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New Design "Duplo-Headstock"

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Abstract

The quality of machine tools is critical in determining their productivity and the accuracy of the finished work piece. The headstock of the machine tool has the greatest impact on these parameters. The tool or work-piece holder must meet specific demands for maximum speed and rigidity. These two parameters are variable, but always in contradiction, and depend mainly on the Spindle-Bearings System (SBS). In this context, SBS are increasingly being produced in combination with roller bearings, and with various combinations of radial ball bearings. This is mainly because the radial ball bearings allow groupings of different combinations to achieve the optimal compromise between the required maximum speed and the desired stiffness of the SBS. Stiffness, especially in ball bearings, is not constant but dependent on the magnitude of the load. The SBS is a statically indeterminate system, and an accurate calculation of the bearings and its nodes, as well as the whole system, is only possible using iterative methods. The exact calculation of SBS stiffness cannot be achieved without the use of powerful computers and high-quality software. Selection of the optimal configuration is achieved by analyzing a number of potential, alternative SBS solutions. The exact calculation of a large number of variants, and manufacturing their prototypes, is time consuming and very expensive. The solution is to quickly determine, with sufficient reliability, the parameters of the bearing nodes, which are influenced by the radial ball bearings. It is only in the final variation that an accurate calculation using iterative methods can be made, followed by subsequent production of a prototype for verification. At our workplace, we dedicate our time to intensive research into bearing nodes and the complete SBS.

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Keywords: ball bearing angular contact; bearing node; spindle bearing system; machine tool spindle; spindle duplication; stiffness

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1. Introduction

The decisive criteria of the quality of machining tools are their productivity and working accuracy. One innovated method for improving the technological parameters of manufacturing machines (machine tools) is to optimise the structure of their nodal points and machine components.

Because of the demands on machine tool productivity and accuracy, the spindle-housing system is the heart of the machine tool, Figure 1, [1]. Radial ball bearings with angular contact are employed in ever increasing arrays. The number of headstocks supported on ball bearings with angular contact is increasing proportionally with the increasing demands on the quality of the machine tool [2]. This is because these bearings can be arranged in various combinations to create bearing arrangements which can enable the reduction of both radial and axial loads. The possibility of varying the number of bearings, their preload value, dimensions and the contact angle of bearings used in the bearing nodes, creates a broad spectrum of combinations which enable us to achieve the adequate stiffness and high speed capabilities of the Spindle-Bearings System (SBS) [2], [3]. Adequate stiffness and revolving speed of the headstock are necessary conditions for meeting the manufacturing precision quality and machine tool productivity required by industry.

When designing a machine tool headstock, the starting point is the design of the spindle support, as this limits the stability, accuracy and production capacity of the machine by its stiffness and revolving speed. However, the parameters influencing the stiffness and frequency can act in opposition to each other. The selection of the type of bearing has to take into consideration the optimization of its stiffness and revolving speed characteristics. The maximum turning speed of the bearings is a function of the maximum revolving speed of the individual bearings, their number, pre-load magnitude, manufacturing precision, and the types of lubrication used.

The stiffness of the SBS depends on the stiffness of the bearings and the spindle itself. There are several methods that can be employed for determining the static stiffness of the spindle system, e.g. [1] and [2].

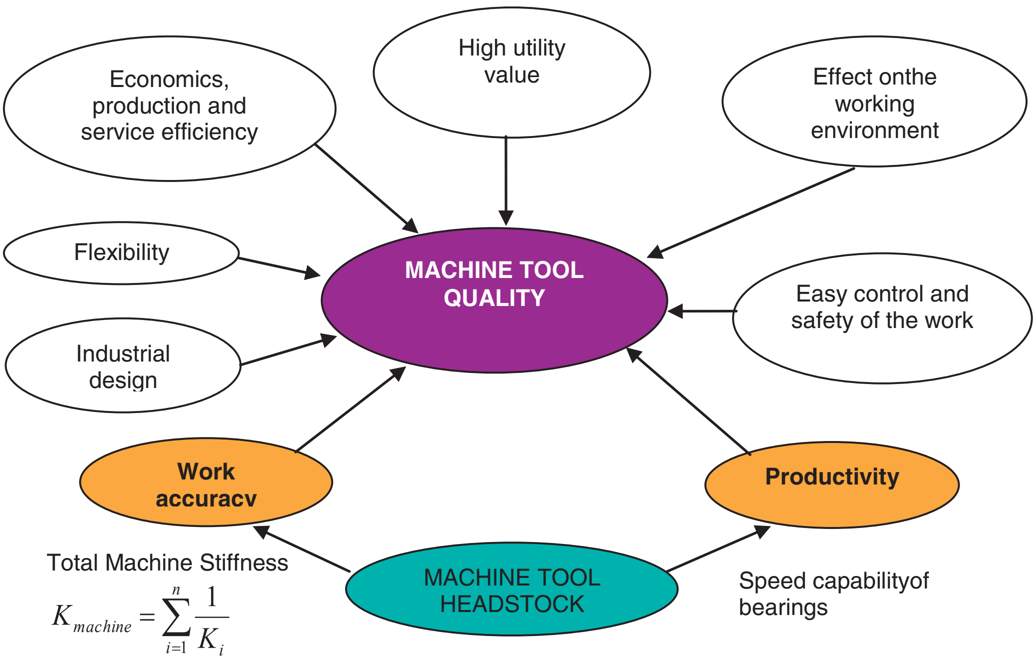

Fig. 1.Factors influencing the Quality of Machine Tools, [4].

However, one problem which has not yet been solved is the calculation of the stiffness of the bearings, (or nodes of bearings) in the individual housing, [7], [8], [9]. Accurate calculation of the stiffness of the bearing nodes requires the determination of the static parameters of each bearing. From a mathematical point of view, this can be solved by using a system of non-linear differential equations, which requires the use of computers. To simplify the design, we need a static analysis which provides the basis for the dynamic characteristics of the mounting, and of the machine itself. Designers often prefer the conventional and proven methods of mounting, without taking into account the technical and technological parameters of the machine.

For the design engineer, it is important to be able to undertake a quick evaluation of various SBS variants at the preliminary design stage. The success of the design will depend on the correct choice of suitable criteria for the SBS, and if the design engineer has adequate experience in this field.

2. Headstock – the heart of the machine tool

The headstock, whether tool or workpiece carrier, has a direct influence on the static and dynamic properties of the cutting process. The spindle-bearing system (SBS) stiffness affects the surface quality, profile, and dimensional accuracy of the parts produced. It also has a direct influence on machine tool productivity because the width of cut influences the initiation of self-induced vibration; it is directly proportional to machine tool stiffness and damping.

Complex analysis of the SBS is very difficult and complicated, [5]. The analysis requires an advanced understanding of mathematics, mechanics, machine parts, elasto-hydrodynamic theory, rolling housing techniques, and also programming skills. The results of our research into SBS have been divided into three parts:

- new design of headstock
- new design of "Duplo–Headstock“

2.1. New design of headstock

In the new design of a headstock which connects to a CNC system, the maximum width of cut is limited by the point at which self-exciting vibration starts.

From a constructional point of view, the headstock design can be classified as follows:

- classical headstock,
- headstock with an integrated drive unit.

The classical headstock is a mechanical unit, where a spindle is driven by a motor through a gearbox without any control system.

The disadvantages of the classical construction are as follows:

- problems with the gears at higher revolving frequencies,
- actual cutting speeds are not continual because of the discontinuous nature of the gearboxes,
- large dimensions of complete units.

2.2. New design of "Duplo–Headstock“

The "Duplo-headstock“ has been designed in order to achieve technological parameters comparable to the performance of standard electro-spindles, but at a lower production costs and with higher controllability. This particular headstock is assembled from readily available elements (bearings, single drives). The demands on the other peripheral devices are reduced, as are the costs.

Figure 2 [5] shows the spindle (1), with built-in armature (2), is supported by bearings (3), (4). The stator (5) of the internal motor is supported in internal cylindrical body (6) on bearings (7), (8). The clutch (9) connects a hollow shaft with an external electro-motor (10). The stator feeding rings (11) are located in the rear part of the shaft. The clutch (12) enabling switching between working modes is located in the front part of the shaft. The advantage of this design, which is already in use, is that the headstock can work in three different modes:

- stator is engaged on the spindle,
- stator is engaged on the body,
- no engagement.

The "Duplo-headstock" can be described as a spindle with double supports, driven by two separate motors which can operate independently or together. Figures 3, 4, 5, 6 show the design of „Duplo–headstock".

Connecting such a headstock with a suitable control system can provide optimal cutting conditions for various technological operations. The intelligent control system, Figure 7, can operate in any one of the working modes and ensure nominal or optimal technological parameters best suited to the machining process, [4]. Figure 8 shows the design for the construction of the "Duplo" Headstock. [6].

In the third mode (Figure 2), the clutch (12) is switched off. The spindle is driven by both motors, (Figure 5), providing the maximum speed, which is required, for example, in grinding.

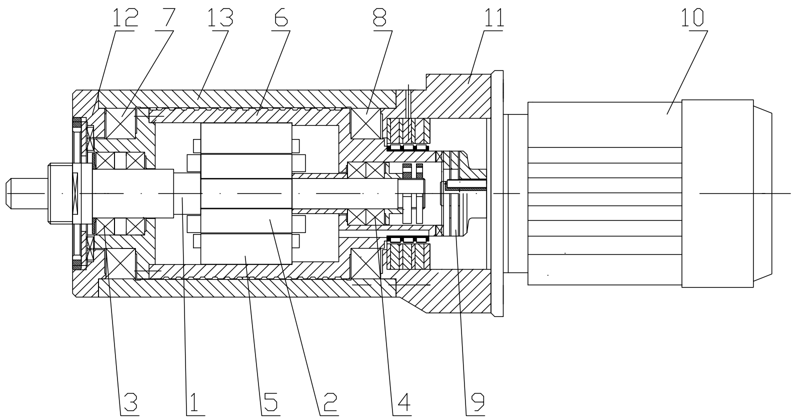

Fig. 2. High-speed headstock "Duplo".

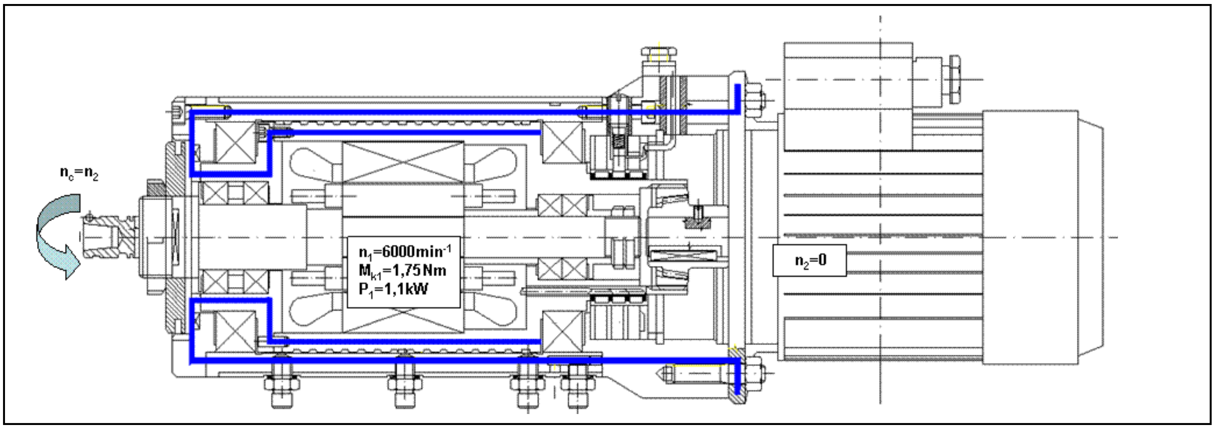

Fig. 3. The stator engaged on spindle, Speed: n1max=6000 (min-1); n2=0, nc_spi=n1
Torque moment: Mkc_sp=Mk1=1,75 (Nm) by n1max, Power: Pc_sp=P1=1,1 (kW).

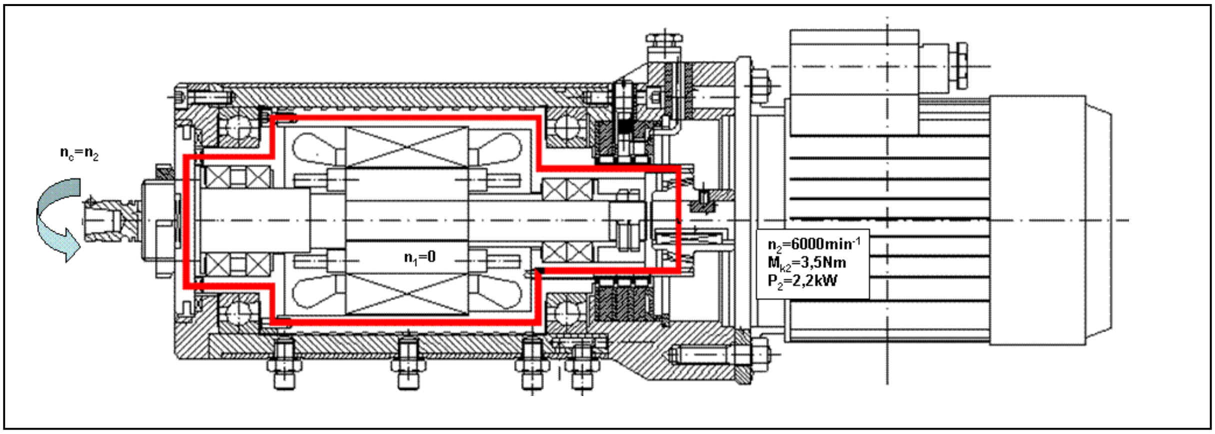

Fig. 4 The stator engaged on body, Speed: n1max=0; n2=6000 (min-1), nc_sp=n2
Torque moment: Mkc_sp=Mk2=3,5 (Nm) by n2max, Power: Pc_sp=P2=3,5 (kW).

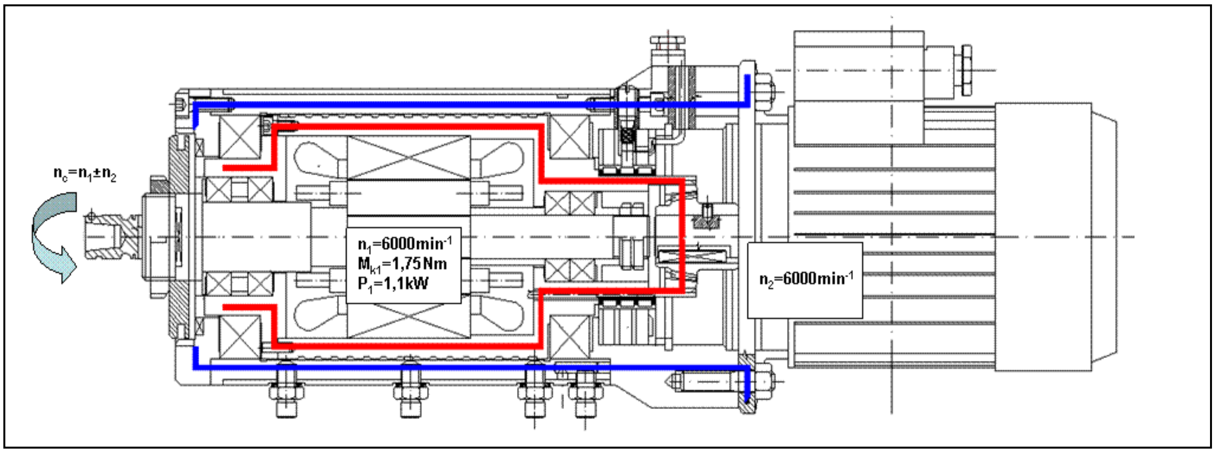

Fig. 5. Disengaged, Speed: n1max=6000 (min-1); n2=6000 (min-1), nc_sp= n1 + n2 by one direction of rotation, nc_sp= n1 - n2 by opposite direction of rotation, Torque moment: Mkc_sp=Mk1=1,75 (Nm) by n1max, Power: Pc_sp=P1=1,1 (kW).

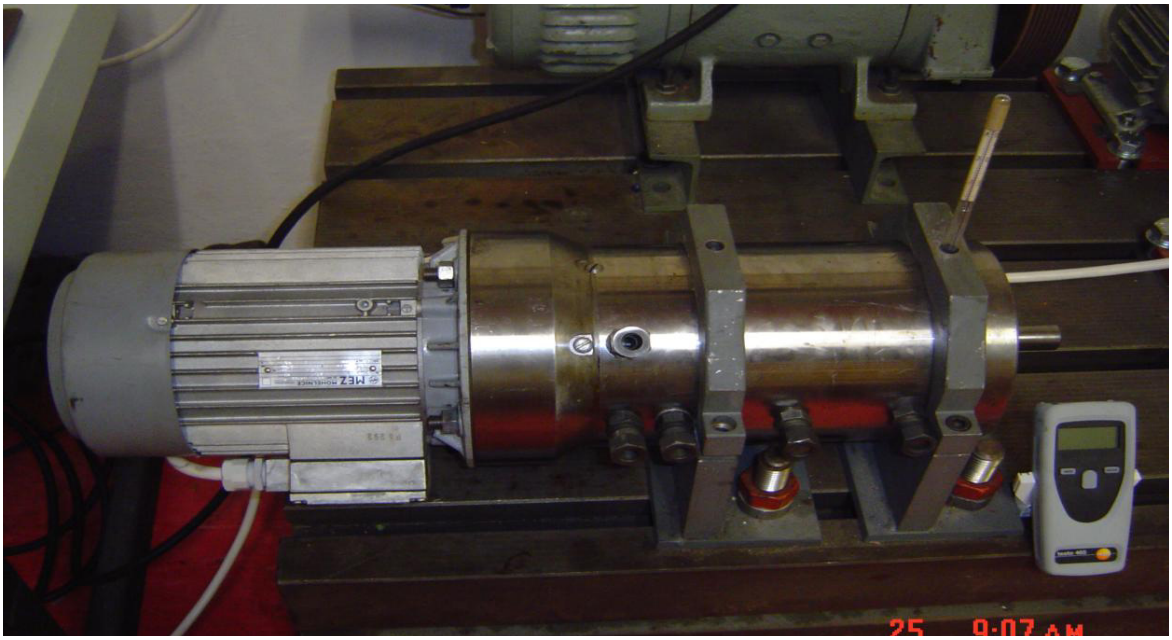

Fig. 6. Stand of "Duplo" Headstock.

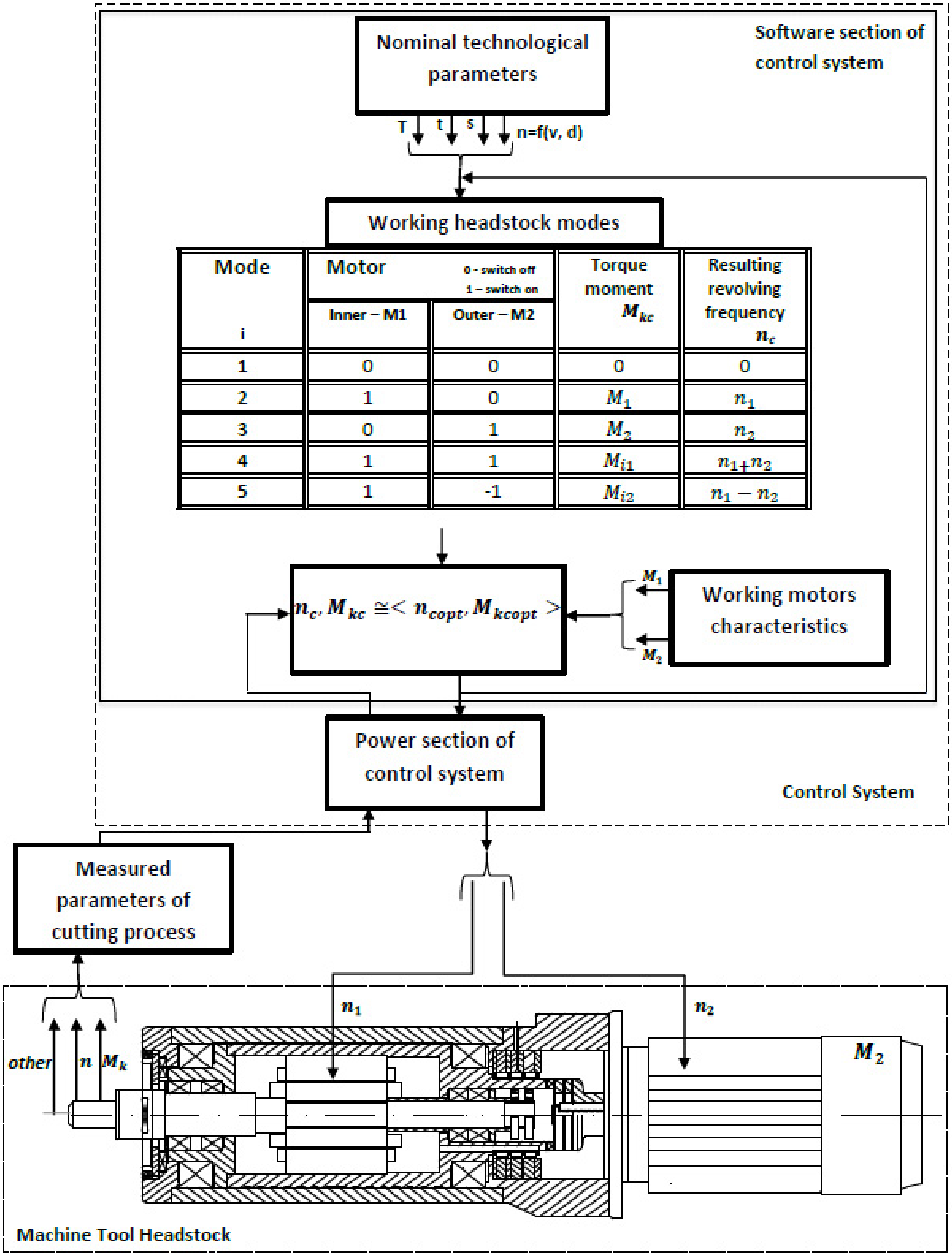

Fig. 7. Scheme of Machine Tool Headstock Control.

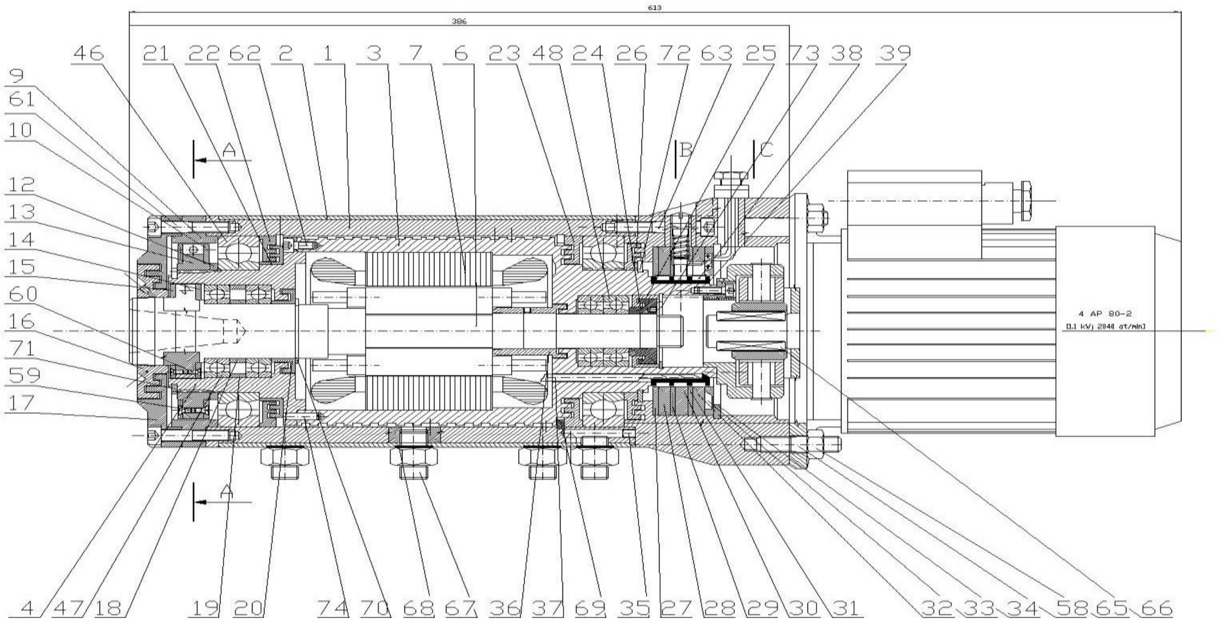

Fig. 8. Design for the construction of "Duplo" Headstock.

3. Conclusion

The paper presents in a very concise form summary of our results in research of new design of the spindle-housing system. Special attention is paid to two designs of headstock namely classical headstock and headstock with an integrated drive unit. Description of these two versions is introduced. The paper also presents the function model based on the patent as well as the real headstock according to the patent [5]. The design of the generator of movements can also be used for other industrial applications in practice [5].

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