

# Remanufacturing of Heavy Duty Machine Tools

## Guideways Plating with Plastic Materials

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*This paper introduces some results of the researches that the authors conducted in the field of using plastic materials for plating the surfaces of the guideways for heavy duty machine tools. There are mentioned theoretical aspects about the calculation and selection of these guideways and the results of the experimental researches performed on the occasion of the remanufacturing of a rotary table intended for the machining on two axes of large mass and overall size workpieces, specific to heavy industry. It is also shown the technology of assembling and machining the plates made of plastic materials. It is about the translational sliding guideways and about the rotational guideways too. They operate with intermittent, continuous or hydrostatic lubrication. The research results can be also applied in the case of remanufacturing of other heavy duty machine tools such as: standard or vertical lathes, Gantry type milling machines, grinding machines or table type HBM-s and floor type HBM-s etc.*

**Keywords:** *guideways, plastic materials, heavy duty machine tools, manufacturing, remanufacturing*

The guideways for machine tools are meant to materialize the generating paths, rectilinear or circular ones, necessary for generating the machined surfaces [1-4]. During operation, they guide the live elements like: saddles, rail heads, rams etc. The guideways are also supporting these elements and ensure their accurate travel. The guideways must meet specific requirements such as [3]: accuracy, resistance to wear, stiffness and durability [1, 3, 4]. In the case of heavy duty machine tools [5], the plane profile guideways [2-4] are mostly used. Figure 1 shows one of the methods of achieving the guiding for translation in the case of heavy duty machine tools [5].

Saddle 2, made of cast iron or welded steel, travels on the fixed guideways 14, made of special steel. The guiding plates 3, 4, 7, 8, 9 and 11 are usually made of bronze or, more rarely, of cast iron. In the second case, some of them may be missing and the guiding is made directly between the saddle 2 and the guideways 14. The closing plates 5 and 6 are provided with the adjusting screws 12 and 13 that make possible the adjustment of the vertical pre-clamping [2-4]. The horizontal backlash taking-over is performed by means of the wedge 10 [3]. The system

performed in this way allows the guiding on X direction only and is provided on Y and Z directions and during the eventual rotations.

The constructive solution in figure 2 is specific to the guiding in rotational movement ( $B$  axis) and can be found in the case of rotary tables but also of the vertical lathes [2, 5, 6] with hydrostatic suspension [2, 3, 5-7].

The plates 5 made of cast iron or bronze are clamped on the table 2. The bed 1, made of cast iron or welded steel, is provided with pressure oil feed orifices. This oil, thanks to hydrostatic suspension phenomenon, is able to lift the table 2 with a maximum size equal to  $J_{Max}$ , which ranges from 1/100 to 1/10 mm. In these conditions, when the table rotates, there is no more friction between metal surfaces practically. If the oil film disappears, the system can still work for a short time in friction mode; in this case the contact between two cast iron surfaces can cause the seizing. The seizing can appear even if the plates are made of bronze. The main spindle 6 keeps the coaxiality of the parts 1 and 2 by means of the bearings 4 and 7. Cover 3 does not allow the entry of chips and other elements into the area of supporting on bearings.

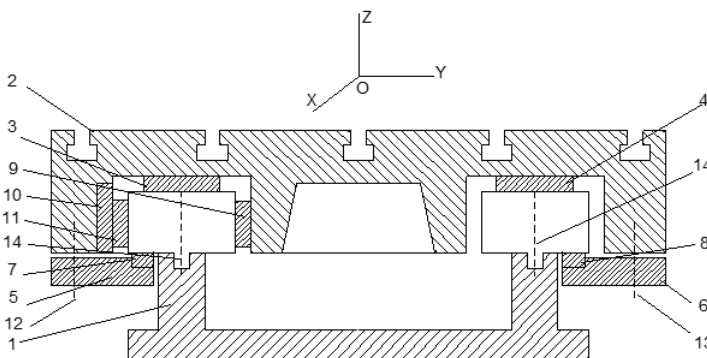


Fig. 1. Translational sliding guideways

1 - bed; 2 - saddle; 3, 4, 7, 8, 9, 11 - guiding plates (bronze or cast iron); 5, 6 - closing plates; 10 - closing wedge; 12, 13 - adjusting screws for guideways clamping; 14 - fixed guideways

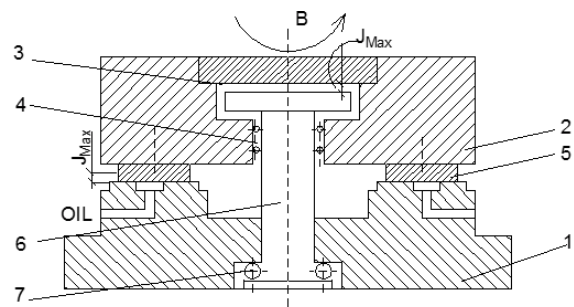


Fig. 2. Rotational sliding guideways

1 - bed; 2 - rotary table; 3 - cover; 4 - radial supporting on bearings for centering (bearings); 5 - guiding plates; 6 - main spindle; 7 - axial supporting on bearings;  $J_{Max}$  - maximum axial backlash

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Thickness [mm]	1.5	2.0	3.0	4.0	5.0
Surface size [mm <sup>2</sup> ]	2,000×490	2,000×490	2,000×460	2,000×440	2,000×430

**Table 1**  
STANDARD SIZES OF  
PLASTICS STRIPS

### Remanufacturing of machine tools

Remanufacturing is a modern solution, widely applied by specialized companies from Europe and USA. After a certain period of heavy duty machine tools utilization, it comes the time to remanufacture or modernize them so that a continuity of their use is ensured in the new conditions required by the current production: high productivity, increased utilization, versatility etc.

It is considered that a remanufacturing was done if the machine tool was completely disassembled and its structural components were submitted to various interventions such as: new machining or replacement of guideways, modification of the bed, columns, cross-rails and guideways. It is also considered a remanufacturing if architectural changes of the machine tool are performed, for example: the table of a vertical lathe is assembled on a saddle that travels on the guideways; a gantry of a vertical lathe is adapted and can travel on the bed of a floor type HBM thus obtaining a Gantry type milling machine [6].

Along with the remanufacturing, machine tools are modernized too. Through this activity, which can also be a freestanding activity, interventions are made on the:

- mechanical part (by replacing guideways, changing the leading screws, modifying the gear boxes or feed boxes),
- electric part for driving or control (by replacing electrical motors, converters, electric cabinets, control panels),
- hydraulic part (by replacing the old hydraulic devices, such as pumps, distributors, valves etc.),
- electronic part (by replacing CNC equipment, encoders included),
- associated units (by replacing the lubrication unit, by introduction of the pneumatic drive, by using modern accessories etc.).

This paper introduces some researches on the use of plastic materials for making guideways (slip couplings) for heavy duty machine tools. These types of guideways can be used for remanufactured machines but also in the case of brand new machine tools production. At the present moment, more and more manufacturers of heavy duty machine tools use guideways plated with plastics taking into account the results of the studies developed by various researchers [8-11].

### Experimental part

#### Use of plastics in the construction of guideways for heavy duty machine tools

Plastic materials (polyamides) are successfully used in the construction of guideways for machine tools, replacing materials such as bronze and cast iron. The plastics most commonly used for plating the guideways are also shown in the paper [14].

Thanks to their composition (plastics with fillers such as bronze, glass, graphite, molybdenum disulphide (MoS<sub>2</sub>), ceramic or a mixture of them) they have a friction coefficient of 0.003-0.05 approximately, superior to the friction coefficient of bronze, which is 0.05 in optimum conditions.

Maximum working speeds can exceed 2 m/s [1] which is far more than the value required for heavy duty machine tools where the rapid travel speeds rarely exceed 10 m/min.

Other advantages can also be mentioned [12]:



Fig. 3. Plastic materials used for plating the guideways

- total elimination of the risk of seizing and occurrence of scratches,
- diminution of wear of counterparts, especially the ones made of cast iron,
- diminution of the consumption of ferrous materials, more expensive than plastics,
- reducing the work load and the intervention time in case of remanufacturing.

Among the specific disadvantages one can mention:

- plastics realize the thermal insulation of the guideways and do not allow their cooling at very high speeds which is not the case of heavy duty machine tools,
- specific conditions of assembling and machining are required,
- in case of a faulty clamping or sticking, the plastics can come off in scales over time.

Plastic materials designed to make guideways are delivered by the specialized manufacturers [13] under the form of plates or strips. These ones can have different thickness or size of the surfaces. Table 1 shows values of plastics strips.

In figure 3 are shown the plastic materials used for plating the guideways. The guiding plates 3, 4, 7, 8, 9, 11 of figure 1 are presented in figure 3,a and the plates 5 of figure 2 are presented in figure 3,b.

Plastic materials are made in layers; a fabric made of synthetic fibers is thermally stuck on one of their surfaces enabling an optimal clamping on the saddle (or on the bed). The clamping is achieved by means of special screws made of brass (fig. 3) and/or using special adhesives.

Usually, the adhesives are based on two solvent free components, *A* and *B*, which are mixed in a certain proportion before sticking. For example: for a thixotropic adhesive based on polyurethane, mixture of grey color and density of about 1.45 [g/cm<sup>3</sup>], the proportions used are the following ones:

- component *A* : component *B* = 3: 1 - for mixture ratio as weight,
- component *A* : component *B* = 12 : 5 - for mixture ratio as volume.

The times of linking and setting of the adhesives (approximate values) are listed in table 2.

**Table 2**  
FEATURES OF ADHESIVES

Temperature [°C]	Linking time	Setting time	
		50 %	100 %
100	15 min	48 min	75 min
60	30 min	90 min	7 h
20	6 h	48 h	7 days

**Table 3**  
PERMISSIBLE PRESSURE  $P$  OF HEAVY MACHINE TOOLS

	Grey Cast Iron/ Grey Cast Iron	Grey Cast Iron/Steel	Steel/Steel	Grey Cast Iron/Brass	Steel/Brass	Steel/ Thermoplastic Material
Slow Speed	5-10	5-10	6-12	5-10	5-10	2-20 The load-carrying capacity is dependent on the thickness of the bearing material and the surface roughness
High Speed	2-4	3-4	3-5	2-5	2-5	

**Table 4**  
SPECIFIC DIAGRAMS OF THE CONTACT PRESSURE

		<ul style="list-style-type: none"> <li>• <math>F_N</math> - resultant of forces that act on a flat guideway</li> <li>• <math>B</math> - width of the flat guideway</li> <li>• <math>X_N</math> - coordinate of the point of application of the force <math>F_N</math> related to guideway centre</li> <li>• <math>p_{NMax}</math> - maximum contact pressure</li> <li>• <math>p_{NA}</math> - average contact pressure</li> </ul>
$0 < X_N < \frac{B}{6}$ (1) $p_{NMax} = p_{NA} \cdot \left(1 + \frac{6 \cdot F_N}{B}\right)$ (2)	$X_N = 0$ (3) $p_{NMax} = p_{NA}$ (4)	
$X_N > \frac{B}{6}$ (5) $p_{NMax} = \frac{4}{3} \cdot p_{NA} \cdot \frac{1 - \frac{X_N}{B}}{1 - 2 \cdot \frac{X_N}{B}}$ (6)	$X_N = \frac{B}{6}$ (7) $p_{NMax} = 2 \cdot p_{NA}$ (8)	

Adhesives are usually charged on a single surface. In the case of plastics with high power of absorption, both surfaces will be charged. No pressing is required.

There are also variants when the strip is self-adhesive. In this case, after pickling the properly machined surface, the sticking can be made without using adhesives.

In paper [14] there are presented the most important factors that influence the optimum operation of the plastics used.

In order to calculate the guideways, it should be determined the value of the contact pressure that appears on guideways during the operation of machine tools. This one depends on several factors among which we can mention: · form of contact pressure diagram; · value of friction coefficient; · feed (positioning) speed; · type of lubrication. Also it should be known the permissible values of the contact pressures  $p$  [daN/cm<sup>2</sup>] for different couples of material (table 3).

Table 4 shows specific forms of the contact pressure diagram and the proper calculation formulas in the case of a flat guideway upon which acts the resultant force  $F_N$ . In the case of heavy duty machine tools, the weight of saddles, rams, tables and other live elements give the greatest share of the forces that stress permanently various components vertically. Depending on the type of machine [2] one can also add the vertical components of the cutting forces.

The composition of all these forces leads to the resultant force  $F_N$ .

In formulas (1) – (8) it was considered that:

$$p_{NA} = \frac{F_N}{S} \quad (9)$$

where  $S$  is the surface of discharge on the guideway.

In the case of saddles of length  $L$ , the surface  $S$  is obtained by means of the formula:

$$S = B \times L \quad (10)$$

If lubrication grooves are machined in the surface  $S$  then the formula (9) becomes:

$$p_{NA} = \frac{F_N}{S - S_C} \quad (11)$$

where  $S_C$  is the surface of lubrication grooves.

Depending on the final roughness, plastic materials used for guideways plating are compressed under the action of the compression forces  $F_N$  according to the diagram in figure 4.

Friction coefficient depends on the nature of materials, their level of machining but also their lubrication conditions.

For the heavy duty machine tools, after the precision milling and grinding of the surfaces that will make the guiding, it will be also performed a scraping operation. This operation will be applied in saddle guiding surface, on

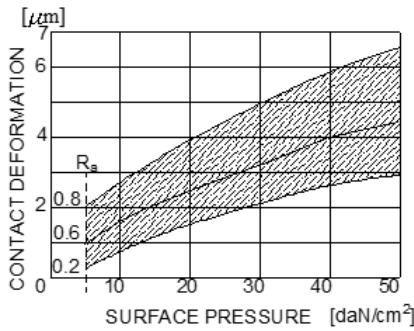


Fig. 4. Variation of contact deformation

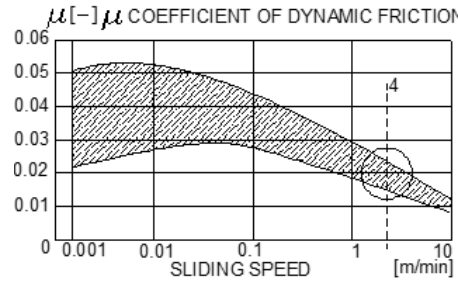


Fig. 5. Variation of dynamic friction coefficient

Application	No. of spots in 1 inch <sup>2</sup> (25.4 × 25.4 mm <sup>2</sup> )	Surface finish $R_a$ [μm]
Guideways for heavy machine tools before scraping	4±1	3.2
Guideways for heavy machine tools after scraping	10±2	1.6
Guideways for high precision machines	25+7 25-1	0.4-0.2

**Table 5**  
NUMBER OF THE CONTACT SPOTS ADMITTED AND THE ROUGHNESS OF THE SCRAPPED SURFACE

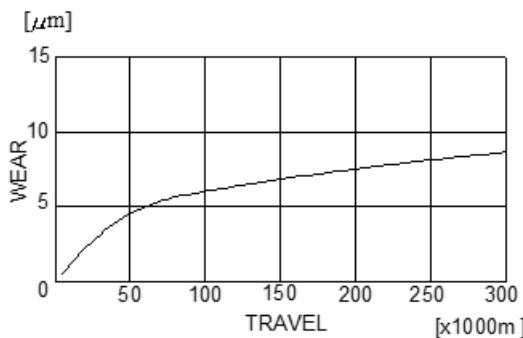


Fig. 6. Variation of the wear

surfaces made of cast iron, bronze (brass) and plastics. Following up these operations it is desirable to fulfill the conditions in table 5.

In these machining conditions, in the case of the metallic guideways we can talk about a friction coefficient which can vary in the range of 0.07 - 0.25 during mixed friction (oil intermittent lubrication). In case of the hydrostatic suspension there is no more metal on metal contact because the oil film exceeds the level of irregularities, while the friction coefficient decreases by about one or two orders of magnitude.

Friction coefficient  $\mu$  of plastics vary also depending on speed such as in figure 5.

In the case of a maximum speed of 10 m/min, limit speed for most heavy duty machine tools, the friction coefficient ranges from 0.015 to 0.025. The behavior of plastics at low speeds is very good, eliminating the danger of stick-slip effect [7]. Another advantage of these materials related to the metallic ones is the resistance against corroding agents, which allows their use for the guideways with and without covers [15].

The wear of the guideways made of plastics varies over time depending on the spaces covered as shown in figure 6. After more than 300,000 m covered, this wear is lower than 1/100 mm, which usually does not affect the accuracy of the machine.

If the guideways made of plastics will operate in hydrostatic regime [2, 3, 5] there is the danger that the pressure developed in the hydrostatic pockets penetrates into the clamping area A, as in figure 7a, and entails the phenomenon of separation. To avoid this phenomenon, it is recommended to use pressed and secured bushings,

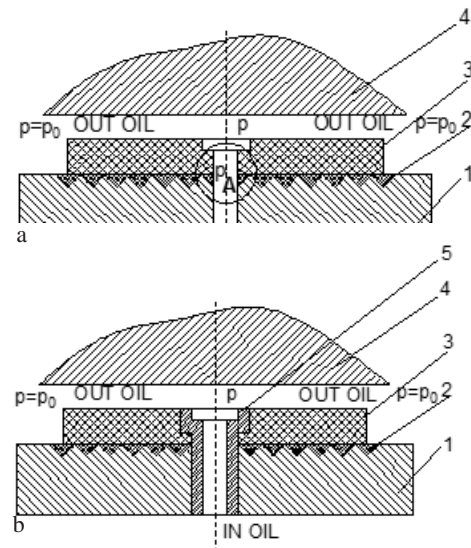


Fig. 7. Use of guideways made of plastic materials in hydrostatic regime 1 - piece on which is applied the guideway of plastic mass, 2 - adhesive, 3 - plate of plastic material, 4 - metallic part of the hydrostatic guideway (cast iron or steel), 5 - insulating bushing, IN OIL - supply with oil under pressure ( $p$ ), OUT OIL - area lacking pressure ( $p = p_0$ )

like in figure 7b. These ones are made of brass and insulate the sticking area (mechanical clamping).

The lubrication grooves for the intermittent lubrication of sliding guideways for heavy duty machine tools can have various forms, depending on the width  $B$  of the guideway. Figure 8 shows some variants of these ones. The sizes that define the lubrication grooves are specified in figure 8,d and have the values shown in table 6 [3].

#### Replacement of the guideways of the rotary table MRD 1700×2000×100 with guideways made of plastic materials

Next we present the research made on the occasion of the remanufacturing of a rotary table MRD 1700×2000×1000 type.

Rotary tables are intended for the machining of large workpieces; they are associated to boring and milling

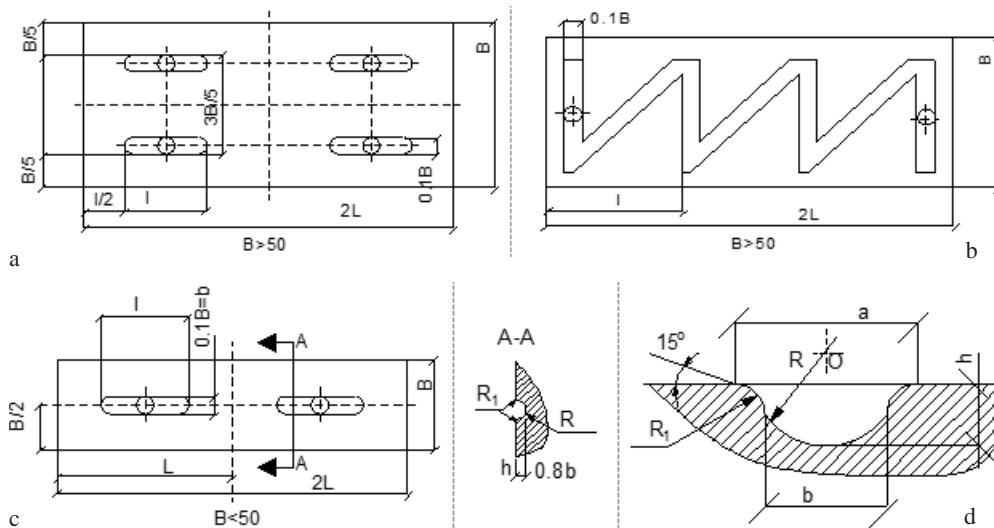


Fig. 8. Lubrication grooves made in the sliding guideways for intermittent lubrication

Table 6

CONSTRUCTIVE CHARACTERISTICS OF THE LUBRICATION GROOVES

Nominal size of groove $h$ [mm]	$R$ [mm]	$R_1$ [mm]	$a$ [mm]	$b$ [mm]	Recommended for width of guideway $B$	
					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

machines such as table type HBM-s and floor type HBM-s [2, 6]. They make possible the travel of the workpiece in one or two straight directions perpendicular to each other ( $X$ ,  $Z$  or  $W$  type axes) and the rotation of this one on a vertical axis ( $B$  axis).

The most important initial characteristics of the rotary table [16] that was remanufactured are the following ones:

- maximum weight of the workpiece - 15,000 daN;
- translation maximum speed - 5 m/min;
- continuously adjustable feed speed in the range - 0 - 1.600 mm/min;
- maximum tangential speed at rotation ( $B$  axis) of circular guideways - 4 - 4.500 mm/min;
- lubrication of guideways on  $X$  axis - intermittent lubrication with dispensers of 0.2 cm<sup>3</sup>;
- lubrication of circular guideways - lubrication in hydrostatic system with  $p_{Max} = 25$  daN/cm<sup>2</sup>;
- total weight - 12,000 daN;
- installed capacity - 25 kW.

The remanufacturing process of the rotary table consisted of:

- replacement of the translational guideways of the saddle by new guideways made of plastic material,
- replacement of the rotation guideways of the table by new guideways, made of plastic material, which will operate in hydrostatic regime, at a maximum pressure of 25 daN/cm<sup>2</sup>,
- complete replacement of the hydraulic unit and lubrication unit,
- replacement of DC electric motors by AC motors with rpm adjustable by means of frequency converters.

For the guideways of  $X$  axis and for the rotation axis ( $B$  axis) there were selected two materials of different colors [13] with the following common features:

delivery condition: medium to dark brown or white; · color after mechanical machining: grey; · water absorption:  $< 0.01\%$ ; · coefficient of linear thermal expansion:  $6 \times 10^{-5}$  1/K; · max. pressure load for 1% deformation: 93 daN/cm<sup>2</sup>; · hardness:  $60 \pm 5$  Shore D; · modulus of elasticity: 1,000 N/mm<sup>2</sup>.

Figure 9 presents some of the machining phases of the translational guideways ( $X$  axis) and the rotation axis ( $B$  axis).

On the occasion of introducing the guideways made of plastics it was also measured the hardness and the roughness of the metallic guideways that were preserved. The values measured are listed in table 7 for the guideways of  $X$  translational axis and  $B$  axis of rotation.

By introducing the elements made of plastics, the hardness of the metallic guideways is no more so important, especially for  $B$  axis where, due to the hydrostatic suspension, the metal/plastic friction is practically impossible. It can occur in emergency operation only, when the hydrostatic unit does not run.

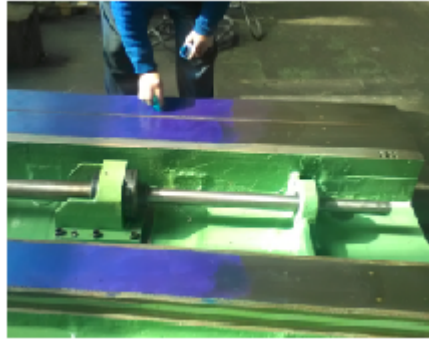
For measuring the hardness of the guideways made of steel, it was used the portable hardness tester shown in figure 10.

For measuring the roughness, it was used a portable roughness tester Mitutoyo SJ-210 type (fig. 11) with which measurements in narrow spaces can be performed.

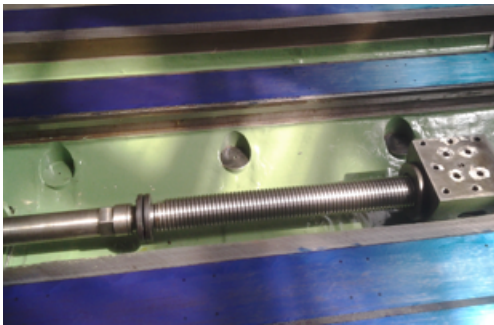
The rotary table is provided with two identical motors for the two movements ( $X$  axis and  $B$  axis). Their power is 11 kW. The driving on the two axes is performed by means of two reducers: the reducer for  $X$  axis has the transfer



sticking and mechanical clamping of the rotational guideways



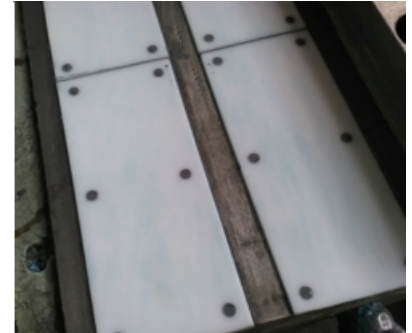
rotational guideways after sticking and clamping by screws



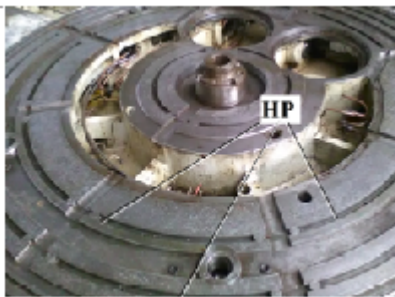
preparation of the translational guideways for determining the contact spot



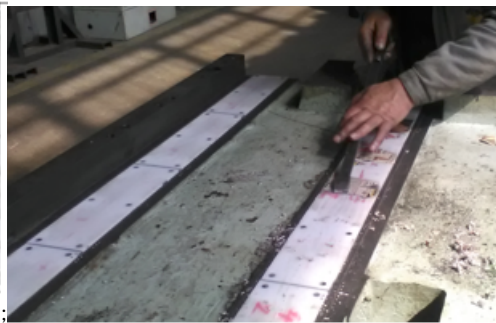
rotational guideways after scraping



translational guideways after sticking and clamping by screws; screw heads were covered with adhesive



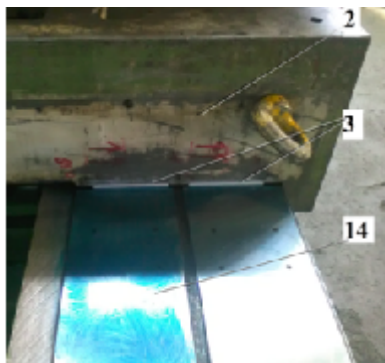
metallic guideways of *B* axis (are fixed); hydrostatic pockets *HP* can be observed



manual machining (scraping) of the translational guideways



preparation of the rotational guideways surfaces for making the contact spots



verification of the number of contact spots (notations are the same as in figure 1)

Fig. 9. Machining phases of the guideways plated with plastic materials

**Table 7**  
FEATURES OF REMANUFACTURED GUIDEWAYS

Application	No. of spots in 1 inch <sup>2</sup> (25.4 × 25.4 mm <sup>2</sup> )	Surface finish <i>R<sub>c</sub></i> [μm]	Hardness
Guideways for <i>X</i> axis; steel no scraping	8-11	0.4-0.8	45-48 HRC
Guideways for <i>B</i> axis; cast iron after scraping	9-11	1.6	160 HB

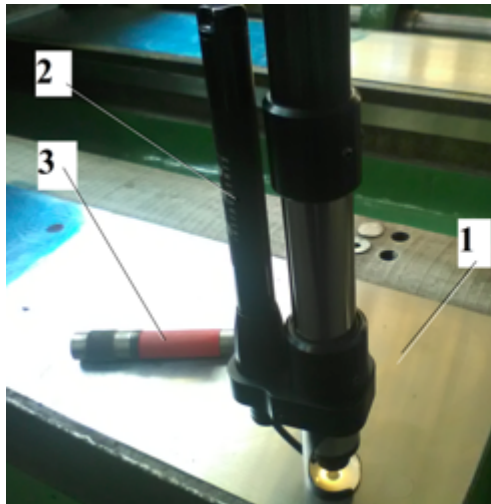


Fig. 10. Measurement of guideways hardness 1 - guideway whose hardness is measured, 2 - fiber optic microscope calibrated, 3 - standard hammer (diamond tip) for performing the hardness test, 4 - standard workpiece

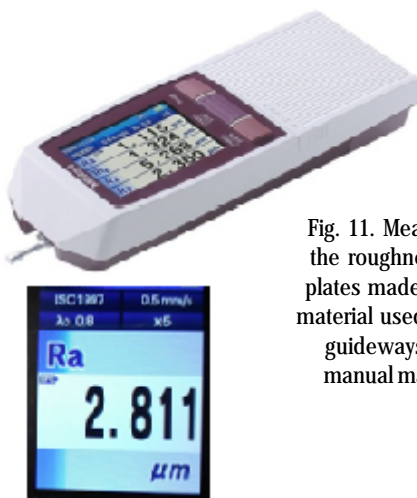


Fig. 11. Measurement the roughness of the plates made of plastic material used for X axis guideways before manual machining

ratio  $i_x = \sim 1$ , and the reducer for rotation has  $i_b = 0.27$ . A ball screw is used for translation.

Table 8 summarizes comparatively the required torque values (in percentage) for saddle travel with a speed of 5 m/min with a workpiece of 10,000 daN. The estimated yield of the transmission on X axis is  $\eta = 89\%$ .

In table 8 it was noted:  $P_{EM}$  - power of the electric motor,  $T_{EMMax}$  - maximum torque developed by the motor at rated speed,  $T_{EMT}$  - theoretic torque required by motor at the speed of 500 rpm,  $T_{EMM}$  - torque measured at motor at the speed of 500 rpm after stabilizing the speed on the travel of 600 mm.

## Conclusions

The accuracy of a machine tool is given by its supporting on bearings and guideways. The guideways are the ones that allow fulfilling the linear and/or rotation geometrical conditions required for the workpieces. Guideways are the elements stressed during machining operations and during auxiliary phases too; in the case of heavy duty machine tools one can say that guideways *operate* even when the machine does not run.

In these conditions, in the case of brand new machines manufacture, especially on the occasion of re-manufacturing, it is recommended - if possible - to use guideways plated with plastics. We can mention some of their advantages:

- high load on the guideway (over 800 daN/cm<sup>2</sup> - static load) and guaranteed avoidance of a cold flow phenomenon (creep),

**Table 8**  
VALUES OF THE PERCENTAGE TORQUE

$P_{EM}$ [kW]	$T_{EMMax}$ [Nm]	$T_{EMT}$ [Nm] / [% $T_{EMMax}$ ]	$T_{EMM}$ [% $T_{EMMax}$ ]
11	210	30.4 / 14.47 %	18 %

- simple and cheap assembling, by sticking; we recommend special adhesives based on 2 components; for the mechanical clamping it is recommended to use special screws,

- simplification or even elimination of the lubrication unit, depending on the operation conditions, which means to reduce substantially the price of the machine / unit,

- machining by scraping, grinding and milling at very high speed; plastic material can be cut by abrasive disks or band saw; on the occasion of re-manufacturing it is possible to eliminate the machining by cutting operations of the surfaces on which the plastics is applied,

- elimination of the risk of seizing or stick-slip effect occurrence,

- for the metallic components kept in guideways building (cast iron or steel) can be accepted a lower hardness than in the case of metal on metal guideways,

- in case of using hydrostatic systems, at the accidental loss of supply pressure it does not occur any seizing; in terms of the metal on metal guideways, especially for the heavy vertical lathes (table larger than 8,000 mm) when the pressure is accidentally lost, the seizing appears in most cases.

Replacing conventional guideways with plastics guideways requires their recalculation in terms of load, cutting forces and travel speeds.

As seen, in this paper also occur some specific elements such as the insulation of joining areas in order to avoid delamination.

It is recommended to protect the guideways made of plastics against the penetration of corroding agents. In terms of penetration of negligible amounts of coolant (emulsion) there is no danger.

The remanufactured rotary table is designed for the oil equipment manufacturing industry and it will operate in conditions of loading, utilization and energy consumption superior to the initial ones.

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