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RETROFITTING OF THE HYDRAULIC INSTALLATION OF A CNC LATHE FOR RE-PROFILING RAILWAY WHEELSET

Dan PRODAN[1,*], **George CONSTANTIN**[2], **Anca BUCUREȘTEANU**[3]

[1, 2, 3)] Prof., PhD, Eng., Machines and Manufacturing Systems Department, University "Politehnica" of Bucharest, Romania

Abstract: *On the occasion of refabrication of a specialized parallel lathe, designed for the processing of railway wheels (whellset), the authors of this article designed and built a new hydraulic installation. This new installation correlates with the new working method of the machine tool. Initially, the lathe, fitted with two main shafts that work "in the mirror", realized the specific profile of these wheels by copying. After refabrication, the machine tool works in with CNC. After the realization of the hydraulic project, the simulation of the dynamical operation of the lifting/lowering system of the blank/workpie was performed. The lifting/lowering system works with inertial masses up to 2000 kg, requiring positioning precision and repeatability. Due to the large weight of the semifinished, but also due to the precision requirements specific to the CNC machine tools, it is imperative that the clamping and locking systems to be very firm and secure.*

Key words: *Special parallel lathe, wheelset processing, refabrication, hydraulic installation, simulation.*

1. PRESENTATION OF THE CINEMATIC-STRUCTURAL SCHEME OF MACHINE TOOL

The machine tool designed for the simultaneous machining of the two wheels, in the conditions specific to the CNC machines of this type [15], has the kinematic-structural diagram in Fig. 1. On the bed 1, provided with horizontal guides, the slides 7 can be positioned depending on the size of the blank 15. The positioning of the two slides is done with the trapezoidal screws 12 [4 and 5] driven by the reducer 11 and by the electric motor EM_1 – 10. The two positioning screws are kinematically connected by the coupling 13 [4 and 5]. After positioning, the slides are locked by means of four cylinders *C*3 provided with the claws 25. The blank 15 is raised to the working position by means of the elevator 14 driven by the hydraulic cylinder *C*1. In addition, the same system ensures the descending and evacuation of the workpiece. The clamping of the blank is made on each side by means of three jaws 9 driven by the cylinders *C*2. The cylinders are fed through the *A* and *B* paths by means of the rotary connectors 6. These are provided with drainage systems *D*. For processing the two *S* surfaces, specific cutting movements are required [17]. The control of the machining is done by means of specific systems of these machines and is facilitated by the presence of the control equipment [16]. The main cutting motion is ensured by the electric motor EM_1 (2) at the shaft I, which by means of the V-belts transmission 3, drives the common shaft II. The gears 4 and 5 transmit the motion to the two main spindles III_1 and III_2 and the chuck plates 8. For the simultaneous processing of the two S surfaces according to the specific profile [15 and 16], two feed drives on *Z* and *X* directions. For the *Z* axis, the EM_3 motors operate the ball screws 18 by means of backlasch free reducers 17. They supply the feed of the slides 19. The slides 19 move the slides 21. These slides, on which the tools 20 are attached, move along the *X* axis with the help of the kinematic feed chains consisting of the motors EM_4 – 22, gearboxes 23 and the ball screws 24 [4, 5, 6, 14].

From the scheme shown in Fig. 1 it is noticed that the hydraulic system must ensure the following functions for this machine:

1 – locking and unlocking the sleeves 7 with four cylinders (*C*3);
2 – tightening and loosening the chuck jaws at the two chuck plates with three cylinders (*C*2);
3 – raising and lowering the blank/workpiece in the feed area at the level of the axis of the main spindle by means of the *C*1 cylinder.

2. HYDRAULIC DIAGRAM

In order to design the hydraulic scheme for the refabricated machine tool in the CNC variant, the following particularities and requirements were taken in consderation:

- the machine being with numerical control, the realization of any controled function should be confirmed electrically;
- both locking and unlocking of the slides should be made firmly, without the possibility of sliding and purely hydraulic;

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[*] Corresponding author: Splaiul Independenței 313, district 6, 060042, Bucharest, Romania
Tel.: 0040 21 402 9174;
E-mail addresses: *prodand2004@yahoo.com* (D. Prodan), *george.constantin@icmas.eu* (G. Constantin), *ancab66@yahoo.com* (A. Bucureșteanu)

- the clamping/unclamping of the jaws is purely hydraulic with reliable confirmations of the controled states [6];
- the operation of the hydraulic jaws is done with rotary connections, which have losses through the drainage circuits;
- the locking and clamping functions will be enssured in case of electric failure using electric or hydraulic power [1, 6];
- the cylinder for lifting and lowering the blank will work depending on the semi-product operated and the phase, at two different pressures and will have the possibility of initial adjustment of speeds in both directions;
- in case of hydraulic and/or electrical failure, the cylinder *C*1 is locked so that there will be no risk of damage of the work or injury to the human operator [1, 2, 8].

The hydraulic design scheme is shown in Fig. 2.

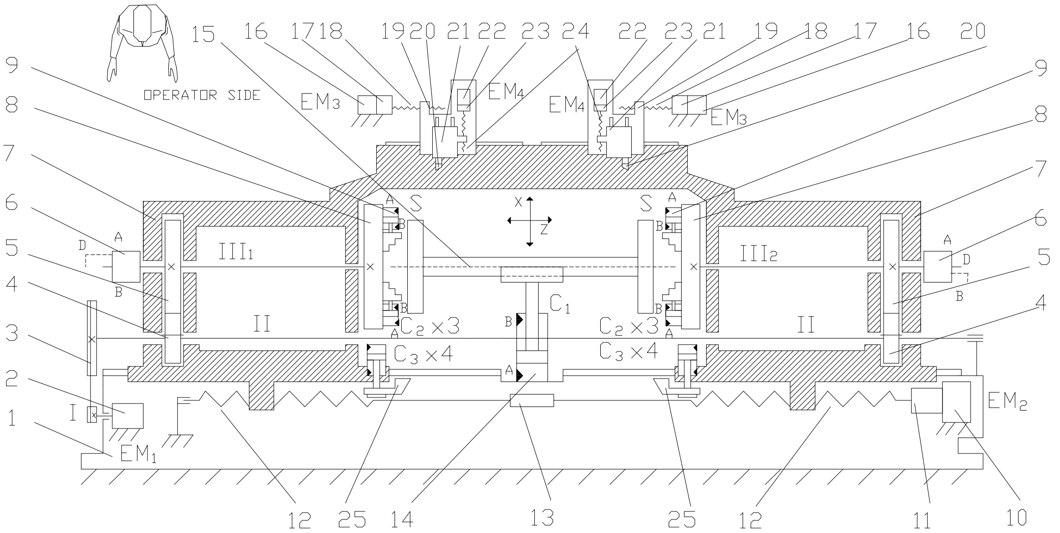


Fig. 1. Kinematic-structural diagram of the lathe: 1 – bed with guides, 2 – *EM*1 electric motor of the main drive, 3 – V-belt drive; 4, 5 – gears, 6 – rotary copling, 7 – slides, 8 – chuck plate, 9 – hydraulic iaws; 10 – EM2, electric motor for relative positioning; 11 – reducer; 12 – trapezoidal screws; 13 – coupling; 14 – hydraulic lifting /lowering of blank/workpiece; 15 – blank/workpiece, 16 – *EM*3 electriv motors for feed on axis *X*; 17 – backlasch free reducers; 18 – ball screws; 19 – slides on axis *X*; 20 – cutting tool (special turning cutters), 21 – slides on axis *Z*; 22 – *EM*4 feed drive elevtric motors on axis *Z*; 23 – backlash free reducers; 24 – ball screws; 25 – hydraulic blocking claws; *C*1 – cylider of system 14; *C*2 – claws drivind cylinders, *C*3 – cylimders for actuating claws 25; I, II, III$_1$, III$_2$ – shafts; *S* – processed surfaces; *X*, *Z* – CNC axes having the possibility of working with interpolation.

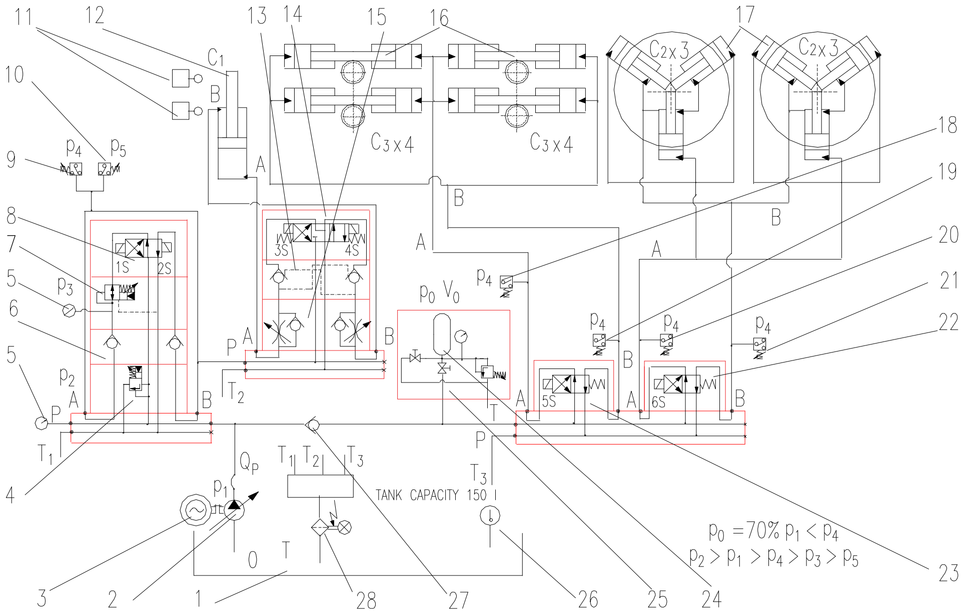


Fig. 2. Hydraulic scheme: 1 – tank *T*, 2 – pump with pressure regulator, 3 – electric drive motor; 4 – pressure relief valve; 5 – manometers; 6 – double check valve; 7 – pressure reducing valve; 8 – directional valve; 9,10,18,19,20,21 – pressure switches; 11 – limit swithes; 12 – cylinder C_1; 13 – check valve hydraulically operated; 14 – directional valve; 15 – throttle valve; 16 – actuation cylinders of blocking clamps C_3; 17 – actuation cylinders of jaws C_2; 22,23 – directional valves; 24 – accumulator; 25 – safety block; 26 – electronic temperature transmitter; 27 – check valve; 28 – retur filter; 1*S* ÷ 6*S* – electromagnets; p_0–p_4 – adjusted values of the presures.

The pump 2, driven by the electric motor 3, sucks oil from the tank 1. The pump regulator is set to a value p1. To protect the installation, it is recommended that the pressure valve 4 to be adjusted to a pressure p_2 above the p_1 value. The pressure p_1 is the maximum pressure at which the plant will normally work and at which it is acived the C_3 – 16 cylinder locking and the clamping/unclamping of jaws through the cylinders C_2 – 17. The C_1 – 12 cylinder will only work at the pressure p1 when lifting heavy parts. When lifting lighter parts and always for lowering, this cylinder will work at the pressure p3. This pressure is ~ 20 bar lower than the pressure p_1 and is adjusted by means of the reducing valve 7 [2, 3, 8]. The pressure values are visualized by means of the pressure gauges 5. The working pressure is selected by means of the distributor 8. The separation of the circuits is provided by the double-sense check valve 6. The pressure p_3 is confirmed by the pressure relay 9 set to p5. Superior pressure p_1 is confirmed by relays 9 and 10. The latter is set to p4. To select the working pressure, the electromagnets 1*S* and 2*S* should be energized. The positions between cylinder C_1 works are confirmed by limit switches 11. The lifting and lowering control of this cylinder is performed by directional valve 14 by actuating 3*S* and 4*S* electromagnets. The lifting and lowering speeds are adjusted in the installation test phase by means of the double throttle valve 15. The cylinder C_1 stops in the safe and firmly controlled position, there being no risk of position loss due to the unlocking valve 13 [2, 3, 8]. This also ensures that the cylinder is locked in the event of an electrical failure. The circuit supplying the C_2 and C_3 cylinders is separated from the rest of the circuit by means of the check valve 27 and contains the accumulator 25 and safety block 25. The accumulator has the useful volume V_0 and is charged with nitrogen at the pressure p_0. The accumulator enables actuating of the clamps by means of the cylinders 16 and the cylinders of jaws 17 in the absence of an command at the directional valves 22 and 23 [11, 12, 13]. In this case, blockages and tightening are confirmed by the pressure relays 18 and 20 respectively. If the electromagnet 5*S* is contrloled, the unlocking of the clamps is performed. This unlocking is confirmed by the pressure relay 19. If it is desired to loosen the jaws, the electromagnet 6*S* is controlled. The loosening is confirmed by the pressure relay 21. The pressure relays 18, 19, 20 and 21 are set to the pressure p_4. The oil temperature is monitored by means of the electronic temperature transmitter 26. For filtering the oil, the return filter 28 is provided.

3. MODELING AND SIMULATION OF THE OPERATION OF BASIC ELEMENTS IN THE HYDRAULIC INSTALLATION

The basic characteristics of the pump, cylinder C_1 and accumulator used are presented below. These resulted from the processing of catalog information or from calculations and simulations of their operation in static or dynamic mode.

3.1. Pump with pressure regulator

Pump with pressure regulator chosen has the characteristic pressure-flow rate presented in Fig. 3 [2, 8].

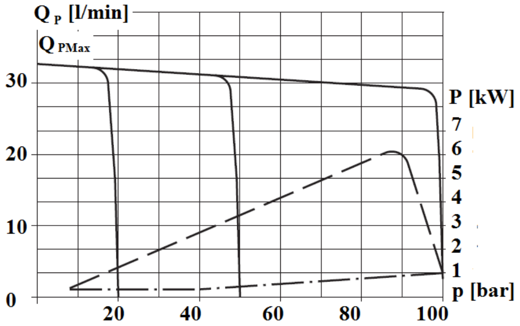


Fig. 3. Characteristic of the pump with pressure regulator.

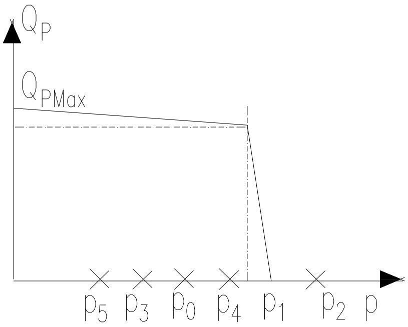


Fig. 4. Pressure-flow rate characteristic of the installation.

In Fig. 4, the flow rate-pressure characteristic of the pump with pressure regulator and adjusting presure distribution are shown.

According to the characteristics in the Figs. 3 and 4, it may be considered that the dependency of useful flow rate on pressure has the expression:

$$Q_P = Q_{PMax} - a \cdot p. \tag{1}$$

where: Q_p – pump flow rate [l/min]; $Q_{P\max}$ – maximum pump flow rate [l/min]; p – working pressure [bar]; a – linearized ratio of flow rate losses proportional to pressure [l/min/bar].

For the chosen pump, according to its characteristic it results a = 0.025. Adjustment pressures obtained from the static calculation are: p_0 = 35 bar, p_1 = 55 bar, p_2 = 60 bar, p_3 = 25 bar, p_4 = 40 bar, p_5 = 20 bar. The accumulator chosen has the useful volume V_0 = 2.5 l. The equipment selected is DN10 [8]. According to relation (1), the minimum flow rate available at the lower pressure of 55 bar is ~ 30 l/min.

3.2. Cylinder intended for the supply of semi-finished products

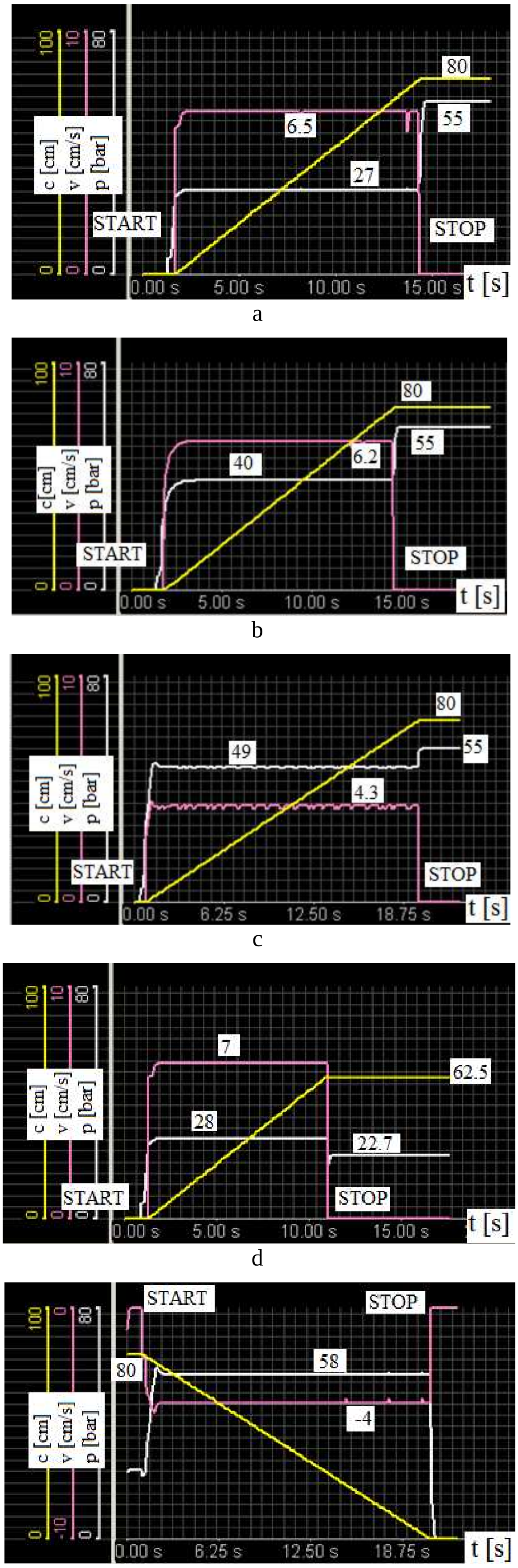
After calculating the system in static mode and without taking into account the losses [2] the speeds v and working pressures p in Table 1 are obtained for climbing and lowering of cylinder C_1.

To determine the behavior of the system in the lifting, lowering and stop phases, in the dynamic regime simulations were made in AUTOMATION STUDIO [9 and 10]. Figure 5 shows some of the results.

Table 1

Working parameters of cylinder *C1*

C_1	v [cm/s]	p [bar]	**Throttle valve B-T 45%, A-T 20%**
Up To	6.6	22.5	
Down To	8.8	17	



a

b

c

d

e

Fig. 5. Simulation results: *a* – lifting, throttle valve B–T open 50%; *b* – lifting, throttle valve B–T open 20%; *c* – lifting, throttle valve B–T open 7%; *d* – failure, STOP on double unblocking check valve (13 in Fig. 2); *e* – lowering, throttle valve A–T open 10%.

From the characteristics presented in Fig. 5 we can observe the following:

- influence of the opening of the throttle valves in the ascending and descending phases, Fig. 5;
- an opening of over 25–30% of the throttle valves has very little influence on the speeds;
- in dynamic mode, the system behaves like a super-damped one.
- the choice of a pump with a pressure regulator is justified given that if the pump was with constant flow rate, the consumed power would have been ~ 3 kW. The presence of the regulator causes the Q_p flow rate to zero [8] when the pressure reaches p1. Under these conditions, the power consumption is also very low, eliminating the risk of heating the system and the need for a heat exchanger (cooler).
- if the voltage falls accidentally, valve 13 (Fig. 2) locks and secures the blank.

3.3. Calculation of the accumulator that can cover the losses from rotary couplings

Due to their construction, the rotary connectors function with flow losses. To calculate the value of these losses, one can use the relationship:

$$\Delta Q = \frac{\pi\cdot D\cdot \Delta p\cdot J^3}{96\cdot L\cdot \mu}, \tag{2}$$

where: ΔQ – flow rate loss through the rotating connection; D – diameter of the plunger of the connection; Δp – pressure drop on the connection; J – functional play between the shaft and the bore of the connection; L – piston length; M – dynamic viscosity of the oil used.

According to relation (2), it can be considered that the loss of flow depends on a constant K having the expression below and the pressure drop Δp as follows:

$$\Delta Q = K\cdot \Delta p, \tag{3}$$

$$K = \frac{\pi\cdot D\cdot J^3}{96\cdot L\cdot \mu}. \tag{4}$$

The constant K can also be determined experimentally by measuring the lost flow at maximum speed.

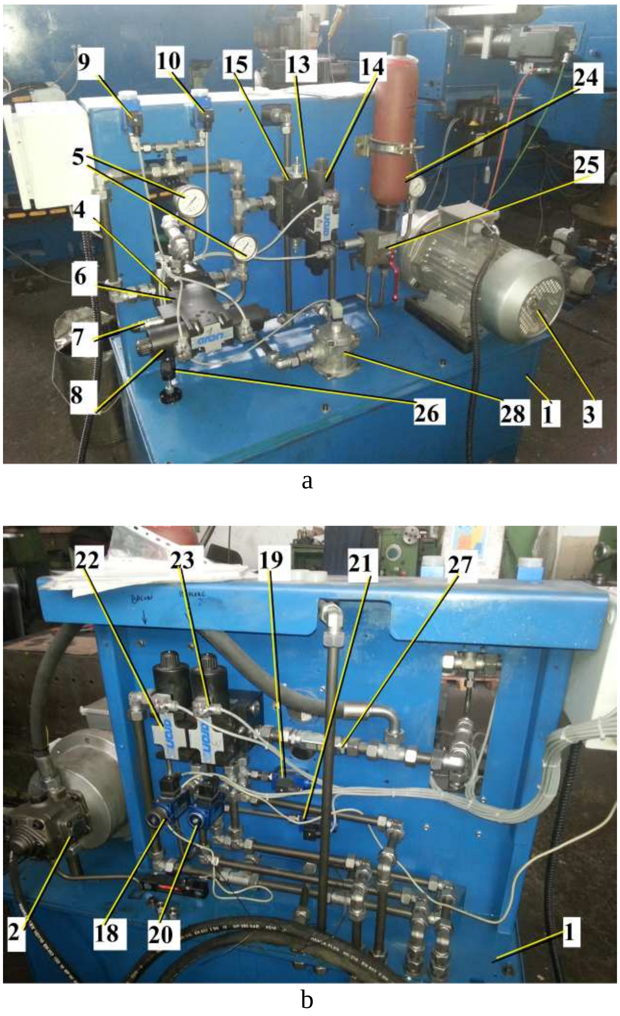
The flow losses are compensated in the case of the scheme of Fig. 2 by the accumulator 24. It has the useful volume V_0 and is loaded with nitrogen at the pressure p_D. It works in the pressure range [p_4–p_1]. In this case, the volume it can provide to compensate for losses is [13]:

$$\Delta V = p_0\cdot V_0\,\frac{p_1-p_4}{p_1\cdot p_4}. \tag{5}$$

In this case, taking in consideration that the machine has two rotating connections, it can be assumed that the time interval Δt in which the battery can cover the losses after stopping the machine according to the above relations is:

$$\Delta t = p_0\cdot V_0\,\frac{p_1-p_4}{K\cdot p_1\cdot p_4\cdot (p_1+p_4)}. \tag{6}$$

The above relationss were obtained considering that the transformations suffered by the nitrogen in the battery during operation are isothermal [2, 12, 13].



a

b

Fig. 6. Hydraulic installation of the machine tool: *a* – front view; *b* – rear view.

For the real data, we obtain with relation (6): Δ*t* ~ 100 min.

On the occasion of testing the hydraulic installation it was found that in reality the time is longer than two hours. The time is sufficient for the controlled release of the blank.

4. PRESENTATION OF THE HYDRAULIC INSTALLATION

The entire hydraulic installation was achieved in the form of a unit shown in Fig. 6.

In Fig. 6, the notations in Fig. 2 were retained. During the operation of the hydraulic installation, the measured noise level was 70–78 dB and the working temperature stabilized at 32 °C, in conditions in which the temperature of the environment was 21°C.

The retrofitted lathe for re-profiling railway wheelset at the beneficiery is shown in Fig. 7.

5. CONCLUSIONS

Machine tools intended for the processing of wheelsets are part of the heavy-duty lathes. In this case, refabrixation of machines even older than 20 years is cost-effective and is a technical and economical solution for many users of such machines. Refabrication is done so that machines with convetional control and copy systems are transformed into CNC machine tools. At refabrication it is recommended to redesign the specific hydraulic systems so that they meet the requirements of the CNC machines. Locks and unlocks must be done hydraulically and be electrically confirmed. The clamping of the semifinished parts in the opposite chuck systems is also done hydraulically, with electrical confirmation and ensuring for possible electric and / or hydraulic failure. In this case, the use of pneumo-hydraulic accumulators becomes mandatory. Semi-finished (wheelsets) feed systems, taking into account their weight, will also be hydraulically driven and will have firm locking elements.

The static calculation of hydraulic systems in this case is also recommended to be supported by their dynamic modeling and simulation. For these simulations, it is recommended to develop mathematical models and / or use specialized programs.

The hydraulic installation that is the subject of this work has been completed and tested for a machine tool that is currently working at full capacity.

Different types of modeling and simulation were also considered for the entire structure of the machine (see [18]) in the context of refabrication.

Fig. 7. Retrofitted lathe for re-profiling railway wheelset.

REFERENCES

[1] D. Prodan, A. Bucureșteanu and E. Bălan, *Increasing the Operating Safety of the Machine-Tools by Using Hydro-pneumatic Accumulators. Modeling – Simulation*, Advanced Materials Research Vols. 463–464 (2012) pp. 1111–1115.

[2] D. Prodan, M. Duca, A. Bucureşteanu, T. Dobrescu, *Acţionări hidrostatice-organologie* (Hydrostatic drives-components) Edit. AGIR, 2005.

[3] H. Exner, R. Freitag, H. Geis, R. Lang, J. Oppozer, P. Schwab, E. Sumpf, U. Ostendorff, *The Hydraulic Trainer*, Vol. 1 Rexroth, 199.

[4] B. Perovic, *Handbuch Werkzeug-Maschinen* (Machine tools handbook), Carl Hanser Verlag, Munchen, 2006.

[5] P.H. Joshi, *Machine tools handbook*, McGraw-Hill, New Delhi, 2007.

[6] D. Prodan, *Masini-unelte grele. Sisteme mecanice si hidraulice* (Heavy machine tools. Mechanical and Hydraulic Systems), Printech Publishing House, Bucharest, 2010.

[7] T. Deaconescu, *Acţionări hidraulice* (Hydraulic Drives), Publishing House of University "Transilvania" of Braşov, Braşov, Romania, 2007.

[8] *** Bosch Rexroth, SIEMENS, GE FANUC, Berarma, Parker, Atos, Aron, HYDRO LEDUC, FOX, catalogs.

[9] *** Software package: Automation Studio by Famic Technologies Inc.

[10] D. Prodan, *Maşini-unelte, modelarea şi simularea elementelor şi sistemelor hidrostatice* (Machine tools, modeling and simulation of hydrostatic systems and elements), Edit. Printech, Bucharest, 2006.

[11] D. Prodan, A. Bucureşteanu, E. Bălan, *Sistem hidraulic de securitate pentru maşinile de rectificat cu masă magnetică* (Hydraulic system for grinding machines with magnetic table), HERVEX 2007, Editor INOE 2000-IHP, pp. 334–337, Râmnicu Vâlcea, Romania, 2007.

[12] *** Hydro-Pneumatic Accumulators, NAKAMURA KOKI CO., LTD.

[13] A. Bucureșteanu, *Acumulatoare pneumohidraulice. Utilizare si Modelare* (Pneumo-hydraulic accumulators. Use and modelling), Edit. Printech, 2001.

[14] C. Teixido, J-C. Jouanne, B. Bauwe, P. Chambraud, G. Ignatio, C. Guerin, *Guide de construction mecanique* (Mechanical constructuin guide), Delagrave Edition, Paris, 2000.

[15] T. Mazilu, M. Dumitriu, *Tehnologia fabricării şi repararii materialului rulant de cale ferată* (Fabrication and repair of railway rolling stock), Edit. Matrix Rom, Bucharest, 2013.

[16] W. Hoehne, A. Lohmann, J. Dede, M. Rettig, J. Stephanides, *Running profile of railway wheel*, U.S. Patent: US 7669906 B2, 2 March 2010, `http://www.google.com/patents/US7669906`

[17] I-G. Sandu, *Generarea Suprafețelor* (Surface generation), Edit. Academiei Române, Bucharest, 2008.

[18] G. Constantin, A. Ghionea, I. Ghionea, C. Bîșu & D. Cioboată, *Integration of CAD-RBS-FEM techniques in refabrication of a lathe used for profiling wheelset*, International Journal" Advanced Quality", Vol. 45, No. 2, 2017, pp. 27–35.