# Hydraulic Press with LS System for Modelling of Plastic Working Operations

***Janusz Pluta***[1]

***Hydraulický lis so systémom LS pre modelovaniu procesov plastických deformácií***

*At first, the paper describes destination of the presented hydraulic press. Next, the substance of load sensing (LS) systems' operation was introduced, and electro-hydraulic system of this type, installed in laboratory hydraulic press, was described. The control and measurement circuit of the device was also described, and exemplary test results obtained during plastic working operations on soft non-ferrous alloys were presented.*

***Key words:*** *electro-hydraulic system, hydraulic press, load sensing system, plastic working operation*

## Introduction

Press with hydrostatic drive belongs to group of units, which are widely used in plastic working of materials. Presented in article hydraulic press makes an example of modern solution application in electro-hydraulic technology domain for getting of specified functional and operational unit properties. Such a press is intended for wide range research leading, especially plastic working operations on non-ferrous alloys physical modelling in one of laboratories at AGH-UST in Krakow. Operations of upsetting and compressing, forging modelling, hot and cold extrusion are conducted on press. Experiments are carried out mainly on soft metals such as: aluminium, tin, lead and their alloys. Interesting powder metallic materials extrusion process is also in research project. For sake of nature, number and range of conducted investigations, simple servicing and possibility of manual or automatic cycle work is required from the press. Simultaneously assurance of following job parameters and fulfilment of basic requirements is needed:

- overcame loads range: 0 ÷ 3000 kN,
- plunger velocity range 5 ÷ 200 mm/min,
- possibility of stepless adjustment and plunger motion velocity stabilization regardless of applied loads,
- possibility of long-lasting work with high experimentation frequency,
- energy losses minimization in hydraulic system,
- possibility of measurement and data logging of selected physical values.

Analyzing different kinds of control used in hydrostatic systems, were made decision about constructing a press with „load sensing" type electro-hydraulic control system. Construction, functioning and properties of „load sensing" systems is described in next chapter.

## The substance of the hydraulic LS system operation

As an aim of loosed power minimization in hydraulic systems or obtaining precision control of hydraulic receiver velocity more frequently are used systems in which supply pressure generated by hydraulic pump is adapting to current receiver load in the way of holding constant pressure drop on restrictor controlling receiver working. In English literature these systems are known under the name of „load sensing" systems (Ebertshäuser, 1989; Pluta, 2002), in German „lastdruckkompensation" or lastkompensation" [1]. Basing on definitions written in (Ebertshäuser, 1989; Osiecki, 1998; Stryczek, 1995; Makowski, 2001), in further considerations by *Load Sensing system* (in abbreviation, *LS system*), in most general sense, will be understand as hydraulic system in which there is a feedback from load and which automatically adapting instantaneous circulation (or circulations) working parameters to receiver (or receivers) requirements or setting work conditions. Construction and properties of individual LS systems variety's depends among other things on: kind of hydraulic circulation (open, closed, semi-closed), kind of hydraulic pump (fixed or variable displacement pump) and kind of used throttle valve construction. One

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of the main aim of construction and using the LS systems is desire for elimination or at least minimization of energy losses. For achievement of this aim three kinds of controllers are used in LS systems: [2]:

- type I controller, working according to *p* = const principle, which eliminate power losses due to excessive output flow of hydraulic pump,
- type II controller, working according to *Δp* = const principle, which eliminate power losses due to excessive output flow of hydraulic pump and minimizing losses due to excessive forcing pressure of hydraulic pump,
- type III controller, working according *p·Q* = const principle, which besides realized by type II controller tasks, fulfil role of power consumed by hydraulic pump limiter.

Type I controller (Fig. 1) consists of: variable displacement pump *1*, cylinder with spring return *2* controlling output flow of hydraulic pump, pressure compensatory valve *3* and safety-valve *4*. Controller working consists in that if output flow of hydraulic pump is bigger than receiver requirements and as a result of that increasing of pressure in working line follow over setting up value on valve *3*, so after that this valve is immediately open connecting working line with cylinder *2*, which decrease output flow of hydraulic pump to level of receiver *5* demanding.

Type II controller (Fig. 2) consists of variable displacement pump *1* controlled by cylinder *2*, differential valve *3* and overflow valve *4*. It's working principle is common to type I controller. Those controller holds constant pressure drop *Δp* on throttle *5*, came 5% of maximum pressure value in system. However pressure in working line of hydraulic pump is variable in this system and is depending on receiver load.

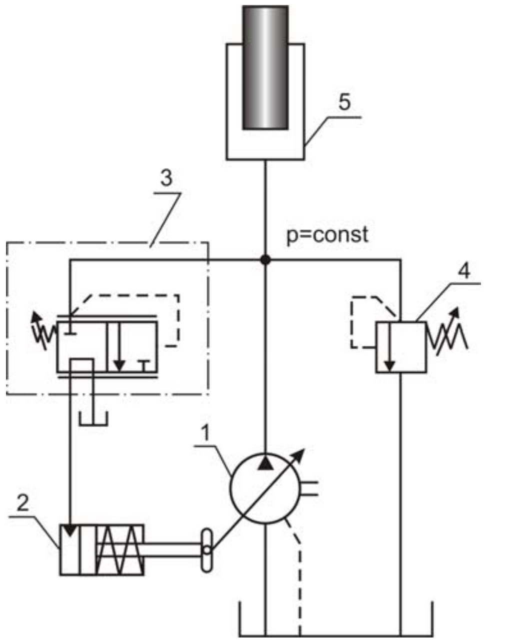


*Fig. 1. Hydraulic scheme of LS system with type I controller.*

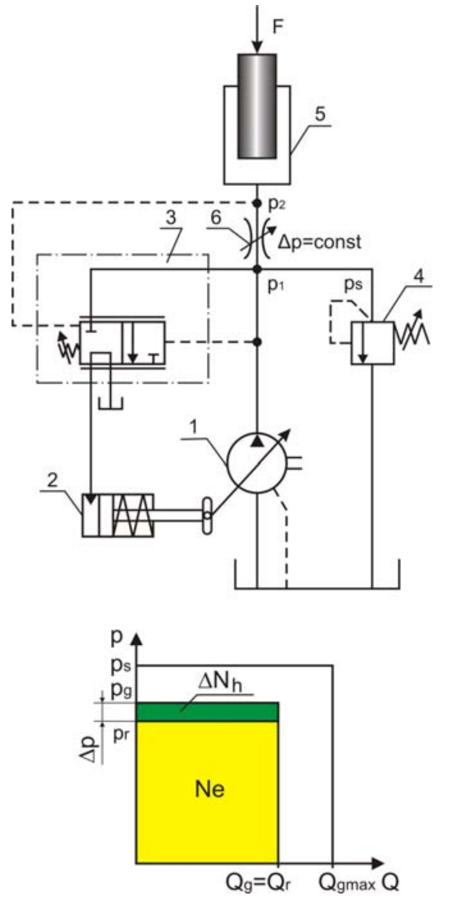


*Fig. 2. Hydraulic scheme of LS system with type II controller.*

Type III controller limits mechanical energy taken from driving motor by hydraulic pump adapting output flow of pump to pressure in working line according to hyperbolic characteristic. Moreover type III controller includes parts consisting to type II controller.

Two fundamental possibilities of LS system idea realization are known, which allow for getting completely distinctness drive properties. They result from that, is hydraulic drive supplied from source of constant flow rate or from variable displacement pump equipped with pressure controller (Osiecki, 1998;

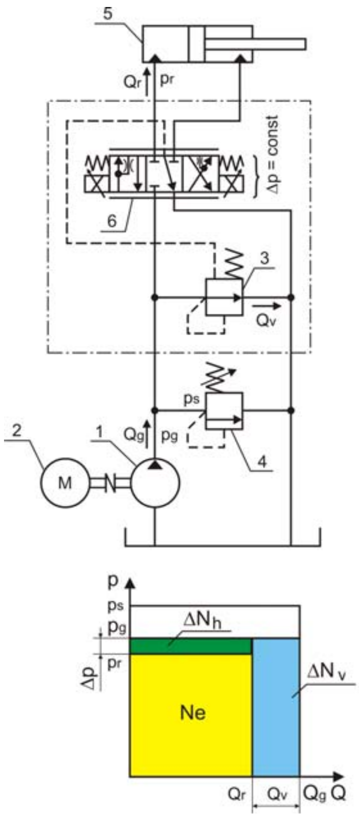


*Fig. 3. LS system scheme with fixed displacement pump.*

Stryczek, 1995). Throttle valves (mostly special construction throttling control valves) are essence of those systems. In connection with two and three way differential valves they form systems, which realize active throttling principle. It consists in that differential valves (named sometimes as compensatory valves (Ebertshäuser, 1989; Osiecki, 1998; Stryczek, 1995) which automatically adapting flow rate of liquid flux reaching hydraulic receiver in dependence of pressure drop value setting up on throttle valve. Setting up of those drop can be done manually or by use of electro-hydraulic control.

Possibility of precise hydraulic receiver velocity control independently from load is the most essential advantage of LS systems with fixed displacement pump (Fig. 3). From energetic point of view those systems didn't give any advantages in comparison with conventional throttling control systems supplied by fixed displacement pump.

Biggest decrease of energy losses can be obtained by connecting throttling control with volumetric control i.e. variable displacement pump equipped with pressure regulator (Fig. 2). Throttling valve *6* works with differential valve reacting on pressure difference $\Delta p$ together. In this manner structural volumetric loss $\Delta N_v$ is eliminated but structural hydrodynamic loss $\Delta N_h$ connected to flow resistance $\Delta p$ through throttling control valve is appearing. System of such type was a starting point for studying a press with electro-hydraulic „load sensing" system.

## The electro-hydraulic LS system of the press

Characterized hydraulic press includes mechanical and hydraulic parts, measurement control system and electric supply system. Mechanical part consist of four vertical columns connecting two horizontal traverse: lower and upper (Fig. 4). Hydraulic plunger cylinder collar which is press driving part is mounted on lower traverse. Those cylinder with connected to them hydraulic supplying and control unit makes hydraulic part of the press. For constructing of pumping engine hydraulic and electro-hydraulic control devices which cooperates with suitable sets of measurement and control system were used. Most of controlling tasks were assigned to electrical part of unit. Working substance of studied hydraulic system of the press and collaborating measurement and control system is the same as hydraulic LS system with type II controller presented at Figure 3. But for the sake of kind and working of used elements more precise name for constructed system will be *electro-hydraulic load sensing system*. In place of manually controlled throttling valve *6* (Fig. 2), two-way electro-hydraulic proportional valve *6* (Fig. 5.) is used.

Pumping unit with hydraulic pressure controller is replaced with pumping unit with fixed displacement pump *1* drive by asynchronous motor *2* working with frequency changer. On inlet and outlet of proportional valve *2* pressure transducers *3.1*, *3.2* which measure of pressure difference on this valve made possible were mounted. In result of changing the load acting on plunger of hydraulic cylinder *5* pressure $p_2$ is changing in outlet of valve *6*. For holding constant pressure drop $\Delta p = p_1 - p_2$ on this valve what is a condition of plunger constant velocity preservation with a change of pressure $p_2$ adequately pressure $p_1$ must change. Inother words change of pressure $p_1$ must go after changes of pressure $p_2$. This task is realized by pumping unit which during changes of output flow affect on pressure $p_1$ change. Output flow change is gained by pump shaft rotational speed change. It's possible due to frequency changer working with asynchronous motor which drives the pump. Thanks to that pumping unit properties can be obtained as in hydraulic system with type II controller (Fig. 2). For assurance of pump correct work with different rotational speed of rotor besides construction type, place and manner of installing is very important factor. Especially the thing is that suction of hydraulic fluid have good conditions. For most pumps producers gives in technical data minimal value of rotational speed in limits of 500 to 900 rpm with suitable pressure in suction line. It means that only above this speed we can change pump output flow up to acceptable velocity for example 3000 rpm. However, if very good pressure and flow conditions in suction line will be assured, rotational speed for some kinds of pumps can be reduced significantly with obtaining correct work. Selection of pump driving motor is important too. In significant range of rotational speeds starting below half of motors nominal value, asynchronous motor with additional (independent) cooling can be used. Parameters of used frequency changer as especially nominal power are important as well. For assurance of correct measure and control system work, frequency changer should be equipped with filter against sensor work interference.

During work of described press three kinds of work state are appear:

- motion of plunger with setting velocity which is a working motion, during which overcoming a resistance to motion connected mainly with plastic working process modelling,
- standstill of plunger designed for making auxiliary actions,
- lowering of plunger under the die block weight which is placed on plunger.

Structure of electro-hydraulic LS system appear only during working motion. During lowering of plunger with die block valve *6* is closed, and directional control valve *7* is in open position. Signal from those directional control valve cause in opening valve *8*, through which hydraulic liquid leaves cylinder *5* forced by plunger and die block outside into the tank. During this phase of work pumping unit works with minimum output flow essential for getting valve *8* opening pressure. During standstill pumping unit output flow is take down to zero but asynchronous motor *2* with frequency changer is in stand-by mode.

*Fig. 4. The press: a) front view, b) rear view.*

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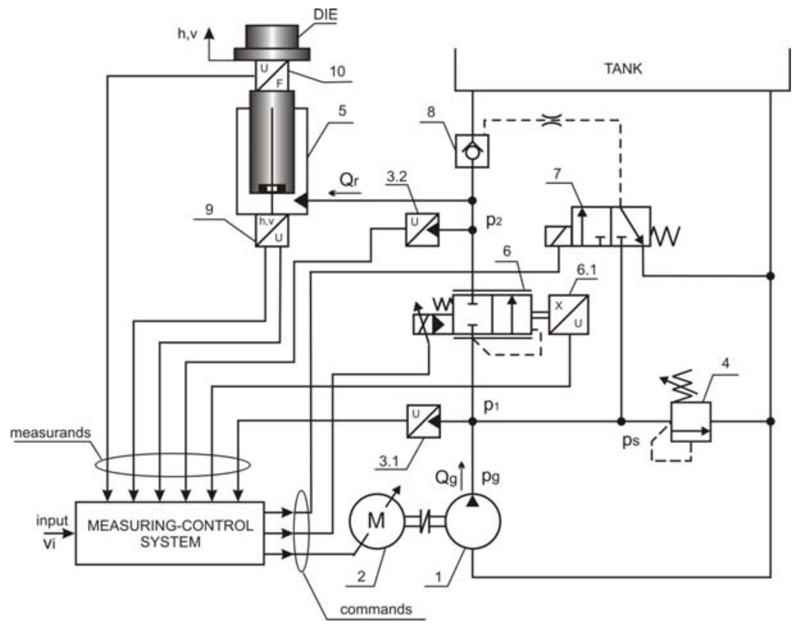


*Fig. 5. Scheme of press with electro-hydraulic LS system: 1 – pump, 2 – electrical motor, 3.1 and 3.2 – pressure transducers, 4 – relief valve, 5 – hydraulic cylinder, 6 – 2/2 proportional flow control valve, 7 –3/2 directional control valve, 8 – controlled check valve, 9 – displacement transducer, 10 – force sensor.*

### The control and measurement system

This system is designed for press working control according to programmed algorithms and made measurements and data logging of selected physical quantities. With excluding of sensors system was placed in control box with electrical elements and components supplying system. The following main systems were used:

- programmable logic controller equipped with analogue input and output modules,
- programmable operating panel,
- frequency converter of vector control.

In press sensors and measuring converters were mounted from which part were used in electro-hydraulic control of LS system, other were used for physical quantities measurement, what make possible determining of made plastic working operations characteristics. There are (Fig. 5): piezoelectric pressure transducers *3.1* and *3.2*, contactless magnetostrictal position and linear velocity transducer *9* of plunger (die block), induction proportional valve *6* slide position sensor *6.1*, compressing force strain gauge sensor *10* working with suitable transducer. The controller software was realized by using Mitsubishi MELSEC MEDOC programme. The software, recorded as a ladder diagram is composed of the main programme and the subroutines. In the main programme the following functional blocks were distinguished:

- work parameter fixing for particular elements of hydraulic and control and measuring system, as initial and limit values and filtration coefficients of measured signals,
- parameter fixing which initialize the work of measuring and control modulus,
- read-out of the measured values together with their filtration,
- collaboration with operation panel (option selection from MAIN MENU or from the control algorithm of functional keys),
- force measuring system calibration,
- tarring of force and distance measuring system,
- data transmission to PC computer,
- control algorithm selection.

Particular control algorithms were recorded as subroutines realizing following research procedures: manual control, upsetting, compressing, forging, extrusion. Operating panel was programmed by using the object MAC Programmer + Packet. Particular screens projector aspect was designed in separate programme blocks, whereas their mutual connections between blocks were realized by using jump function produced on the screens and by functional keys.

## Sample characteristics

First experiments on the presented device were conducted with the test pieces made of lead. Sample characteristics were determined by press control and measuring system during test of lead extrusion are presented at Fig. 5. Upper characteristic shows diagram of extrusion force, lower diagram of plunger (die block) displacement. From the test results it can be concluded, that in case of plastic strain of the soft material increase of pressing force is slight at first, then for some time it is very intensive until the maximum value is reached, and after that continuous and rather slow decrease of force's value occurs. During this experiment pressing force of the press did not reach 20 % of it's nominal value.

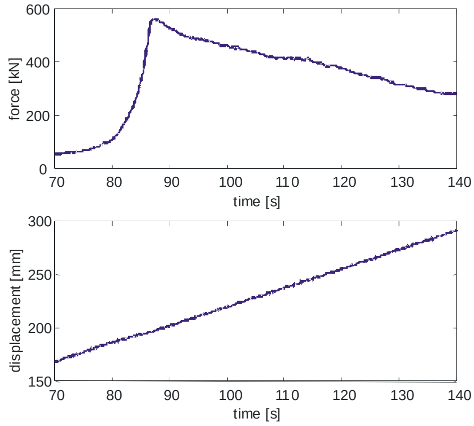


*Fig. 6. Lead extrusion diagrams for plunger velocity 105 mm/min*

## Conclusion

The presented device was set up in Faculty of Non-Ferrous Metals, AGH University of Science and Technology, Krakow Poland. Connecting of modern hydraulic technology and electric drives technique with microprocessor technique and modern measurement technique allow constructing of electro-hydraulic press system with properties of LS system. Hydraulic system were constructed from typical elements with high reliability makes simple and easy construction for maintenance. Used in hydraulic press LS system turn out to be useful in practice. A few year reliable work confirm their usefulness and expected functional and exploitation properties.

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