3.2 MACHINE TOOL HEADSTOCK

Machine tools are working (manufacturing) machines specified to create workpieces with a particular shape, with particular dimensions and the machining quality. It follows from this machine tool definition that the essential machine tool function is to make generating workpiece surfaces with the required geometry and with the required surface quality under the economically efficient conditions. In order to comply with this essential requirement, the necessary condition is to create cutting motions which consist of the mutual coupling of vectors of the rotary motion and of the translation motion [Demeč 2001].

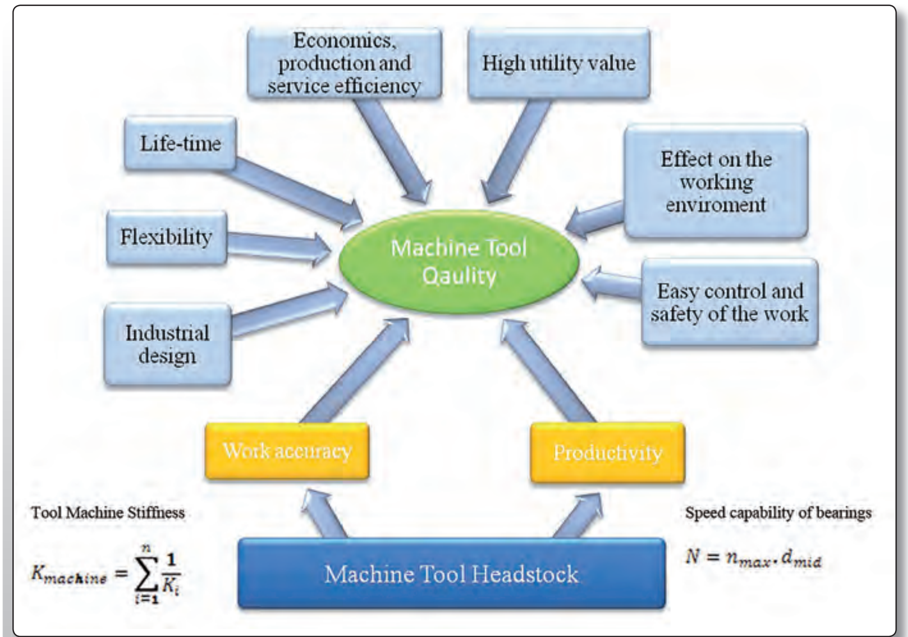


Fig. 3.2.1: Influence of the main factors on the machine tool quality

The accuracy increase of the manufactured volume and the efficiency increase of the manufactured production are to the decisive extent dependent on the technical and technological parameters of machine tools. This places still and still higher demands on utilization of new progressive cutting tools, design materials and machine concepts and on the parameter improvement of the particular machine assembly sets. The main factors having the influence on the machine tool quality are shown in Fig. 3.2.1.

Headstock in the machine tool system

The main quality criteria put on the machine tools are working accuracy and productivity. The tool how to provide the machine working accuracy is the system rigidity and the tool how to provide the machine productivity is the cutting speed.

The machine tool productivity can be efficiently increased by reducing the time necessary to make a workpiece, i. e. the main time and the secondary time. The headstock has the direct relation to the main time reduction, because the cutting speed is increased in the direct proportion with the increase of the spindle rotation frequency and due to this, the machining time is reduced. The machine productivity is limited by the maximum cut width which is the cutting process stability measure regarding to the origination of self excited vibration. The productivity is limited by the dynamic rigidity and by damping of the system "spindle – bearing". Therefore, it is still more and more important to determine the dynamic headstock characteristics at machine tools (natural frequencies, normal modes of vibration, dynamic rigidity, damping, ...) especially in the high speed cutting processes (High Speed Cutting – HSC).

The total working accuracy of machine tools is limited by the whole chain of assembly sets, by their mutual interaction, by static and dynamic properties. The headstock of the machine tool is usually the weakest member in the chain of the machine assembly sets arranged in series; therefore, it is the limiting assembly set of the total machine tool rigidity. The rigidity of the system "spindle – bearing" has the direct influence on the surface quality and on the shape and dimensional accuracy of manufactured parts. This also has the direct relation to the tool productivity, because the final cut course is characterized by initiation of self sustained oscillations and this is proportional to the tool rigidity and to the damping.

According to the definition, the machine tool headstock is the assembly group having the box shape (Fig. 3.2.2) or the tube shape (Fig. 3.2.3), whose main task is to provide the precise rotary motion of the workpiece (at a lathe) or of the tool (at a milling machine, at a drilling machine or at a grinding machine). The precise rotary motion is such a motion, during which the paths of the particular workpiece points or of the particular tool points move along the paths differing from the circle only in certain admissible tolerances. The spindle function is coincident with the function of the circular guiding and the spindle differs from it only by its shape. The headstock together with the spindle system, with the way of its bearing, with the headstock box, with the kinematic coupling and with other peripheries is the dominating quality assembly group

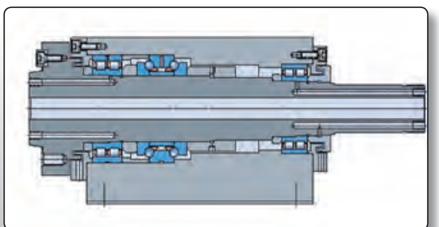


Fig. 3.2.2: Box shape of the headstock body [SKF]

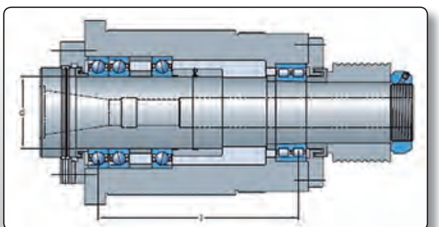


Fig. 3.2.3: Tube shape of the headstock body [SKF]

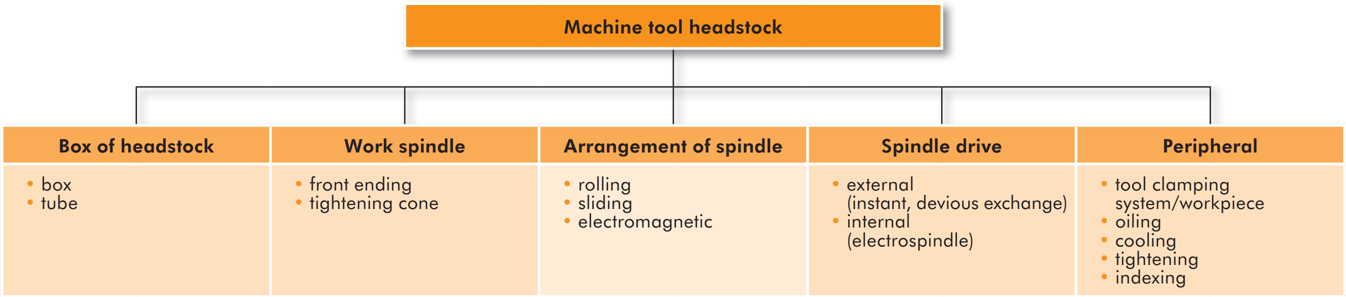


Fig. 3.2.4: Headstock morphology

in relation to the machine tool working accuracy and its productivity.

The headstock rigidity and the maximum spindle rotation frequency are usually in the mutual contradiction. The final solution is practically always a compromise between these requirements. Therefore, the design and the headstock type execution must be implemented for the technical requirements put on the particular machine.

The comprehensive analysis and the headstock design project represent a very hard and a very responsible task. This task requires deep knowledge of elasticity and rigidity, of mathematics, of machine parts and of elastohydrodynamical lubrication theory. The most complicated task in this process may be the bearing system design. The number of systems with antifriction bearings grows proportionally with the increasing demands placed on machine tools, because the systems with antifriction bearings enable to catch radial forces as well as axial forces. The special systems made with radial ball bearings with angular contact offer a wide scope of possibilities at the solution of the compromise "rigidity – maximum rotation frequency".

From the mathematic point of view, the calculation of force ratios or of the rigidity is a solution of a statically indefinite system. This is because the bearings are statically indefinite systems which change their rigidity in dependence on the loading force. Utilization of mathematic models based on the system of non linear differential equations provides a good conformity of theoretical and experimental values. Manufacturers of headstocks have usually special software kinds available. One of these software kinds is Headstock, version 2.8 [Javorčík 1991]. It is necessary to become aware that such a calculation is very demanding in its time and price aspects. It is the task which cannot be practically realized without utilization of the efficient computer technology. When a suitable bearing is selected, a simplified rigidity calculation model of bearing assembly sets is very important for a machine tool designer in the time period of project solution. If this tool – model is not available, the selection is often implemented only based on intuitions and experience. Designers rather prefer the proven classical bearings, even to the detriment of technical and technological machine parameters.

Headstock morphology

The headstock consists of the particular parts and external peripheries which together provide the required functions of the whole assembly set (Fig. 3.2.4). The essential headstock parts include the spindle with the spindle nose, the spindle bearing system, the tool clamping system or the workpiece chucking system and the headstock box. The peripheral devices can include integrated or external systems determined to drive the spindle, to lubricate the bearings, to provide cooling, spindle indexing and monitoring.

Based on the elasticity and rigidity knowledge, it is possible to form the approximate solution of every headstock type. Requirements put on the headstock body boxes:

- maximum symmetry – for the reasons of symmetrical thermal expansions;
- minimum quantity of holes – holes decrease rigidity;
- statically predestined design – it increases rigidity.

The requirements put on the spindle are concentrated on the spindle geometric rigidity, on the selection of design material and on the shape configuration of diameters. The selection of design material for the spindle is conditioned particularly by mechanical properties of the essential core structure which are by the modulus of elasticity *E* and by the coefficient of relative damping *D*. The spindles made of steel comply with the requirements of high static rigidity. The relative spindle quality measure is its specific rigidity, i. e. the spindle nose rigidity compared with the spindle weight. The spindle natural frequency and the dynamic characteristics of the headstock are also connected with it. Composite materials (graphite epoxide) start to be used for high speed spindles. This spindle is lighter and it does not require such a big diameter [Lee].

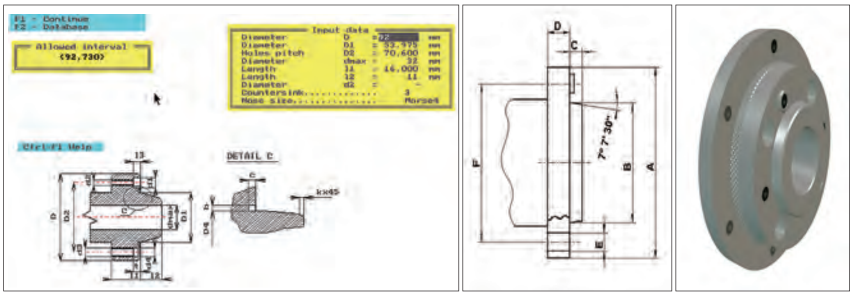
The shape configuration of diameters shall be simple to the maximum possible extent. Those configurations are rational, where the minimum number of graduated diameters can be found and the difference between diameters is determined only by types and dimensions of applied bearing models.

The spindle end which protrudes from the headstock box is called the spindle nose. When designing the spindle, the great attention must be paid to the suitable adaptation of the spindle nose so that it can provide the optimum tool clamping (through the clamping shank) or the optimum workpiece chucking (e. g. by means of the chuck). This connection must be a quick, precise, rigid and reliable one. The type execution and the shape of the spindle nose depends on the machine type, on the machine size and on the required accuracy.

For turning operations we know the spindle noses A1, A2 (ČSN 201006) and B (ČSN 201011):

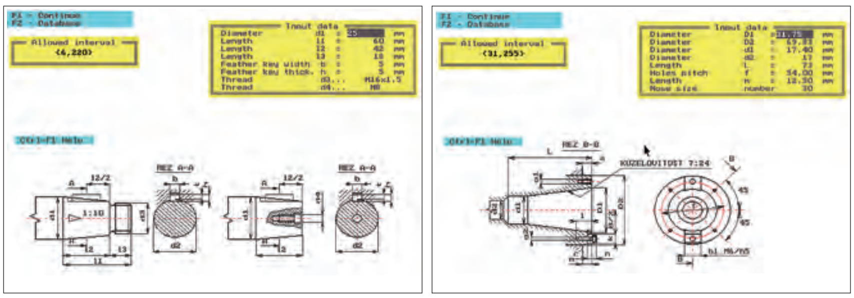
- The type A1 (Fig. 3.2.5a) is the spindle nose with the flange and with the short centring taper – clamping tapped holes are in the spindle flange, DIN-55026/ DIN-55021/ ISO 702/I.

3.2 MACHINE TOOL HEADSTOCK



a) for turning A1/ Morze 5 b) with bayonet lock

Fig. 3.2.5 The ends of the spindle lathes [Javorčík 1991]



a) for grinding, long version b) for milling ISO 40

Fig. 3.2.6 The ends of the spindles grinders and millig machines [Javorčík 1991]

- The type A2 is the spindle nose with the flange and with the short centring taper – clamping tapped holes are in the spindle flange and in the taper face. DIN-55029 /ISO 702/II.
- The type B (Fig. 3.2.5b) is the spindle nose with the flange and with the short centring taper – clamping – with the lug type closure. DIN-55027/DIN-55022/ ISO 702/III.

The spindle face equipped with the centring taper is also subordinated to the standardization efforts. It finds its application mainly at lathes or at cylindrical grinding machines and it is designated as ISO 702/I and DIN 5026 (taper A).

For grinding, it is possible to use the ends in the long type (d1 ≥ 220 mm, Fig. 3.2.6a) and in the short type (d1 < 220 mm).

The following tool holders are used for milling operations (Fig. 3.2.6b):

- ISO tapered shanks (taper ratio 7:24);
- HSK short tapered shanks (taper ratio 1:10), six different types designated A to F;
- cylindrical shanks (less often);
- special profiles, e. g. triangular Sandvik Coromant Capto;
- BIG Plus (essentially like ISO seating on the face).

The essential difference between ISO and HSK ends of spindles consists in the fact, that the tool is clamped only in the taper at ISO but the tool shank is also clamped on the tool holder face at HSK. The tool clamping system must provide quick, precise and reliable clamping (Fig. 3.2.7). At milling headstocks, the clamping system consists of two essential parts, of the mechanical clamping and releasing unit and of the self locking clamping mechanism. The clamping unit is equipped with the drive which extends the draw bar through the gear mechanism. Springs provide tool clamping even at a failure of the tractive force.

Spindle bearing

The spindle bearing system is the most important issue at the design solution of the whole headstock. In dependence on the particular working conditions, it is possible to consider sliding, electromagnetic or antifriction spindle bearing systems (Fig. 3.2.8). Sliding and electromagnetic bearings are used in special cases, when extremely high demands are placed on the rigidity or on the maximum rotation frequency. More than 90 % of all spindle bearings are implemented at machine tools just in the antifriction bearing system. In comparison with the sliding bearing, the antifriction bearing is high efficient and if the essential operation conditions are observed, it is sufficiently reliable. The front bearing support is usually designed so that it can catch also axial forces and on the other hand, the back bearing support is designed so that can enable thermal expansion of the spindle. The rule is also generally valid, that when the bearing diameter increases, the maximum admissible rotation frequency decreases.

Antifriction mounting on the antifriction bearing system

The particular antifriction bearings are specified either for transfer of purely radial forces or axial forces. However, there are also bearing types which enable to transfer axial forces as well as radial forces at the same time, when they are arranged suitably in the sets.

Transfer of the purely axial force

Ball thrust bearings (Fig. 3.2.9) can transfer the highest axial load (in one direction or in both directions), because the connecting line of contact points between antifriction bodies

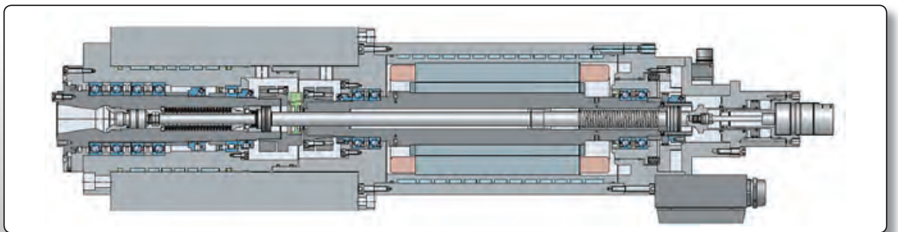


Fig. 3.2.7 Headstock milling machines with clamping system [SKF]