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Interactive multimedia learning environment for geometrical specification indication & verification rules

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Abstract

The concept of application that instructs students on efficient usage of the symbol language for specification of form, orientation, location and run-out tolerances as well as verification of those requirements is briefly presented. The new module of the application developed to present specification elements recently introduced in the 1101:2017 to reduce specification uncertainty is shown. The paper contains a few screenshots of the interactive animated sequences that are employed to demonstrate current possibilities of roundness specification as well as relevant verification methods. The application goal is to help students to gain skills of effective usage of the geometrical tolerancing symbols and rules.

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Keywords: Geometrical tolerancing; Tolerance indication; e-learning

1. Introduction

Geometric part deviations, which are inevitably observed on every manufactured workpiece, have distinct effects on the assemblability as well as on the function and quality of physical artefacts. As a consequence, geometric variations management is an important issue for manufacturing companies [1]. Recently the International Organization for Standardization published new editions of the standards ISO 1101:2017 *Geometrical product specifications (GPS) – Geometrical tolerancing – Tolerances of form, orientation, location and run-out* and ISO 1660:2017 *Geometrical product specifications (GPS) – Geometrical tolerancing – Profile tolerancing* that are crucial for correct, unique specification of workpieces geometry and establishment of relevant verification procedures. A few other standards devoted to the geometrical dimensioning and tolerancing are under revision and will be published soon. Particularly well advanced are works over new upgraded versions of the standards ISO 5458 *Geometrical product specifications (GPS) – Geometrical tolerancing – Pattern and combined geometrical specification* and ISO 5459 *Geometrical product specifications (GPS) – Geometrical tolerancing – Datums and datum systems.*

So there is ongoing need for presentation, explanation and dissemination of the new concepts, rules and indicators implemented in the new standards. The latest provisions shall be taught to students at technical universities and there is demand for vocational training in industry [2], especially in automotive and aviation where performance requirements are increasing and limits for geometry variations of components shall be defined precisely. Currently the European research project *Geometrical Product Specification and Verification as toolbox to meet up-to-date technical requirement* is realized in the framework of Erasmus+ program [3]. The project is carried out by the international consortium consisting of researchers from seven European Universities, including authors of the paper, and Volkswagen AG (Wolfsburg) as an industrial partner. The project will develop and implement a coherent learning system for higher-level vocational training concerning the GPS, which can also be a supplement for existing curricula of engineering studies. Below the concept of the application *Geometrical tolerancing* that is being

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constantly modified and developed for a few years [4] with some modules especially completed for the *GPS&VToolbox* project is presented. Selected animations that explain new concepts from the ISO 1101:2017 standard will be shown in more detail.

It shall be indicated that at present there are only a few applications that use modern visual software tools to facilitate study of the metrology of the geometrical quantities [5], but we have not encountered any application that presents tolerancing of form, orientation, location and run-out in such a way that we have proposed.

2. Concept and main capabilities of the application *Geometrical Tolerancing*

The double-click on the application *Geometrical Tolerancing* icon launches the *Main window* (Fig. 1), which gives the overview of the application content. At the *Main Window* a user can left-click on one of the 14 *Tolerance symbol buttons*, the *Datums button*, any *Modifier button* or the *Size button* to open the *Case selection window* with the list of the cases of its applications. The nine *Modifiers buttons* are listed in the column on the *Main window* left edge. The set of additional symbols is considerably expanded in the ISO 1101:2017 so the *Etcetera button* in the bottom of the *Modifiers column* is added to open *Case selection window* for other additional symbols.

Currently over one hundred cases of the geometrical tolerancing symbol usage to ensure various functional requirements for components are presented and discussed in the application *Geometrical Tolerancing*. The *Main window* of the application with the mouse cursor being dragged and held over the *Roundness button* is shown in Fig. 1. The click event opens the *Case selection window* where four different applications of the roundness symbol (Fig. 2) are enumerated. Selection of the particular case by the *Bar button* opens the *Definition window* (Fig. 3) with the relevant tolerance indicator and other indicators attached to the workpiece, if required. The *Definition windows* are used to present the key rules for each tolerance indication, as well as to explain how

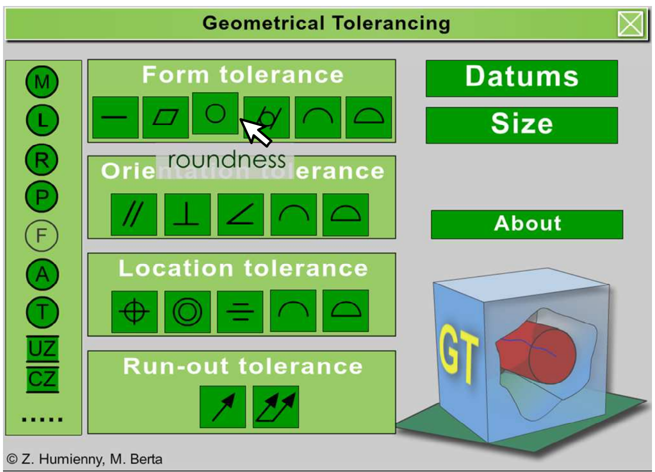

Fig. 1. *Main window* of the application *Geometrical Tolerancing* – the description of the *Roundness button* is displayed adjacent to the button because the arrow cursor is dragged and held over this button.

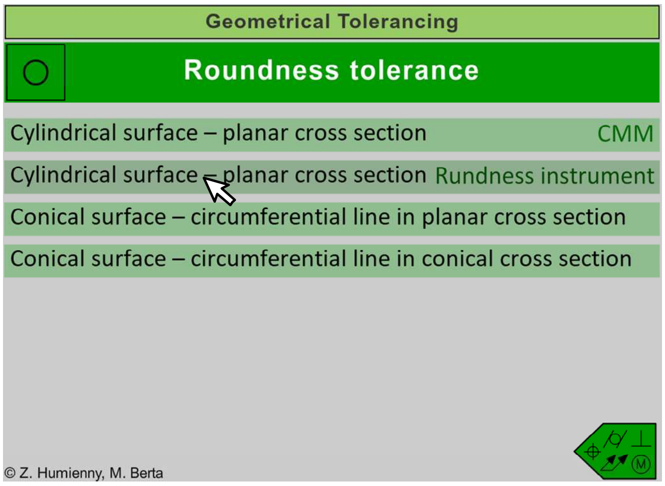

Fig. 2. *Case selection window* with list of *Bar buttons* for the roundness tolerance applications. The roundness tolerance for cylindrical surface verification by roundness measuring instrument is selected for study.

a tolerance zone is established and how a datum (datum system), if required, constrains spatial placement of this tolerance zone. On the right edge of each *Definition window* a pull down menu with four options (*Specification, 2D-drawing, 3D-drawing, Explanation*) is accessible.

The undisputed advantage of the application *Geometrical Tolerancing* is that it combines using multimedia instructional tools to present information on geometrical tolerancing rules with demonstration of selected verification techniques for the particular requirements.

3. The roundness specification

The new GPS tools introduced in the recently published standards allows a designer to carefully define the intended requirements. The additional specifications may drive a verification method, but nonetheless a different method during inspection may be used.

The unambiguous specification of roundness tolerance is possible thanks to usage, in the second section of the tolerance

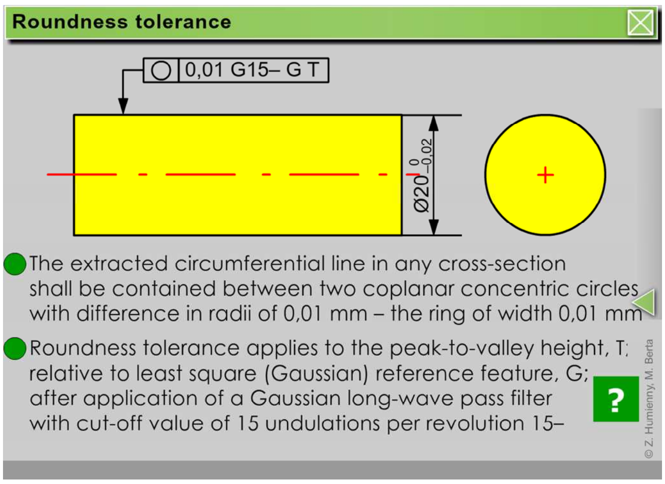

Fig. 3. *Definition window* of the detailed roundness specification. The click on the *Explanation button* at the expanded pull down menu available on the right edge of the window (not shown) guides the user to the next window.

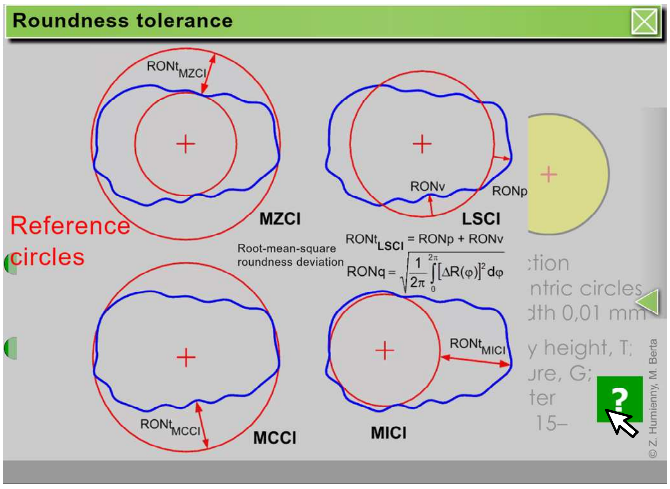

Fig. 4. The *Po-pup window* displayed in *Definition window* due to the arrow cursor that is dragged and held over the *Question mark button* is used to show reference circles that may be applied for the roundness deviation assessment.

indicator, a few of the new specification elements. Now the second section of the tolerance indicator carries information about the tolerance zone, toleranced feature, characteristic and material condition respectively to the particular geometrical requirement. Up to the recent revision of the ISO 1101 standard the set up of the majority measuring parameters during roundness deviation assessment was left to the discretion of the metrologist. Such lack of information from a designer caused that sometimes inspection processes at customer and supplier sites produced contradictory results when components were examined for the conformity with the same specification.

The *Definition window* for precise, unique specification of the roundness tolerance is shown in Fig. 3 – the new specification elements are implemented in the tolerance indicator. The roundness tolerance definition window – as each window in the application – shall be easy to study and communicative, not overloaded with content. So the basic information about each geometrical specification is organized as a bulleted list with not more than three paragraphs. In the

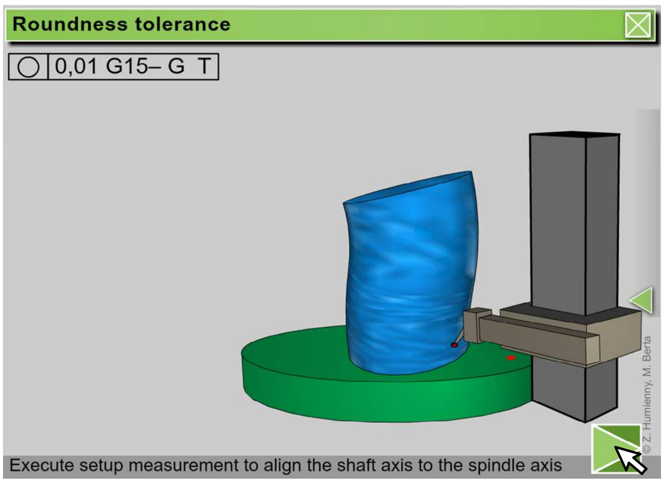

Fig. 5. *Explanation window* – the first scene. The tested component is placed on the form measuring machine rotary table.

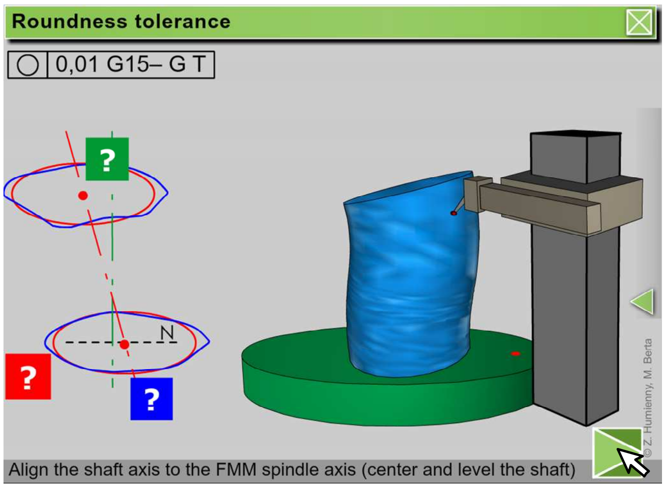

Fig. 6. *Explanation window* – the second scene. The results of initial setup measurement performed to align tested shaft in FMM coordinate system.

case of the roundness tolerance the general information that any circumferential line shall be contained in the tolerance zone defined by the ring of 0,01 mm width is given in the first paragraph. The specification elements are explained in the second paragraph – the deviation peak-to-valley is determined by the parameter T; the least square reference circle (Gaussian) is fixed by the parameter G; the Gaussian long wave pass filter with cut-off value 15 undulations per revolution is set by the parameter G15–. The assessment of the roundness deviation requires usage of a reference element, so the *Question mark button* is used to provide more information about four potential reference circles in the context *Pop-up window* (Fig. 4). The *Pop-up windows* are often applied to provide additional information about the presented tolerance as well as to help a user to verify whether she/he understands well the concepts and rules of the geometrical tolerancing already presented in the application.

The click event on the *Explanation button* initiates a series of scenes developed to show the way how the analyzed roundness specification may be verified on a form measuring machine (FMM). An examined shaft is placed on the FMM rotary table. The command displayed in the *Prompt line* in the window bottom when the arrow cursor is dragged and held over *Forward button* (e.g. *Execute setup measurement to align the shaft axis to the spindle axis,* Fig. 5) informs what action will be demonstrated in the next scene/animation released by click on the *Forward button*. In this scene the click event on the *Forward button* triggers rotation of the table and the first cross-section near the bottom shaft face is measured, next the measuring probe is moved upwards and the second cross-section near the top shaft face is measured (Fig. 6). A user can drag and hold the arrow cursor over the green, red or blue *Question mark button* to understand what is visualized by particular colors, e.g. the red line represents axis of the toleranced feature established from two cross-sections. The command *Align the shaft axis to the FMM spindle axis* displayed in the *Prompt line* in Fig. 6 informs that click on the *Forward button* will released animation that presents centering and leveling adjustments of the tested shaft. The centering and leveling of the shaft is necessary to bring the

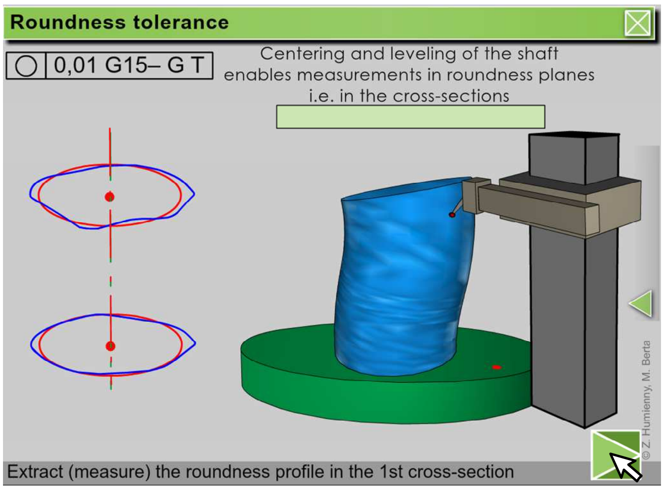

Fig. 7. *Explanation window* – the 3rd scene. The proper alignment of the shaft on the FMM is shown. The test sentence with covered answer is displayed.

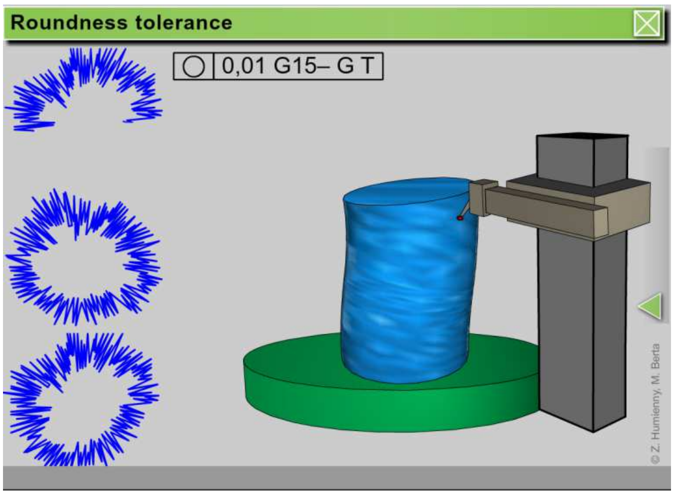

Fig. 9. *Explanation window* – the 5th scene captured during data collection for the extracted circumferential line in the third cross-section.

axis of a component in to line with the FMM spindle axis. The result of the shaft alignment that always has to be performed before the roundness deviation assessment is shown in Fig. 7. The simple test sentence with covered answer is employed to verify whether a user has well understood the aim of the centering and leveling actions. The click on the *Covering button* reveals the right answer (perpendicular to the shaft axis) that a user shall compare with own answer proposed in advance. The single test sentences or *Pop-up windows* with *Covering buttons* are frequently inserted in the application windows to enable a user to assess the progress in the familiarization with the geometrical tolerancing concepts and rules thanks to the application usage. The click event on the *Forward button* in Fig. 7, according to the command *Extract (measure) the roundness profile in the 1st cross-section* displayed in the *Prompt line*, will trigger acquisition of the actual circumferential line points in the first shaft cross-section. The result of the measurement is shown in Fig. 8. Next click event on the *Forward button* initiates measurements in the second and third cross-sections. The results of each measurement are visualized dynamically – the extracted profile is displayed as its points are captured when the shaft rotates during measurement (Fig. 9). The command *Set up measuring parameters listed in the tolerance indicator* is not displayed in Fig. 9 – it will be available after measurements for all cross-sections are completed. It is necessary to emphasize that still under the discretion of the operator is selection of the ball tip diameter and number of the shaft cross-sections that will be tested.

The obtained outcome – three extracted circumferential lines are shown in Fig. 10. The command *Show the deviations according to specification G15– G T* displayed in the *Prompt line* (Fig. 10) refers to the new tools that are given to designers by the recent revision of the ISO 1101 standard. The click event on the *Forward button* is executable subsequent to setting respective parameters. According to the discussed tolerance indication (Fig. 3) the specification elements G15– G T shall be taken into account by an operator to set up FMM to process already extracted and stored raw measurement data – digital representation of the intersections of the real shaft surface and the roundness planes.

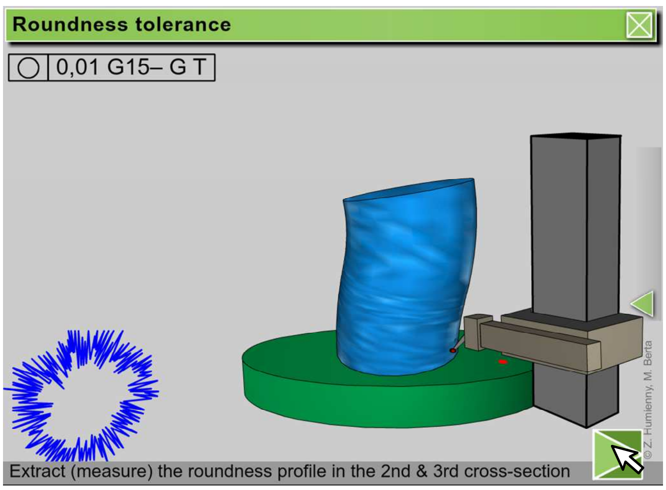

Fig. 8. *Explanation window* – the 4th scene. The actual profile of the 1st cross-section has been measured and is displayed.

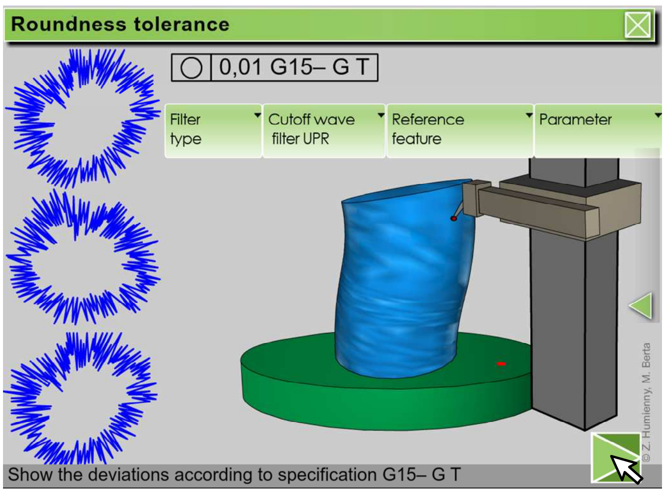

Fig. 10. *Explanation window* – the 6th scene. The measurement raw results – three extracted circumferential lines are shown. To calculate the deviations according specification the measuring parameters shall be fixed.

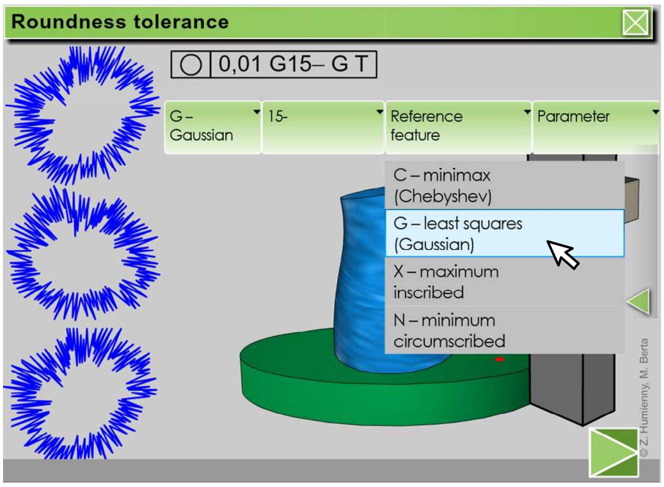

Fig. 11. *Explanation window* – the 7th scene. A user selects the measuring parameters to process raw measurement data according to the specification.

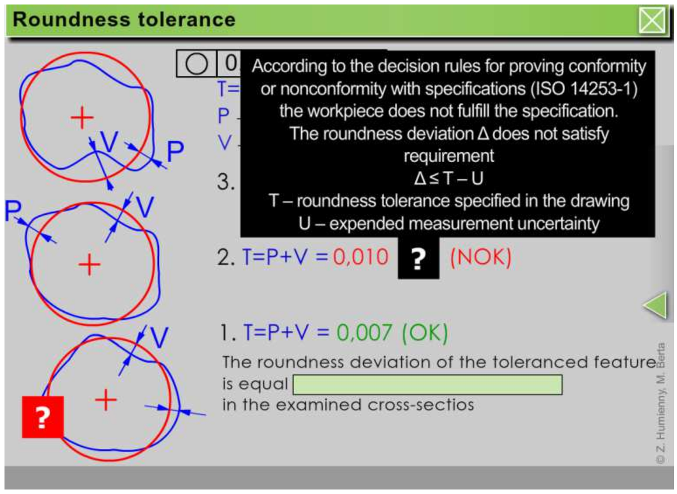

Fig. 13. *Explanation window* – the *Po-pup window* is employed in the last scene to recall rules for conformity assessment.

The light green rectangles in Fig. 11 represent a human-FMM interface available in modern FMM software that enables an operator to select the measuring parameters to process raw measurement data at FMM according to the specification given for a verified component. Each different FMM manufacturer may have a distinct approach to provide these facilities, but the aim of the application is to show that such data shall be now specified by a designer in a tolerance indicator and are available for a FMM operator which shall input them to an instrument.

The process of selecting the measuring parameters is visualized by four pull down lists, from which a user of the application shall select exactly those parameters that are given in the tolerance indicator. The available lists of filter types and the values of the cutoff wave are used only as examples. These two lists are not absolute and for various FMM software will be adjusted by a manufacturer while for the reference feature and the roundness deviation parameter all possibilities are presented. The following four reference features are offered for the roundness deviation assessment:

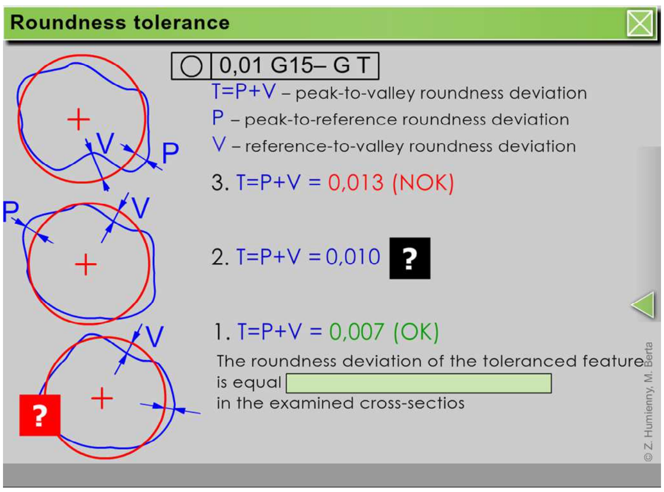

Fig. 12. *Explanation window* – the last 8th scene. The roundness deviations assessed according the specification requirements are visualized as the roundness profiles and respective deviation values are shown.

C – minimax (Chebyshev), G – least squares (Gaussian), X – maximum inscribed and N – minimum circumscribed according to the ISO 12181-1:2011 standard. The expanded list of reference features shown in the *Explanation window* (Fig. 11) corresponds to the reference circles that a user shall study in the *Definition window* (Fig. 4). The list of the roundness assessment parameters contains four options: T – peak-to-valley, P – peak-to-reference, V – reference-to-valley and Q – root mean square (RMS).

It is shown in Fig. 11 that the Gaussian shortwave-pass filter with cutoff value 15 undulations per revolution has been already chosen by a user according to specification (Fig. 3) and currently the reference feature is selected from the pull down list. Next a user has to select peak-to-valley to indicate, that assessment of the specification parameter T that stands for peak-to-valley roundness deviation is required by a designer.

When the selection of four measuring parameters is completed the simulation of the data processing maybe executed – the click event on the *Forward button* at the window given in Fig. 11 produces next window (Fig. 12) with three roundness profiles (extracted circumferential lines intentionally modified by the filter) and the numerical values of the roundness deviations in the tested cross-sections.

The *Pop-up window* in the last scene of the roundness tolerance *Explanation window* (Fig. 13) is introduced to focus attention of the application user on the issue of the decision rules for proving conformity or nonconformity with specifications. Unfortunately the rules given in the standard ISO 14253-1:2017 *Geometrical product specifications (GPS) – Inspection by measurement of workpieces and measuring equipment – Part 1: Decision rules for verifying conformity or nonconformity with specifications* are not well known in industry. At the design stage the terms "in specification" and "out of specification" refers to the interval separated by the sharp borderlines of the upper limit deviation and lower limit deviation for double sided size tolerance or tolerance value for a one sided specification that is typical for geometrical tolerances. This same approach is unfortunately often applied to the measurements results. Actually when dealing with the manufacturing or measurement stages of a process conformance or non-conformance ranges are reduced due to the measurement uncertainty [6]. So for the geometrical tolerance the deviation Δ shall satisfy the condition $\Delta \leq T - U$, were T is the geometrical tolerance value specified by a designer and U is the expanded measurement uncertainty of a FMM used. The roundness deviation in the second cross-section is equal to 0,01 mm, so conformity with the specification is possible only, if the expanded uncertainty will be equal to zero. This is not possible in real word of measurements, so after measurement in second cross-section it is clear that the shaft can't be accepted.

Conclusions and future actions

The application *Geometrical tolerancing* is intended for anyone who needs to understand the concepts, rules and practice of the unique GPS that clearly defines how far an actual component may be different from its nominal, theoretically exact CAD model.

Judicious use of the application supports teaching goals and further engage students in lecture presentations. Numerous participants of the geometrical dimensioning and tolerancing vocational training conducted by the authors in industry pointed out in evaluation questioners, completed after training, that animations included in the application *Geometrical tolerancing* significantly facilitate understanding of many terms and rules e.g. datum system establishment, tolerance zone shape and localization, assessment of geometrical deviation, modifier concepts. More over the usage of the application is indicated in the evaluation questionnaires as a great advantage of the training that enhances the learning effectiveness at universities as well as during vocational training in industry. The mentioned survey results demonstrate that the application *Geometrical tolerancing* is appreciated by training participants and help them to acquire effectively knowledge in the GPS field. Finally it is important to emphasize that the evaluation questionnaires were intentionally developed and used to qualitative assessment of the application *Geometrical tolerancing* usefulness. To perform quantitative assessment of the application effectiveness the training shall be executed in traditional way – oral lecture supplemented by power point slides and complementary chalk and blackboard usage. Such training shall be summarized by test that verify audience perception and understanding of the GPS issues. Next the same scope of the material shall be presented with extensive usage of the application *Geometrical tolerancing* in the course. This alternative course shall be finalized by the same test. The central question then becomes: how first "classical" course might affect the reception on the application *Geometrical tolerancing* and thus results of the second test? In case when two various groups of students will be taken in the survey another central question then becomes: are there any statistically significant differences between the groups – do members of both groups have the same professional background and intellectual capabilities? Thus it seems warranted that only quantitative assessment of the application effectiveness is reasonable and opinions obtained in the surveys encourage us to the further development of the application *Geometrical tolerancing.*

We attach great importance to the application of multimedia in teaching, that is in line with conclusion given in [7] that there is the overall positive effect of studying with animations compared to static graphics. The developed application *Geometrical tolerancing* is highly interactive and quite easy to follow and use because it is well structured since only three window templates are employed in it. The proper speed of the geometrical tolerancing study may be individually adjusted by each user due to seamless application control by the click events on buttons that enable transitions between the application windows.

The application *Geometrical tolerancing* is designed in Adobe Flash CS5, which facilitated the creation of the application content, particularly the animations of the highest quality. HTML files are employed to control the display of the SWF files in any web browser. Such tools are convenient for implementation of the application on line in open and distance learning courses as well as in blended learning courses.

Flash technology has been the standard tool for multimedia creation since the end of 1990 because it provided an effective way to create rich content on the web browsers. Adobe announced in July 2017 that they will stop updating and distributing the Flash Player at the end of 2020 [8]. So we already have made some trials over a couple of authoring tools to initiate the migration of the application *Geometrical tolerancing* to HTML5 to find the most effective way to execute it. The migration will be not so simple, but the first results are encouraging.

References

[1] Schleicha B, Anwerb N, Mathieu L, Wartzacka S. Status and Prospects of Skin Model Shapes for Geometric Variations Management. Procedia CIRP vol. 43, 2016. 154-159.
[2] Werner T, Weckenmann A. Sustainable quality assurance by assuring competence of employees, Measurement vol. 45, i. 6 (2012). 1534-1539.
[3] http://gpsvtoolbox.ath.eu
[4] Humienny Z, Berta M. Using animations to support the understanding of geometrical tolerancing concepts. Technisches Messen, 82(9), 2015. 422-431.
[5] Górmez E, Maresca P, et al., Developing a new interactive simulation environment with Macromedia Director for teaching applied dimensional metrology. Measurement, vol. 44, i. 9, 2011. 1730-1746.
[6] Płowucha W, Werner T, Savio E, Blunt L, Jakubiec W. A new didactic approach to statistical analysis of measurement data for the evaluation of measurement uncertainty – "SAM–EMU", Measurement, vol. 45, i. 10 (2012). 2359-2367.
[7] Berney S, Betrancourt M. Does animation enhance learning? A meta-analysis. Computers & Education, 2016. vol. 101. 150-167.
[8] https://theblog.adobe.com/adobe-flash-update/, access 10 december 2017.