ACCURACY OF DRAWN SEAMLESS STEEL TUBES MANUFACTURED UNDER REAL MASS-PRODUCTION CONDITIONS

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This paper focuses on assessing the dimensional and geometric accuracy of cold-drawn seamless precision steel tubes manufactured under real mass-production conditions. The primary objective of the research was to determine the variability of key dimensional parameters (outer diameter (OD), inner diameter (ID) and wall thickness (WT)) and geometric parameters (concentricity and roundness) along the full length of the tubes, with a particular focus on evaluating standard deviations. A key novelty of this study lies in the inclusion of concentricity and roundness measurements—parameters that, although critical for certain applications, are not typically included in standard product documentation unless specifically requested by the customer. While standard specifications generally report only basic dimensional parameters, this research extends the scope to include additional geometric characteristics, thereby filling a gap in publicly accessible production data. The results provide valuable and previously unavailable insights for those involved in or interested in precision tube applications.

KEYWORDS

cold-drawn seamless precision steel tubes, accuracy, outer diameter, inner diameter, wall thickness, concentricity, roundness

1 INTRODUCTION

Precision cold drawing of seamless steel tubes under mass-production conditions plays a pivotal role in industries such as automotive, aerospace and energy. These applications demand high dimensional and geometric accuracy—especially in dimensional parameters (such as OD, ID and WT) and geometric parameters (such as concentricity and roundness). As process requirements grow increasingly stricter across modern manufacturing environments, the significance of understanding and controlling every stage of tube deformation increases proportionally.

A key concept underlying cold drawing is technological heredity, which refers to the transmission of deviations and errors from one manufacturing stage to the next. Görög and Görögová [Gorog 2020] demonstrated this principle through a detailed harmonic analysis of roundness profiles in cold-drawn tubes. Their findings highlighted the importance of early-stage control to prevent the accumulation of defects. In a subsequent study, Görög et al. [Gorog 2023] explored how both contact and non-contact measurement systems—particularly those based on coordinate measuring machines, optical 3D scanning (structured light measuring) and computed tomography (CT)—can enhance monitoring deviations across production stages.

In connection with measurement technologies, Havran [Havran 2021] used advanced optical 3D scanning system (structured light measuring) to monitor changes in geometry before and after cold drawing, demonstrating the value of high-resolution 3D surface acquisition. Morovič et al. [Morovic 2022] supported this approach through factorial experiments on the cold drawing process, revealing how pre-tube dimensions (diameter, WT) and drawing die selection significantly affect output roundness, OD and WT. The results indicated that a single-pass drawing process may be insufficient for maintaining geometric precision without meticulous control of tooling, lubrication and process history.

Mojžiš [Mojzis 2018] contributed an in-depth experimental study on cold drawing conducted under industrial conditions, providing a comprehensive analysis of strain states, microstructural evolution and mechanical properties such as strength and microhardness. Moreover, his work incorporated modelling and simulation using DEFORM-3D (Scientific Forming Technologies Corporation, Columbus, Ohio, USA) software, along with innovative measurements of surface temperature and drawing forces, thus offering valuable insights into the interaction between process parameters and material behavior during cold drawing.

The integration of accurate, robust measurement systems into industrial practice is a recurring theme. Ridzoň et al. [Ridzon 2015] employed experimental and simulation techniques to model the drawing of E235 seamless precision steel tubes without intermediate annealing, demonstrating that consistent accuracy is achievable under real mass-production constraints. This builds upon theoretical formulations from Ridzoň [Ridzon 2012], who presented foundational models of plastic deformation and strain during multi-pass drawing, considering effects such as residual stress, strain localization and dimensional change.

Parallel to experimental analysis, simulation has emerged as a powerful tool for understanding cold drawing mechanics. Palengat et al. [Palengat 2013] used finite element modelling to explore the cold forming of 316L stainless steel thin-walled tubes, emphasizing the value of accurate constitutive models in predicting deformation behavior. In a more recent study, Żaba and Trzepieciński [Zaba 2023] evaluated AISI 321 stainless steel thin-walled seamless tubes processed by floating plug drawing. Their work demonstrated improved surface quality and increased microhardness.

Ding et al. [Ding 2025] investigated cold pilgering as an alternative forming technique for thick-walled tubes. By optimizing feed rate and reduction ratio, they achieved dimensional deviations under 0.05 mm and surface roughness Ra below 0.2 µm. Similarly, Abe et al. [Abe 2016] explored pilgering's influence on ovality and residual stresses, revealing the self-centering nature of the deformation and its potential benefits for high-precision tube production. In their review, Gulyayev et al. [Gulyayev 2020] traced the historical evolution of pilger rolling and other seamless tube forming methods, highlighting key technological improvements aimed at increasing efficiency and product quality throughout the 20th and early 21st centuries.

Rolling-based processes have also been studied extensively over the past decades. Orlov [Orlov 2024] presented hybrid process schemes combining rolling and drawing operations, effectively reducing surface marks and mitigating uneven WT. In practical industrial applications, Kán et al. [Kan 2019] focused on the dimensional stability of 25CrMo4 steel tubes under temperature-variable drawing conditions, clearly highlighting the critical importance of thermal control during extended mass-production runs.

The role of simulation and experiment also converges in the work of Sobota et al. [Sobota 2022], who used software DEFORM-3D to simulate cold drawing of steel tubes and validated it with physical testing. Their results confirmed the method's effectiveness in predicting WT variation and reducing dimensional deviations.

Bílik et al. [Bilik 2021] compared one-pass and two-pass drawing strategies in terms of their effects on WT variation. Their results showed that single-pass approaches, when carefully controlled, can meet the ±7% WT tolerance, reducing manufacturing time and rupture risk. Kapustová et al. [Kapustova 2021] extended this by analyzing plastic strain distributions during cold drawing and their effects on WT uniformity, while Kapustová et al. [Kapustova 2022] compared different steel grades (E235, E355), revealing material-specific responses to deformation that influence final dimensional consistency.

Process design is further complicated by geometric deviations like eccentricity. Ďurčík et al. [Durcik 2021] modeled the piercing stage of tube formation and showed how initial eccentricity can propagate through subsequent deformation stages if not properly managed. This emphasizes the need for precision in upstream stages to ensure geometric conformity downstream.

Industrial digitization is another key dimension in modern production. To capture full-field geometric imperfections, Xu et al. [Xu 2023] employed laser scanning on 71 circular steel tubes of four commonly used types (hot-rolled carbon steel, cold-rolled carbon steel, cold-drawn stainless steel and cold-rolled stainless steel) to determine their actual geometry. The study concluded that, although cross-sectional ellipticity and thickness unevenness were prevalent—particularly in cold-drawn tubes—these imperfections had a negligible influence on compression and bending capacity, and may therefore generally be disregarded in finite element modelling. Kritikos et al. [Kritikos 2019] demonstrated that, when properly calibrated, industrial CT scanning offers an effective alternative to contact-based measurements techniques for assessing the ODs, IDs, WT and concentricity of seamless steel tubes, although accurate calibration for metal density remains critical.

Bílik et al. [Bilik 2023] presented a comprehensive overview of technological processes involved in seamless tube production, with a focus on hot rolling and cold drawing methods and provided essential theoretical and technological background relevant to process optimization. The same practical orientation was taken by Ridzoň et al. [Ridzon 2015], whose real-world experimentation in the tube factory without intermediate annealing demonstrated the feasibility of precise multi-pass processes.

The broader importance of seamless precision steel tube production in European manufacturing was underlined by Görög and Görögová [Gorog 2020], Görög et al. [Gorog 2023], and Morovič et al. [Morovic 2022], who collectively emphasized that both scientific understanding and practical innovations are required to improve quality, lower costs, and optimize lead times. Innovations in tooling, simulation, measurement, and data management offer substantial benefits in an industry increasingly driven by automation and accuracy.

To the best of the authors' knowledge, no prior work has directly addressed the specific research problem examined in this paper. The integration of theoretical knowledge [Gorog 2020, Gorog 2023, Havran 2021, Ridzon 2021, Bilik 2023], experimental methodology [Morovic 2022, Ridzon 2015, Mojzis 2018, Bilik 2021, Kapustova 2021, Zaba 2023], simulation-driven design [Ding 2024, Orlov 2024, Pelengat 2013, Abe 2016, Sobota 2022], and modern metrology [Gorog 2023, Havran 2021, Xu 2023, Kritikos 2019] underpins certain aspects of this investigation. The findings aim to inform engineers, researchers, and practitioners about the practical challenges and technological solutions in ensuring dimensional consistency during the cold drawing of long seamless precision steel tubes.

This study builds upon the above findings by examining cold-drawn seamless precision steel tubes (6000 mm in length) produced under real mass-production conditions. Using detailed measurements—including OD, ID, WT, roundness and concentricity—at multiple positions along the tube, this research aims to:

- Assess the degree of geometric variation present in full-length industrial tubes.
- Validate whether current tooling and process setups are sufficient to maintain specification compliance across the entire tube.

2 PRODUCTION AND PREPARATION OF MEASURED SPECIMENS

The seamless precision steel tubes analyzed in this paper were produced by two pass cold drawing (i.e., plug drawing and sinking) (Tab. 1, Fig. 1 and Fig. 2). The specific production conditions are shown in Tab. 1, followed by a brief explanatory description of the individual steps outlined in the table.

Tube (mm) (∅OD x WT)	∅14 x 2	∅16 x 2	∅18 x 2
Billet input	∅22.00 x 2.53	∅24.00 x 2.00	∅31.80 x 2.90
Division (cutting)	Yes	Yes	No
Recrystallization annealing	Yes	Yes	No
Blow-through	No	No	Yes
Swaging	∅15 x 160	∅19 x 160	∅22 x 170
Chemical treatment	Yes	Yes	Yes
Plug drawing (Fig. 1)	up to ∅17.00 x 1.95	up to ∅20.00 x 1.95	up to ∅25.00 x 2.25
Division (cutting)	Yes	Yes	Yes
Recrystallization annealing	Yes	Yes	Yes
Swaging	∅13 x 160	∅15 x 160	∅17 x 150
Chemical treatment	No	No	Yes
Drying	No	No	Yes
Sinking (Fig. 2)	∅14 x 2	∅16 x 2	∅18 x 2
Division (cutting)	Yes	Yes	Yes

Table 1. Production parameters of the measured seamless precision steel tubes

The production of cold-drawn seamless precision steel tubes involves a sequence of carefully controlled operations designed to achieve strict dimensional and geometric tolerances. The following description briefly outlines the process applied to tubes with final dimensions such as Ø14×2 mm, Ø16×2 mm, and Ø18×2 mm, starting from larger-diameter billets.

The process begins with the selection and input of billets, which in the case of Ø14×2 mm final tubes, typically have an initial diameter of Ø22.00 mm and WT of 2.53 mm. These billets are then cut into shorter sections of appropriate length to facilitate further processing, such as swaging and drawing.

Next, the billet undergoes recrystallization annealing. This thermal treatment is essential for relieving internal stresses and softening the material, thereby improving its plasticity and formability for subsequent deformation steps.

After annealing, a blow-through operation is performed, during which air is used to remove residual scale and chips from inside the tube.

A key mechanical preparation step is swaging, which involves reducing the diameter of one end of the tube, which in the case of Ø14×2 mm final tubes —typically to Ø15 mm over a length of 160 mm. This tapered section is essential for gripping the tube during drawing and transferring tensile forces effectively. The geometry of the swaged end must be carefully controlled to avoid breakage or tool damage during drawing [Mojzis 2018].

Surface preparation through chemical treatment follows. Pickling—commonly performed using sulfuric or hydrochloric acid—removes surface oxides and contaminants from both the inner and outer surfaces of the tube. This is typically complemented by phosphating, which improves lubrication during drawing and provides some corrosion resistance.

Drying may follow chemical treatment, depending on the line configuration and requirements [Mojzis 2018].

The first drawing operation, plug drawing (Fig. 1), reduces the tube dimensions significantly—for example, down to Ø17.00 mm with a WT of 1.95 mm for a final Ø14×2 mm tube.

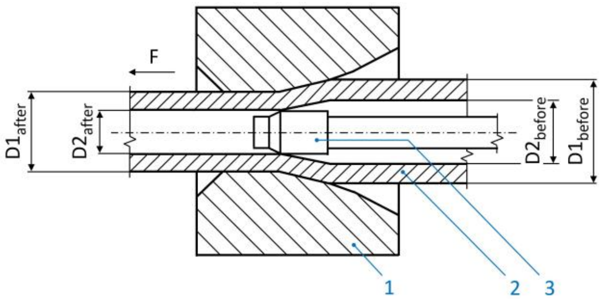


Figure 1. Schematic representation of plug drawing (i.e., cold drawing of a seamless steel tube with a plug): $D1_{before}$ – outer diameter before drawing, $D2_{before}$ – inner diameter before drawing, $D1_{after}$ – outer diameter after drawing, $D2_{after}$ – inner diameter after drawing, F – drawing force, 1 – drawing die, 2 – drawn tube, 3 – shaped (profiled, trapezoidal) plug

After drawing, the tube is again cut into lengths suitable for further processing. A second cycle of recrystallization annealing and swaging is then carried out. In the second swaging stage, the tube end is further reduced—e.g., which in the case of Ø14×2 mm final tubes, to Ø13 mm with a length of 160 mm—ensuring compatibility with the final drawing stage. The chemical treatment step (including pickling and possible phosphating) is repeated to prepare the surface for the final drawing pass.

In the final drawing stage, the tube is drawn through a drawing die without the use of an internal plug (Fig. 2), achieving the target OD of Ø14 mm and WT of 2 mm. Final drawing defines surface finish and dimensional precision of the tube.

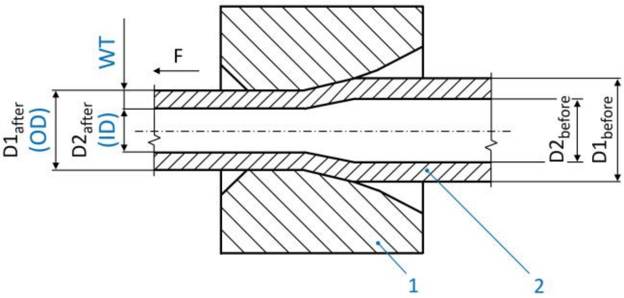


Figure 2. Schematic representation of sinking (i.e., cold drawing of a seamless steel tube without a plug): $D1_{before}$ – outer diameter before drawing, $D2_{before}$ – inner diameter before drawing, $D1_{after}$ – outer diameter after drawing, $D2_{after}$ – inner diameter after drawing, WT – wall thickness, F – drawing force, 1 – drawing die, 2 – drawn tube

Lastly, the finished tube is cut to the required delivery lengths, which are typically 6000 mm. The same general process is applied to other tube dimensions such as Ø16×2 mm and Ø18×2 mm, with proportional adaptations to billet sizes, swaging diameters, and intermediate drawing dimensions. The OD, ID and WT indicated in Fig. 2 specifically refer to the values measured in this research.

Since the final dimensions of the tubes are defined by the second pass—performed by the sinking process—all measured parameters presented in this study correspond to the tube geometry after the completion of the full two-pass drawing sequence.

As already indicated by Tab. 1, seamless precision steel tubes with OD of ∅14, ∅16 and ∅18 mm were used for the experimental work. All tubes had a WT of 2 mm and a length of 6000 mm. The parameters specified by the tube manufacturer are presented in Tab. 2.

Tube (∅OD x WT)	∅14 x 2	∅16 x 2	∅18 x 2
Material	E355		
Dimensional standard	EN 10305-4:2016		
Outer diameter (OD) (mm)	14.00±0.05	16.00±0.05	18.00±0.05
Inner diameter (ID) (mm)	10.00±0.10	12.00±0.10	14.00±0.05
Wall thickness (WT) (mm) (tolerance ±7.5%)	2.00±0.15	2.00±0.15	2.00±0.15
Length (mm)	6000		
Weight (kg/m)	0.592	0.691	0.789

Table 2. Parameters of the measured precision seamless steel tubes specified by the tube manufacturer

The mechanical properties of E355 steel are as follows: Yield stress Re = 355 MPa, tensile strength Rm = (490– 630) MPa, elongation A_{min} = 22%. Chemical composition of low-carbon steel E355 according to EN10305-1 is given in Tab. 3. These properties make E355 steel suitable for cold drawing processes.

C	Si	Mn	P	S
0.220	0.550	1.600	0.025	0.025

Table 3. Chemical composition of steel E355 (wt %)

For the purposes of our research, all three tubes were cut into 500 mm pieces (Fig. 3). During the cutting process, individual sections were marked to allow identification of their orientation and sequence.

Figure 3. Measured cold-drawn seamless precision steel tubes: 36 specimens (500 mm in length), obtained by cutting three 6 m tubes into three groups of 12 pieces: OD Ø14 mm, Ø16 mm and Ø18 mm (all with WT of 2 mm)

3 MEASUREMENT OF SPECIMENS

To determine the dimensional parameters and geometric parameters of the specimens, the Prismo Ultra (Zeiss, Germany) coordinate measuring machine (Fig. 4) with Calypso measurement software and the Rondcom 60A (Accretech, Japan) roundness measuring instrument (Fig. 6) with Acctee software were used. The following parameters were measured and evaluated:

Dimensional parameters:

- Outer diameter (measured by Prismo Ultra),
- Inner diameter (measured by Prismo Ultra),
- Wall thickness (calculated as half the difference between the outer and inner diameter values).

Geometric parameters:

- Concentricity (measured by Prismo Ultra),
- Roundness (measured by Rondcom 60A).

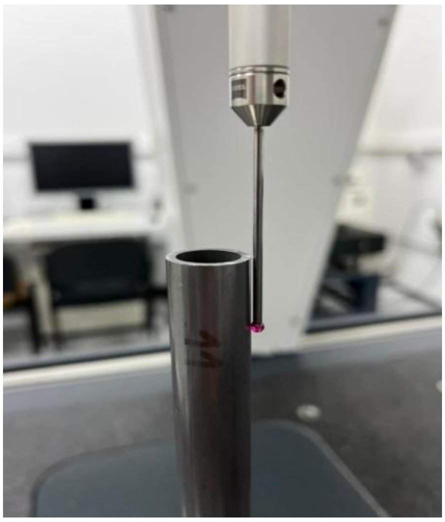
During measurements with the coordinate measuring machine Prismo Ultra (Zeiss, Germany) (Fig. 4), the specimen was clamped in a chuck. At both ends of each specimen, three paired cross-sectional measurements (outer and inner circular profiles) were taken at distances of 10 mm, 25 mm and 40 mm (Fig. 5).

Each profile was scanned using 500 points along its circumference, with a ruby-tipped probe traversing the surface at a speed of 7 mm.s^{-1}. The diameter was evaluated using the Least Squares Circle method. The software also evaluated concentricity by comparing the outer and inner circular profiles.

Each measured tube (length 6000 mm) consisted of 12 measured specimens (each 500 mm in length). On each specimen, 6 outer and 6 inner circular profiles were measured. Therefore, for each 6000 mm tube, 72 OD values, 72 ID values, and 72 concentricity values were obtained.

From the closely spaced measurement points, the arithmetic mean and standard deviation were calculated. For better graphical representation, only these values are shown in the individual charts. This approach ensures a clear visualization of the dimensional variability along the tube length, facilitating easier interpretation and comparison of the results.

a)



b)

Figure 4. Specimen measurement: a) coordinate measuring machine Prismo Ultra (Zeiss, Germany), b) close-up view of the measured object (seamless precision steel tube) and the contact measuring probe

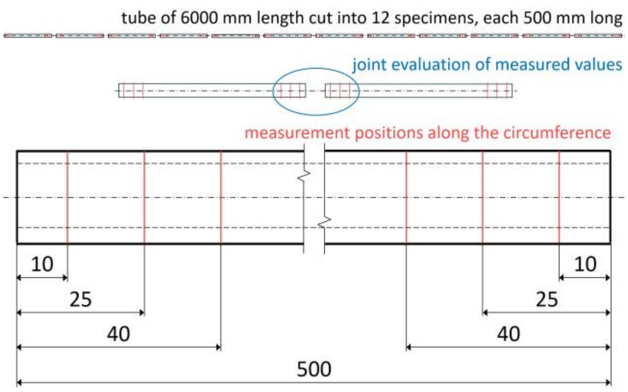
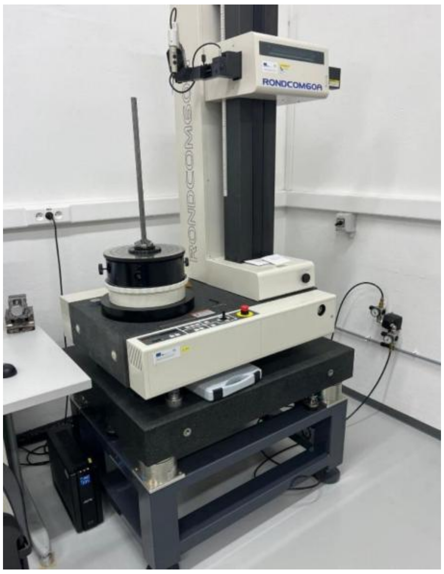


Figure 5. Measurement positions for outer diameter, inner diameter and concentricity along specimen circumference (measured by Prismo Ultra coordinate measuring machine)

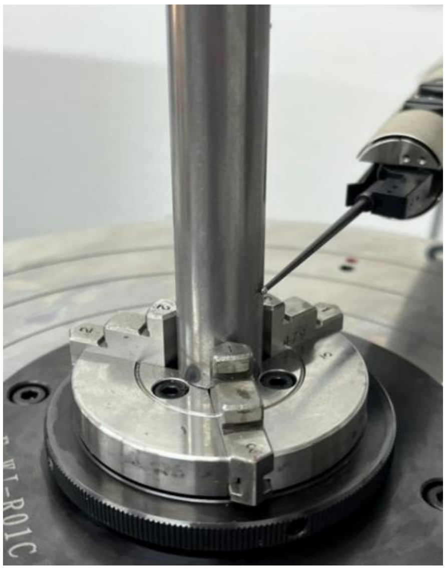
Roundness measurements on the outer surface of the tube were performed using the Rondcom 60A (Accretech, Japan) roundness measuring instrument (Fig. 6). The specimen was clamped in a chuck. Roundness was measured at a section located 25 mm from the specimen's front face and then at subsequent intervals of every 50 mm along the tube (Fig. 7).

For each 6000 mm tube, 120 roundness values were measured – from 12 specimens (each 500 mm in length), with 10 roundness measurements per specimen. Each profile was scanned with 3600 points at a measurement speed of 3 min^{-1}. The recorded profiles were filtered using a Gaussian low-pass filter (50 undulations per revolution). The Minimum Zone Circle method was used for evaluation.

By employing a high-resolution scanning process and advanced evaluation techniques, the study provides a comprehensive insight into the geometric integrity of cold-drawn seamless precision steel tubes under real-mass production conditions. This approach supports accurate quality control and ultimately improves the reliability and performance of tubes used in demanding industrial sectors.



a)



b)

Figure 6. Specimen measurement: a) roundness measuring instrument Rondcom 60A (Accretech, Japan), b) close-up view of the measured object (seamless precision steel tube) and the contact measuring probe

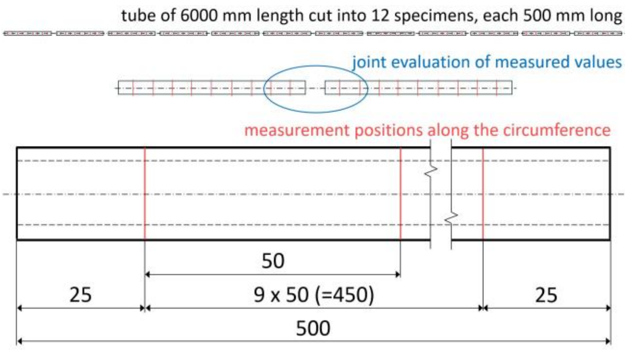


Figure 7. Measurement positions for roundness along specimen circumference (measured by Rondcom 60A roundness measuring instrument)

4 MEASURED VALUES

Figure 8 shows the deviations of the OD at various measurement points along the tube. Diameter deviations are calculated as the difference between the measured diameter and the nominal diameter. The graph displays the arithmetic means and standard deviations of the measured values. Also indicated are the arithmetic means of all measured values along the entire tube. Similarly, Fig. 9 shows the deviations of the ID. These measurements are crucial for understanding the quality of the cold-drawing process and its effect on final tube dimensions.

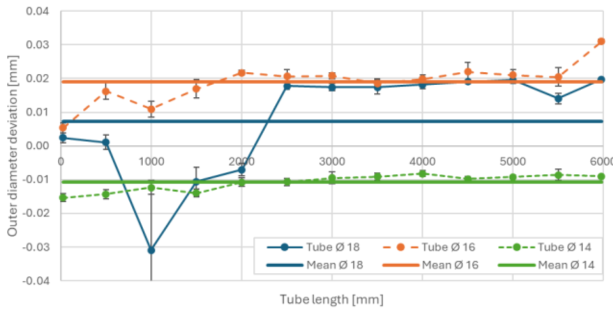


Figure 8. Outer diameter of the tube along its length

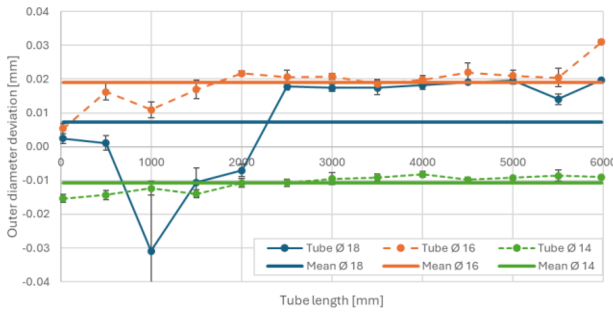


Figure 9. Inner diameter of the tube along its length

Based on the measured OD and ID, the average WT of the tube was calculated according to the following relation:

$$WT = (OD - ID) / 2 \quad (1)$$

Figure 10 presents the average WT of the tube.

The software of the coordinate measuring machine also evaluated concentricity by comparing the outer and inner circular profiles. Essentially, this indicates the eccentricity of the inner profile relative to the outer one, which is a key indicator of WT uniformity around the tube circumference.

Figure 11 presents how the concentricity changes along the length of the tube.

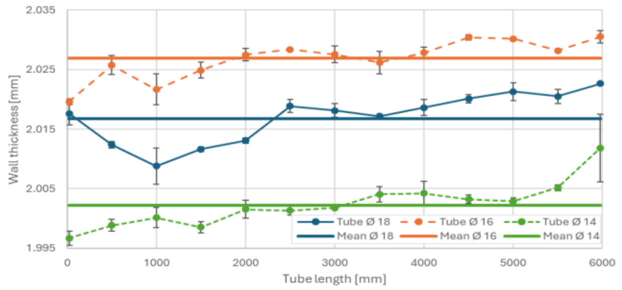


Figure 10. Average wall thickness of the tube along its length

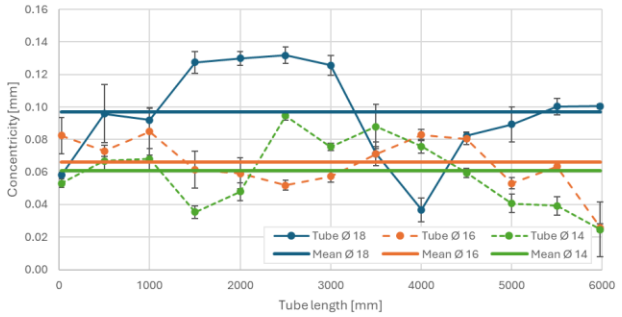


Figure 11. Concentricity of the tube along its length

Roundness was measured evenly along the entire length of the tube. For each tube (6000 mm in length), 120 roundness measurements were performed at cross-sections spaced 50 mm apart (Fig. 7.). Figure 12 shows the measured values as well as the average roundness values for each tube.

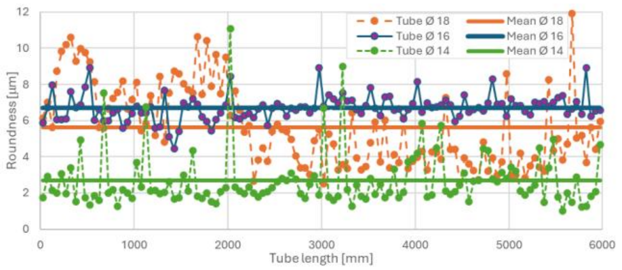


Figure 12. Roundness of the tube along its length

In addition to dimensional parameters, concentricity and roundness measurements provide crucial insight into the geometric integrity of the tubes. Variations in concentricity along the tube length indicate slight eccentricity of the ID relative to the OD, which may lead to uneven WT distribution and impact mechanical properties. Similarly, roundness deviations point to potential ovality, which could compromise fitting accuracy and sealing in precision applications. These geometric assessments, rarely included in standard specifications, therefore represent a vital complement to traditional dimensional controls, enabling manufacturers to guarantee the overall quality and reliability of cold-drawn precision steel tubes. Their monitoring also helps detect early process deviations.

A total of 72 measurements per tube (6000 mm in length) were conducted for OD, ID and concentricity. Based on the OD and ID, average WT was also calculated 72 times per tube. Additionally, 120 roundness measurements were taken for each tube (6000 mm in length).

Three tubes (each 6000 mm long) were analyzed in total, with nominal ODs of Ø14, Ø16 and Ø18 mm. Altogether, 1224 values were measured and evaluated (408 per tube).

Table 4 presents the average values (arithmetic means) and standard deviations of the individual monitored parameters. Values closest to the nominal dimensions as well as those with the lowest standard deviations are highlighted in color.

Tube (OD x WT) (mm)	∅14 x 2		∅16 x 2		∅18 x 2	
Para-meter	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
Outer diameter (mm)	13.989	0.002	16.019	0.005	18.007	0.017
Inner diameter (mm)	9.985	0.005	11.965	0.003	13.974	0.010
Wall thick-ness (mm)	2.002	0.003	2.027	0.003	2.017	0.004
Concen-tricity (mm)	0.061	0.021	0.066	0.016	0.097	0.029
Round-ness (µm)	2.677	1.531	6.705	0.705	5.635	2.238

Table 4. Average values (Mean) and standard deviations (St. dev.) of measured data

5 DISCUSSION

The tube manufacturer specifies dimensional parameters with defined tolerances—OD, ID and WT—in accordance with EN 10305-4:2016. Geometric parameters such as concentricity and roundness, while critical for certain applications, are typically not included in the product specification unless explicitly requested by the customer.

In this study, cold-drawn seamless precision steel tubes made of E355 material and produced under real mass-production conditions were analyzed. All measured tubes (Ø14×2 mm, Ø16×2 mm and Ø18×2 mm) met the prescribed tolerances for OD, ID and WT, confirming dimensional conformity with the standard. These findings support the conclusion that current production tooling is capable of consistently maintaining dimensional specifications along the entire tube length.

The main objective of the experimental work was to determine the variability of both dimensional and geometric accuracy. Variability was evaluated through standard deviations of the measured parameters — the lower the standard deviation, the more stable the production process. Since absolute deviation values may not fully reflect quality differences across diameters, percentage-based evaluations were also employed for better comparability.

The results of the experimental work lead to the following statements:

– Although the prescribed values were met with high accuracy, the tube with a nominal OD of Ø16 mm deviated the most from the nominal values of diameters and WT. Its average OD deviated from the nominal value by 0.12%, the ID by 0.29%, and the WT by 1.35%.

– The ODs and IDs of all tubes show low variability of results, remaining below 0.1% — the values of standard deviations are less than 0.1% of the average value.

- The variability of WT results for all tubes is below 0.21%.
- The smallest variability of measured values (smallest standard deviations) was found in the tube Ø16 mm. Only the OD showed the smallest variability in the tube Ø14 mm.
- The variability of concentricity reached levels as high as 30%. The standard deviation was lower only for the tube Ø16 mm (23.54% of the average value).
- The worst variability was found in the roundness of the tube Ø14 mm, where the standard deviation reached up to 57.19% of the average value. The best stability of roundness results was observed in the tube Ø16 mm (10.52% of the average value).
- The tube Ø16 mm showed the greatest deviation from the nominal values in terms of average values. However, it also had the lowest variability of the monitored parameters.

These findings indicate that while dimensional accuracy is generally well-controlled and consistent, geometric parameters such as concentricity and roundness exhibit significantly greater variability. This discrepancy is especially relevant because such parameters are neither covered by the current standard nor included in manufacturer specifications.

From a production perspective, the Ø16 mm tube showed both the largest average deviation and the lowest variability. This suggests the presence of a systematic offset in the production process, which could be corrected through calibration without compromising stability. Conversely, the high variability in the Ø14 mm tube's roundness highlights potential inconsistencies, such as tool wear or misalignment, that merit further investigation.

The variability observed in geometric parameters may have implications in applications where concentricity and roundness are critical for performance, such as hydraulic or rotating systems. Deviations in these parameters may lead to increased wear, unbalanced loading and premature failure.

These results underscore the value of including concentricity and roundness measurements in both research and industrial practice. By extending the evaluation beyond the standard dimensional parameters, this study provides a more complete understanding of tube quality under real manufacturing conditions. Future work should aim to identify the root causes of geometric deviations and explore the relationship between process parameters and output variability. It is also recommended to verify whether the inclusion of geometric tolerance ranges could enhance product reliability and functional performance in critical applications.

6 CONCLUSIONS

This study has investigated the dimensional and geometric accuracy of cold-drawn seamless steel tubes manufactured under real mass-production conditions. Based on the analysis in the discussion, the following key conclusions summarize the production process and its industrial relevance:

- The study confirmed that all analyzed tubes met dimensional tolerances according to EN 10305-4:2016, demonstrating stable control of OD, ID and WT dimensions under real mass-production conditions.
- While dimensional parameters remained within specified tolerances, higher variability was observed in geometric parameters such as concentricity and roundness. Since these parameters may be important for certain applications, continued monitoring and potential process adjustments could help maintain consistency across all relevant quality aspects.
- The findings emphasize the importance of including geometric parameter evaluations in quality assurance to improve product reliability in precision applications.
- Online monitoring systems with automatic process calibration could be a promising approach to enhance product quality by detecting deviations in real time and enabling corrective actions.

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The results presented in this paper were obtained during the implementation of research projects and will also be used in the teaching of technical subjects.

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We appreciate the opportunity to integrate practical manufacturing challenges into both research and education.

REFERENCES

[Abe 2016] Abe, H., et al. Dimensional accuracy of tubes in cold pilgering. Journal of Materials Processing Technology, 2016, Vol.231, pp 277-287. ISSN (print) 0924-0136, ISSN (online) 1873-4774. https://doi.org/10.1016/j.jmatprotec.2016.01.001

[Bilik 2021] Bilik, J., et al. Vplyv veľkosti pretvorenia na presnosť rúr pri prievlačnom ťahaní jedno a dvojťahovou technológiou (The influence of strain size on accuracy of tubes during die drawing using single-pass and two-pass technology). Technológ, 2021, Vol.13, No.3., pp 20-24. ISSN 1337-8996

[Bilik 2023] Bilik, J., Necpal, M. & Sobota, R. Výroba bezšvových rúr. Teoreticko-technologické aspekty výroby (Manufacturing of Seamless Tubes. Theoretical and Technological Aspects of Manufacturing). 1st ed. Bratislava: Slovak University of Technology in Bratislava - Vydavateľstvo SPEKTRUM, 2023. 71 p. ISBN 978-80-227-5308-1

[Ding 2024] Ding, X., et al. Influence of Cold-Rolling Processes on the Dimensional Accuracy and Roughness of Small-Diameter Thick-Walled Seamless Tubes. Metals 2024, Vol.14, No.11, Article 1297. ISSN (online) 2075-4701. https://doi.org/10.3390/met14111297

[Durcik 2021] Durcik, R., et al. Numerical simulation of eccentricity creation in the production of hot rolled tubes. Acta Tecnología, 2021, Vol.7, No.4, pp 125-129. ISSN 2453-675X. https://doi.org/10.22306/atec.v7i4.122

[Gorog 2020] Gorog, A. & Gorogova, I. Stability analysis of roundness profiles of drawn tubes. Manufacturing technology, 2020, Vol.20, No.3, pp 307-312. ISSN 1213-2489. https://doi.org/10.21062/mft.2020.051

[Gorog 2023] Gorog, A., Morovic, L. & Kritikos, M. Measurement of Dimensional and Geometric Accuracy of Tubes. Plzeň: Vydavatelství a nakladatelství Aleš Čeněk s.r.o., 2023. ISBN 978-80-7380-919-5.

[Gulyayev 2020] Gulyayev, Yu.G., et al. Perfection of processes of seamless steel tubes production. Metalurgija, October 2011, Vol.50, No.4, pp 285-288. ISSN 0543-5846.

[Havran 2021] Havran, F. Vyhodnotenie presnosti vybraných rozmerov bezšvíkových oceľových rúr pomocou 3D digitalizácie (Evaluation of the accuracy of selected dimensions of seamless steel tubes using 3D digitization). MTF-5288-85530. Trnava: Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology, Institute of Production Technologies, 2021.

[Kan 2019] Kan, M., et al. The influence of technological parameters for the manufacture of precision seamless tubes for automotive industry. Hutnik-Wiadomości Hutnicze, 2019, Vol.86, No.8, pp 250-252. ISSN 1230-3534. https://doi.org/10.15199/24.2019.8.5

[Kapustova 2021] Kapustova, M., et al. Research into the Influence of the Plastic Strain Degree on the Drawing Force and Dimensional Accuracy of the Production of Seamless Tubes. In: Durakbasa, N. M. and Gençyılmaz, M. G., eds. Digitizing Production Systems: Selected papers from ISPR 2021, 07-09 October 2021, online, Turkey. 1st ed. Cham: Springer, 2022, pp 219-229. ISSN 2195-4356. ISBN (print) 978-3-030-90420-3. ISBN (online) 978-3-030-90421-0. https://doi.org/10.1007/978-3-030-90421-0_19

[Kapustova 2022] Kapustova, M., et al. The research of influence size strain and number of draws on dimensional accuracy of seamless tubes made of steel E235 and E355. Journal of Metallic Materials, 2022, Vol.74, No.1, pp 9-14. ISSN 2657-747X. https://doi.org/10.32730/imz.2657-747.22.1.2

[Kritikos 2019] Kritikos, M., et al. Evaluation of accuracy of seamless steel tube scanning by industrial computed tomograph. In: Bâlc, N. and Leordean, D., eds. MATEC Web of Conferences, 2019, Vol.299, pp 1-8. Modern Technologies in Manufacturing (MTeM 2019), 9-12 October 2019, Cluj-Napoca (Romania). United Kingdom: EDP Sciences. ISBN 978-2-7598-9083-5. https://doi.org/10.1051/matecconf/201929904009

[Mojzis 2018] Mojzis, M. Výskum a optimalizácia technológie ťahania presných bezšvových rúr (Research and Optimization of the Drawing Technology of Precision Seamless Tubes). MTF-10907-28482. Trnava: Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology, Institute of Production Technologies, 2018.

[Morovic 2022] Morovic, L., et al. A Statistical Approach in the Analysis of Geometrical Product Specification During the Cold Tube Drawing Process. Applied Sciences, 2022, Vol.12, No.2, pp 1-22. ISSN 2076-3417. https://doi.org/10.3390/app12020676

[Orlov 2024] Orlov, G. Precision of the Tubes Produced by Drawing and Cold Rolling. In: Brebbia, C. and Connor, J., eds. Progress in Materials Science and Engineering, 2024. Cham: Springer, pp 171–177. ISBN 978-3-319-75340-9

[Palengat 2013] Palengat, M., et al. Cold drawing of 316L stainless steel thin-walled tubes: Experiments and finite element analysis. International Journal of Mechanical Sciences, 2013, Vol.70, pp 69–78. ISSN (print) 0020-7403, ISSN (online) 1879-2162. https://doi.org/10.1016/j.ijmecsci.2013.02.003

[Ridzon 2012] Ridzon, M. The Effect of Technological Parameters Influencing the Properties of Seamless Cold-Drawn Tubes. 1st ed. Köthen: Hochschule Anhalt, 2012. ISBN 978-3-86011-048-5

[Ridzon 2015] Ridzon, M., et al. Manufacturing of Precision Seamless Steel Tubes Using Cold Drawing Technology: Simulation and Experiment. Applied Mechanics and Materials, 2015, Vol.808, pp 80–85. ISSN (print) 1660-9336, ISSN (online) 1662-7482. https://doi.org/10.4028/www.scientific.net/AMM.808.80

[Sobota 2022] Sobota, R., et al. Analysis and comparison of geometric dimensions of cold drawn tubes using FEM simulation. Journal of Metallic Materials, 2022, Vol.74, No.2, pp 21-28. ISSN 2657-747X. https://doi.org/10.32730/imz.2657-747.22.2.3

[Xu 2023] Xu, Y., Wu, B. & Zheng, B. Full-field geometric imperfection and effect on cross-section capacity of circular steel tubes. Journal of Constructional Steel Research, February 2023, Vol.201, Article 107749. ISSN (print) 0143-974X, ISSN (online) 1873-5983. https://doi.org/10.1016/j.jcsr.2022.107749

[Zaba 2023] Żaba, K. & Trzepieciński, T. Cold Drawing of AISI 321 Stainless Steel Thin-Walled Seamless Tubes on a Floating Plug. Materials, 2023, Vol.16, No.16, pp 5684-5695. ISSN (print) 1996-1944, ISSN (online) 1996-1944. https://doi.org/10.3390/ma16165684

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