Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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Annals of DAAAM International

HEAVY MACHINE-TOOLS. FEED-POSITIONING SYSTEMS FOR CROSSRAILS

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Abstract: *The paperwork presents some of the systems more often used for moving the crossrails on heavy machine-tools: Vertical Boring Mills, Plano-millers, Gantry Milling Machines, Guideway Grinding Machines. It includes kinematic diagrams and specific mathematical models, required for dimensioning or verification calculation.*

Key words: *crossrail, feed-positioning kinematic chain*

1. INTRODUCTION

The crossrail equips heavy machine tools having the working heads performing various machinings: turning, milling, drilling, grinding, etc. Such machines are: Vertical Turning and Boring Mills, Plano-millers, Guideways Grinding Machines. For large gaps between the columns – which are specific to these machines – the crossrail represents the only solution. One or several working heads can be provided on the crossrail. The movement of the crossrail can be for positioning only, or for machining with accurate CNC control of the travels. If the crossrail performs only positioning, then it can have indexing systems (Prodan, 2010).

2. METHODS FOR CROSSRAIL MOVEMENT

One of the most frequently used driving systems is shown in Figure 1. The crossrail 2 moves on the columns guideways 1 together with the saddle and the working head 3. For the up and down motion, the electric motor 8, through the clutches 7, actuates the worm gears 6 in the reducers 5. The rotation motion is converted into translation motion by the trapezoidal screws 4 having the pitch p (Catrina et al., 2005). X and Z represent the two working axes. The motion of the crossrail is for positioning only (Sandu, 2008). The positioning of the crossrail is done with the velocity:

$$v = n \cdot i \cdot p \qquad (1)$$

where: *v*-velocity [mm/min]; *i*-transmission ratio of the worm gears [-], usually *i*=1/40; *p*-trapezoidal screws pitch [mm].

If the friction is neglected and the efficiency for all mechanisms is considered being 100%, then the torque *M* developed by the motor for lifting the *G*-weight crossrail:

$$M = \frac{p \cdot G \cdot i}{2 \cdot \pi} \qquad (2)$$

The usage of indexing mechanisms is recommended to ensure the positioning accuracy. Figure 2 shows the operating mode of the indexing mechanisms. The crossrail 1 is moved with the help of the positioning kinematic chain that is not shown in the figure. The hydraulic cylinders 2 and 3 are fixed on the crossrail. The hydraulic cylinders are single action type, the rod being extended by the disk springs sets mounted behind the pistons (ON). The rods allow an accurate positioning on the scales 4 and 5 mounted on the columns under the imposed parallelism condition. When moving the crossrail, by supplying pressured oil to the two hydraulic cylinders, the rods withdraw over dimension c, which allows the repositioning (OFF).

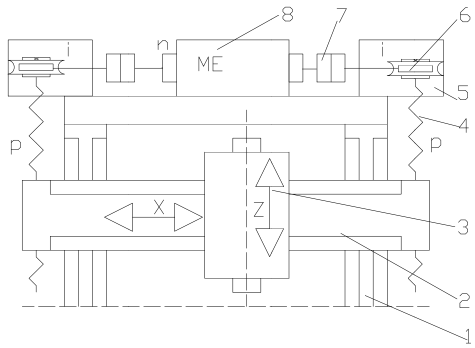

Fig. 1. The most frequently used driving systems

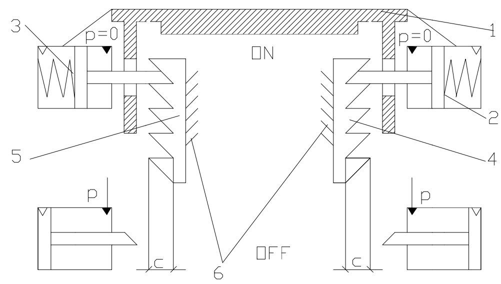

Fig. 2. The operating mode of the indexing mechanisms

After reaching the required position which is confirmed by electric micro switches, the supply of pressured oil is interrupted. The springs extend again the rods into the new position and then the crossrail is locked.

For some heavy machine-tools, the electric motor and the two reducers are replaced by a hydraulic system for positioning (Figure 3). In this case, the crossrail 2 and the working head 3 are positioned on the columns guideways 1 with the help of two hydraulic cylinders 4. The minimum driving pressure p_{min} – when neglecting the friction and the losses – should be:

$$p_{\min} = \frac{G}{2 \cdot S_2} \qquad (3)$$

Given the fact that the weight components taken over by each cylinder depend on the position of the working heads, the hydraulic system for synchronizing the movement of the two cylinders is rather complicated (Prodan, 2004).

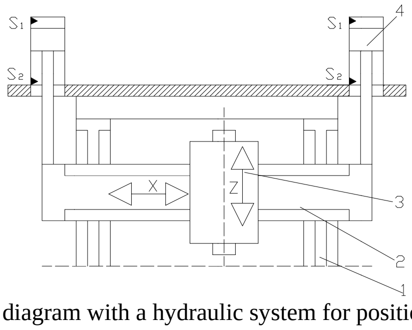

Fig. 3. The diagram with a hydraulic system for positioning

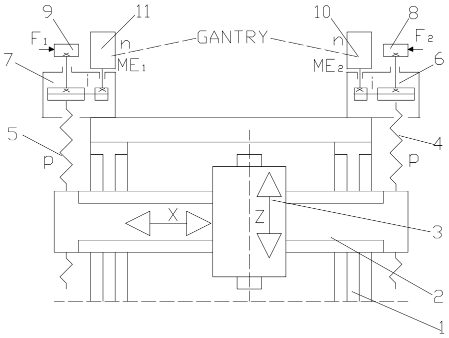

Fig. 4. The diagram for a feed-positioning kinematic chain

If the positioning kinematic chain is a feed kinematic chain as well – fact that increases the machining capabilities of the machine – then using CNC systems for accomplishing GANTRY function is necessary. Figure 4 shows the principle diagram of such driving.

The crossrail 2 moves along the columns guideways 1, together with the saddle and the working head 3. For the up and down movement, the electric motors ME_1 and ME_2 (10 and 11), through the reducers 6 and 7 drive the ball-screws 4 and 5 which have the pitch *p*. Since the ball-screws (Perovic, 2006) are not provided with self-locking systems, then it is necessary to use electromagnetic brakes 8 and 9. The reducers 6 and 7 should be backlash-free. Usually they are timing belt or planetary type. Their transmission ratio is smaller than the one of the worm gear reducers in Figure 1, *i*=1/2-1/5. There is a linear transducer for each column and the electric motors are equipped with rotary encoders. The synchronous movement is ensured by the CNC equipment, through the GANTRY function. The hydraulic balancing of the crossrail is recommended (Prodan, 2010) for large machines.

The theoretic torque at each motor is given by the relation:

$$M = \frac{p \cdot G \cdot i}{4 \cdot \pi} \tag{4}$$

Of course, the torque of the two motors is different, depending on the crossrail position, working heads position and other causes. Practically, they can be screened by CNC equipment during the operation.

3. UNLOADING OF THE CROSSRAIL FEED-POSITIONING KINEMATIC CHAIN

The solution shown in the Figure 5 can be used for very heavy machine-tools. The control crossrail 1 is moved by means of the feed kinematic chain 9. The crossrail does not take over the weight of the working heads. The working heads (3) can move on the power crossrail 2. Through the trolleys system 5 mounted on the crossbeam 4, the crossrail 2 and the working heads 3 are moved by the hydraulic cylinders 8 according to the command given by the follower pistons 7 kept in touch with the control crossrail by the springs 6. The control pistons (follower) 7 control trough the edges x_{01} and x_{02} the supply of pressured oil to the cylinders 8.

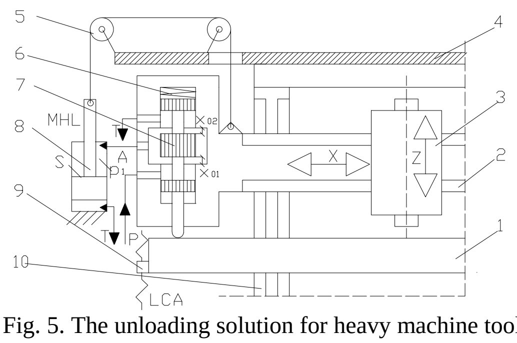

Fig. 5. The unloading solution for heavy machine tools

The supply pressure of the system is *p*. Due to the losses trough the edge x_{02}, the pressure at the level of the pistons surfaces *S* is p_1. In fact, the control given to the crossrail 1 is amplified in force by the hydraulic system moving the crossrail 2 and the working heads.

The mathematic model for such system of unloading is described by the relations below:

$$Q_p = Q + Q_T \tag{5}$$

$$Q = S \cdot \frac{dy}{dt} + a \cdot p_1 + \frac{V}{E} \cdot \frac{dp_1}{dt} \tag{6}$$

$$Q = C_D \cdot \pi \cdot d \cdot (x_{01} + x - y) \cdot \sqrt{\frac{2}{\rho} \cdot (p - p_1)} \tag{7}$$

$$Q_T = C_D \cdot \pi \cdot d \cdot (x_{02} - x + y) \cdot \sqrt{\frac{2}{\rho} \cdot p_1} \tag{8}$$

$$M \cdot \frac{d^2 y}{dt} + b \cdot \frac{dy}{dt} + M \cdot g = p_1 \cdot S \tag{9}$$

where: Q_p–flow provided by the pump; *Q*–flow at the motor; Q_T–flow toward the tank; C_D–throttling factor; *d*–diameter of follower piston; *x*-input (movement); *y*-output (movement); *p*–pressure at the pump (supposed as being constant); p_1–pressure in the motor; ρ-oil density; *M*–mass moved; *b*–linearized coefficient of the force loss in proportion with the velocity; *Mg*–weight to be balanced; *S*–piston surface.

The ratio required for pause overlaps is obtained from the relations above.

$$\frac{x_{01}}{x_{02}} = \frac{\sqrt{p - p_1}}{\sqrt{p_1}} \tag{10}$$

The pressure p_1 which represents the minimum required pressure can be determined. The selection of the overlaps in the relation (10) is made taking into consideration that larger overlaps lead to a higher promptness and smaller overlaps decrease the flow losses.

The calculation for STOP phase is not sufficient and that is way the study of these systems using computer simulation is recommended.

4. CONCLUSION

The movement of the crossrails of the machine-tools can be accomplished electro-mechanically or electro-hydraulically. If the movement is for positioning only, then the usage of indexing systems is recommended for an accurate positioning. For technological movements, feed type, two motors controlled in GANTRY system are to be used. In such cases there will be provided: backlash-free reducers, brakes and ball-screws. In either case, firm locking systems with disk springs should be provided for safety and stiffness reasons.

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