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ENERGY SAVING BY INTEGRATION OF LASER CONTROLLED HYDRAULIC SERVOMECHANISMS INTO THE NAVVY LEVELING MACHINES

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Abstract: *This paper represents a project proposal submitted in PNCDI III- Programme 2 Subprogramme 2.1 - Research, Development and Innovation - Project experimental – demonstrative, with number PN-III P2-2.1-PED-2016-0309.*
Actual materialization of the concept of automatic land leveling against a laser benchmark plane, horizontal or inclined, emitted by a rotating laser generator, leads to substantial fuel savings and low material / labour costs. At the same time accuracy of leveling increases, as maximum deviation compared to the benchmark plane is of ±2cm, and reduced soil compaction, due to reducing the number of crossings for the navvy machine, promotes environmental protection.
Automatic leveling against a horizontal or inclined laser benchmark plane is increasingly used on construction sites for: water supply, irrigation, land reclamation and construction of highways, railways, airport runways, buildings, dams, earth banks, et al. Such leveling can be done only after in the structure of navvy leveling machines there are embedded automated mixed systems, with laser-hydraulic parts. Integration is a slow and expensive process, because of the possibility of testing the embedded system only while on the machine, in the presence of a land parcel "to be sacrificed".
This project, falling into the smart specialization domain "Energy, Environment and Climate Change", proposes the development of a demonstrator product, type 3-axis electrohydraulic tracking system (D3A), able to test, in laboratory conditions, the system to be embedded. This project would be the follow-up of own previous research completed with a single-axis electrohydraulic tracking system (D1A).
The demonstrator (D3A) will be able to simulate both land unevenness and orders sent to the blade/ bucket of the navvy machine so that the latter could perform leveling against a programmed laser benchmark plane, inclined in one or two directions.
The project will involve a research-development institute, holding 55 years of experience in the field of fluid power systems, (CO), and also a university research center, with important achievements in the theory and concept of industrial electrohydraulic servomechanisms, (P1).

Keywords*: hydraulic servomechanisms, 3-axis tracking system, laser benchmark plane, navvy leveling machine.*

1. Introduction

Thanks to quality and precision of land leveling, achieved with substantial energy savings and environmental protection, the concept of automatic land leveling against a laser benchmark plane is increasingly materialized in use on construction sites for: water supply, irrigation, land reclamation and construction of highways, railways, airport runways, buildings, dams, earth banks, et al.
Capability of a navvy machine to work in automatic mode is usually acquired after the equipment is manufactured, by embedding in its structure complex systems, of the type consisting of worldwide known laser equipment, which are specific to geodetic measurements, and electrohydraulic distribution systems, which are specific to fluid power.
Project Scope *is to develop and test a demonstration model*, able to verify, in laboratory conditions, the operation of laser-hydraulic systems intended to equip the navvy leveling machines,

in order to acquire quality to operate in automatic mode, against a laser benchmark plane which could be a horizontal one or a plane inclined in one / two directions.

2. State-of-the-art; Project General Objective

State-of-the-art in the field of this project is marked by three important stages (milestones):
Stage 1. Global leaders on the market for development of precision positioning equipment, namely TOPCON, in Japan, APACHE and SPECTRA PRECISION in USA et al., in collaboration with manufacturers of mobile machines and manufacturers of electrohydraulic distribution equipment, switched to the implementation of mixed laser-hydraulic systems into the functional structure of the navvy machines.

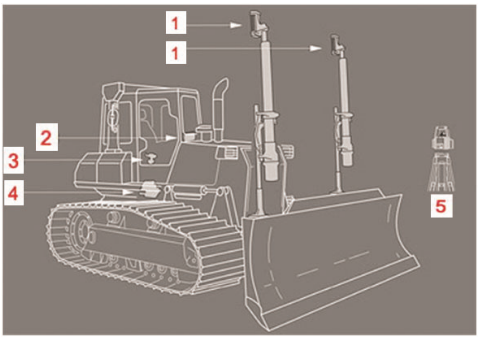
Fig. 1. Laser emitter.

Fig. 2. Laser receiver.

Fig. 3. Electronic tracking and control module.

Fig. 4. Electrohydraulic distribution block.

Stages 2-3. The main parts of the mixed laser-hydraulic systems, Figures 1…4, are installed on the navvy machine, Fig. 5, and testing is conducted under real operating conditions, Fig.6.

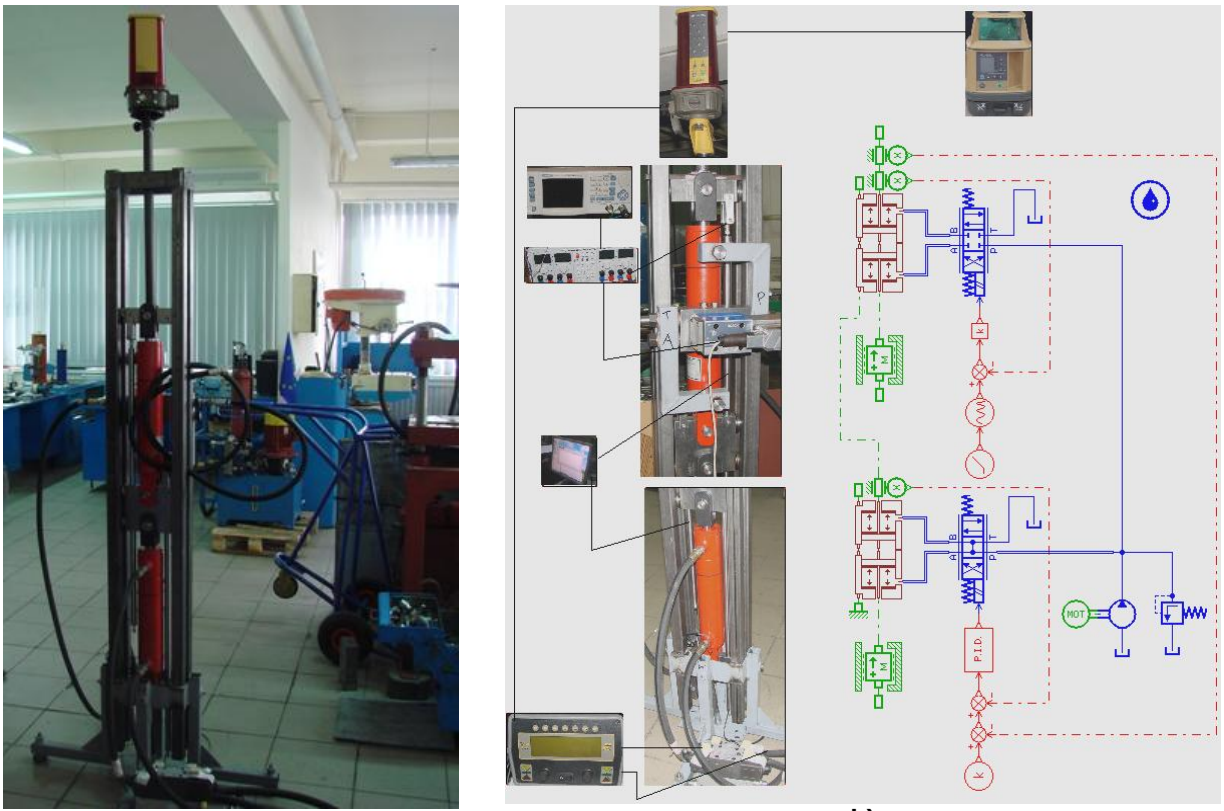


1= Laser receiver
2= Electronic control module
3= Selector of operating mode: manual or automatic
4= Hydraulic distribution block
5= Laser emitter

Fig. 5. Installing parts on the machine.

Fig. 6. System adjustment and testing.

Project General Objective is to capitalize some own research efforts - resulted in 2008 in a demonstrator product type single-axis electrohydraulic tracking system necessary to test the laser-hydraulic systems intended for the navvy machines that perform leveling against a laser benchmark plane, Fig.7- in order to switch to the development of a testing device (type 3-axis electrohydraulic tracking system) for laser-hydraulic systems intended for the navvy machines that perform automatic leveling against a benchmark plane inclined in one / two directions.
Development of the demonstrator type 3-axis electrohydraulic tracking system, which is a novelty compared to the international and national state-of-the-art, implies achieving five specific (phase) objectives: **O1:** making an **analysis study** on the main types of hydraulic diagrams for driving the working bodies, buckets or blades, specific to the navvy leveling machines; making an **analysis study** on using TOPCON laser components, embedded in the functional structure of the navvy machines in order to perform automatic leveling against a laser benchmark plane inclined in one / two directions; **O2:** developing a **mathematical model and** a **numerical simulation model** of the demonstrator dynamics; **O3: designing and developing** the demonstrator: **O4:** elaborating the demonstrator **testing procedure** and the **testing procedure for the system** and the laser-hydraulic components embedded in the functional structure of the navvy leveling machines; **O5: experimental identification** of the demonstrator, validating the mathematical model and the numerical simulation one.



a) **b)**

Fig. 7. Demonstrator type single-axis electrohydraulic tracking system, developed by INOE 2000-IHP Bucharest: **a)** the demonstrator; **b)** equivalence between the demonstrator and the AMESim simulation model.

Current situation of the proccess of embedding laser-hydraulic systems in the structure of the navvy leveling machines is marked by some difficulties related to:
- *inhomogeneous nature of the system components*, which has three different manufacturers: one for the machine, another one for the laser parts, and another one for the hydraulic parts;
- *different price policies, in the interest of their own units*, practiced by the three above mentioned manufacturers, which often lead to an unreasonably high price for the final beneficiary of the automated navvy equipment;
- the current fact that *integration of the mixed laser-hydraulic systems into the functional structure of the navvy machines is performed exclusively by the representatives of laser parts manufacturers*, who have no specific training in the field of Fluid Power.

Integration of the mixed laser-hydraulic systems on the machines requires qualified intervention in the hydraulic drive systems of the latter, which are very diverse, on the distribution of hydraulic oil to the cylinders driving the buckets or blades, and also requires mechanical removable fastening of the laser components on the machines.

This project aims to accelerate and increase efficiency of integration of laser-hydarulic systems into the structure of the navvy leveling machines by involving in the integration teams also specialists in the field of Fluid Power, who have at their disposal specific testing means. They will contribute to lowering the cost of implementation of the complex laser-hydraulic systems on the machine, through the following:

- *designing and developing hydraulic blocks of the electrohydraulic distribution devices, with low repeatability and high diversity at lower prices*. To a variety of hydraulic drive systems of the navvy machines, of varying complexity, current manufacturers of hydraulic components respond with a unique solution, "covering" the case of the most complex machine, but more expensive by 30 ... 40% for the simplest equipment.

- *using demonstrator stands*, type electrohydraulic tracking systems - single-axis, 2 or 3-axis - which allow, in laboratory conditions, not requiring the presence of the equipment and the land to be leveled, the following: to demonstrate the technical performance of mixed laser-hydraulic systems; to perform pre adjustments of system components prior to installation on the machine; to detect, during the warranty and post-warranty period, any faulty parts.

By implementing this project there will be achieved **qualitative leap in knowledge** in the field of the proposed topic from the current state, which is **the possibility to test**/functionally check the laser-hydraulic parts and systems **only on the machine**, **TRL 2**, to the state of conducting these **tests in laboratory conditions, TRL 3**. There will also be capitalized the experience of developing the demonstrator type single-axis electrohydraulic tracking system to develop the demonstrator type 3-axis electrohydraulic tracking system. In this line, the first type of demonstrator - needed to test the laser-hydraulic systems which equip the machines for automatic leveling against a horizontal benchmark plane - will become a special case of the 3-axis demonstrator.

3. Presentation of the concept of technology / product

The starting point of this project concept, mentioned in References section, is represented by both state-of-the-art in this field, [1...7], and the preliminary results of the authors of this project proposal [8...18], completed with a single-axis demonstrator, which can be found in: the PhD thesis of the project director, 1 national research project, 1 book published in our country, 2 book chapters published in an international volume, 7 ISI and IDB-indexed papers.

In order to test the laser-hydraulic systems for the machines that perform automatic land leveling against a benchmark plane inclined in one or two directions, there can be used two or three identical test devices, similar to the one described in leveling against a horizontal benchmark plane.

For the case of a benchmark plane inclined in two directions, those three devices are placed nonlinearly, and then there are operated manually the screws that adjust the vertical position of the three laser receivers, till the latter ones receive the inclined plane profile generated by the rotating laser emitter (when intercepting the laser plane the receiver emits a light signal).

The basic diagram of the 3-axis demonstrator, type electrohydraulic tracking system, Fig.8, includes three single-axis electrohydraulic tracking devices composed of three laser feedback tracking servo cylinders, namely *1.1*, *1.2*, *1.3*, fixed body and mobile rod, and three servo cylinders which simulate profile of uneven ground, namely *2.1*, *2.2*, *2.3*, mobile body and rod.

The laser benchmark plane, inclined in two directions, is depicted as the triangle ABC, with its vertices in the optimal detection levels of the three laser receivers.

The two categories of servo cylinders are fitted with the inductive stroke transducers *3.1*, *3.2*, *3.3*, and respectively *4.1*, *4.2*, *4.3*. Three laser receivers 5.1, *5.2*, *5.3* are attached to the upper cylinders rods, and it is possible to manually adjust quota from the floor, until they receive the inclined benchmark plane, *7*, emitted by the rotating laser generator *6*. When the servo cylinders that simulate the uneven ground profile are excited, the electronic block *8* of the laser system takes the information about positioning outside the benchmark plane of the three laser receivers and starts sending control signals to the proportional directional control valves *9.1*, *9.2*, *9.3*, which actuate the servo cylinders *3.1*, *3.2*, *3.3*, towards reducing the positioning errors against the benchmark plane. The servo cylinders that simulate the uneven ground profile, controlled by the proportional directional control valves with embedded electronics *10.1*, *10.2*, *10.3*, are supplied by the electropump *11*, with the safety valve *12*, while the tracking servo cylinders are supplied by the electropump *13*, with the safety valve *14*. By means of the signal generators *15.1*, *15.2*, *15.3*, data acquisition board *16*, power source *17* supplying the electromagnets of directional control valves *10.1*, *10.2*, *10.3*, and also by digital-to-analog converters *18.1...18.6* a control signal is sent to excite the servo cylinders that simulate the uneven ground profile and there are acquired data on the dynamic behaviour of the two groups of servo cylinders.

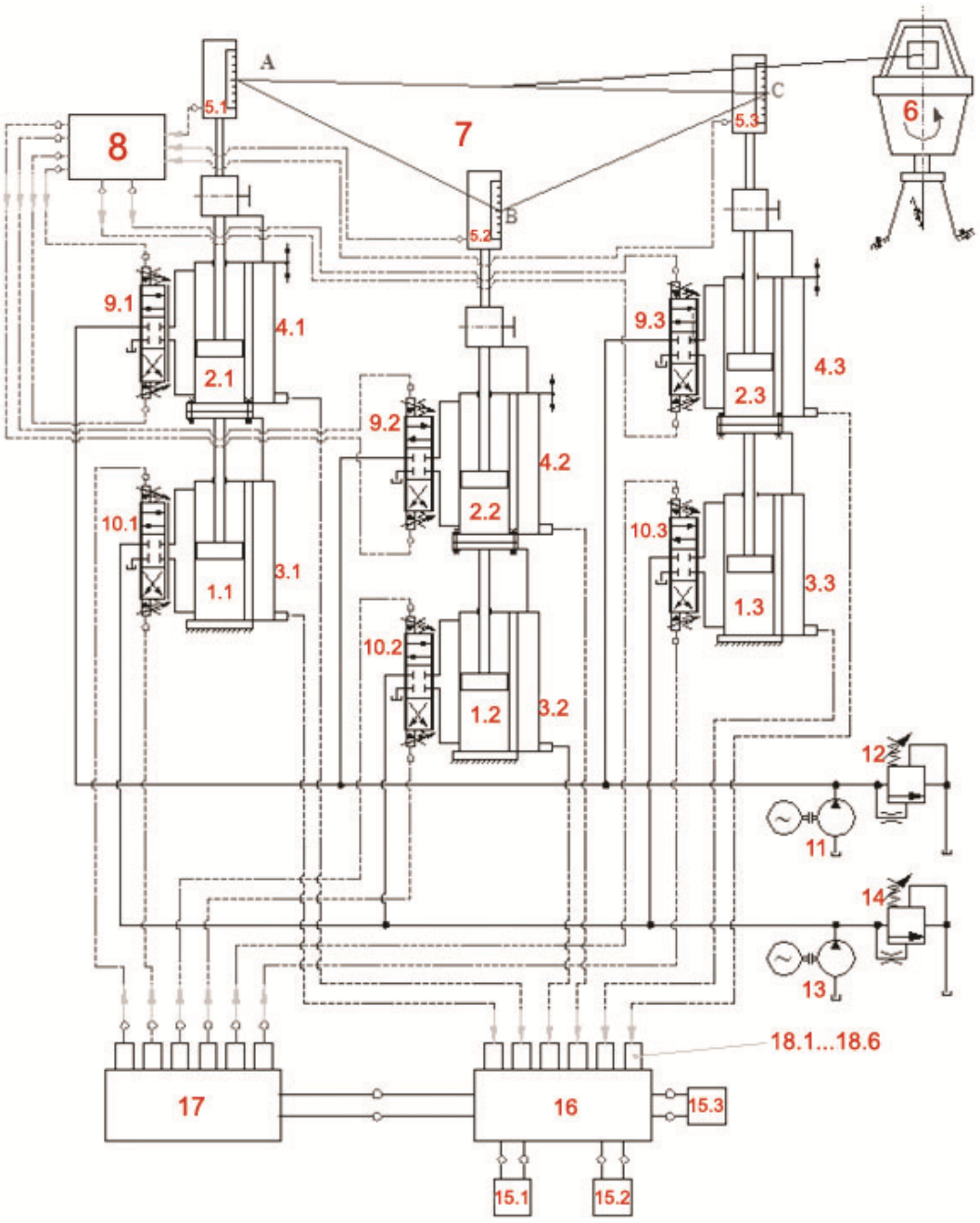


Fig. 8. Basic diagram of the 3-axis tracking electrohydraulic demonstrator

Although it has a clearly defined practical nature, this project aims at an inter-, multi- and transdisciplinary scientific approach. Thereby, for the analysis of the main hydraulic drive diagrams specific to the navvy leveling machines, and the analysis of the main types of TOPCON laser equipment dedicated to these machines, two studies will be elaborated on: types of navvy leveling machines; types of movements of the machine working bodies (buckets and blades); types of hydraulic linear and rotary motors, actuating these working bodies; types of hydraulic distribution devices existing on the navvy machinery; types of hydraulic drive diagrams for the working bodies; operation and usage of TOPCON laser equipment installed on the navvy leveling machines. The two above mentioned analysis studies, in the fields of ***Mechanics, Fluid Power*, and *laser equipment***, will provide the input information for a provisional theme in view of the development project of the demonstrator. Finalizing the design theme will be done following ***mathematical modeling*** and ***numerical simulation*** of the dynamic behavior of the demonstrator.

Designing and developing the demonstrator, type 3-axis electrohydraulic tracking system, modular structure, will call on knowledge at the interface between the following scientific disciplines: ***Mechanics*** *and* ***mechanisms***-for metallic structure and degrees of mobility of the demonstrator; ***Electronics*** *and* ***automated systems*** for hydraulic servomechanisms (**HSM**); ***Fluid Power***–for development of electrohydraulic distribution blocks; ***Electrotechnics, Fluid Mechanics, Hydraulic drive systems***-for development of hydraulic pumping units; ***inductive and laser displacement transducers, pressure transducers and flow transducers*****,** ***pressure and flow control elements, data acquisition, Mechatronics, dedicated software apps*** *for dynamic tests on hydraulic drive systems*, needed to test the final product type demonstrator.
To reach the objective set, between these scientific disciplines there will be made connections in successive loops of mathematical modeling - numerical simulation - experimental identification. Validation of the mathematical model, which will ground the numerical simulation model of the demonstrator, will be ensured by consistency between results of experimental tests and results obtained by numerical simulation.
All these specializations mentioned as necessary in order to reach the project final objective are covered by the research team structure, i.e.:
from behalf of CO, there will be involved in this project a team of experienced researchers who have achievements in the field of Fluid power systems specific to fixed and mobile equipment, in the field of navvy leveling machinery, as well as in the field of automated systems and applied electronics specific to hydraulic drives, along with young researchers specialized / under training in numerical simulations, transducers and data acquisition systems;
from behalf of partner P1, there will be involved in this project a team of professors from P.U.B., who have experience and outstanding results in the field of mathematical modeling and numerical simulation specifice to electrohydraulic servomechanisms, along with young lecturers, PhD-s, interested in knowing the theoretical applications related to dynamics of 3-axis electrohydraulic tracking systems.
The team of CO will be in charge with activities related to industrial research and experimental development, and the team of partner P1 will be in charge with activities related to fundamental research. The two teams will jointly contribute to wide dissemination of project results.

Conclusions

This project propose a new manner to approach the issue of integrating mixed laser-hydraulic systems in the structure of leveling navvy machines; this manner is based on using stands type electrohydraulic system for tracking on one, two or three axes, allowing to:
- increase the speed of integrating the automatic mixed laser-hydraulic systems, by attracting in this activity also small companies, profiled on repairing / upgrading hydraulically driven mobile equipment, besides the companies representing the manufacturers of laser components, already on the market;
- reduce the costs of integration, by reducing the price for the hydraulic component of these systems, due to the fact that the hydraulic blocks that the electrohydraulic directional control valves are installed on can be produced at a lower price, by the aforementioned companies;
- test in the laboratory the electrohydraulic directional control valves, installed on hydraulic blocks produced at a lower price, within mixed laser-hydraulic systems;
- quickly detect with minimal costs, during warranty and post-warranty service, the system component/ components with possible failures;
- provide pre-settings for the parameters of the mixed laser-hydraulic systems, before installing and integrating these systems on the machine.

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