

DEVELOPMENT HYBRID HIGH-SPEED ELECTRO PNEUMATIC SPINDLES DRIVE UNIT

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Abstract: The essence of the research is the search for geometric, material and technological limits of the new concept of spinning spindles. Considering the trend of introducing new generation electric drives into the segment of high-speed spinning spindles (over 120,000 rpm), it is necessary to map and describe the basic physical connections, to find the necessary dependencies and correlations of individual design parameters and their limits for the design of a new generation of spindles. Due to the design limitations of the original and years-used spindle drive concept with a belt and the requirement for the production and development of a new generation of spun fibers, it is necessary to expand the basic knowledge for the design of spindles of the new concept, the design of which will be based on the knowledge and dependencies obtained by measuring and examining the basic principles and determining parameters for the design of spindle structures of a new progressive concept.

KEYWORDS: spinning machine, loading, progressive design, high speed rotor, analysis

1 Introduction

The theoretical outputs of the research will be the starting points for the experimental and analytical part of the research with the aim of determining the appropriate design parameters of the experimental spindle. On the basis of simulations, complex analytical methods and experiments, we want to determine the importance of structural and technological parameters essential for the design of a new generation spindle. At the beginning of the research solution, we will focus on updating the research on the given issue from the available literature [1-3] and proceed to the fulfillment of the goals. In our research, we focus on the following areas.

- Measurement and evaluation of the starting characteristic of the spinning spindle, creation of mathematical models.
- Evaluation of the operational requirements of the spinning spindle in terms of running dynamics, simulation models.
- Determination of the dynamic response of the spindle during start-up and simulations for design and optimization purposes.
- Applying the results of the first three stages, determining the basic requirements of the drive unit in terms of power, torque, maximum speed.
- Determination of the basic requirements for the cooling of the new generation spinning spindle drive.
- Research and evaluation of the possibilities of storing the shaft of the new generation spinning spindle.

- Research and evaluation of the possibilities of grouping bearings for spindles of the new generation.
- Research and evaluation of new generation spindle drive alternatives. Investigation of the impact of damping on spindle operation.
- The influence and possibilities of setting the resonance areas of the system, the significance of the influence of individual parameters.
- Completion of the physical model of the selected alternative of the new generation experimental spindle (Fig. 1) [4-6].

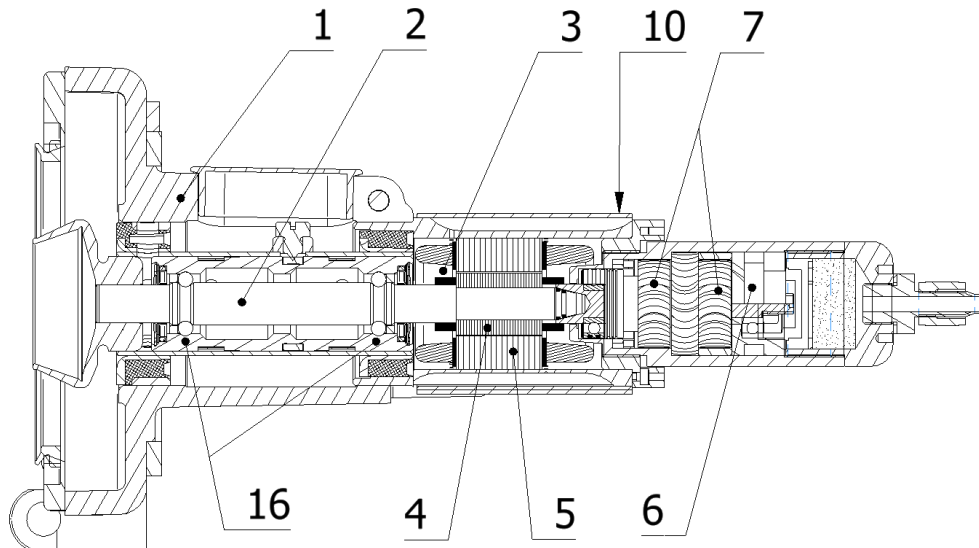


Fig. 1 Section of the construction patented spindle

- Experimental measurement and evaluation of the operating characteristics of the new generation spindle.
- The outputs and objectives of the research can be applied in the development and design of new technical solution.

In the context of achieving research goals, it is necessary to focus research capacity on the development of new procedures and design approaches in the field of designing spindles of spinning units, but also machine tools, workshop tools, medical technology and special technology. The driving force behind this innovative potential are new technologies in the field of materials, production, drives and new requirements for specific production and functionality of systems equipped with high-speed spindles. The industry demands to maximize production performance and quality, which requires adequate development and research in the field of construction.

Currently, various types of spindles are used in industry: electric spindles (Fig. 2) or pneumatic spindles (Fig. 3). A special application of the drive is machine tool coolant drives for SPINJET spindles (Fig. 4).

In the field of spinning machines and the drive of spinning units, the principle of drive by an "endless" belt is used, which is in contact with several spindles, and by friction the speed of the movement of the belt is transferred to the peripheral speed of the shaft. Furthermore, the principle of rolling the shaft between two drive cylinders with parallel axes – Autocoro for company SAURER, (Fig. 5) or an electric drive with different types of bearings is used. These principles are also applied in companies such as Schlafhorst, SAURER, RIETER, SAVIO.

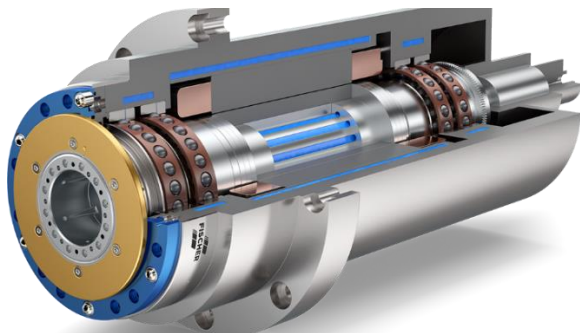


Fig. 2 Electric drive spindles

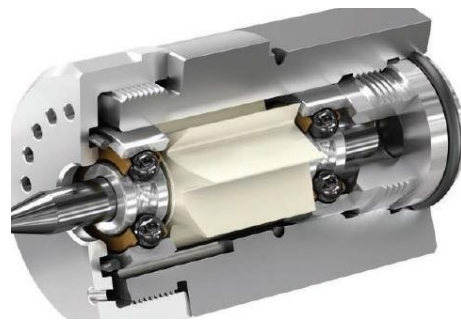


Fig. 3 Pneumatic drive spindles



Fig. 4 SPINJET spindles



Fig. 5 Mechanic drive spindles whit twin Disc.

The current principles of spindle drives in spinning machines in the textile industry are mainly based on the mass drive of several spindles by one electric unit. In the event of a failure of any spindle, it stops and thus reduces the performance of the entire spinning machine. With the mass drive of the spindles, there are differences in the rotation frequencies between the individual spindles caused by slippage or different mechanical properties of the individual spindles, which means that it is not possible to sufficiently synchronize the revolutions of the individual spindles or to control them separately in case of special production requirements. With a mass drive, monitoring the state of individual spindles and possibly correcting their operation is very demanding. Currently, the share of spinning spindles with a frequency of revolutions above 90,000 rpm is increasing. From the point of view of the machine development tendency, it can be assumed that the storage requirement for the rotation frequency of 100,000 to 130,000 rpm and above is completely relevant. Increasing the frequency of rotation of the spinning rotors places higher demands on the entire spinning machine, but especially on the spinning units and above all on the storage of the spinning rotors and their drive [1, 3].

Demands for higher performance of compact spindles with a high degree of diagnostics and regulation in the sense of the Industry 4 philosophy are increasingly appearing on the market. In terms of the described situation, there is an opportunity to solve the requirements of the industry with technical means that are able to ensure complex requirements for modern spindles [2].

This effort envisages development in the field of new progressive design procedures, the need for experimentally obtained design values and the acquisition of functional dependencies necessary for the effective development of new spindles of progressive design [1, 3]. Measuring and evaluating the start-up characteristic of a suitable spinning spindle or spindles will help us find functional dependencies for determining the performance of the drive unit [1, 4]. Based on the evaluation of the operational requirements of the spinning spindle in

terms of running dynamics, it will be possible to simulate the dynamic response of the spindle during start-up and process design diagrams or functional dependencies of the design parameters of new progressive spindles [7 – 9].

Applying the results will be decisive for determining the basic requirements of the drive unit in terms of power, torque, maximum revolutions. The search for a methodology for the development of a spinning system equipped with a new type of spindles follows from the above. One of the key issues will be determining the basic requirements for the cooling of the new generation spinning spindle drive. Methodology for choosing suitable storage options for the new generation spinning spindle shaft. In the context of the research, it will be necessary to deal with the possibilities of grouping bearings in spindles of the new generation, to investigate the alternatives of the spindle drive, or to analyse the effects of damping on the operation of the spindle. An important area of research is the influence and possibilities of setting the resonance areas of the system and the assessment of the significance of the influence of individual parameters [10 – 12]. As part of the completion of the technological infrastructure, we expect the commissioning and completion of the experimental model of the new generation spindle (Fig. 6).

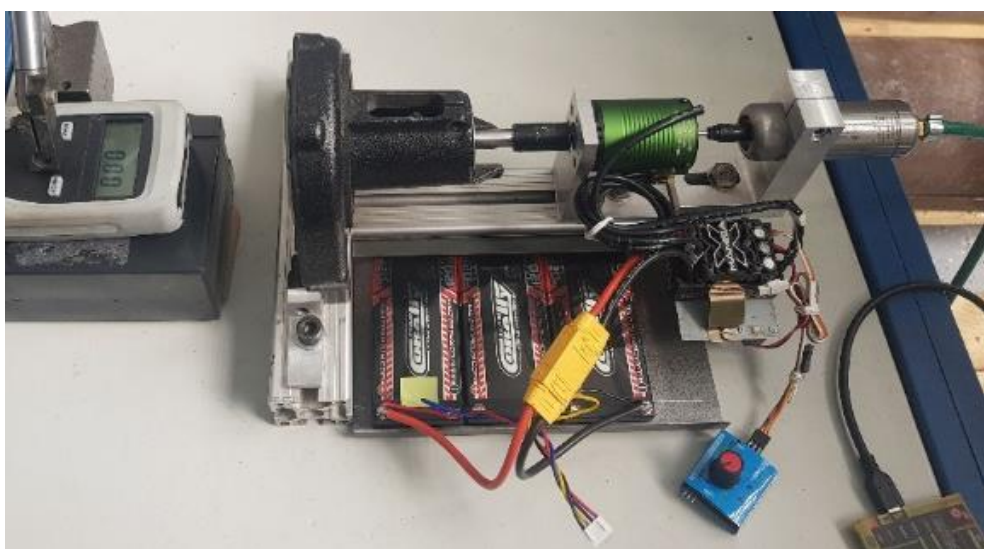


Fig. 6 The new generation hybrid spindle drive model installed on the test bench.

2 Descriptions of applied methods

The proposed hybrid drive of the spinning machine rotor consists of an air turbine and a high-speed electric motor, which are rigidly connected to the rotor shaft. When the rotor accelerates, both elements are immediately put into operation and, therefore, will have the same rotation speed. The air turbine in this drive performs several functions – it reduces the rotor acceleration time by the electric motor, and at the nominal operating mode, it reduces the load on it from the operating rotor and cools its components. Obviously, the acceleration characteristics of the air turbine and the electric motor are nonlinear. For the turbine, this is the dependence of the speed and air pressure at the inlet to the turbine, and the traction performance of the electric motor is affected by the current strength, its frequency and other parameters. In this case, the acceleration characteristics of both drive elements depend on the speed. Therefore, an important task in creating an effective hybrid drive is to determine the input parameters for obtaining the greatest torque from each traction element of the drive over the entire range of rotor shaft rotation frequencies. It is clear that such acceleration characteristic will be described by a very complex mathematical model based on analytical formulas and measurement results. Therefore, in order to obtain approximate results for a pre-

set geometry of the spinning machine, a three-dimensional parametric solid model will be created in this project, on the basis of which a finite element model will be built in the CAE software systems. It will allow specifying and analyzing friction in bearings, aerodynamic friction of fast-rotating parts, moments of inertia and other factors.

However, for the initial assessment of the torque required for acceleration and operation of the rotor of the spinning machine, we will use the methods described in detail in [1].

There are two main power consumers in a rotor spinning machine: mechanical and aerodynamic.

Mechanical power losses are associated with overcoming frictional resistance inside friction or rolling bearings. These frictional resistances are created due to dynamic reactions in the bearings and, consequently, due to static imbalance. They can be minimized by dynamic rotor balancing.

Aerodynamic losses are related to the air resistance around the fast-rotating parts of the rotor and its drive: the power requirements due to either bearing friction or air resistance depend on the value of the rotor eccentricity and the amount of air around the rotor cup. This can be explained as follows:

1. Since the rotor eccentricity after manufacture should not exceed 1 micrometer, the friction resistance in the rotor spindle bearings is neglected. It has been experimentally found that bearing friction requires 0 watts for a rotor speed of 40,000 rpm; bearing friction typically accounts for 8%-10% of the total power [1].

2. Air resistance around the rotor causes additional power consumption, but its value depends on the amount of air around the rotor. As the amount of air around the rotor decreases, the watts required per rotor will decrease. Thus, the total rotor power loss will be the sum of 1 and 2.

Methods of power calculation in this project: the Shirley Institute Method and Zurich Method (SFIT) [1].

The Shirley Institute (1968) proposed two formulae.

The power of the rotor without considering its driving unit. The power is calculated by (1) [1]:

$$P = 3.5 \cdot 10^{-12} \cdot N^{2.5} \cdot D^{3.8} \quad (1)$$

where:

P – power requirements of the rotor,

N – rotor's RPM,

D – rotor's maximum diameter in inches.

In the formula, rotor 1 is considered as an initially thin disk, but in reality, the rotor has thickness and height. Formula 2 allows us to determine the rotor power taking into account the power requirements of the drive device (2), [1]:

$$P = 8.2 \cdot 10^{-12} \cdot N^{2.5} \cdot D^{3.8} \quad (2)$$

Zurich Method (SFIT) formulae [1].

In Zurich, the Swiss Federal Institute of Technology (SFIT) method introduced a number of empirical formulas into the rotor spinning machine, one of which concerns the rotor, as shown in equation 3 (rotor with drive device):

$$P = 36 \cdot \dot{d}_R \cdot \dot{d}_w \cdot \dot{n}_R^2 \quad (3)$$

where:

P – required power to drive the rotor with a driving unit,

$\dot{d}_R$ – rotor diameter in meters and rotor speed in kilos RPM divided by 1000 or the rotor's RPM, that is, without kilos (k)

$\dot{d}_w$ – wharve diameter in meters (Krause and Soliman, 1980).

We can predict the behavior of critical components using calculation-simulation methods and advanced CAx systems, Catia V5-V6, ANSYS, SolidWorks Simulation, SIMULIA from Dassault Systemes complete package of PLM system 3D EXPERIENCE including advanced simulation tools, topological optimization tools, dynamic and static analysis. Using dynamic simulation in the MSC Adams environment, significant factors affecting the reliability of spindle operation at high speeds can be identified. Based on the parametric models of the investigated mechanical systems, we can determine the functional dependencies of some design parameters and create their design diagrams.

The planned experimental measurements will be evaluated using advanced statistical methods and statistical prediction also at the workplace accessible by Minitab statistical software. Identification of critical component frequencies can be key. The kinematic ratios will be displayed and evaluated with respect to the measured vibrations, and with the help of the transformation of the time recording of the vibrations into the amplitude-frequency area, it will be possible to observe the manifestations of the components in the form of the magnitude of the amplitude at the given frequency. In other words, if the component shows a defect, we can expect an increased signal amplitude precisely at the rotation frequency of the given component. The described method serves only to illustrate the basic principle of the measurement method in the area of vibrations, currently the project managers are further along in this area. As far as possible, today we are able to compare the level of vibrations of components in a group, distinguish the source of vibrations, determine the size of kinematic slips, identify the interruption of elasto-hydrodynamic friction, identify critical revolutions, etc. The topic of vibration measurement and analysis is constantly a source of new information, and currently there is more hidden in the measured time record of vibrations.

For the planned experiments, we want to modify and retrofit the technical background and developed physical models for this area of development at the same time. Our workplace has a 12-channel measuring card B&K PULSE 3053-B-120 analyzer with a usable frequency range up to 25,600 Hz for recording measured signals. This analyzer represents an open system that provides wide possibilities and a higher standard of information, reliability in the process of measurement, analysis, evaluation and expertise.

Accelerometers B&K 4534-B-001 and B&K 4533-B-001 with usable frequency ranges 0.2 Hz – 12,800 Hz with a weight of 8.6 g and a sensitivity of 10 mV/g and a B&K 4518 with usable frequency ranges of 1 Hz - 20,000 Hz weighing 1.5 g and sensitivity 10 mV/g. Furthermore, we have available the 4189 A 21 measuring microphone designed for measurements in the free field with a usable frequency range of 20 Hz – 20,000 Hz and a dynamic range (16.5 – 134) dB. The equipment includes the PULSE software package for processing and analyzing measured data.

We have a special measuring set with high-speed cameras for measuring the starting characteristics of spindles and other applications. It is a Phantom Miro M310 camera (max. measurement frequency at full image resolution 1280x800 is 3260 fps). The measurement can be realized at an estimated measurement speed of 3260 fps at a full resolution of 1280x800

pixels per frame and at a measurement speed of 39700 fps at a resolution of 256x256 pixels per frame. Imaging will be synchronized using a digital trigger from the National Instrument company. Both the camera and the synchronization unit are part of the Dantec Q-650 measuring system. Spindle revolutions will be evaluated using a two-color contrast spray on the surface of the spindle [1].

The measurement of the starting characteristic will be evaluated in the MATLAB program environment, by reading the change in the position of the guide (created by the color interface of the contrast spray) on the surface of the spindle. The result of the measurement will be the time dependence of the spindle speed during start-up in operation close to reality.

3 Current state

To achieve the defined goals of the research in the first year of the project, the solvers identified the following task namely measurement and evaluation of the starting characteristic of the spinning spindle.

The pilot tests were on spindles with spinning bowls made of different materials (aluminum, steel) (Fig. 6). Measurements are carried out at different levels of rotation speed (110,000 – 130,000 rpm). During the measurement, it is also possible to record evaluate the temperature of the bearings. As part of the development of a new design, it is subsequently possible to create a simulation model of the spinning spindle. Based on the developed model of the finite element method (FEM), it is possible to determine the dynamic response of the start-up of the proposed rotary system depending on the measured acceleration. Then we can determine the technical and performance requirements for the spindle drive and bearing. An approximate ramp-up curve is integrated into the FEM calculation model, the shape of which is obtained experimentally. Subsequently, it is possible to further optimize the spindle design by using advanced simulation and design techniques in the CAx environment.

The evaluation of the operational requirements of the spinning spindle in terms of running dynamics is carried out on the basis of determination of the dynamic response of the spindle during start-up.

CONCLUSION

Based on the results of the first stages of the application, we can determine the basic requirements for the drive unit in terms of the required power input during the start-up of the spindle, the torque depending on the revolutions over time.

In the second year of the solution, we will focus on the possible guidance of the research methodology in the context of the findings, and then proceed to the next planned steps:

We are planning in the next period, research and evaluation of the possibilities of storing the shaft of the new generation spinning spindle, research and evaluation of the possibilities of grouping bearings for spindles of the new generation. Research and evaluation of new generation spindle drive alternatives. Investigation of the impact of damping on spindle operation. The influence and possibilities of setting the resonance areas of the system, the significance of the influence of individual parameters. Completion of the physical model of the selected alternative of the new generation experimental spindle. Experimental measurement and evaluation of the operating characteristics of the spindle of the new generation, determination of forecasts, conclusions and other goals.

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