

3.1 SUPPORTING STRUCTURE OF MACHINE TOOLS

Twelve following subsections will discuss the essential assembly groups of CNC machine tools which are common for all types. Theoretical bases and principles which are used and quoted here to the great extent are borrowed from [Borský 1991], [Borský 1992a], [Borský 1992b] and from company literature. Moreover, author's knowledge especially in the field of servo drive dimensioning is applied here.

Requirements put on the supporting structure

While designing a supporting structure, the designer must respect many points of view which can be summarized in some essential and generally valid requirements as the following ones are:

- application of the top-quality material for the frame;
- good static rigidity;
- sufficient dynamic and temperature stability;
- to enable good chip removal;
- simple and efficient manufacture;
- small weight;
- easy manipulability;
- good installation on the foundation.

Moreover, some essential questions will be discussed which must be taken into consideration to comply with the mentioned requirements. It is the right place to declare that the information mentioned in the following text must be assessed at the particular application in comprehensiveness of all conditions varying in the particular cases, which is conditioned by specific machine-tool operation.

Properties of parts and assembly groups of CNC machine tools are determined mainly by:

- the material;
- topology – shaping, ribbing, wall thickness, proportions of parts;
- connections – the quantity, position and type execution of fixed connections and movable connections.

The manufacturer and the designer can influence all of these properties to a certain extent. However, there are many limitations here. For example, these are cost limitations. It is clear that it is not always possible to use that possibility or variant which is the most suitable one in its technical aspect, but it is necessary to select such a possibility or variant which has adequate costs. Other limitations are often

very complicated optimization processes leading to improvement and increase of machine parameters. In many cases the application of these advanced optimization methods requires not only great demands

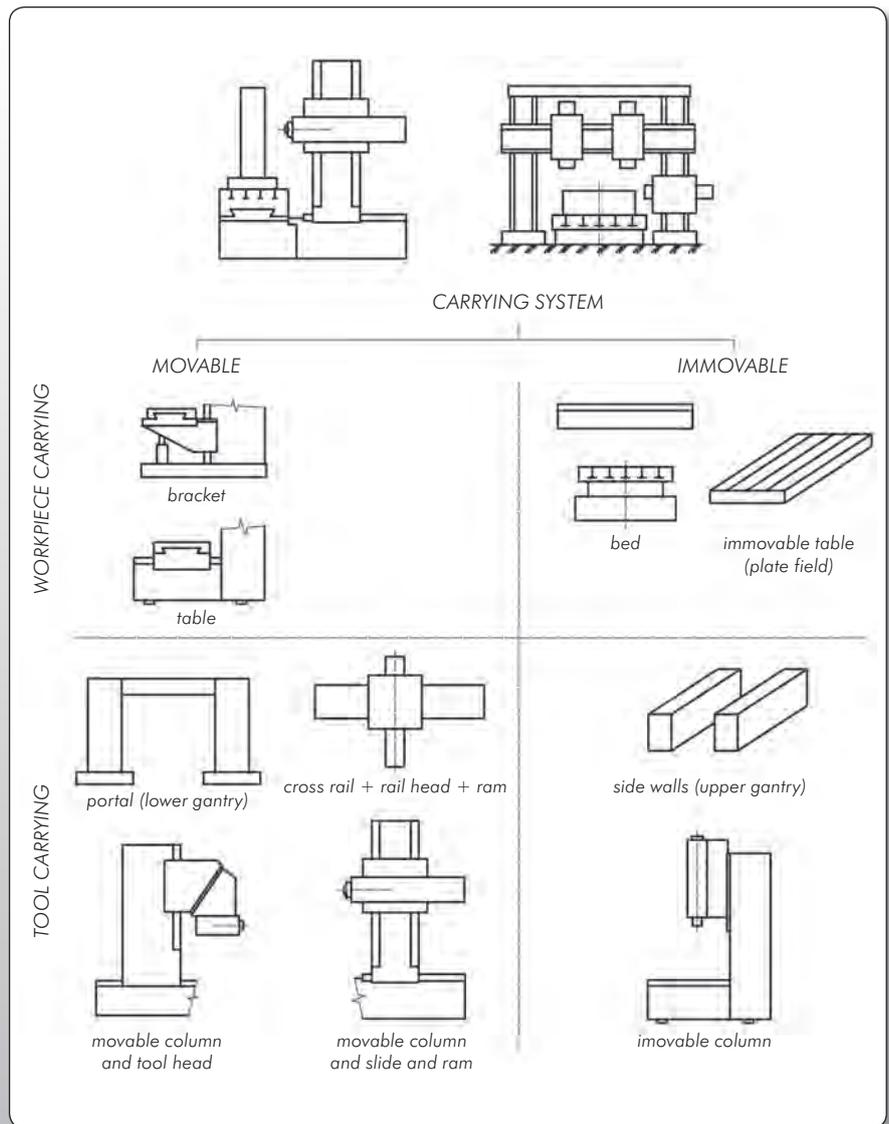


Fig. 3.1.1: Morphology of the CNC machine-tool supporting structure

Materials for building of supporting structures			
metallic	non-metallic	combined	natural
<ul style="list-style-type: none"> • cast iron • cast steel • steel (weldments, castings) 	<ul style="list-style-type: none"> • particle composites • fibre composites 	<ul style="list-style-type: none"> • steel weldment and filling with damping material 	<ul style="list-style-type: none"> • stone (granite)

Fig. 3.1.2: Types and properties of materials for building of supporting structures [Marek 2010], [www-1]

					Fibre composites with epoxy resin					
	Metallic materials		Particle composites		Carbon fibre HM stiffening	Carbon fibre HM stiffening #	Carbon fibre HT stiffening	Carbon fibre HT stiffening #	Aramid fibre stiffening	Fibre from E-glass stiffening
	Steel	Cast iron	Polymere concrete	HPC concrete						
Specific weight [kg.m ⁻³]	7 850	7 200	2 300–2 500	2 200–2 500	1 600	1 600	1 600	1 600	1 400	2 000
Poisson's ratio [-]	0,3	0,2–0,3	0,25–0,3	0,2–0,3	–	–	–	–	–	–
E-modulus [GPa]	210	70–10	30–44	50–60	360	120	144	48	50	40
Tensile strength [MPa]	400–1 600	150–400	10–40	8–10	1 200	400	2 400	800	200	1 100
Compression strength [MPa]	250–1 200	700–1 200	140–160	100–200	–	–	–	–	–	–
Bending strength [MPa]	150–600	100–300	15–50	3–8	–	–	–	–	–	–
Damping decrement [-]	0,002	0,003	0,02–0,03	0,02–0,03	–	–	–	–	–	–
Coefficient of linear expansion [10 ⁻⁶ /K]	11–18	10	9–18	10,6	-0,5	-1	0	0,5	-3,5	5
Thermal conductivity [Wm ⁻¹ K ⁻¹]	47–	50	1–3	1,7	50	1	10	1	0,1	0,6
Specific heat capacity [KJkg ⁻¹ K ⁻¹]	0,49	0,45	0,7–1,3	0,9	1	1	1	1	1,5	1,1

Tab.3.1.1: Physical properties of materials for supporting structures [Mráz, Talácko 2006]

on developers but it also requires costs on commercial calculation systems enabling to perform optimization. Another problem is unfamiliarity with linkages or spare calculation models describing behaviour of the real supporting structure accurately enough. Due to this, the conservative solution is often selected to avoid unexpected complications and uncertainties, not the optimum solution or the solution which is very close to the optimum one.

Material

It is possible to use various materials for the design of the machine-tool supporting structure, grey cast iron, steel and cast steel are most often used, but lately also various nonferrous materials, especially concrete and polymere concrete have been used to a still greater extent (Fig. 3.1.2).

While selecting the material kind, it is always necessary to assess especially the essential physical properties of the particular material which directly influence the specific technical and operation machine properties (Fig. 3.1.2). The material must have these important properties:

- high rigidity and strength (safety against permanent deformation and breakage);
- low weight (static and dynamic properties);
- high damping of vibrations (dynamic properties);

- low internal stress (long-term accuracy);
- low thermal dilatability (thermal stability);
- low energetic costs for material acquisition;
- low material costs.

As it can be seen from the above-mentioned facts, the requirements are often contradictory ones. The mechanism of the physical damping principle is very complicated and it is still the subject of research. From the technical point of view, it is possible to state that high values of internal damping can be found especially at materials composed of more macroscopic phases or at materials with many internal interfaces

among the particular components. From this point of view, the following materials are important ones: fibre or particle composites, materials containing foamy filling or macroscopic combinations of these materials with conventional materials based on Fe-C designated as hybrid structures.

Tab. 3.1.1 summarizes the essential physical properties of materials for supporting structures.

The most common material used for supporting structures are metallic materials (ferro-alloys) (Fig. 3.1.3).

The principles given in Fig. 3.1.4 [Janda, Divišová 1990] are valid for designing of castings, especially for continuity of ribs and countersurfaces.

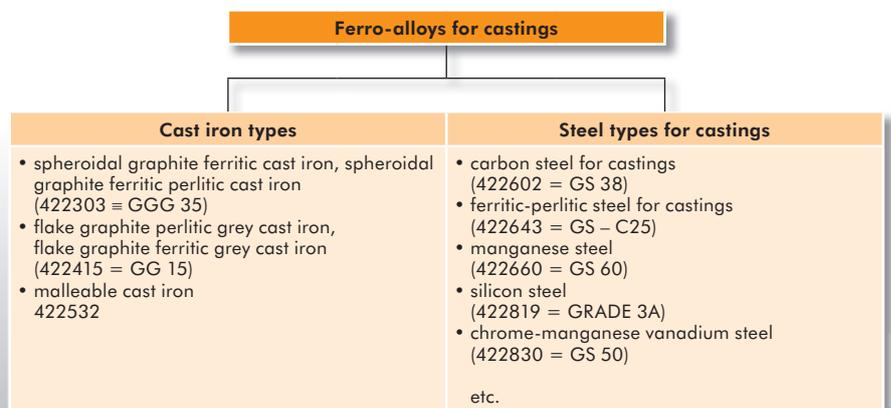


Fig. 3.1.3: Ferro alloys used for building of supporting structures

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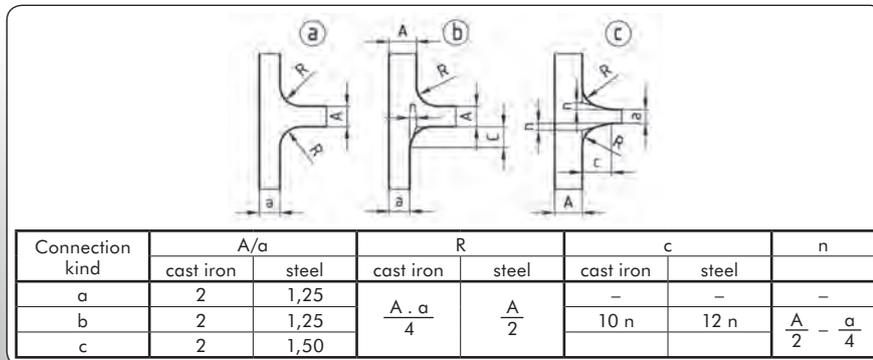


Fig. 3.1.4: Principles for designing of castings at ferro alloys [Janda, Divišová 1990]

The preliminary wall thickness determination is performed according to the characteristic dimension:

$$N = \frac{2 \cdot l + b + h}{3} \quad (3.1.1)$$

where l , b , h are the length, the width and the height of the cast part. The wall thickness is assigned to this number (see Fig. 3.1.5). The casting shape shall be as simple as possible and after the design is made, the shape is almost always adapted to technological practice in the appropriate foundry. Then, the situation generally happens that a compromise must be done between technology and designing. The designer must keep in mind easy manipulation, a possibility to clean the casting after it is taken out from the mould, adequate weight, approach to machined surfaces, casting technology, shape and functional correctness of the casting (rather straight surfaces), uniform hardening in all casting parts, smooth transitions of walls with rounding-off, the position at casting or casting accuracy (backlash between subsequent castings).

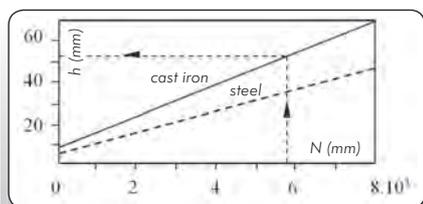


Fig. 3.1.5: Wall thickness at castings from ferro alloys [Janda, Divišová 1990]

The cast bed or the cast column are usually heavier than welded ones for these reasons:

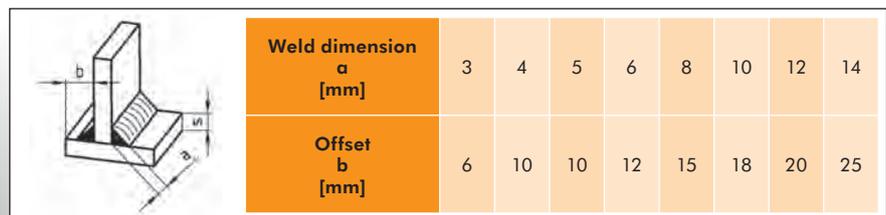


Fig. 3.1.6: Dimensions of welds [Janda, Divišová 1990]

- cast iron has a smaller modulus of elasticity in tension as well as a smaller modulus of elasticity in shear, therefore, at the requirement to obtain the same rigidity it is necessary to select thicker walls at the casting than at the part welded from sheet steel;
- torsionally stressed sections cannot be made completely closed at castings, therefore, it is necessary to select thicker walls and denser ribbing;
- for technological reasons (considering the casting possibilities), it is necessary to select bigger thickness at castings, that it should be necessary according to the required rigidity [Borský 1991].

The casting drawing or the working drawing is decisive for the check of the shape, dimensions and weight of castings made of ferro-alloys. Rests after risers and gates must be removed at the foundry on machined surfaces as well as on unmachined surfaces. Rough castings must not have any surface defects which can cause complications at machining – on the one hand functional failures (ribs are not cast, etc.) on the other hand segregates or other internal failures. Moreover, it is necessary to check mechanical properties of the casting material and its chemical

composition. It is also possible to prescribe mechanical tests (tension, pressure, rigidity, etc.).

Welded designs of machine-tool supporting structures use steel profiles or rolled metal sheets which guarantee weldability. The number of welds, their directions and size must be selected to prevent mutual stress which will warp the weldment profile. Continuous welds with small sizes are selected for these reasons. The recommended size is given in Fig. 3.1.6.

If the model price is not counted, the costs for casting are usually lower than the

costs for welding. Therefore, it is useful to select welded parts at such machines which are manufactured individually or in small numbers of pieces. There was an opinion (supported by tests with simple rods) that cast-iron parts damp vibrations better than welded ones. However, more detailed and deeper experiments and tests prove that this opinion is not the quite right one. Joints in welded places act in a damping way because those parts touch there tightly which move towards each other at vibrations. Although these motions are slight ones, the friction arising at them contributes to damping of vibrations. The possibility to perform irregular profile strengthening also contributes to damping of vibrations [Borský 1991].

The disadvantage of welded beds and columns is that it is practically impossible to use the basic material which these are made from for manufacture of guideways. Therefore, the guideways must be made on strips made of useful material and they must be screwed and fixed by pins (also welded in exceptional cases) to the bed body or to the column body.

In such cases the guideways can be made of cast iron or steel, with hardened active surfaces, or at the slide the can be coated by non-ferrous metal or by plastic, or it is