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A REVIEW OF SOME FACTORS AFFECTING THE ACCURACY OF MEASURING THE GEOMETRIC CHARACTERISTICS OF MORTISE AND TENON JOINTS

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ABSTRACT

The geometric characteristics of mortise and tenon joints represent their ideal shape as well as the permitted deviations from that shape. Measurement accuracy as part of production metrology is of crucial importance for maintaining tolerances and fits as well as quality control in production. The closeness of the measurement results to the actual true value of the measurand depends on many factors. Some factors that affect the accuracy of a measurement are caused by the measuring equipment, the environment in which the measurement is performed, the operator who performs the measurement, the method and procedure of the measurement and the properties of the material.

This review paper presents an investigation of the factors and their affect on the accuracy of measurement of mortise and tenon joints while maintaining manufacturing tolerances. The purpose of this investigation is to consider the possibility of their minimization to obtain a more accurate measurement.

According to the theoretical analysis, the group of factors that express the heterogeneity and hygroscopicity of wood as a material have a great effect on the accuracy of the measurement.

Key words: measurement, accuracy, mortise and tenon joints, geometric characteristics.

INTRODUCTION

The mechanical properties of the joints are the most important factor in the technical quality of wood products. They depend on the type of wood, the structural shape and the manufacturing process. The strength and durability of the construction depend on many factors making this characteristic complex. Joints in wooden constructions represent critical places where defects often occur, so special attention should be paid to tolerances and the type of fit during construction (Eckelman 2003). The geometric characteristics of the mortise and tenon joints represent their ideal shape as well as the permitted deviations from that shape.

The accuracy of the measurement is part of the production metrology, and it is of crucial importance for the preservation of the tolerances and fits as well as for the quality control in the production (Pfeifer 2015). Dimensional accuracy is a key factor in manufacturing. Measurements are carried out through all technological phases: material reception, processing, assembly, final control and allow to create products that exactly correspond to the design and to guarantee the quality of the product.

The basic principle for accurate measurements is to reduce the influence of any factor that directly or indirectly affects the accuracy of the measurement. This is also the basis of the measurement control process, which is a basic concept in quality control. Measurement control is standardized as a measurement management system with the standard (ISO 10012:2003).

The development in the final wood processing is closely related to the introduction and application of adequate measurement methods. The application of measurements today is a decisive factor for the further development of technology. Mainly the measurements in the final wood processing are reduced to dimensional and angular measurements.

This review paper presents an investigation of the factors and how they affect measurement accuracy mortise and tenon joints while maintaining manufacturing tolerances. The purpose of this observation is also to consider the possibility of their minimization in order to obtain a more accurate measurement.

OVERVIEW OF FACTORS AFFECTING MEASUREMENT

The closeness of the measurement results to the true value depends on many factors. The factors that influence the accuracy of measurement are the measuring equipment, the environment in which the measurement is performed, the operator who performs the measurement, the method and parameters for measurement, and the properties of the material. Measurement errors are the result of random and systematic influences produced by the above five main factors. These factors are causal in nature and can best be represented by a diagram (Ishikawa 1990, American Society for Quality 2024).

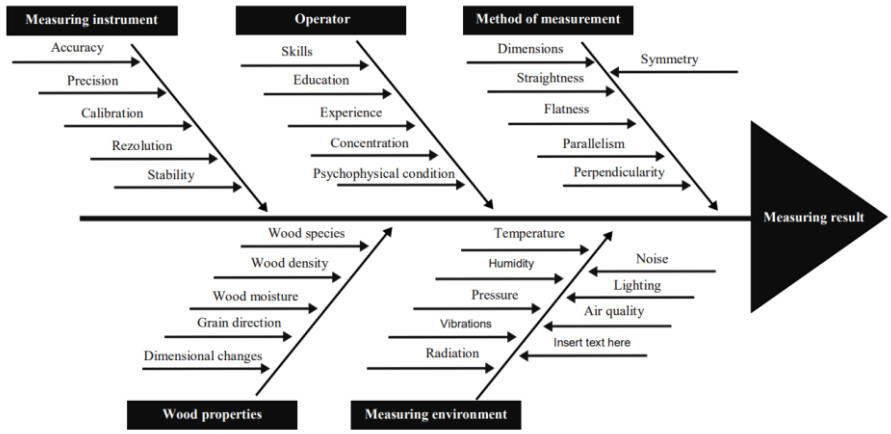

Figure 1: Diagram of factors influencing the measurement of the geometric characteristics of mortise and tenon joints

MEASURING INSTRUMENT

Manual instruments are the most applicable for measuring the geometric characteristics of mortise and tenon joints. This group of instruments includes: calipers, micrometers, dial gauges, lever type dial indicators and dial bore gauges. The advantages of these instruments are multiple: inexpensive, quick to use, long-lasting, portable and provide sufficient accuracy for measuring wood elements. The characteristics of these measuring instruments are covered in the (ISO 14978:2018) standard. When measuring the geometrical characteristics of the mortise and tenon joints, we have a measuring system because several instruments are used in the measurement (VIM – JCGM 200:2012).

The influence of the instrument on the accuracy of the measurement is felt in several ways. Instruments consist of several parts and each of them may fail. Measurement errors can occur when the guides and moving parts of the gauge deviate due to material wear or fatigue. Also, the instruments are subject to temperature expansion. In order to minimize this expansion, the standard (DIN 102:1951-10) prescribes a temperature of 20 °C at which measuring instruments will be used. In the same standard, it is said that when using the instrument at a temperature

different from that specified for it, it causes linear and angular changes. Each instrument has its own metrological characteristics. The static characteristics of the measuring instruments are the most influential on measurement accuracy, of which we will mention: accuracy, precision, calibration, resolution, stability and repeatability during measurement.

The accuracy of the measuring instrument represents the closeness of the measured value to the true value. This parameter is present in the manufacturer's technical specifications, represented by an accuracy class. Accuracy is improved by proper and timely calibration. Most often, accuracy is declared as a percentage of deviation from the nominal value. The accuracy of the aforementioned instruments used for measuring in final production ranges from 0.01mm to 0.1mm. The method of positioning the instrument during measurement has a great influence on the accuracy of the result. As is the case with the caliper, its beaks must be placed perpendicular to the surface on which it is measured in order to have the best possible contact between the instrument and the measuring object. If possible, we should always use Abbe's principle (Abbe 1890), which states that the most accurate measurements are achieved when the quantity being measured is in the same straight line direction as the measuring scale, that is, when it is collinear with the measuring scale of the instrument. Otherwise, an additional measurement error occurs. This rule applies to instruments for measuring length. Therefore, when measuring mortise and tenon joints, it is recommended to use a micrometer rather than a caliper. The resolution is the smallest value that the instrument can measure and is also declared by the manufacturer.

The precision of the instrument is an indicator of the constancy of the value of the measurements, and if the value of the measurements is constant over a longer period of time under the same measurement conditions, then it is a matter of repeatability during measurement. Calibration is important because it ensures that the instrument is capable of measuring to the specifications for which it is intended. Many instruments lose their accuracy over time, so it is necessary to calibrate them regularly. Stability of the instrument is the possibility that it will retain its metrological characteristics over a longer period of time.

THE INFLUENCE OF THE OPERATOR

Errors that contribute to measurement accuracy can also be caused by the person performing the measurement. Namely, the instruments used in the measurement can be analog or digital. With analog instruments, it is possible to make a mistake when reading the measurement results. A reading error with digital occurs when rounding the value. The operator, as a factor, affects the measurement process with his education, experience, skills, current mood, concentration and psychophysical state. The operator has a direct influence on the repeatability of the measurement. A good operator with accurate instruments can make measurements repeatable. However, if the operator's techniques are wrong or he is not that skilled, then repeatable results cannot be obtained. Variations in measurements due to operator error when the measurement system is accurate and precise are called reproducibility. Operator efficiency is as important as instrument accuracy and precision.

METHOD OF MEASURMENT

A measurement procedure is a way of checking the nominal values of the product's characteristics with adequate instruments under the necessary measurement conditions. Measuring only the thickness dimension does not provide an accurate picture of the contact surfaces in the composition. The thickness of the tenon may be within the tolerance interval, but it may be slanted at the side (inaccuracy in location) or its thickness will not be the same

throughout the length of the tenon (inaccuracy in orientation). Due to the complexity of the requirements for functionality and durability of the mortise and tenon joints, we believe that the determination and control of the tolerances and fits of the composition should be within the matrix of (ISO 14638:2015). In this way, all the geometric characteristics of the composition (dimensions, form, direction and position) will be covered.

The measurement procedure must include the following characteristics: dimension tolerances (length, width and thickness); form tolerances (straightness and flatness); orientation tolerances (parallelism and perpendicularity) and location tolerances (symmetry).

WOOD PROPERTIES

The material can participate in the measurement process with its quality, homogeneity, temperature stability, chemical and physical characteristics. In the literature dealing with measurement accuracy, when describing the influence of part material on measurement accuracy, temperature expansion is often cited as the most influential factor. This is not the case with wood because the dimensional changes that occur in wood initially depend on the relative humidity of the air and not so much on the temperature (with the same temperature, different humidity variations are possible).

Wood is an anisotropic, or rather orthotropic, material. It expresses its anisotropy in three directions in which the wood fibers stretch: longitudinal, radial and tangential. Knowledge of their mutual action and the characteristics of a certain direction of wood fibers is necessary when constructing a wood product. Wood fibers are made of cellulose, hemicellulose and lignin. The connection of the cellulose fibers in the cell wall is complex but especially important because the anisotropy of the wood depends on it. It appears in the mechanical and physical properties of the wood and is most evident in the sweling and shrinking of the wood in a different direction of the wood fibers.

Dimensional changes in wood occur as a result of changes in relative humidity in the atmosphere. The moisture in the wood always comes into balance with the moisture from the air. For each percentage of humidity in the air, there is a corresponding amount of moisture in the wood. This point of saturation of wood fibers with water is closely related to the relative humidity of the air, and its change depends on the wood species. The time required to reach equilibrium moisture content in the wood with the relative humidity of the air is about 48 hours, and the most intense change occurs in the first few hours (Thompson 2002). This is especially evident for smaller pieces of wood, as in the case of chair parts. If we have variable conditions in the production plant, the measured dimensions of the compositions immediately after processing and after a delay of several hours would be different. The author (Eckelman 1998) points out this problem in his paper, according to which a change in the relative humidity in the air by a few percent is enough to change the dimensions of the wood, so that it causes a change in the dimensions of the joints and the type of fit. The authors (Sydor *et all*. 2021) also write about a change in the dimensions of the openings when the humidity in the wood increases with a change in the relative humidity of the air. Chair construction where the tenon has a radial direction of the wood fibers has higher strength than construction where the tenon has a tangential direction of the wood fibers (Likos *et all*. 2012, Wu *et all.* 2021). The application of details for chairs with a radial direction is less common, and most often the details are in the tangential direction of the wood fibers. This is an additional problem in measurement accuracy because dimensional changes in wood are greatest in the tangential direction of the wood fibers (Forest Products

Laboratory 2021). It is even more pronounced if it is a wood species with high hygroscopic properties, such as beech (Wagenfuhr 2000), which is also the most commonly used wood species for making chairs.

MEASURMENT EVIRONMENT

The environment has its own characteristics whose parameters affect the measurement, namely: air temperature and humidity, air pressure, vibrations, radiation, noise, magnetic field, air purity, and lighting. The influence of the environment can be on the object of the measurement, on the operator, and on the measuring equipment with which the measurement is performed.

The changing and unfavourable conditions affect the ergonomics of the operator and, thus, the accuracy of the measurement. The influence of the effects of vibration, noise, and wood dust in the air complicates the measurement process. It is necessary that the measurements be carried out outside the production facility in special quality control departments where the conditions will be controlled.

Due to the hygroscopicity of the wood, relative humidity and air temperature have the greatest influence on the mortise and tenon joints as measuring objects. To reduce the influence of environmental conditions on measurement accuracy, the (ISO 1:2022) standard strictly prescribes a temperature of 20 °C for the measurement environment. In the plants for final wood production, this temperature will not be observed most of the time. Especially in the winter period, where the halls are heated only during working hours, in the evening there is a change in air humidity and condensation, and thus a change in the dimensions of the wood. In most European countries, a minimum workplace temperature of 16°C is prescribed, while the maximum is not limited. According to (British Woodworking Federation – BWF) the temperature of the workplace where wood is processed should range from 16°C to 24°C. The author (Babalik 2016) states some general ergonomic workplace conditions, in which he states that for industrial facilities for standing work, the temperature should range from 17°C to 22°C, and the relative humidity of the air from 40% to 70%. Depending on whether the air is heated and how much it flows, different percentages of relative humidity are possible at the same temperature. The relative humidity of the air is more significant for wood due to the appearance of hysteresis. The standard DIN 68101:2012-02 gives percentages of moisture in the wood for each wood species at low, medium and high relative air humidity in the environment. In the same standard, the values of the dimensional changes of the wood in the radial and tangential direction are given when the humidity changes. However, the heterogeneity of the wood should be noted here; that is, the direction of the wood fibers in the mortise and tenon will not always be the same along the entire length of the joint, and thus the dimensional changes will not be the same.

CONCLUSIONS

The factors that influence the accuracy of measurement are the measuring instrument, the environment in which the measurement is performed, the operator who performs the measurement, the method and parameters for measurement, and the properties of the material. Of the mentioned factors, the measuring instruments, the operator, and the measurement procedure are the easiest to control.

The stability of the temperature and the relative humidity in the air of the measuring environment have a great influence on the accuracy of the measurement.

According to the theoretical analysis, the group of factors that express the heterogeneity and hygroscopicity of wood as a material, which are closely related to the relative humidity of the air in the measuring environment, have the greatest effect on the accuracy of the measurement.

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