FEM numerical analysis of the shape bow cross-section for the rigidity of the wheelset measuring device

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Summary
The article shows the results of a computer simulation using the Finite Element Method (FEM) in order to analyze the influence of bows geometry cross-section for the rigidity of the instrument measuring the rolling circle diameter of the wheelset wheels. Two types of bow cross-section were considered, a rectangular shape and a shape of four thin pipes welded together. The considered measuring instruments should fulfil the requirements of the standards ZN-00/PKP-3509-09 and BN-82 3509-13. FEM simulation analysis of the instrument models reveals insufficient instrument rigidity and indicates the need to introduce changes in the construction of the existing measuring instruments for measuring the rolling circle diameter of the wheelsets wheels.

Keywords: rolling circle diameter, measurement, reliability, wheelset, finite element method, FEM

1. Introduction

Maintaining failure-free operation and ensuring railway rolling stock operation safety as much as possible is one of the most important tasks in railway transport. This is ensured by, among others, prearranged periodical checks of the wheelset wheels rolling circle diameters [3]. Users, working in accordance with the statements of the railway rolling stock maintenance files, check rolling circle diameter values in a wheelset and ensure that the permissible difference between two wheels plates of the wheelset is lower than or equal to 0.5 mm [5]. In reality, performing such measurements using manual instruments is very difficult, and sometimes made with large errors emerging from the excessively low rigidity of the instrument bow. The measurements of the rolling circle diameters of the wheels of the wheelsets disassembled from a bogie are performed using, among others, manual instruments measuring wheelset wheels rolling circle diameters. These are constructed in accordance with the branch standard BN-82 3509-13 [4] and the company standard ZN-00/PKP-3509-09 [8]. The main structural dimensions of the device, the characteristics and type of material used, the features of the components, the operation and interaction of the constituent elements are determined by these standards.

Values resulting from the rolling circle diameter measurements, performed with the mentioned instruments on a single wheel plate of a wheelset, may differ more than the permissible 0.5 mm [1]. This can result in difficulties with the correct and credible determination of the difference between rolling circle diameter values of two wheel plates in a single wheelset. The wheelset wheels rolling circle diameter measuring instrument usage manual describes the correct way to perform measurements. Measurements should be performed horizontally. The person performing the measurement should grip the measuring instrument with two hands and keep both ends of the bow. Such a way of measuring can only be applied for measuring wheel plates of the wheelsets which are disassembled from bogies and disassembled components of the braking system. In the case of measuring rolling circle diameter in a way which differs from the one described in the usage manual, values obtained from rolling circle diameter measurements of the same wheel may differ significantly more.

Handling the measuring instrument with one hand, grabbing one end of the device or the end of the bow, making measurements in a non-horizontal but inclined position, can cause differences. The result of the measurement may vary from five to ten times, smaller or larger than the true measurement result.

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2. Research problem and research method

The low rigidity of the bow of the manual instrument, for measuring wheelset wheels rolling circle diameter, which was constructed in accordance with the requirements of the appropriate standards [4, 8], has been noticed in the course of performing measurements. In order to investigate this problem two 3D numerical models were prepared in CAD SolidWorks software. These models represent the geometry of wheelset wheels rolling circle diameter measuring instruments. The models differ by intersection of the bow (Figs. 1 and 2). FEM computer simulation of those models under gravitational load ("under deadweight") were made with different fastenings and in different positions simulating the use of the instrument. The simulations were aimed at determining displacements of the points on elements of the measuring instruments which will reveal the stiffness of the measuring device and its bow.

Reference standards [4, 8] for measuring instruments for measuring wheelset wheels rolling circle diameter, require bow constructions ensuring appropriate rigidity of the instrument. These standards require such instrument rigidity and construction of the bow as is necessary for measuring the results difference (change) between the indication of the diverted instrument (measuring assembly up) and indication when vertically mounted by a bow, with a size gauge between the measuring ends and an extension arm additionally loaded with a force of 49 N, not higher than 0.05 mm [4, 8]. The article shows results of the FEM simulation of the instruments in a vertical position and in a horizontal lateral position.

3. Test results

Simulations were performed by the Finite Element Method FEM in SolidWorks software. The mesh four-node TETRA elements and variable of the mesh size were received as the initial conditions of the description of the mesh. Solid mesh based on curvature, Jacobian points 4, quality of "high" mesh were selected in the software as the mesh parameters. The assumed initial conditions were the mounting way ensuring a "fixed geometry", which means that all 6 degrees of freedom were taken away. In each case, the model of the device was externally loaded with force from its own weight, "gravitation 9.81 m/s^2", each time setting an appropriate direction of force. The chosen measuring instrument material was cold rolled steel 1.0038 (PN: ST3S; EN: S235JR).

3D models of the wheelset wheels rolling circle diameter measuring instrument with two types of bow intersection were taken for FEM simulation: with an intersection of the four thin-walled pipes welded together with a wall thickness of 2.0 mm (variant A of the cross-section) (Fig. 1) and a thin-walled profile having a rectangular intersection with a wall thickness of 2.5 mm (variant B of the cross-section) (Fig. 2).

The computer simulation was performed in the SolidWorks software in a dedicated MES simulation calculation module. Two 3D models of the device were analyzed, which differed in the type of bow cross-section (welded thin-walled pipes or rectangular profile) and were rigidly fixed vertically and horizontally (Figs. 3–18). The computer simulation was performed in two places where the device was fixed, in which 6 degrees of freedom (fixed geometry) were taken – fastening at the end of the measuring device's bow from the side opposite to the measuring unit, and mounting at the end of the measuring device from the side opposite to the measuring unit. The boundary conditions were assumed in the case of 6 degrees of freedom: translation on the axes x, y and z, Tx = 0, Ty = 0, Tz = 0; rotation relative to the x, y, z, Rx = 0, Ry = 0, Rz = 0 axes.

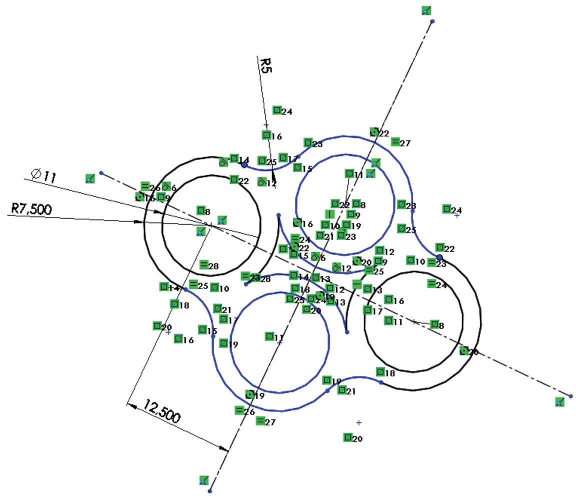

Fig. 1. Intersection of a bow of the wheelset wheels rolling circle diameter measuring instrument constructed by four thin-walled pipes welded together (variant A of the cross-section) [the author's own elaboration]

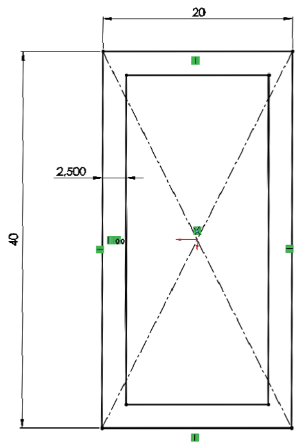

Fig. 2. Intersection of a bow of the wheelset wheels rolling circle diameter measuring instrument constructed by a rectangular thin-walled profile (variant B of the cross-section) [the author's own elaboration]

The paper presents the results of displacement distributions computer simulation (static displacements) of the individual points on elements of measuring instruments models for measuring the wheelsets wheels rolling circle diameter, loaded with gravity forces “under their own weight (Figures 3–18). A compilation of the maximum displacements of the points on elements of the measuring instruments under gravitational load is shown in Table 1 and Table 2.

Table 1

Compilation of the FEM simulation results as maximum displacements of the points on elements of the measuring instruments under gravitational load, with mounting at the end of the measuring instrument bow on the side opposite to the measuring assembly

Way of mounting	Type of bow cross-section	
	Variant A [mm]	Variant B [mm]
vertically, measuring assembly down	0.11	0.08
vertically, measuring assembly up	0.11	0.08
horizontally, bow bulge up	1.63	1.21
horizontally, bow bulge down	1.63	1.21

[the author’s own elaboration]

Table 2

Compilation of the FEM simulation results as maximum displacements of the points on elements of the measuring instruments under gravitational load, with mounting at the end of the measuring instrument on the side opposite to the measuring assembly

Way of mounting	Type of bow cross-section	
	Variant A [mm]	Variant B [mm]
vertically, measuring assembly down	2.64	2.16
vertically, measuring assembly up	2.64	2.16
horizontally, bow bulge up	13.04	11.67
horizontally, bow bulge down	13.04	11.67

[the author’s own elaboration]

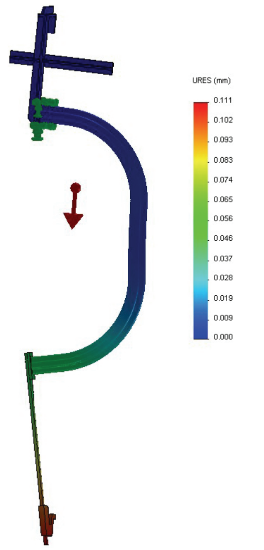

Fig. 3. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument’s bow on the side opposite to the measuring assembly, vertically with measuring assembly down, variant A of the bow cross-section [the author’s own elaboration]

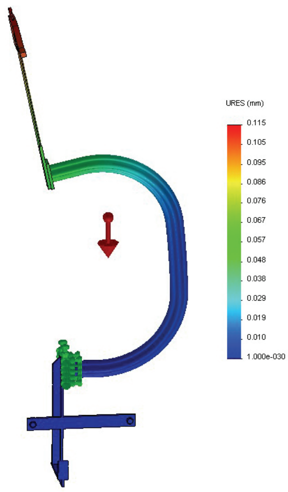

Fig. 4. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument’s bow on the side opposite to the measuring assembly, vertically with measuring assembly up, variant A of the bow cross-section [the author’s own elaboration]

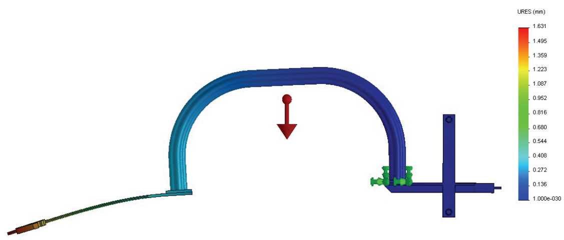

Fig. 5. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument’s bow on the side opposite to the measuring assembly, horizontally with bow bulge up, variant A of the bow cross-section [the author’s own elaboration]

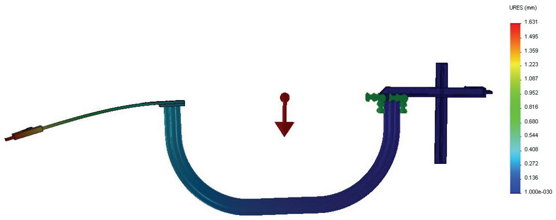

Fig. 6. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument's bow on the side opposite to the measuring assembly, horizontally with bow bulge down, variant A of the bow cross-section [the author's own elaboration]

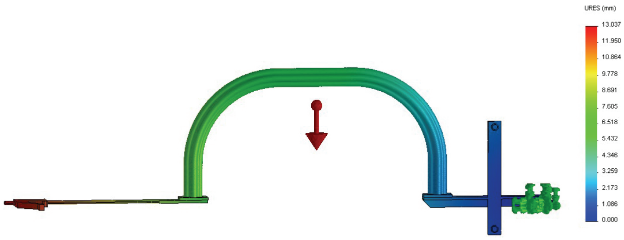

Fig. 9. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, horizontally with bow bulge up, variant A of the bow cross-section [the author's own elaboration]

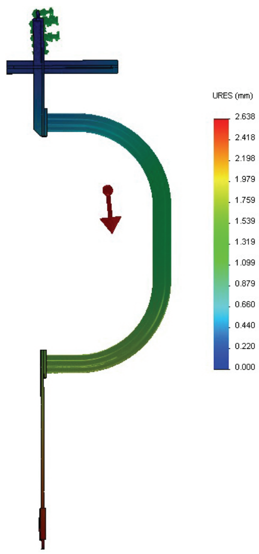

Fig. 7. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, vertically with measuring assembly down, variant A of the bow cross-section [the author's own elaboration]

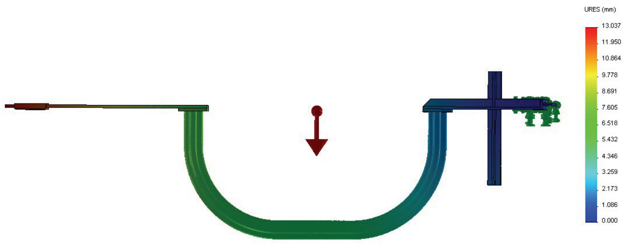

Fig. 10. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, horizontally with bow bulge down, variant A of the bow cross-section [the author's own elaboration]

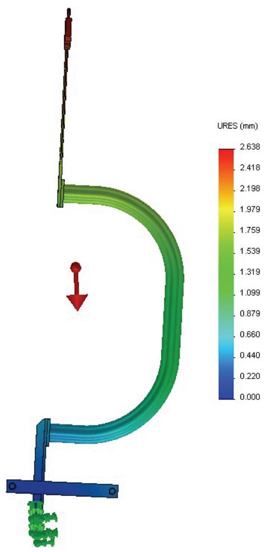

Fig. 8. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, vertically with measuring assembly up, variant A of the bow cross-section [the author's own elaboration]

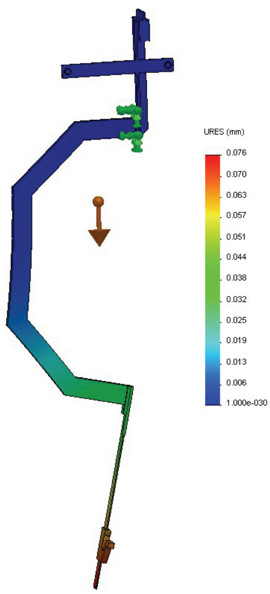

Fig. 11. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument's bow on the side opposite to the measuring assembly, vertically with measuring assembly down, variant B of the bow cross-section [the author's own elaboration]

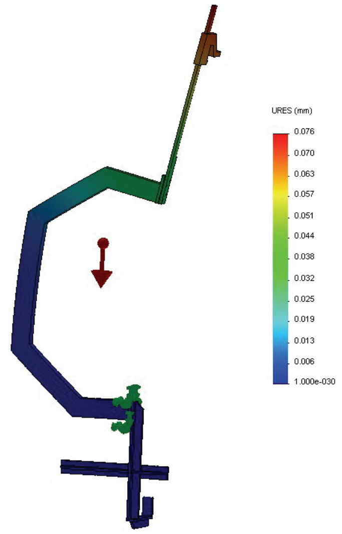

Fig. 12. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument's bow on the side opposite to the measuring assembly, vertically with measuring assembly up, variant B of the bow cross-section [the author's own elaboration]

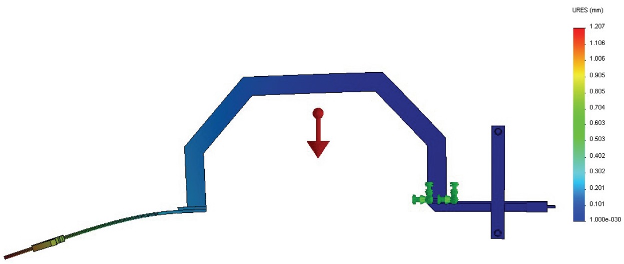

Fig. 13. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument's bow on the side opposite to the measuring assembly, horizontally with bow bulge up, variant B of the bow cross-section [the author's own elaboration]

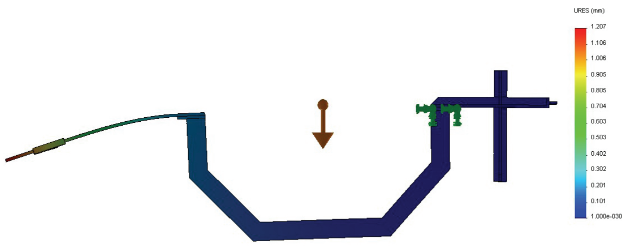

Fig. 14. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument's bow on the side opposite to the measuring assembly, horizontally with bow bulge down, variant B of the bow cross-section [the author's own elaboration]

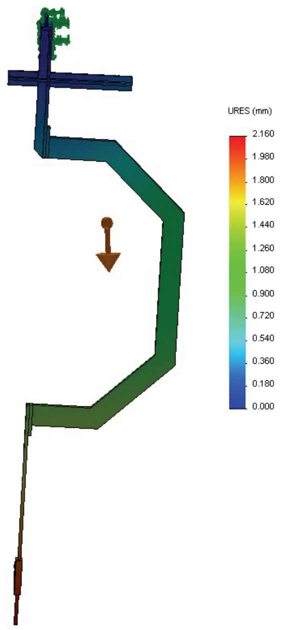

Fig. 15. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, vertically with measuring assembly down, variant B of the bow cross-section [the author's own elaboration]

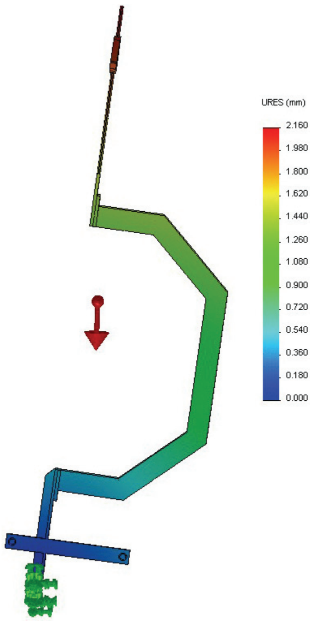

Fig. 16. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, vertically with measuring assembly up, variant B of the bow cross-section [the author's own elaboration]

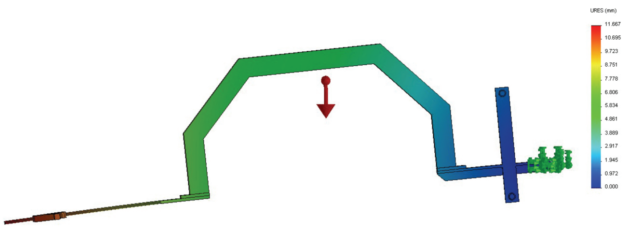

Fig. 17. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, horizontally with bow bulge up, variant B of the bow cross-section [the author's own elaboration]

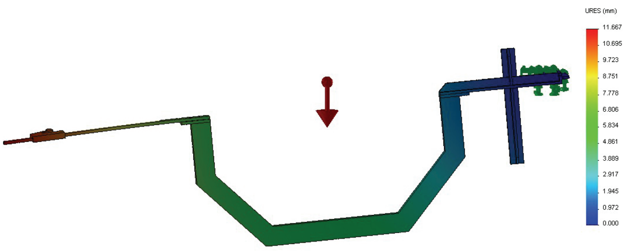

Fig. 18. Results obtained from the simulation of the displacements of the individual points on elements of the measuring instrument mounted at the end of the measuring instrument on the side opposite to the measuring assembly, horizontally with bow bulge down, variant B of the bow cross-section [the author's own elaboration]

The measuring instrument is calibrated in accordance with the standard [4, 8] and accredited by the Polish Center for Accreditation and used in the Laboratory of the Railway Institute Metrology measurement procedure[7]. The measuring instrument is calibrated lying down flat position on its side with the measuring surfaces facing upwards with use of appropriate size masters for fine adjustments measuring instruments is calibrated in accordance with the requirements of PN-EN ISO / IEC 17025: 2005 [6]. The zero location of the instrument sensor is also adjusted with the use of a size master in the same position.

A change caused only by lifting of the fully calibrated measuring instrument, previously lying down flat, and hanging it vertically up or vertically down by a bow of the measuring instrument causes displacement of the end of the measuring strip by 0.1 mm. As the simulation results show, if the measuring instrument is mounted at the end of the measuring device, the displacement of the measuring strip end is 2.6 mm. When the instrument is mounted horizontally by the end of a bow or by the end of the instrument (rare in practice), displacement of the end of the measuring strip is 1.6 mm or respectively 13.0 mm. Such displacement values are relatively large, exceeding the permissible measurement values to which the device is used. For example, when the instrument is used for determining the difference between rolling circle diameters of the wheelset wheel plates, for which the permissible maximum value is 0.5 mm.

The displacement of the non-fixed end of the brace of the vertically suspended measuring device determined on the basis of Figures 3-6 and Figures 11–14 is respectively 0.04 mm (cross-section from four thin-walled tubes, Variant A of the cross-section) and 0.06 mm (cross-section from a rectangular thin-walled profile, Variant B of the cross-section). If the instrument is mounted horizontally, the bending deflection of the bail is 0.3 mm (A-section variant) and 0.2 mm (B-section variant) respectively.

The displacement of the unmounted end of a bow of the hanging measuring instrument determined on the basis of Figures 3–6 and Figures 11–14 is respectively 0.04 mm (intersection of four thin-walled pipes, Variant A of the cross-section) and 0.06 mm (intersection of a rectangular thin-walled profile, Variant B of the cross-section). When the instrument is mounted horizontally by the end of a bow, deflection of the bow is 0.3 mm (Variant A of the cross-section) and 0.2 mm (Variant B of the cross-section). A compilation of the maximum displacements of an un-mounted end of the measuring instrument bow under gravitational load is shown in Table 3.

Table 3

Compilation of the FEM simulation results as maximum displacements of the end of the measuring instruments bow under gravitational load, with mounting at the end of the measuring instrument bow on the side opposite to the measuring assembly

Way of mounting	Type of bow cross-section	
	Variant A [mm]	Variant A [mm]
vertically, measuring assembly down	0.06	0.04
vertically, measuring assembly up	0.06	0.04
horizontally, bow bulge up	0.30	0.20
horizontally, bow bulge down	0.30	0.20

[the author's own elaboration]

4. Summary and conclusions

During the measurements with the instrument measuring the rolling circle diameter of the wheelset wheels ambiguous results of the rolling circle diameter measurements were obtained [1]. Displacements of the measuring surfaces of the instrument in FEM simulations have relatively large values. They are important especially when the instrument is used for determining the difference between rolling circle diameters of the wheelset wheel plates, for which the permissible maximum value is 0.5 mm. They will be revealed in particular when the measurements are carried out in a different way by different persons performing the measurement.

The obtained results confirm the low, insufficient rigidity of the bow of the instrument and point to the necessity to perform further detailed research on constructions of the existing wheelset wheels rolling circle diameter measuring instruments in order to increase the stiffness of existing measuring instruments for measuring the rolling circle diameter *for wheelsets.*

Rolling circle diameter measurement methods should be validated by performing diameter measurements with different measuring instruments. As a result of inspecting the way measurements are performed, and the way instruments are gripped when the measurements are performed, a suitable way should be determined and introduced in end-user practice. Performing further simulations is necessary e.g. to select new construction materials for constructing instruments, especially for the bow, and to select other intersections and shapes for the bows of the measuring instruments.

Literature

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