Hydraulic System of Return Backlash Takeover with Pressure Bearing and without Rotary Fitting

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Abstract: *This paper makes a brief presentation of the systems of return backlash takeover currently used in the kinematic chains for circular feed in machine tools but also of a new system patented by the authors. This system is uncomplicated, effective and simplifies the kinematic chains of the machine tools. It can be applied to vertical lathes that can make milling operations too because it allows the overlapping of the kinematic chain for turning operations with the circular feed kinematic chain for boring or drilling operations. The system comes as a result of minimum modifications of the final pinion and can be used for all machines remanufactured but for the brand-new machines too. With minor constructive modifications, this system can be also applied in the feed and positioning kinematic chains for linear feed movements that use rack and pinion mechanisms.*

Keywords: *Machine tools, hydraulic system for backlash takeover*

1. Introduction. Influence of the return backlash on the accuracy of the kinematic chain for positioning/feed [1]

Figure 1 shows the crown and pinion mechanism used in most vertical lathes and rotary tables as the final mechanism of the kinematic chain for feed/positioning (C axis).

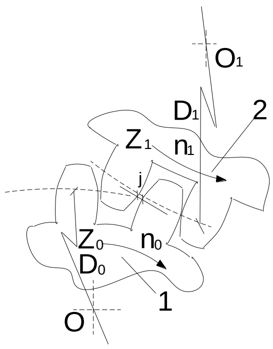


Fig. 1. Return backlash of the crown and pinion mechanism

Pinion 1, with center O, teeth Z_0 and rolling diameter D_0 engages crown 2, according to the sense in the figure above. The crown has the center O_1, teeth Z_1 and rolling diameter D_1. If the transfer ratio of the mechanism is i we can write down:

$$\frac{n_1}{n_0} = \frac{D_0}{D_1} = \frac{Z_0}{Z_1} = i \tag{1}$$

The flank clearance for this gearing is j. Because of this clearance, when the rotation sense at pinion 1 is changed, there is a delay between the return control moment and the effective performance of this one. If this clearance j is not constant, it cannot be compensated by the electronic equipment [2]; this situation affects the machining and positioning accuracy.
The error ε that will occur depends on the position of the machined surface related to the rotation center O'.
Many vertical lathes that have the table diameter in the range from 1200 to 4000 mm use the backlash takeover systems with two pinions having the same axis.
Figure 2 shows how they operate.

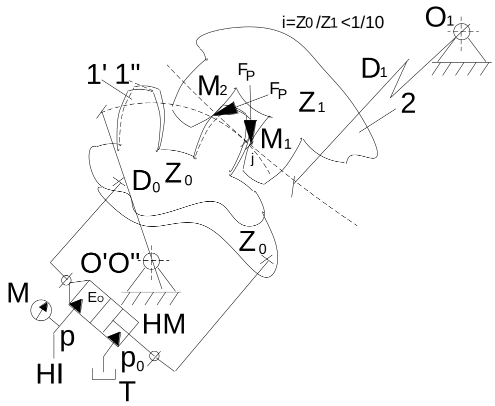


Fig. 2. System of backlash taking over with two coaxial pinions with hydraulic tensioning

Pinions 1' and 1'' are identical; they have the same number of teeth Z_0 and the rolling diameters D_o. They turn in the same sense related to the center O' = O'' but they are tensioned relatively through the agency of the hydraulic motor HM and they are gearing with crown 2, having teeth Z_1 and the rolling diameter D_1, on opposite flanks, in the points M_1 and M_2. Due to pressure p of the hydraulic motor, the gearing is made in the points M_1 and M_2, simultaneously but on opposite flanks. In these conditions, even if there is the backlash j, when the rotation sense changes at the two pinions, the contact between the crown and the pinions system is permanent. The hydraulic unit HI provides the pressure p that causes the apparition of the opposite forces F_p.
The construction of the system is compact and is schematically shown in Figure 3.

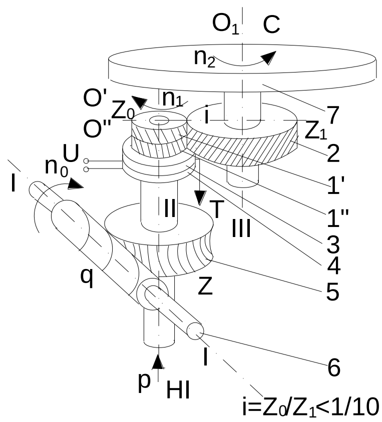


Fig. 3. Construction of circular feed box

Pinions 1' and 1'' turn the crown 2 that is secured to table 7. Movement is brought from the electric motor to the duplex worm 6 that engages with the wormed gear 5. On the shaft III there is also located the vane-type hydraulic motor 3 and the electric clutch 4. When table 7 is rotated by the main kinematic chain (not shown in the figure above) the hydraulic unit is stopped and the coupling 4 is not actuated. If one wants to use the kinematic chain for circular feed, it is necessary to start the hydraulic unit and to actuate the clutch 4. Pinions 1' and 1'' are tensioned and positioned on the opposite flanks of crown gear 2. Oil is supplied by the lower part of the construction by means of a rotary fitting.
By disabling the electric clutch 4, the pinions 1' and 1'' start to rotate freely during the turning operations; in this case, crown 2 takes over the movement from another pinion, not shown in figure, from the main kinematic chain. Such a feed box is shown in Figure 4. Notations are the same as in the previous figure.

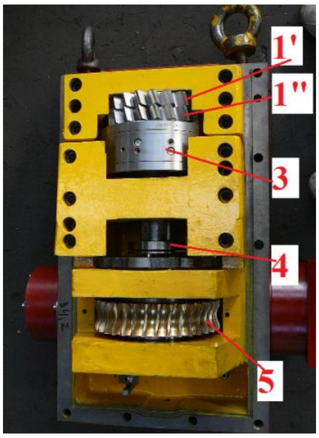
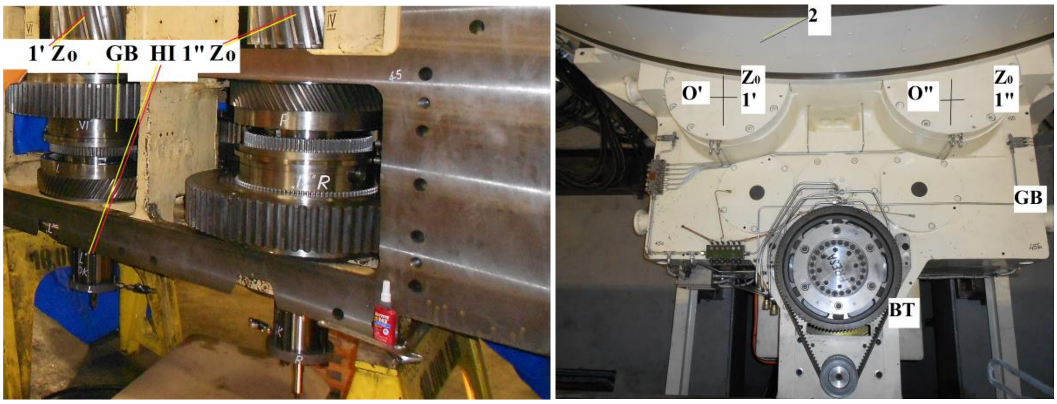


Fig. 4. Circular feed box with backlash taking over by relative tensioning with a vane-type hydraulic motor

The gear box and the circular feed box can be included in a small construction such as in Figure 5. Gear box is provided with a backlash takeover system and is used for a CNC vertical lathe with the table of 5600 mm. During turning operations, the tensioning hydraulic system is not actuated. The movement gets to pinions 1' and 1", which have parallel shafts [1], directly from the main motor via the gear box GB. In order to use the circular feed system, it is necessary to disconnect the main motor, to actuate the backlash takeover system and to couple the feed motor. This one brings the movement to the crown gear 2 by means of the toothed belt GB transmission.



a. b.

Fig. 5. Backlash takeover system with parallel shafts pinions integrated in the gear box

Among the disadvantages of the systems above it can be mentioned:

- the need for two motors, one for driving the main kinematic chain and one for the feed kinematic chain;
- existence of an electromagnetic coupling that is activated only when using the feed kinematic chain;
- use of a rotary distributing coupling (fitting).

2. Backlash takeover system provided with two pinions, hydraulic piston, pressure bearing and without rotary coupling [3, 4, 5, 6]

In the case of the vertical lathes, the main kinematic chain is ended by a pinion as shown in Figure 6, which engages with the gear clamped on the table.
Pinion 1 is supported on the bearings 3 related to bed 2. The pinion drives the gear on teeth flanks corresponding to the direction of rotation. When stopping or reversing the direction, the contact flanks are changed because of the functional backlashes, resulting in positioning errors.

Starting from the construction of the pinion presented in Figure 4, it is possible to achieve a variant that allows to take over the return backlash only when necessary, thus for accurate positioning and milling operations.

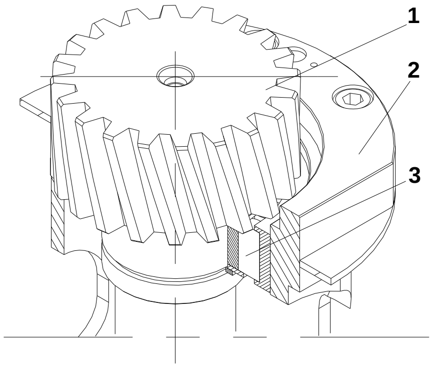


Fig. 6. Pinion that engages with the toothed gear in vertical lathes

In terms of vertical lathes, the crown and pinion mechanism belongs to the main kinematic chain in the case of turning operations and to the circular feed kinematic chain for the milling operations. Figure 7 shows schematically the new variant patented by the authors and how it operates.

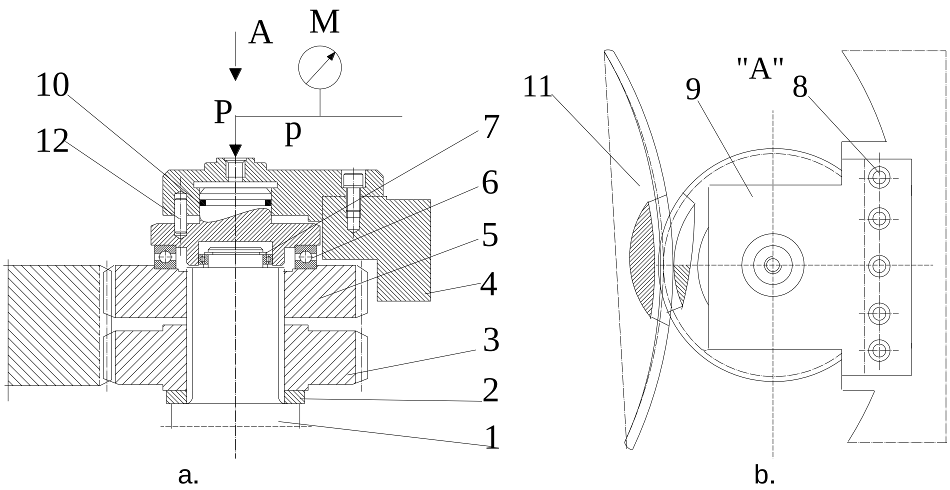


Fig. 7. New system of backlash takeover without rotary fitting

The main pinion 3 and the secondary pinion 5, which are identical in terms of teeth geometry, receive the rotation movement from the spline shaft 1. This one is supported on bearings related to bed 4 and receives the movement from the main kinematic chain, identical in this case with the circular feed chain of the machine. Support 9 is clamped to the bed by means of the screws 8. Piston 10 operates axially related to support 9 when it is supplied with oil at pressure p on the path P. The value of the supply pressure is displayed on manometer M. The axial positioning of pinion 3 is performed by means of the distance plate 2. By means of the pressure bearing (axial) 6, piston 10 presses pinion 5. The construction is centered by the radial bearing 7. The pins 12 prevent the rotation of piston 10.

During the turning operations, pinions 3 and 5 operate on the same flank of the crown 11; in this case, the system is not supplied with oil. For the milling operations, oil at pressure p will be brought on P path. The oil under pressure drives the piston 10, of diameter D, pushing it downward. The two pinions 3 and 5 have inclined teeth [7, 8, 9] same as the driven crown 11. For this reason, pinions will operate on different flanks at driven crown 11, taking over the backlash. Any losses are recovered in the bed of the machine that is also the oil tank of this one.

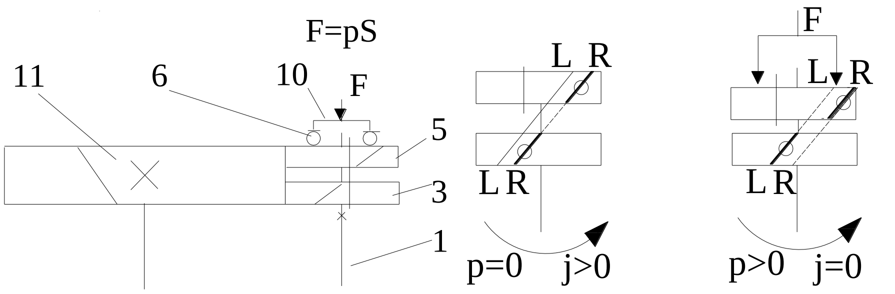
If the angle of inclination of teeth related to the vertical is β, the following equations can be taken into consideration:

$$F = p \cdot \frac{\pi \cdot D^2}{4} \tag{2}$$

$$F_N = \frac{F_A}{\sin \beta} \tag{3}$$

$$F_T = F_A \cdot ctg\beta \tag{4}$$

In the equations (2) ÷ (4) it was noted: F - axial force, F_N - normal force at teeth, F_T - tangential force.
Force F is dimensioned so as to ensure the permanent takeover of the backlash regardless of the instantaneous value of the torque reduced at pinion level.
Figure 8 shows the kinematic diagram of this construction, keeping the same notations above.



a. b.

Fig. 8. Kinematic diagram of the backlash takeover system without rotary fitting

In the absence of pressure p, the two pinions are not tensioned (p = 0, F = 0). If we take into account the direction of rotation shown in the figure above, we notice that the meshing is performed only on the right side flanks (R) of the pinions. If the system is supplied with oil at pressure p, for the same direction of rotation, the two pinions are placed on the opposite flanks of the crown gear. The upper one transmits the movement on the right flank (R) and the lower one on the left one (L).
Specific to this system [6] is that the backlash is taken over because of the axial relative movement of two pinions with inclined teeth. The relative pushing down is made by means of a pressure bearing (axial) [10], which reduces the frictions and allows the elimination of the rotary fitting [5]. The pressure with which is taken over the backlash is introduced directly in the assembly mounted and not in other motor (linear or rotary) as in other versions; the same mechanism is used for turning operations (deactivated) and for milling operations (activated). Compared to the solutions presented above but also to a system previously patented [5] the new system has the advantage that it does not require a rotary fitting.
This solution allows the use of a single electric drive motor for both turning and milling operations and of a single coupling with the crown gear. In terms of kinematics, the new and modern machines that use such systems are much simpler.
Figure 9 shows the kinematic diagram of a vertical lathe equipped with a classic system for backlash takeover provided with two drive motors.
In Figure 9 there were noted: 1 - machine bed, 2 - electric motor for the main kinematic chain (M1), 3 - gear box for turning operations, 4 - crown and pinion mechanism without backlash takeover for the main kinematic chain, 5 - machine table, 6 - backlash takeover system with two tensioned pinions with vane-type hydraulic motor (with big losses) for the feed kinematic chain, 7 - feed box (constructively complicated and expensive), 8 - rotary fitting, 9 - electric motor (M2) for actuation of feed kinematic chain, P - pressure intake port, at the rotary fitting level.
Motors M1 and M2 are driven successively, depending on the operations performed: M1 for turning, M2 for milling, drilling or positioning.

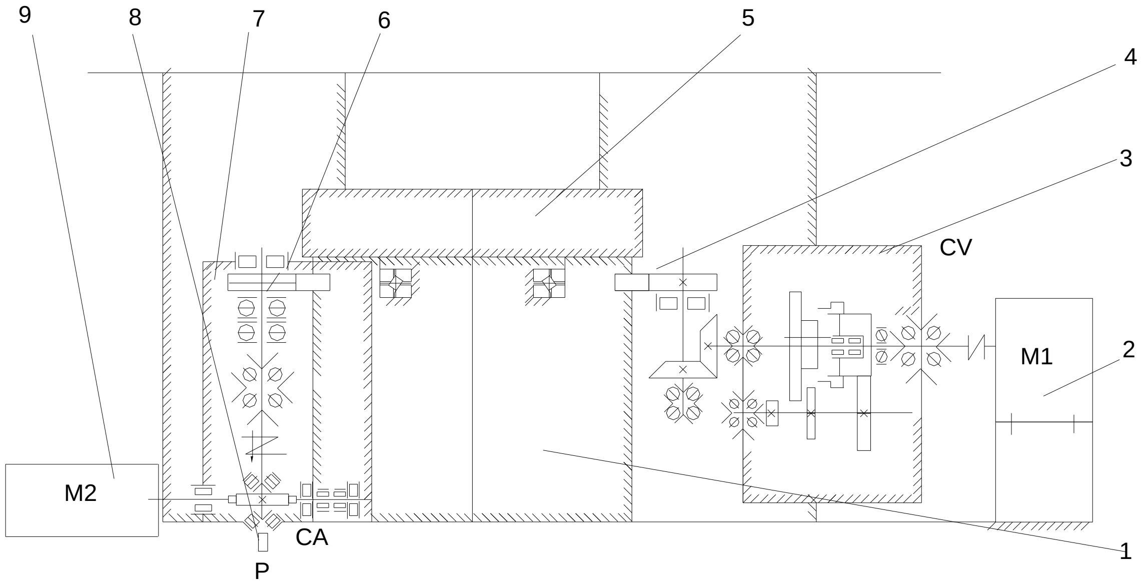


Fig. 9. Kinematic diagram of the main kinematic chain and of the circular feed chain in a vertical lathe equipped with a standard gear box and a circular feed box

The return backlash takeover system with pressure bearing and without rotary fitting, if used for modern machine-tools, equipped with two speed gear box [2, 7], leads to the simplification of the kinematic diagram as shown in Figure 10.

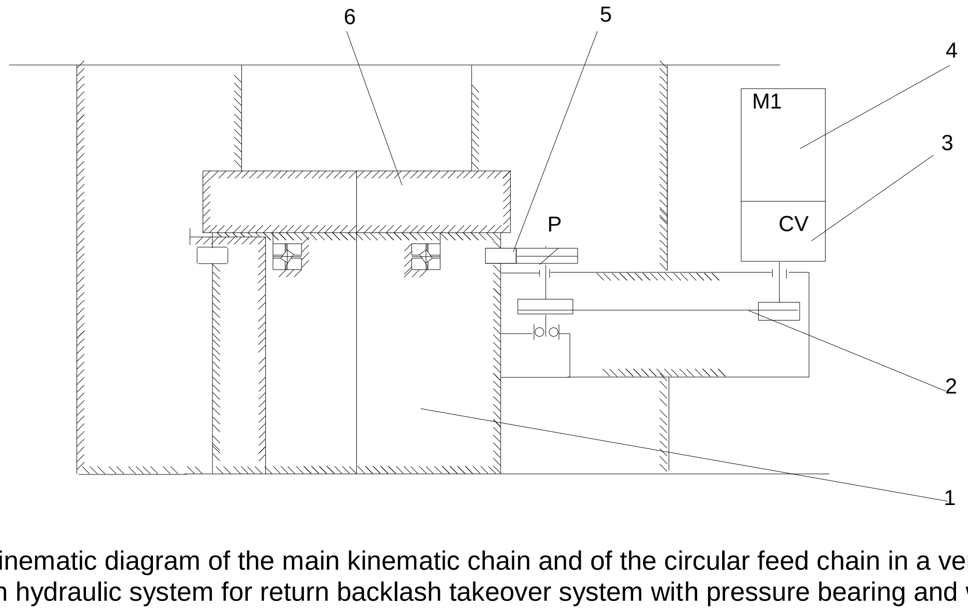


Fig. 10. Kinematic diagram of the main kinematic chain and of the circular feed chain in a vertical lathe equipped with hydraulic system for return backlash takeover system with pressure bearing and without rotary fitting

In Figure 10 there were noted: 1 - bed of the machine, 2 - toothed belt transmission, 3 - feed and gear box, 4 – ONLY ONE electric motor for turning and milling (M1), 5 - the new system for backlash takeover without rotary fitting, including the two pinions pushed down by the pressure bearing, that meshes with the crown gear, 6 - table, P - pressure intake port that does not require a rotary fitting.
Both speed steps are used for the turning operations (usually i_1 = 1/1 and i_2 = 1/4 [2, 7]). For positioning or machining operations that require C axis it shall be used only the second step of the gear box. In this case, the circular feed speed is adjusted by means of the variator of motor M1 [2].

The hydraulic unit that supplies the backlash taking over system shall include a pump of lower flow than in the case of the system shown in Figures 3 and 4 because, unlike the cane-type hydraulic motor, the patented system has no losses. The unit shall be equipped with a pressure regulating valve and elements for monitoring this one. In Figure 11, the basic hydraulic diagram is shown.

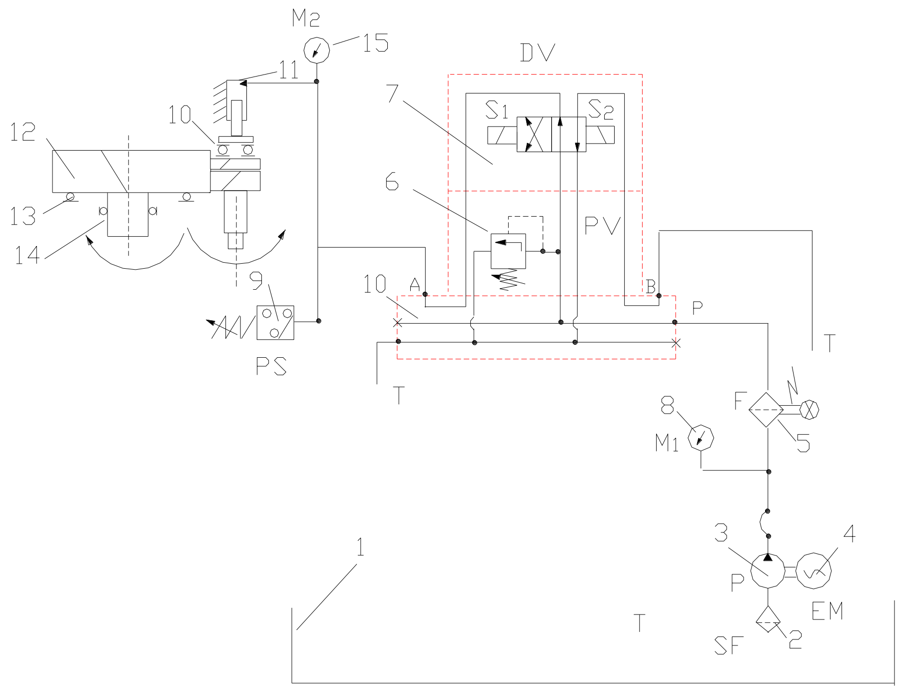


Fig. 11. Hydraulic diagram of backlash takeover system

The electric motor (EM) 4 drives the constant flow pump (P) 3. This one sucks in oil from the tank (T) 1 through the strainer (SF) 2. The oil pureness is ensured by the pressure filter (F). This one is provided with an electric indicator of clogging. The oil coming out of the filter supplies the plate 10 on which are located the pressure valve (PV) 6 and the distributor (DV) 7. Path A of the plate supplies the cylinder for backlash takeover 11. This one presses relatively the two semi-pinions via the pressure bearing 10. Path B of the plate 11 is directly connected to the tank. To view the general pressure and the pressure in the backlash takeover cylinder one shall use the manometers (M_1 and M_2) 8 and 15 respectively. The electric confirmation of existence of the required pressure is performed by the pressure relay (PS) 9. In the figure above there are also noted: 12 – crown gear, 13, 14 – table supporting on bearings. If the electromagnet S_1 is actuated, the system is uncoupled and the turning operation is made. In this case the electric motor (EM) 4 can be stopped too. If positioning or milling operations must be made (with interpolation of axes [7, 9, 11]) it is necessary to actuate the electromagnet S_2. Usually the pressure adjusted at the pressure valve (PV) 6 does not exceed 60 bar. In order to achieve turning operations exclusively, the electric motor is stopped. To achieve only milling operations, the motor is started and the electromagnet S_2 is actuated about 10 - 15 s; afterwards the voltage is cut off. If turning and milling operations are performed alternatively, for short time, the electromotor does not stop; only the electromagnets S_1 and S_2 shall be actuated, depending on needs.

The backlash takeover system presented hereby can be applied to brand-new machines or remanufactured ones, with the table up to 5000 mm. For larger size vertical lathes it is recommended to use the electric takeover of return backlash [1, 12].

3. Conclusions

In the case of positioning and machining operations with interpolation of axes performed on vertical lathes it is necessary to have systems of return backlash taking over included in the circular feed kinematic chain.

Usually, to enable fast and easy setup, these systems are driven hydraulically.
On most machines CNC type, the main kinematic chains and the circular feed kinematic chains have different motors. They are operated depending on the type of operation that is performed.
By using the patented backlash takeover system, in some cases, these two kinematic chains can be driven by a single motor.
With the patented system, the backlash takeover is made by a piston and not by vanes as in some existing variants. The system with piston has no losses, which reduces the required flow to the pump and thus the driving motor power. The possible losses must not be recovered by special elements, as they have direct access to the machine oil tank, located in the bed of the machine.
The coupling and uncoupling of this system is easy, without requiring other elements operated hydraulically or electrically.
The system can be applied to the vertical lathes with table in the range of 1200 ÷ 4000 mm.

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