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EXPERIMENTAL RESEARCH ON A CLAMPING DEVICE

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Abstract: *In the catalogs of the manufacturers of hydraulic devices, we do not find the operating characteristics that, in industrial practice, the application of too high forces caused deviations in the shape of the parts processed on NC machining centers.*
In this paper we report our experience in the experimental research of a hydraulically actuated modular technological device. The special test stand, with three operating positions (calibration, radial stroke measurement, radial force measurement), with 2 digital measuring chains with multiparametric output signal, the proposed virtual instrumentation and established research methodology determine the innovative character of the work.

Keywords: *Hydraulic, test stand, experimental research, clamping device*

1. Introduction

In an extensive monographic study [1] I highlighted, at length, almost all aspects regarding the current state of knowledge related to technological devices in general, and hydraulically actuated ones in particular. From this study, the current trends in the use of hydraulic drives in different branches of activity resulted, considering their indisputable advantages, demonstrated theoretically and validated by the practice of applications; they refer, in particular, to: high power density, ensuring an optimal regulation of work processes, increasingly faster response speeds to commands, good dynamic performance, their compatibility with electronics, informatics and mechatronics through specific elements interface etc. For these reasons, the use of hydraulic systems has experienced a spectacular trend highlighted by the increase in equipment production, with increasingly higher performances, between 20÷35%, in the last 25 years.
It should be noted that, due to the increase in the performance of current equipment, the usual working pressures have increased from 10÷25 MPa to 35, 50, 70 or even 100 MPa with notable applications also in the hydraulic actuation of processing devices in the automotive industry. Devices operated in this way achieve an extremely high clamping capacity, unthinkable in the past, at small dimensions and dimensions, with major consequences regarding their architecture. Associated with original orientation solutions, for example with purely technological ("non-functional") orientation surfaces and modularization, Fig. 1, such devices allowed the development of intensive processing technologies with significant economic effects.

Fig. 1. Modularized hydraulic device

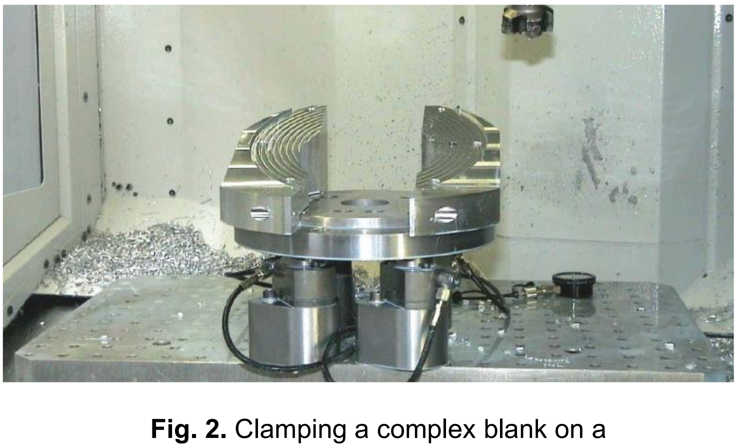

Fig. 2. Clamping a complex blank on a 5-axis CNC machining center

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The previous own research [2] was developed with new research methods for the design and optimization of the construction and operation of these types of devices, in the category of those hydraulically operated from medium and high-pressure units, with wide application in the processing technologies specific to the automotive industry from Romania (Fig. 2).
Starting from some observations and findings based on Ishikawa diagrams, with effect on the precision of machining parts on CNC machining centers, we experimentally researched the influence of clamping forces and strokes because in the catalogs of the manufacturers of hydraulic devices we do not find the operating characteristics.
The research was carried out on a modularized device, hydraulically actuated, Fig. 3 and Fig. 4, with the characteristics:
- maximum force: 26 kN;
- maximum axial stroke: 9 mm;
- minimum fixing diameter: 16+0.1 mm;
- maximum radial stroke of the jaws: max. 1 mm;
- maximum working pressure: 35 MPa;
- - the jaws of the device perform a radial extension movement, self-centering, as a result of the movement on an inclined plane of a plunger, multiple wedge type, integral with the piston of the hydraulic cylinder.

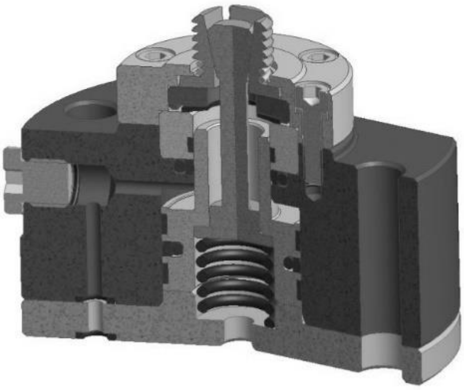


Fig. 3. The pull-down clamping device

Fig. 4. Assembly scene of the hydraulic clamping device

2. Innovative stand for testing the hydraulic clamping device to be optimized

We designed, using Autodesk Inventor, a special stand (Fig. 5÷9) to testing the hydraulic device.

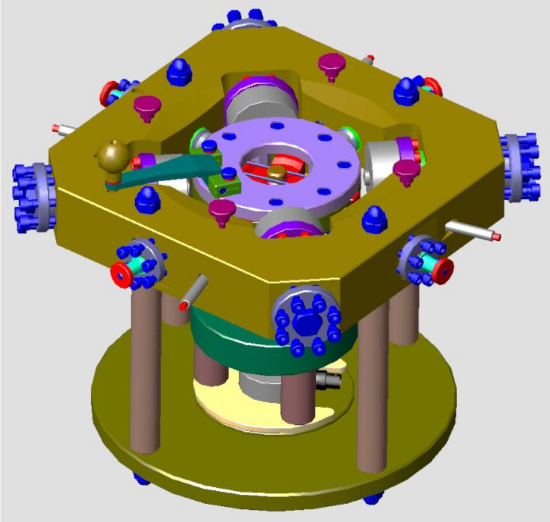
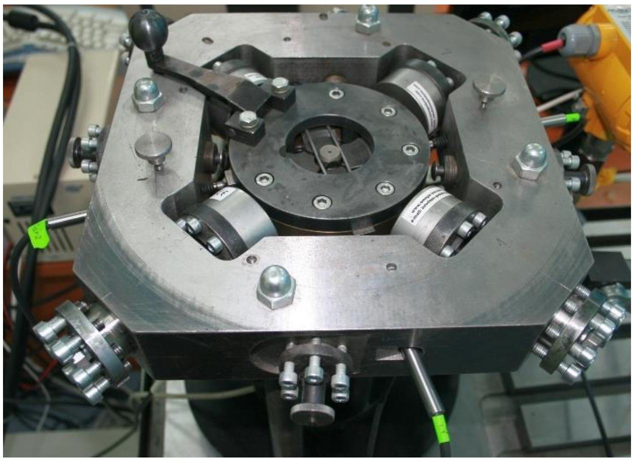
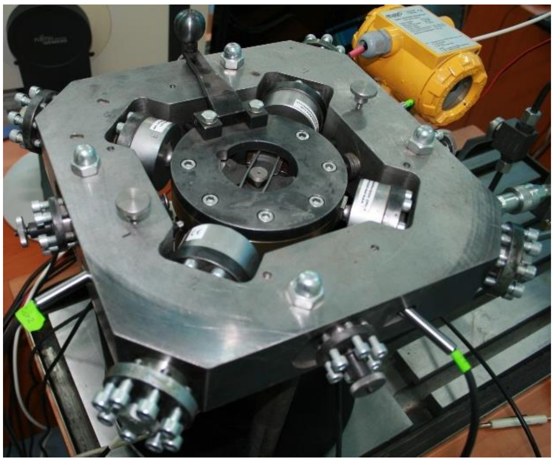


Fig. 5. 3D design: the test-stand equipped to evaluate the stroke and the force operation

Fig. 6. Test-stand with the plate with the plunger indexed middle/ in calibration position

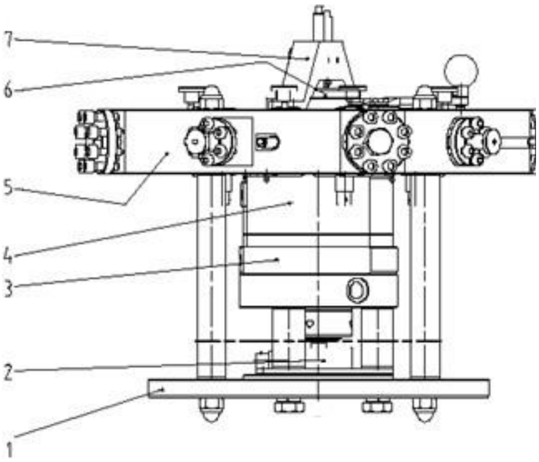


a) left indexing - the plunger takes the tightening stroke of each bar and transmits it to the displacement transducer

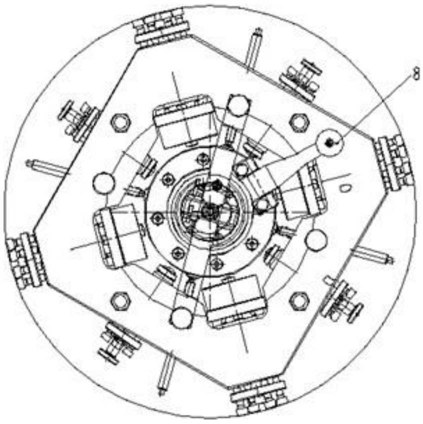


b) right indexing - the plunger takes the clamping force of each bar and transmits it to the force transducer

Fig. 7. Details of the other two indexing positions of the plunger plate



a) lateral view



b) upper view

Fig. 8. 2D design: the test-stand for pull-down clamping device

1 – Main body; 2 – Force transducer (for axial force, action or/and clamping force); 3 – Support alimentation – pressure circuit; 4 – Testing device; 5 – Motion transducers assembly (4 pieces, for radial/clamping strokeevaluation) 6 – Force transducer (preliminary force evaluation); 7 – Displacement transducers assembly (1 piece for action stroke evaluation, 1 piece for preliminary and clamping stroke evaluation); 8 – Adapters with radial plungers.

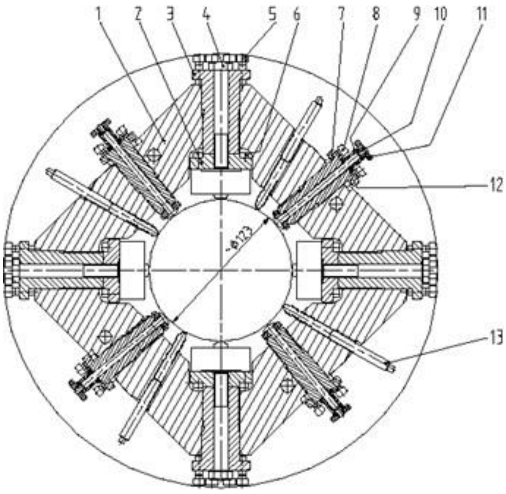
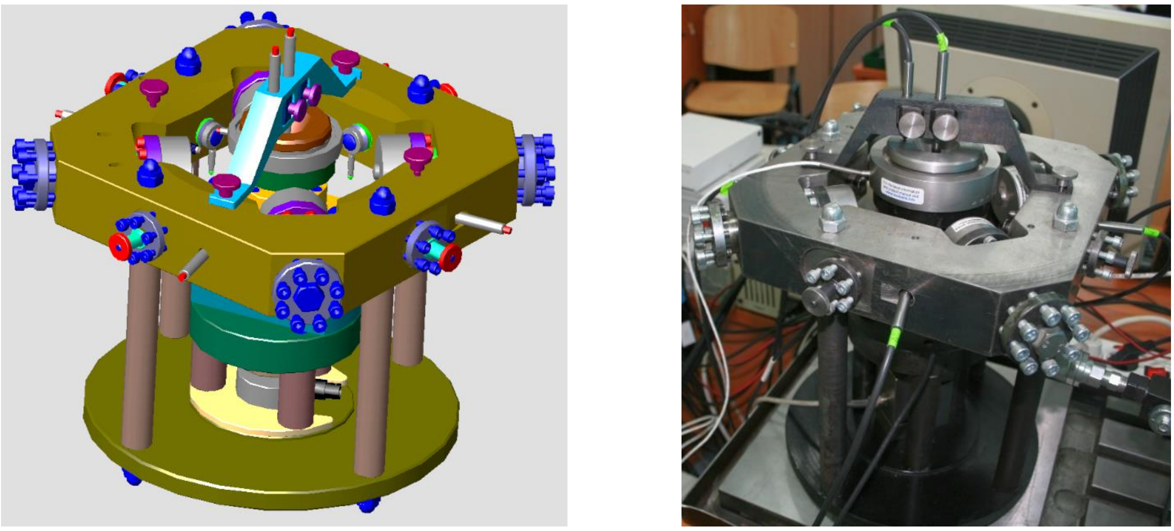


Fig. 9. 2D section/ test-stand for pull-down clamping device

1 – Transducer support for displacement and force; 2 – Force transducer (for radial/clamping force evaluation); 3 – Force transducer support; 4 – Clamping screw for force transducer assembly; 5 – Screw for force transducer pre- charging; 6 – Clamping screw for force transducer; 7 – Position system for displacement transducer; 8 – Special nut; 9 – collar bush; 10 – Plunger with spherical head; 11 – Bush; 12 – Elastic washer; 13 – Displacement transducer.

The stand allows for additional equipment, Fig. 10, with a displacement and force translation yoke for evaluating the force and axial travel of the blank clamping.



a) 3D design b) Photo

Fig. 10. The test-stand with the additional equipped to evaluate the axial stroke and force

3. Research apparatus for experimenting with the hydraulic clamping device to be optimized

The hardware and software components used for the displacement parameters measurement chain are shown in Fig. 11, Fig. 12 and Tab. 1.

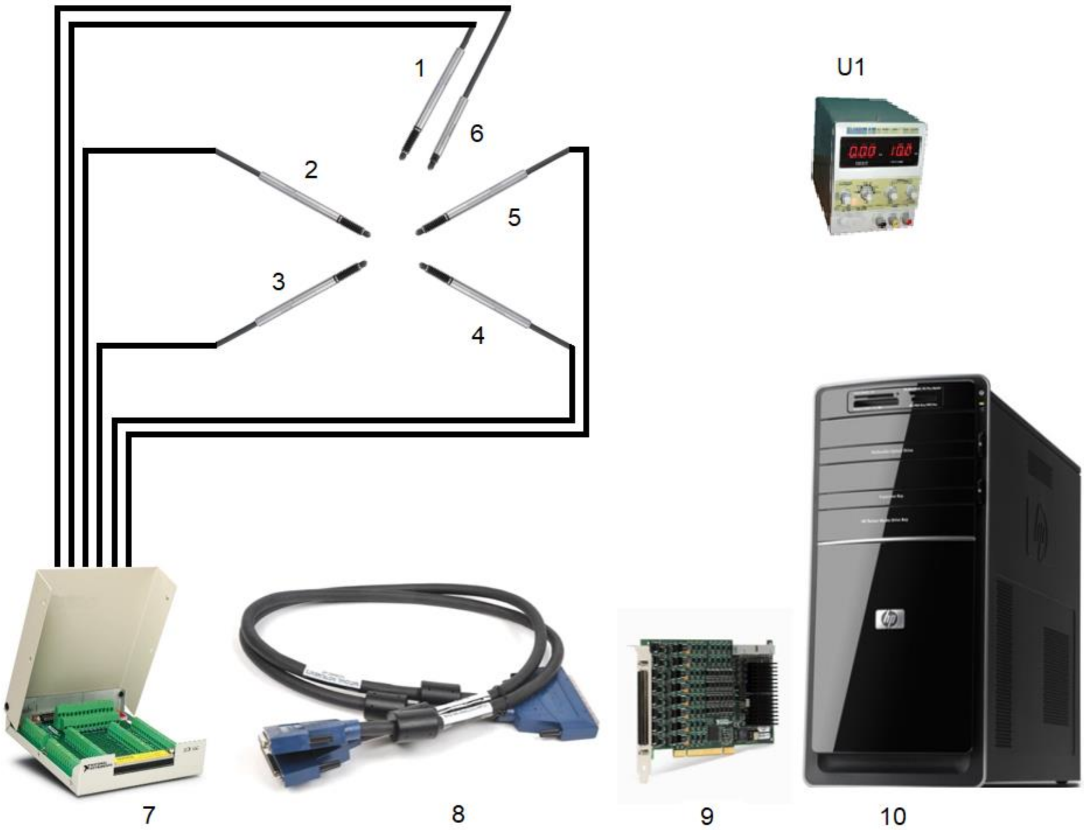


Fig. 11. Sketch of the displacement parameter measurement chain

Table 1: The hardware and software components used for the displacement parameters measurement chain

Pos	The measured parameter		Transducer type	Code/ licence	Characteristic sizes	
	Symbol	Race of			specific	common
1	c_a	actuation/ displace-ment of the piston	digital, displace-ment, with three-phase A/ B/ Z output signal of voltage-differential, rectangular shape	DK812R5 / Sony	- measurement range: 0-12 mm; - resolution: 0.5μm; - accuracy: 1.5 μmp-p; - maximum response speed: 100 m/min.	- with output signal with three phases A/B/Z of voltage-differential, rectangle-round shape (according to the EIA-422 norm); - fixing diameter: ø8-0.009 mm; - fixing length: 18 mm; - the maximum tightening torque of the notched bush screw: 0.6 Nm; - signal period/step: 40μm; - vibration resistance (10-2000 Hz): 100 m/s2; - impact resistance (11ms): 1000 m/s2; - supply voltage: +5 VDC; - consumed power: 1.8 W; - protection class: IP66; - temperature range: 0-50°C; - signal cable length: 2.5 m.
2	c_{sr1}	radial clamping / jaws 1, 2, 3 an4		DK812R5 / Sony		
3	c_{sr2}					
4	c_{sr3}					
5	c_{sr4}					
6	c_{sa}	axial clamping of the blank		DK802R / Sony	- measurement range: 0-2 mm; - resolution: 0.1μm; - accuracy: 1 μmp-p; - maximum response speed: 42 m/min.	
Pos	Name			Code/ licence	Characteristic sizes	
7	Multi-function DAQ I/O connection box			SCB-100 / National Instruments	- SCSI socket with 100 pins; - 6 microswitches for multi-functional I/O settings; - 101 screws for fixing signal cables; - separate temperature sensor connection option.	
8	Data cable			SH100-100-F / National Instruments	- male SCSI plug with 100 pins/ connection to SCB-100; - length 2 m; - male plug with 100 pins/ connection to NI 6624..	
9	PCI acquisition card			6624 / National Instruments	- number of input channels: 26 (3 for each transducer and 2 extra PFIs); - maximum input frequency: 400 kHz; - minimum input pulse width: 1 μs; - recommended power: 0.75 A at +5 VDC; - number of output channels: 8; - maximum current: 100 mA/ channel; - output supply voltage: 8-48 Vdc; - I/O resolution: 32 bits; - female plug with 100 pins/ connection SH100-100-F; - PCI socket/ desktop computer connection.	
10	Desktop computer			ACH67/ Dell	- minimum Intel Core 2 Duo, 1 GHz, 2 GB RAM, minimum 100 GB HDD, minimum 2 PCI ports, minimum power supply 400 W, video card with 2 VGI/DVI/DisplayPort outputs; - minimum Windows 7 Pro license; - minimum NI-DAQ 7.1 license; - peripherals: 2 LCD monitors, keyboard, mouse.	
U1	Stabilized power supply			TXN-1502D / Hiaoxin	- supply voltage/ mains frequency: 220 VAC/50 Hz; - protective fuse: 0.5 A; - stabilized output voltage: 0-15 Vdc adjustable; - output current: 0-0.2 A adjustable.	

The equipment and software used for the force, pressure, temperature parameter measurement chain are shown in Fig. 13, Fig. 14, Fig. 15 and Tab. 2.

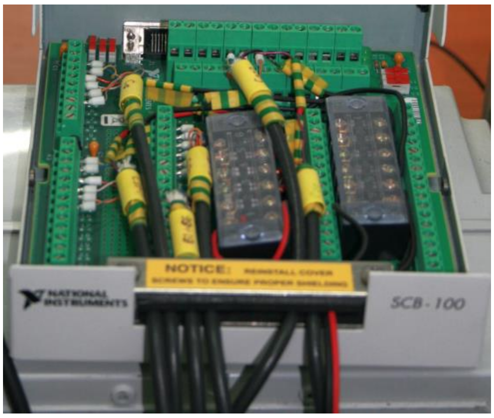


Fig. 12. Detail of the connections made in the DAQ connection box multifunctional I/O SCB-100

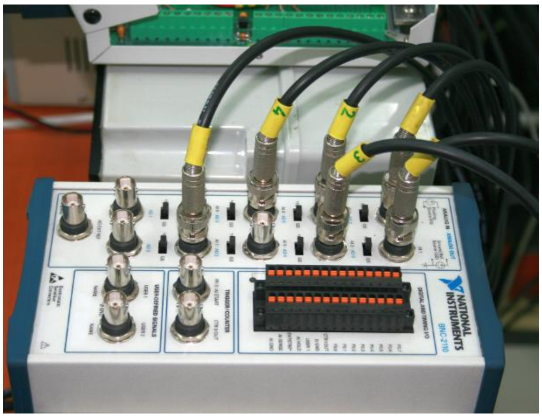


Fig. 13. Detail of the connections made in the BNC-2110 multifunctional DAQ I/O connection box

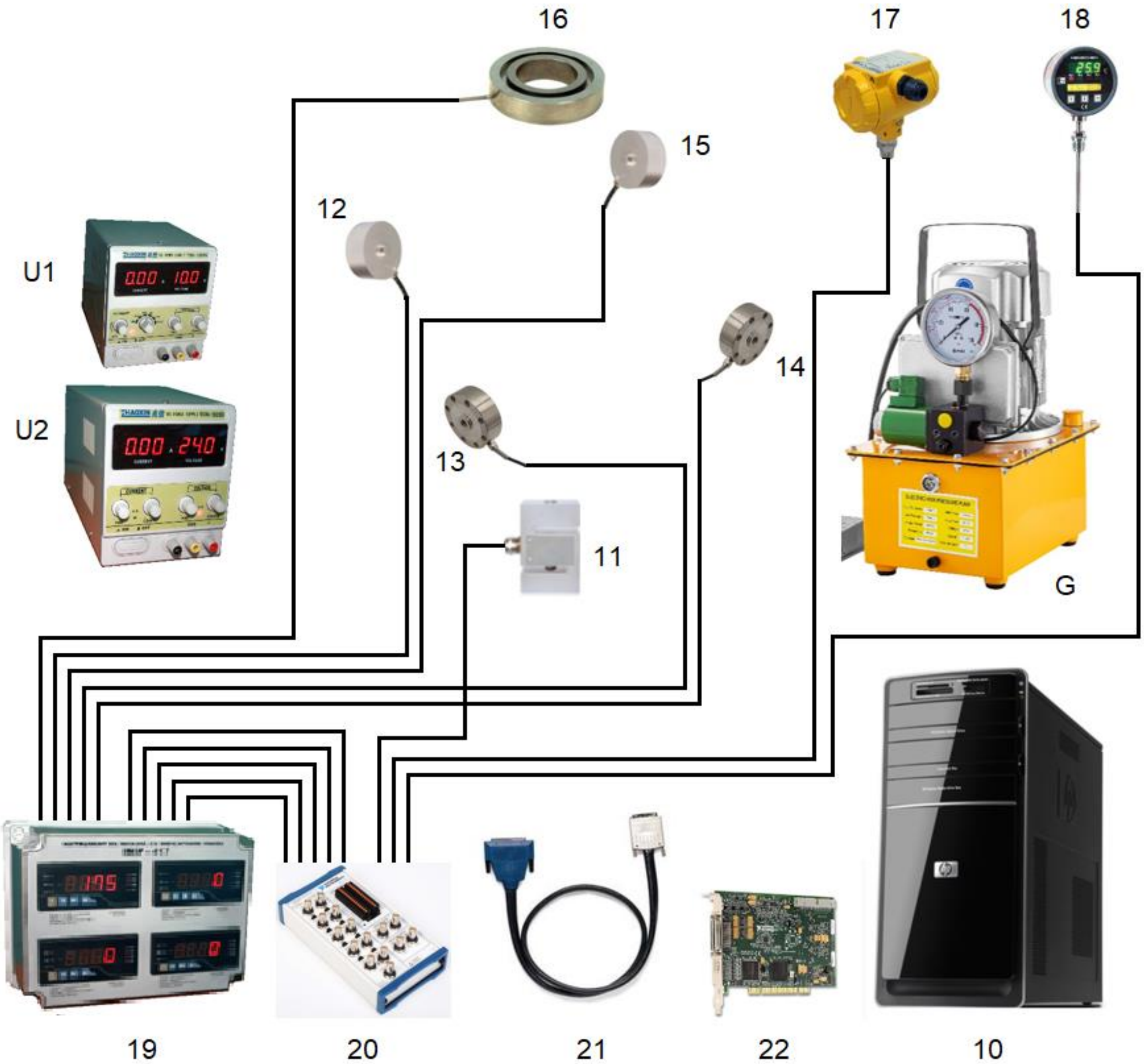


Fig. 14. Sketch of the of the force, pressure, temperature parameter measurement chain

Table 2: The hardware and software components used for the force, pressure, temperature parameter measurement chain

Pos	The measured parameter		Transducer type	Code/ licence	Characteristic sizes
	Symbol	Force of			
11	Q	hydraulic cylinder actuation	Load cell, compression - traction, with tensometric marks	K-25 / Lorenz	- measurement range 2-50 kN; - sensitivity: 2 mV/V; - compression precision class: 0.1%; - maximum dynamic force (DIN 50100): 35 kN; - supply voltage: 2-12 VDC; - repeatability: 0.08%; - signal converter for strain gauge cells, input signal 2 mV/V, output signal 12±8 mA, accuracy class 0.1, protection class IP60.
12	S_{r1}	radial clamping / jaw 1, 2, 3, 4	Load cell, compression with tensometric marks	LC305-20K lbs / Omega	- measurement range 0-8.9 kN; - excitation: 10 Vdc (maximum 15 VDC); - output signal: 2 mV/V (±0.25%); - 5 calibration points: 0, 50, 100, 50, 0 %; - linearity: ±0.15% FSO; - hysteresis: ±0.1% FSO; - repeatability: ±0.05% FSO - zero balance: ±2% FSO.
13	S_{r2}				
14	S_{r3}				
15	S_{r4}				
16	S_a	axial clamping of the blank		LC8400-213-10K lbs / Omega	- measurement range 0-4.45 kN; - excitation: 10 Vdc (maximum 15 Vdc); - output signal: 2 mV/V; - linearity, hysteresis, - repeatability: ±0.5% FSO< - zero balance: ±2% FSO.
17	p	pressure generated by the hydraulic power unit	with tensometric mark	APCE 2000-AL / Applisens	- measurement range: 0-50 MPa; - accuracy class: 0.075%; - output signal: 4-20 mA; - supply voltage 13.5-36 VDC.
18	T	hydraulic oil temperature		DTMF580P B1A40S / Henschen	- measurement range: 0-80°C; - accuracy class: 0.5; - output signal: 4-20 mA; - supply voltage 15-30 VDC.

Pos	Name	Code/ licence	Characteristic sizes
19	Display panel with 4 digital indicators and signal conversion (Fig. 15)	IMIP-417/ ACH innovation	- 4 x Asahi Keiki A5212-17 modules; - input: tensometric mark 2 mV/V; - output: analog and 0-10 V; - accuracy ±0.1%; - supply voltage 24 Vdc.
20	Multi-function DAQ I/O connection box	BNC-2110 / National Instruments	- 8x Analog In, 2x Analog Out, 1x Analog Ext Ref, 2x digital and timing I/O, 2x Trigger/Counter, 2x User-defined signals; - 68-pin SCSI socket.

Table 2: (continuation)

Pos	Name	Code/ licence	Characteristic sizes
21	Data cable	SHC68-68-EPM / National Instruments	- male SCSI plug with 68 pins/ connection to BNC-2110; - male plug with 68 pins/ connection to NI 6229.
22	PCI acquisition card	6229 PCI/ National Instruments or 6036E PCMCIA/ National Instruments	- number of input channels: 16 differential; - ADC resolution: 16 bits; - simple rate: 250 kS/s; - signal bandwidth (-3 dB): 700 kHz; - input voltages: ±0.2 / ±1 / ±5 / ±10 Vdc; - number of output channels: 4; - maximum current: ±5 mA; - output supply voltage: ±10 Vdc; - female socket with 68 pins/ connection SHC68-68-EPM; - PCI socket/ connection to desktop computer or PCMCIA-PCI adapter or laptop PCMCIA socket.
10	Desktop computer	ACH67/ Dell	- minimum Intel Core 2 Duo, 1 GHz, 2 GB RAM, minimum 100 GB HDD, minimum 3 PCI ports, minimum power supply 400 W, video card with 2 GI/DVI/DisplayPort outputs; - minimum Windows 7 Pro license; - minimum NI-DAQ 7.1 license; - peripherals: 2 LCD monitors..
U1	Stabilized power supply	TXN-1502D / Hiaoxin	- supply voltage/ mains frequency: 220 ±10% Vac/ 50 Hz; - protective fuse: 0.5 A; - stabilized output voltage: 0-15 Vdc adjustable; - output current: 0-0.2 A adjustable.
U2	Stabilized power supply	RXN-305D / Hiaoxin	- supply voltage/ mains frequency: 220 ±10% VAC/ 50 Hz; - protection fuse: 1.5 A; - stabilized output voltage: 0-30 Vdc adjustable; - output current: 0-0.5 A adjustable.
G	70 MPa hydraulic power unit with multiplier or high pressure pump	UAH.700 or UH.700 / Hydramold	- maximum pressure: 70 MPa; - maximum flow: 0.2 l/min; - installed power: 2.2 kW; - supply voltage/ frequency:220 VAC/50 Hz - 500 bar throttle for flow limitation.

The innovative display panel with 4 digital indicators and signal conversion is shown in Fig.15. The characteristic sizes are indicated in table 2, at position 19. The panel was needed for:
- conversion of the strain gauge signal into a 0-10 Vdc output signal for 5 load cells, compression with strain gauges;
- stand calibration without National Instruments acquisition system; the Asahi Keiki A5212-17 modules were set to display the compression force value.

a) view from the digital displays b) the In and Out connections

Fig. 15. Display panel with 4 digital indicators and signal conversion from 2 mV/V to 0-10 V

The signal is received from 5 compression load cells, maximum 4 simultaneously (5xIn 2 mV/V 2+2 Out 0-10VDC, 14-36 VDC), which imposed the condition of introducing some electrical couplers on the data cable of the LC8400-213-10K load cell as well as on the data cable of a single load cell load LC305-20K.

4. Conception in LabView of the virtual instrument and the block diagram for the analysis of the dependence between the parameters measured at the hydraulic cylinder and the radial clamping force at the jaws of the device

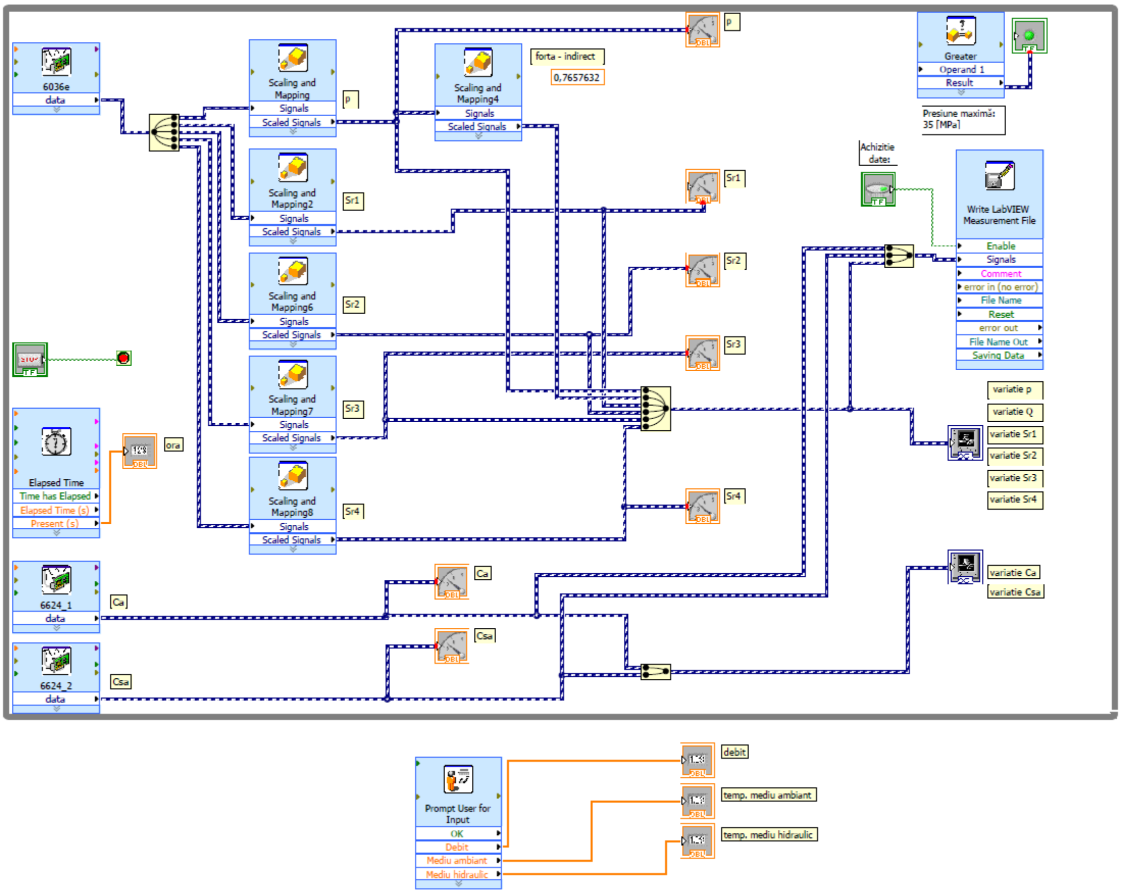


Fig. 16. Block diagram for the analysis of the dependence between the parameters measured at the hydraulic cylinder and the radial clamping force of the jaws of the clamping device

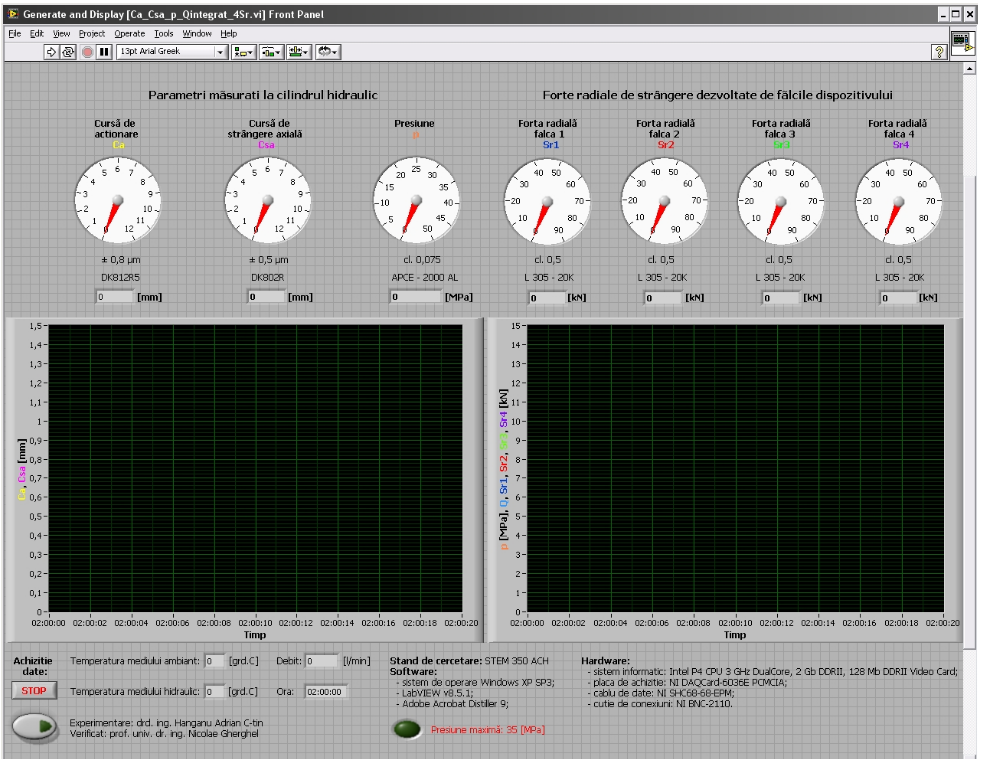


Fig. 17. Virtual LabView innovative tool for analyzing the dependence between parameters measured at the hydraulic cylinder and the radial clamping force of the clamping device jaws

5. Experimental research on the analysis of the dependence between the parameters measured at the hydraulic cylinder and the radial clamping force of the device jaws

I used the previously mentioned virtual tool and stand equipment 2; in Fig. 18 we presented photo captures during the experiment and in Fig. 19 and Fig. 20 are plots of the real-time plotting of the signals of the pressure transducer, two displacement transducers and 4 compression load cells with strain gauges / time evolution of the quantities c_a, c_{sa}, p, S_{r1}, S_{r2}, S_{sr3} and S_{r4}.

Fig. 18. Photo capture during the experiment

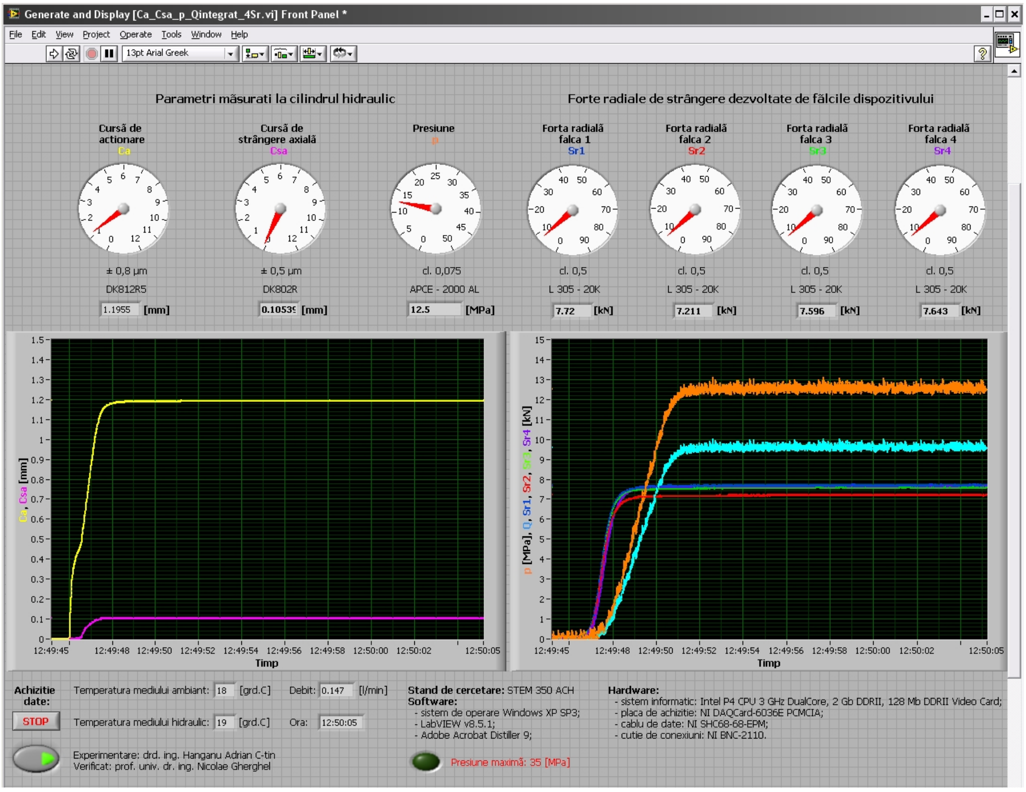


Fig. 19. Screenshot of the visual data acquisition interface with 7 measuring instruments and two graphs of real-time plotting of the quantity signals of c_a, c_{sa}, p, S_{r1}, S_{r2}, S_{sr3} and S_{r4} (adjusted pressure:12,5 MPa)

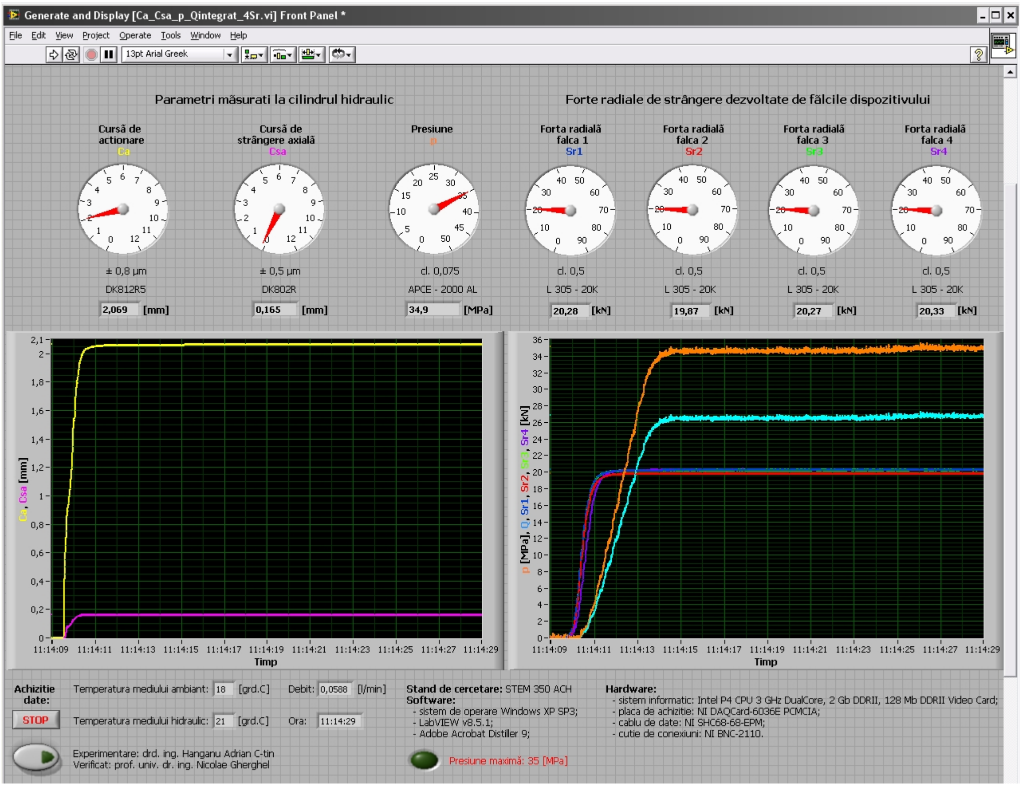


Fig. 20. Screenshot of the visual data acquisition interface with 7 measuring instruments and two graphs of real-time plotting of the quantity signals of c_a, c_{sa}, p, S_{r1}, S_{r2}, S_{sr3} and S_{r4} (adjusted pressure:35 MPa)

For the evaluation of the parameters measured at the hydraulic cylinder and the radial clamping force of the device jaws, semi-finished products of different brands of alloy steel were used, with improvement heat treatment at various hardness values, with a technological fixing hole of the same nominal size, then it was ordered the connection to the hydraulic group where the pressure has been adjusted to values between 12.5 and 35 MPa (Fig. 19 and Fig. 20), in steps of 2.5 MPa. According to the diagrams $c_a(t)$, $c_{sa}(t)$, p(t), Q(t) – obtained by integration as pressure filtering, respectively $S_{r1}(t)$, $S_{r2}(t)$, $S_{r3}(t)$ and $S_{r4}(t)$ an increase proportional to the value of the regulated pressure at the hydraulic group of the actuation stroke, the axial clamping stroke and the radial clamping forces of the jaws is observed.
The experimental determinations were carried out 10 times, using three blanks of different materials and with a technological hole of the same nominal size.
The displayed values are recorded by LabView and allow the data to be saved on the computer's hard disk in a text file with a dedicated name with the extension .lvm.

6. Analysis and interpretation of the results regarding the dependence between the parameters measured at the hydraulic cylinder and the radial clamping force of the device jaws

The inputs were the data of the experimental determinations presented in the previous paragraph, recorded by LabView on the hard disk of the computer; data files were imported into MsExcel to make characteristic plots for detailed data analysis/interpretation.
In Fig. 21 and Fig. 22 we superimposed the characteristic curves for the actuation stroke $c_a(t)$, the axial clamping stroke $c_{sa}(t)$, pressure p(t), and the radial clamping force specific to each jaw of the device: $S_{r1}(t)$, $S_{r2}(t)$, $S_{sr3}(t)$, $S_{r4}(t)$ – data acquisition specific to the visual data acquisition interfaces diagrams in Fig. 19 and Fig. 20.

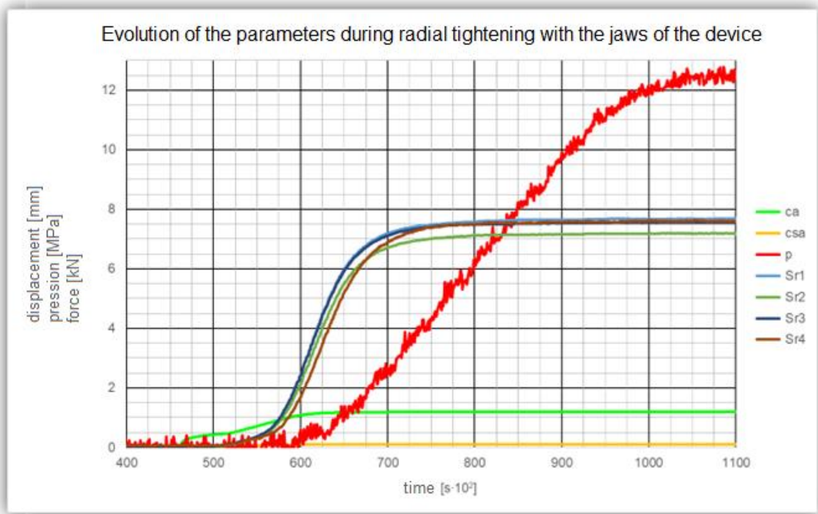


Fig. 21. Variation over time of parameters c_a, c_{sa}, p, S_{r1}, S_{r2}, S_{sr3} and S_{r4} for a pressure of 12.5 MPa regulated at the hydraulic group

By analyzing the characteristic curves in Fig. 21 and Fig. 22, for semi-finished products of different brands of alloy steel, with heat treatment for improvement at various values of hardness, but with technological fixing hole having the same nominal size, we observed all the curves of the parameters c_a, c_{sa}, p, S_{r1}, S_{r2}, S_{sr3} and S_{r4} have the same allure but all have steeper ramps and higher stall values as hydraulic group pressure increases.
The characteristic curves of $S_{r1}(p)$, $S_{r2}(p)$, $S_{sr3}(p)$ and $S_{r4}(p)$ in Fig. 23 and Fig. 24 were drawn for pressures adjusted to the hydraulic group of 12.5 MPa, respectively 35 MPa; it can be seen that they have similar grooves regardless of the pressure value, being of the 2nd degree curve type.

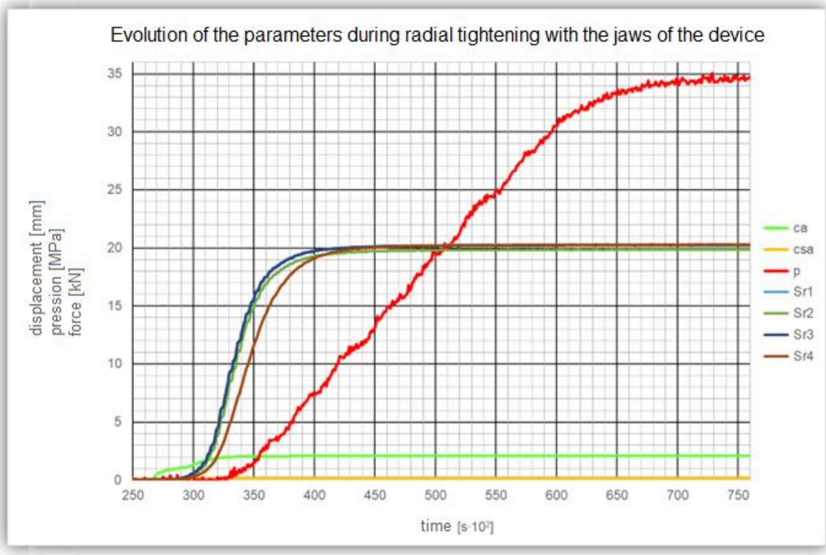


Fig. 22. Variation over time of parameters c_a, c_{sa}, p, S_{r1}, S_{r2}, S_{sr3} and S_{r4} for a pressure of 35 MPa regulated at the hydraulic group

For a pressure of 12.5 MPa set at the hydraulic group, it is observed that the maximum average value of the radial clamping force on a jaw, of 7.5 kN, corresponds to a pressure of 7.5 MPa, and when the pressure increases up to 12 .5 MPa, the maximum value of 7.5 kN is kept.
Similarly, for a pressure of 35 MPa set at the hydraulic group it is observed that the maximum average value of the radial clamping force on a jaw, of 20 kN, corresponds to a pressure of 20 MPa, and up to 35 MPa the maximum value is maintained and never mind the increase in pressure.
This means that the maximum values of 7.5 kN and 20 kN, respectively, correspond to the force developed by the cylinder piston, force demultiplied by the multiple wedge. In Fig. 21 and Fig. 22 it is observed that when the actuation stroke reaches the bearing value, the maximum value of the radial force is obtained. Thus, the safety factor for maintaining the maximum value of the radial tightening force is between 1.(6) and 1.75, for pressures between 12.5 MPa and 35 MPa.

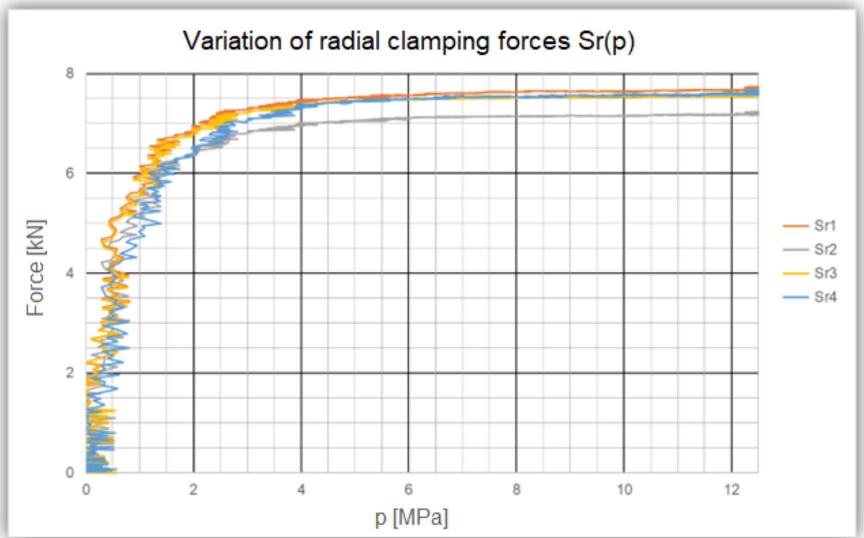


Fig. 23. S_{r1}(p), S_{r2}(p), S_{sr3}(p) and S_{r4}(p) characteristics for a pressure of 12.5 MPa regulated at the hydraulic power unit

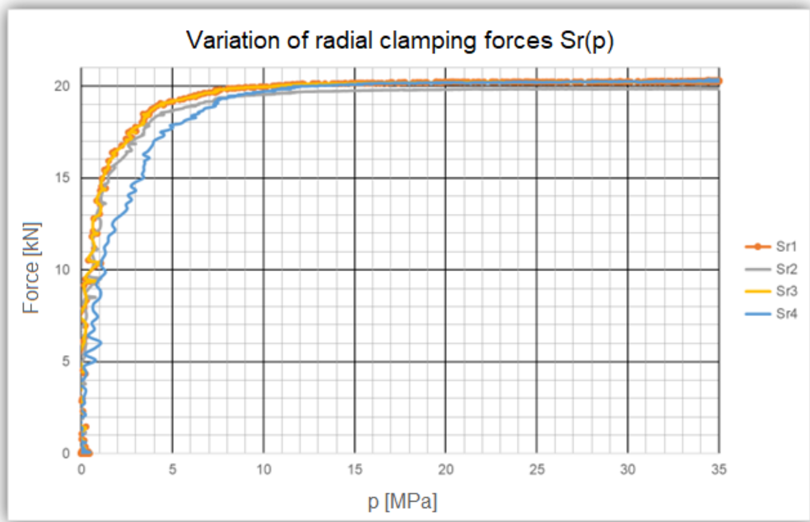


Fig. 24. S_{r1}(p), S_{r2}(p), S_{sr3}(p) and S_{r4}(p) characteristics for a pressure of 35 MPa regulated at the hydraulic power unit

7. Conclusions

The analysis of the results of the experimental research was carried out by importing the data files into Excel, from the Microsoft Office package, with data processing and creating graphs according to the proposed objective, as appropriate by superimposing the evolution over time of the values displayed on the visual acquisition interface or by making of characteristic curves depending on the working pressure.
The characteristic curves have a similar appearance to the one found in the specialized literature, with the difference that we used a measurement system that allowed the acquisition of signals with at least 250 kS/s, LabView and Excel instead of reading the values displayed by analog or digital instruments followed by editing graphics by interpolating the read values.
By using the digital instrumentation and the fourth virtual instrument in LabView we plotted the characteristic curves for the radial forces at different values of the regulated pressure at the hydraulic group, between 11.5 and 35 MPa. The characteristic curves S_{r1}(p), S_{r2}(p), S_{sr3}(p) and S_{r4}(p) have similar shapes regardless of the pressure value, being of the 2nd degree curve type, the maximum values being reached at pressures from 1.(6) times up to 1.75 times lower than the value set at the hydraulic group, these being precisely the safety coefficients for keeping the maximum radial force constant.
All acquired data can be further processed by making details in the desired intervals or in inflection areas, but other characteristic curves can also be made.

References

[1] Hanganu, Adrian Constantin. *Optimization of technological devices with hydraulic actuation*. / *Optimizarea dispozitivelor tehnologice cu acţionare hidraulică*. Iași, Politehnium Publishing House, 2007.
[2] Hanganu, Adrian Constantin, and Cătălin Gabriel Dumitraș. "Test stand for hydraulic clamping devices." *Bulletin of the Polytechnic Institute of Iași. Construction Machinery Section* 63 (67), no. 1 (November 2017): 75-88.