intelligent Hydraulics and Automation (IHA);
[3] M. Sethson, "The digital hydraulic challenge, to switch or not to switch", Division of Fluid and Mechatronic Systems, Linköping University Sweden;
[4] M. Linjama, K. Huhtala, "Digital hydraulic power management system–towards lossless hydraulics", *Proceedings of the Third Workshop on Digital Fluid Power*, pp. 13-14, 2010;
[5] Al. Dell'Amico, et al., "Investigation of a Digital Hydraulic Actuation System on an Excavator Arm", *13¬th Scandinavian International Conference on Fluid Power*; June 3-5, Linköping, Sweden, No. 092. Linköping University Electronic Press, 2013;
[6] M. Jelali, A. Kroll, "Hydraulic servo-systems: modelling, identification and control", Springer Science & Business Media, 2012;
[7] C. Cristescu, C. Dumitrescu, G. Vrânceanu, L. Dumitrescu, "Considerations on energy losses in hydraulic drive systems", *"Hidraulica" Magazine*, ISSN 1453-7303, Romania, No.1, pp. 36-46, 2016;
[8] http://www.hydraulicspneumatics.com;
[9] http://www.directindustry.com;
[10] ***http://www.valmet.com, "Digital Hydraulics", Technical Paper Series, U.S.A., March 2016, accessed in April 2017;
[11] https://eu.hsm.eu;
[12] M. Linjama, M. Paloniitty, L. Tiainen, K. Huhtala, "Mechatronic Design of Digital Hydraulic Micro Valve Package", *Procedia Engineering*, Elsevier, vol. 106, pp. 97 – 107, 2015;
[13] M. Linjama, M. Huova, P. Bostöm, A. Laamanen, L. Siivonen, L. Morel, M. Walden, M. Vilenius, "Design and Implementation of Energy Saving Digital Hydraulic Control System", Vilenius, J. & Koskinen, K.T. (eds.), *The Tenth Scandinavian International Conference on Fluid Power (SICFP'07)*, May 21-23, Tampere Finland, 2 , pp. 341-359, 2007.