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INTERMITTENT LUBRICATION OF HEAVY-DUTY MACHINE TOOL GUIDES

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Abstract: *In this work, some of the theoretical and practical researches and achievements of the authors regarding the lubrication of the guides of heavy machine tools are presented. Calculation methods, simulations and the practical achievements used and obtained on the occasion of the modernization or remanufacturing of heavy machine-tools, such as: carousel lathes, boring and milling machines (AF) and gantry type milling machines, are presented. The work deals with the intermittent lubrication of the guides of these machines with the help of typical elements and systems, offered by different manufacturers of such equipment.*

Key words: *machine tools, guideways, lubrication systems, lubrication calculation, simulation.*

1. NECESSITY OF LUBRICATING GUIDES

Lubricating machine tool guides is an important operation for at least two reasons, namely:

- Ensuring a good operation, with the reduction of the friction of the elements in contact to avoid the increase in temperature, the induction of unwanted thermal deformations and even the wear and destruction of the guides;
- Reducing as much as possible the amount of lubricant used for ecological reasons.

There are authors [1] that research ways to optimize the lubrication of the guides, especially at high speeds of movement of the mobile element to increase the precision of the machine tool and save energy.

Other works are studding lubrication of guideways at very low speeds for giving solutions of eliminating the stick-slip motion [2].

In heavy machine-tools, the guides are made of steel, and the slides that work on them are made of cast iron, plated with plates made of bronze or special plastic materials [3–7]. In these conditions, friction is reduced [8]. On these slides there are components such as uprights, casings, carts, etc. whose mass can be of the order of tons [4, 5, 9, 10, 11].

The steel guides are rectified, and the plates mounted on the breasts are finely milled and manually adjusted to achieve the required number of contact spots [6]. As a rule, with these types of machine tools, the rapid travel speeds do not exceed the value of 10–12 m/min.

In these conditions, it is necessary to lubricate the contact surfaces. Anointing can be done in several ways [4, 9, 10, 11]:

- intermittent – the oil film is created with the help of small amounts of oil, sent intermittently and which creates a discontinuous film;
- continuous – the oil film is made with large quantities of oil which, thanks to the specific geometry of the surfaces and the high travel speeds, creates a continuous oil film (hydrodynamic systems);
- continue – the oil film is created continuously with large quantities of oil that are permanently sent by a pressure source [4, 9, 10, 11] (hydrostatic systems).

In this work, the systems of the first type, those of intermittent lubrication, are treated.

The introduction of oil between the working surfaces has the following roles:

- reduction of friction,
- cooling of surfaces,
- elimination of possible impurities resulting from operation or accidentally arrived.

2. CALCULATION OF INTERMITTENT GUIDE LUBRICATION SYSTEMS

It is considered a table that works on guides as in Fig. 1. The bed 2 is attached to the foundation 1. The worktable 3 has the length B and rests on the guides 4, these having the widths $L1$ and $L2$. To secure the slide, closing plates 5 width L3 were provided. Securing and centering on the Y direction is achieved with the wedge system 6. These have a total width of $L4$. The nut 7 is actuated by the feed drive corresponding to the X direction. On the entire length B of the slide, lubrication points marked 8 are provided, in different planes. In order to achieve minimal lubrication, it is considered that at any moment there must be a film of oil of thickness h on all surfaces on which there is friction during movement.

In this case, the friction surface can be considered as:

$$S_F - B(L_1 + L_2 + 2L_3 + L_4). \qquad (1)$$

It is recommended that the minimum film thickness h be h = 0.01–0.02 mm.

Under these conditions, the volume of oil V that must be permanently on the guides is:

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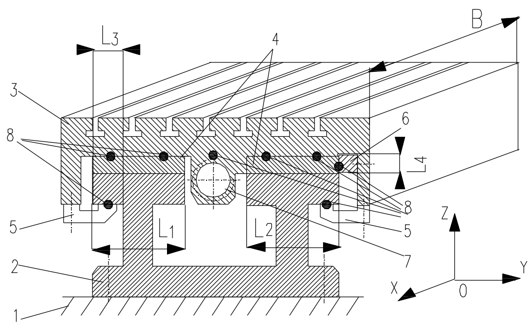

Fig. 1. Lubrication points for a heavy machine tool table.

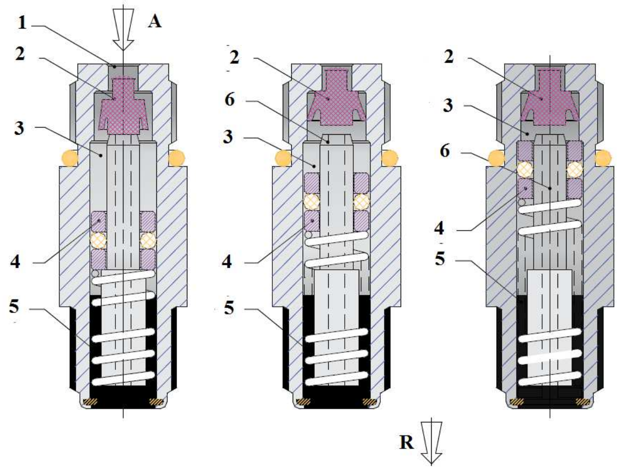

Fig. 2. Operation of lubrication dispensers.

$$V = Bh(L_1 + L_2 + 2L_3 + L_4). \quad (2)$$

Next, it is considered that after the oil has been applied in the necessary areas, the oil is evacuated. The evacuation process is facilitated by the speed of the slide, but also by the guide wipers used [9, 10, 11]. As a rule, this oil is no longer reintroduced into the lubrication circuit.

3. OPERATION OF LUBRICATION SYSTEMS

In each of the points where lubrication is carried out, there is a dispenser [7, 12, 13] whose working mode is shown in Fig. 2.

The oil supply under pressure (*A*) is made through hole 1. The sleeve 2 is pushed and closes the hole in part 6. The oil enters the free volume in the body 3 and pushes the piston 4 against the spring 5, expelling the existing oil from a previous phase. When the supply stops, sleeve 2 rises through hole 1, piston 4 is pushed by the spring which expands and expels the accumulated oil through the existing hole in part 6.

The supply pressure, as a rule, does not exceed 20 bar, and the dispensers are characterized by the volume they expel when actuated, expressed in cubic centimeters or millimeters [7, 12, 13]. Depending on the size and type of the machine tool, the construction of the slide, closing and centering wedges, identical or different useful volume dispensers can be used. If we consider that there are types of dispensers with volumes V_1, V_2 and VZ, each type in number of n_1, n_2 and n_Z, finally the condition must be verified:

$$\sum_{i=1}^{Z} n_i V_i > V. \quad (3)$$

In Eq. (3), V is the one defined by Eq. (2).

The feeding of the dispensers is done with the help of simple hydraulic power plants. They are characterized by: V_0 – the useful volume of oil, as a rule it is included in the range 3–7 l, the maximum working pressure (20–25 bar), the type of motor driving the pump.

The pump is activated for a time t_1 necessary to fill all the dispensers. It is considered that when the pump is stopped, the dispensers perform lubrication at all points during t_2, after which the installation has a minimum waiting time t_3. These times must be determined in such a way that there is no risk of lubrication failure or that the pump works continuously.

If the pump flow rate is QP, it is necessary to respect the condition:

$$t_1 > \frac{\sum_{i=1}^{Z} n_i V_i}{Q_P}. \quad (4)$$

To confirm that the entire circuit has been filled, it is recommended to install a pressure relay in the furthest lubrication point from the pump. It will confirm the loading of the circuit at a pressure that ensures the full actuation of the springs in the dispensers, but is lower than the pressure set at the pump pressure [14]. For machines with numerical control, for safety in operation, a confirmation delay of 1–2 s is introduced in the equipment after receiving the signal from the pressure relay.

The discharge time t_2 depends on a number of factors specific to the installation: the characteristics of the dispensers used, the size of the machine and the length of the supply pipes and hoses, the type of oil used, etc.

It can be determined experimentally when starting the machine and can be considered as a reference for the equipment after introducing a delay of 1–2 s. This total time will be taken into account when starting the kinematic chain that moves the slide so that there is no movement without lubrication. Once the first lubrication is done and the slide moved, the problem arises of determining the time interval t_3 after which a new lubrication is ordered.

There are two methods of programming the t_3 interval between two lubrications:

a) tests are made when assembling the machine and the value of t_3 is established so that the slide and the guides are lubricated in case of movement at maximum speed over the entire possible distance. In this case, if movements are made at low speed (processing), lubrication is done too often, which leads to the emptying of the tank and the appearance of unsightly oil leaks on the machine's components.
b) taking into account the length of the slide (*B*) and the working speeds, a certain run is established at which a new lubrication is ordered. In this case, if the slide

is standing and not working on the respective axis, lubrication is not performed. In this case, the oil in the tank is saved and there are no unsightly leaks. As a rule, this minimum stroke, after which the lubrication command is given, will correlate with the times t_1 and t_2.

The central lubrication units are provided with minimum level indicators that signal their emptying. For example, an installation with a volume of 6 l serving 12 dispensers with a volume of 0.4 cm^3 is emptied after approximately 1200 lubrication commands. If they are given at an interval of 1 minute, it means that if the car works 10 hours a day, the tank will be filled with oil once every two days. However, if the lubrication is programmed according to the race, the commands will be given only when the slide moves for certain distances, quickly or in a technological cycle. For example, if the lubrication command is given for a work stroke of 2 m, and the work cycle is 20 m/10 hours, it means that in a day 10 commands are given, to which a few more are added during the start-ups. Even if it is considered that 30 commands are given per day, it turns out that the tank will be filled every month.

4. SIMULATION OF LUBRICATION SYSTEM OPERATION

To check lubrication installations in the design phase, simulation methods can be used based on specific programs [15].

As an example, consider the lubrication installation of the guides on the *X* and *Z* axes from an SC17 CNC carousel lathe with the diagram in Fig. 3.

The P pump is driven by the *EM* electric motor and sucks oil from the *T* tank through the *F* filter. The maximum pressure is regulated with the PV pressure valve. The instantaneous pressure is visualized with the help of the pressure gauge *M*. The emptying of the tank is signaled by the electric minimum level indicator I_{Min}. The system ensures the lubrication of the *X* and *Z* axes independently or simultaneously according to the cyclogram in Table 1, by actuating the electromagnets 1*S* and 2*S* from the distributors 1*D*1 and 2*D*1. The operation of the power plant is confirmed by the pressure relay 1*PS*1, and the lubrication of the axle guides is ensured by 10 dispensers each and confirmed by the pressure relays 2*PS*1 and 3*PS*1.

The pump has a capacity of q = 1 cm^3/rot and is driven by the engine with a speed of 1500 RPM. The *PV* pressure valve was adjusted to 20 bar, and the pressure relays 1*PS*1, 2*PS*1 and 3PS1 are adjusted to 15–18 bar. The dispensers have volumes V = 0.4 cm^3.

To study the operation of this system, it was simulated using the Automation Studio package [15].

In the first phase, it was considered that the car is started and the *EM* electric motor that fills the circuit up to distributors 1*D*1 and 2*D*1 also starts. From the characteristic in Fig. 4 results that the loading time is approximately 20 s.

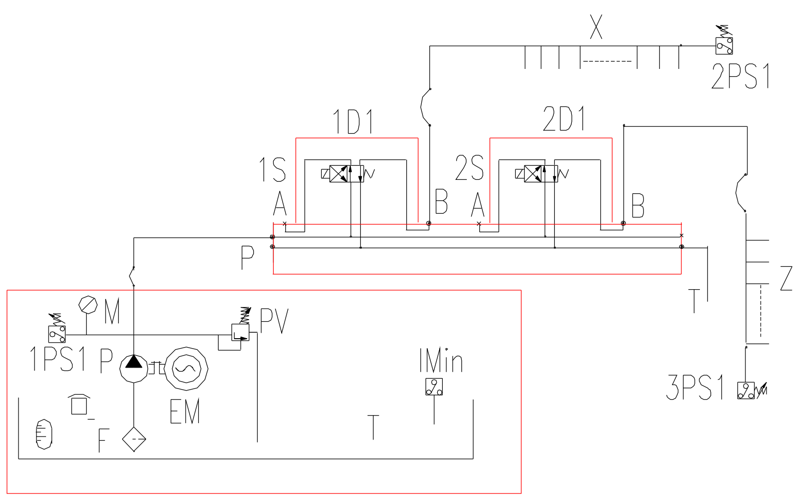

Fig. 3. Diagram of the *X* and *Z* axis guide lubrication system for a carousel lathe.

Table 1

Cyclogram of lubrication of the *X* and *Z* axes

	EM	1*S*	2*S*	1*PS*1	2*PS*1	3*PS*1	IMin
STOP	-	-	-	+	-	-	-
START X	+	+	-	+	+	-	-
START Z	+	-	+	+	-	+	-
START X & Z	+	+	+	+	+	+	-
Minimum Level							+

The dispenser expels a maximum flow rate of 2 cm^3/s according to the *ABC* triangle characteristic. The duration of the discharge is approximately 0.25 s. The amount discharged is given by the area of the triangle *ABC* and is approximately 0.4 cm^3, so lubrication is carried out according to the characteristics of the dispenser.

According to the simulation shown in Fig. 5, after approximately 2.5 s, the system has recharged and can deliver the oil required for a new lubrication.

During this time, the dispensers were refilled and they can perform the new anointing.

If it is necessary to feed the dispensers that ensure the lubrication of the guides of both axes (for processing by interpolation), then the time required for reloading increases according to the characteristic in Fig. 6.

The time required between two successive commands, in this case, must be greater than 6 s.

Assuming that the slide has the length B = 1 m, and its movement is made with a maximum speed of 10 m/min, in the interval of 6 s it has moved a distance equal to the elevation *B*, which means that there are no areas of unsolicited guides.

5. INSTALLATIONS FOR GREASING THE GUIDES OF HEAVY MACHINE TOOLS

In order to improve lubrication and preserve the oil film, lubrication channels are made in the guides of the slides. The lubrication channels can have different shapes, depending on the width *B* of the guide. In Fig. 8, several variants of channels used for the intermittent lubrication of the sliding guides from heavy machine tools are presented.

In Fig. 7,*a* solution is presented for lubrication channels made in guides narrower than 50 mm. If the width of the guides is greater than 50 mm, one of the solutions in Figs. 7,*b*, *c* and *d*. The elevations that define the lubrication channels are those in Fig. 7,*e*. and have the values presented in Table 2.

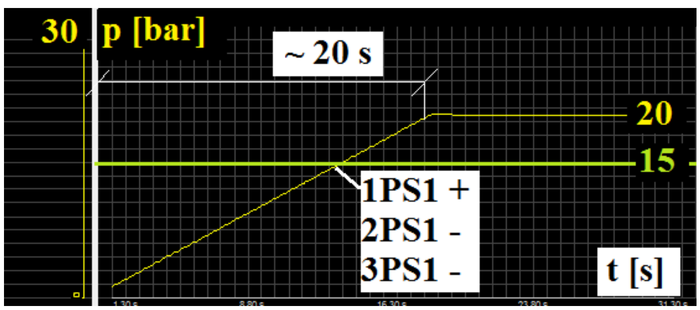

Fig. 4. Determination of the initial oil loading time at the programmed pressure.

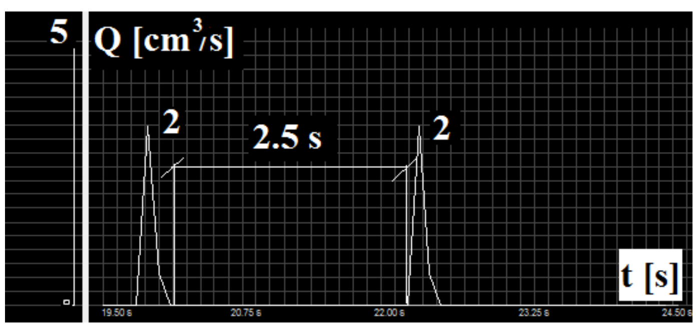

Fig. 5. Determining the reloading time when greasing an axis.

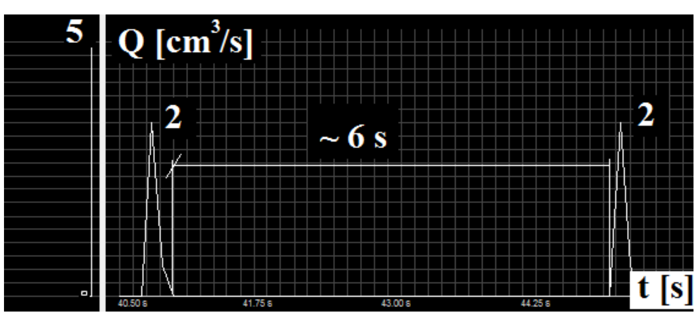

Fig. 6. Determining the reloading time when greasing both axes.

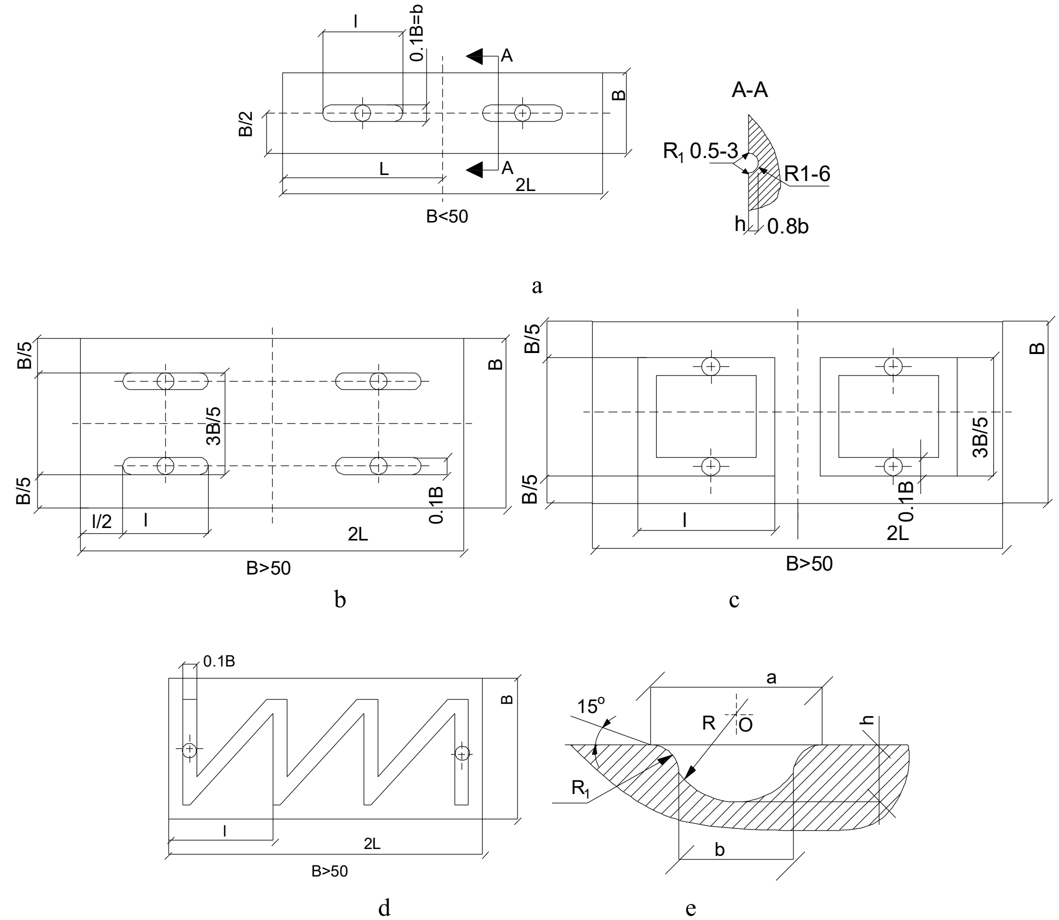

Fig. 7. Lubrication channels cut on the guideway surface.

Table 2

Values of evaluation of channel lubrication

Nominal Size of Groove h [mm]	*R* [mm]	R_1 [mm]	*a* [mm]	*b* [mm]	Recommended for width of guideway *B* [mm]	
					Over	Up to
0.8	1	0.5	3	1.6	25	40
1.2	1.6	0.8	4	2.5	40	60
2	2.5	1.2	7	4	60	100
3	4	2	10	6	100	160
5	6	3	16	10	160	250

These channels are made by milling, usually in the softer material: bronze, cast iron or plastic material [6]. After making the channels, the sliding surface is roughened and processed with the help of sabers to obtain an optimal contact. Figure 8 shows the guides provided with lubrication channels in the phase of this operation.

The hydraulic units are positioned in such a way that they are easily accessible for refueling with oil. The central lubrication system from the diagram shown in Fig. 3 has a useful volume of 6–7 l and is attached to the mobile cross member of the car. In Fig. 9 shows this lubrication unit, keeping the notations from Fig. 3.

The pressure relays 2*PS*1 and 3*PS*1 are mounted in the area of the dispensers, in the lubrication points furthest from the boiler, as Fig. 10 shows.

The supply pipes and hoses have an inner diameter of 4−8 mm. The pressure relays 1*PS*1, 2*PS*1 and 3*PS*1 sense values 2–5 bar lower than the pressure set at the *PV* pressure valve.

6. CONCLUSIONS

In the case of heavy machine-tools, where the rapid travel speeds are a maximum of 10–20 m/min, one can use intermittent greasing of the guides. In this case, the lubrication installation must be sized correctly: pump, tank, capacity and number of dispensers used. It is necessary to take into account the way of working, the speed of advance and rapid movement of the slide. The oil film must be continuous, without interruptions, but without an excess of flow that can lead to the appearance of oil stains.

Fig. 8. Guides with lubrication channels in the manual processing phase.

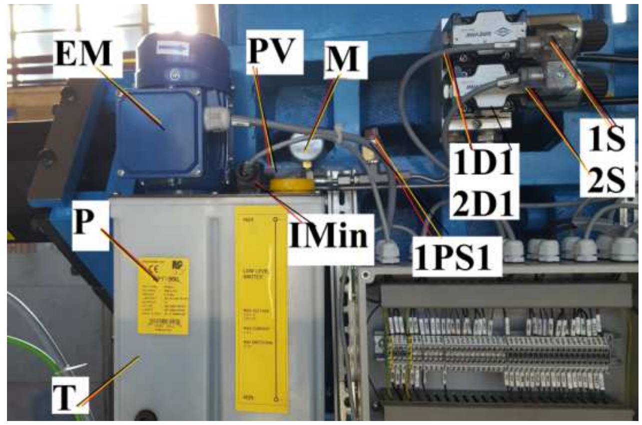

Fig. 9. Location of the lubrication station.

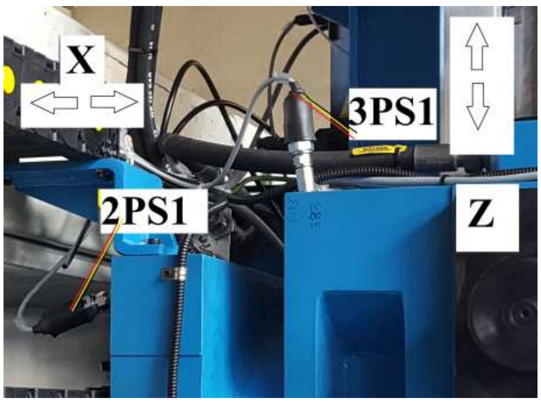

Fig. 10. Location of the pressure relays that confirm the lubrication of the *X* and *Z* axes.

The used oil, as a rule, is no longer reintroduced into the lubrication circuit, as such, systems for its safe disposal will be provided.

The lubrication stations do not work permanently, they only ensure the filling of the circuit. For a fair choice of start/stop times, simulations can be done initially using specialized programs.

For CNC machines, it is recommended that lubrication be done according to the strokes made and not according to time.

If the loads are very high, for the considerable reduction of friction, it is possible to switch to hydrostatic lubrication systems. In this case, the installations are more complicated and more expensive, more difficult to adjust and maintain. There is a need for a more efficient oil filtration being recovered and reintroduced into the system.

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